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Comparison of Wood Harvesting Methods in the Republic of Karelia

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Abstract

Impacts of cut-to-length, tree-length and full-tree harvesting technology on direct operating costs, productivity, forest environment, ergonomics and work safety, as well as on wood quality were studied in 2007 and 2008 in 15 harvesting companies in the Republic of Karelia, Russia.

Productivity varied within a relatively wide range from 20 to 150 m^3 per shift. Fully mechanized full-tree harvesting provided the maximum productivity. The professional skills and experience of harvesting machine operators had a significant impact on the productivity. Direct operating costs had insignificant differences – the average costs were 250 RUB/m^3. In the traditional Russian tree-length and full-tree harvesting, real harvesting costs were higher than in the cut-to-length technology, due to additional work at the central processing yard.

All the technologies demonstrated an almost identical impact on the lower layers of soil, when applied on sandy or sandy loam soils. Porosity was reduced by 9–10%. On clay loams, the tree-length technology resulted in significant topsoil compaction but, at the same time, formed almost no track. The studied full-tree technology was only acceptable in harvesting sites where no undergrowth preservation was required. Partially mechanized cut-to-length technology ensured high undergrowth preservation. In thinnings the tree-length and the fully mechanized cut-to-length technology resulted in less damage to the remaining trees compared to the other technologies.

The best working conditions in terms of ergonomics and occupational safety were provided by the chain consisting of a harvester and a forwarder. It was closely followed by the chain “feller buncher and wheeled skidder”. Traditional tree-length harvesting with cable skidders demonstrated the worst results in terms of ergonomics, work severity and occupational safety.

Fully mechanized cut-to-length technology provided with the best results in the preservation of wood quality The quality of wood harvested with the tree-length or partially mechanized full-tree technology turned out to be the lowest, especially during the summer season.

Keywords

Wood harvesting, harvesting costs, productivity, forest environment, ergonomics, work safety, wood quality, Russia

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Other information

This publication is a translation of the original Russian book “Сравнение технологий лесосечных работ в лесозаготовительных компаниях Республики Карелия”, available in open access at the internet service www.lesinfo.fi.

Contents

Preface

This report presents the results of the data collection and analysis performed to study the impacts of different harvesting processes on operational costs, labour productivity, the forest environment, ergonomics, work safety, and the quality of roundwood in harvesting companies operating in the Republic of Karelia. The main purpose of the report is to provide harvesting companies with information about the advantages and disadvantages of the harvesting methods currently used in the Republic of Karelia, and to serve as a supporting material for decision-making when selecting relevant technology and machinery.

The report was first published in Russian language (Сравнение технологий лесосечных работ в лесозаготовительных компаниях Республики Карелия, 2008) as a result of a research project titled "Comparison of Harvesting Methods – Impacts on Wood Quality and Overall Performance of Wood-harvesting Companies", financed by the EU-Russia "Euregio Karelia Neighbourhood" programme during the period 2006–2008. This English version is produced in the framework of the project "Wood Harvesting and Logistics in Russia - Focus on Research and Business Opportunities" supported by the Finnish Funding Agency for Technology and Innovation (Tekes). Further analysis of the collected data is also continued in this project.

The work was performed by the researchers of the Petrozavodsk State University (Faculties of Forest Engineering and Economics) and the Finnish Forest Research Institute.

Joensuu, Petrozavodsk, May 2009

The Authors

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1 Introduction

1.1 Studied harvesting methods

Three harvesting methods are currently used in Northwest Russia: the full-tree, tree-length, and cut-to-length methods. Full-tree harvesting means that the trees are felled and the stem, intact with branches, is initially transported to the upper landing (i.e., loading site) using a skidder. The delimbing and, if necessary, any cross-cutting are done at the upper landing by the roadside. The tree-lengths or assortments of logs are then transported by log trucks or by railroad to a wood-processing industry. In the tree-length method, trees are delimbed immediately after felling, then the intact stems are skidded to an upper landing. At the upper landing, stems are loaded into trucks for intermediate secondary transport to the lower landing (i.e., processing yard) where they are bucked into assortments and loaded into trucks or trains. The third method, cut-to-length, means that the trees are both delimbed and bucked into log assortments in conjunction with the felling operation. The assortments are then transported by forwarders to the roadside where they are piled to await secondary transport to a wood-processing industry.

Each of the harvesting methods also has its specific features that depend on natural and production conditions, the types of machines and mechanisms used, or on the relative share of manual operations in the overall process. Thus, depending on the level of mechanization and the type of equipment used, all the identified harvesting systems can be divided into the following groups:

1. *Fully mechanized cut-to-length harvesting*: felling, delimbing and cross-cutting with a harvester, and skidding with a forwarder: **CTL (h+f)**;
2. *Partially mechanized cut-to-length harvesting*: felling, delimbing and cross-cutting with a chainsaw, and skidding with a forwarder: **CTL (cs+f)**;
3. *Partially mechanized tree-length harvesting (traditional*): felling with a chainsaw, delimbing with a chainsaw/axe, and skidding with a cable skidder: **TL (cs+s)**;
4. *Fully mechanized full-tree harvesting:* felling with a feller buncher, and skidding with a grapple skidder: **FT (fb+s)**;
5. *Partially mechanized full-tree harvesting:* felling with a chainsaw, and skidding with a cable skidder: **FT (cs+s)**.

1.2 Indicators for evaluation

The efficiency and functionality of a particular harvesting system depends 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 (trail depth or degree of soil compaction), damage to undergrowth or remaining trees, etc. Certainly, the *wood quality* cannot be ignored when comparing different technologies. This indicator is determined by evaluating the quality of timber in accordance with the quality specifications in the customer contracts, as well as with other quality requirements. 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.

Hence, there is a need for a comprehensive approach towards the evaluation of efficiency and selection of the most appropriate technology for the given natural and production conditions. This evaluation should be based on a number of indicators including economics, environmental issues, ergonomics and the quality of timber produced.

1.3 Studied companies

To evaluate the efficiency of the harvesting methods currently used in Northwest Russia, the authors performed comprehensive field studies on the earlier mentioned indicators. The Republic of Karelia was selected as a study region, because its territory is very representative in terms of the wide range of harvesting machinery used and in terms of nearly all felling technologies being employed in different natural conditions that are typical for Northwest Russia. The study was performed in 2007–2008 and involved 15 harvesting companies that provide approximately 40% of the total harvesting volume in the republic. The selected companies perform harvesting operations across the whole territory of the Republic of Karelia in different conditions and apply all the mentioned technologies, using both Russian and foreign machinery (Table 1.1).

Table 1.1. Basic data about companies

Company	Technology	Average skidding distance, km	Average transportation distance, km	Average stem volume, m^3	Species composition of stands	Annual harvesting volume, m^3
1	a) CTL (h+f)	0.3	60	0.303	pine 40%, spruce 50%, birch 10%	63 400
	b) TL (cs+s)	0.3	60	0.488	pine 60%, spruce 40%, birch <5%	75 400
	c) FT (fb+s)	0.7	60	0.276	pine 50%, spruce 40%, birch 10%	103 300
2	a) CTL (h+f)	0.4	78	0.130	pine 30%, birch 70%	106 800
	b) CTL (cs+f)	0.4	78	0.130	pine 30%, birch 70%	71 800
3	a) CTL (h+f)	0.3	26	0.272	pine 50%, spruce 30%, birch 20%	50 000
	b) CTL (cs+f)	0.3	26	0.272	pine 50%, spruce 30%, birch 20%	34 400
4	CTL (h+f)	0.2	25	0.356	spruce 80%, pine 10%, birch 10%	90 000
5	a) CTL (h+f)	0.6	56	0.282	pine 40%, spruce 20%, birch 20%, alder 20%	144 800
	b) TL (cs+s)	0.7	56	0.251	spruce 40%, birch 30%, alder 30%, pine <5%	176 400
6	CTL (h+f)	0.4	8	0.127	pine 20%, birch 80%	48 000
7	CTL (cs+f)	0.4	43	0.257	pine 30%, spruce 20%, birch 50%	58 000
8	CTL (cs+f)	0.3	96	0.313	pine 10%, spruce 30%, birch 40%, alder 20%	102 600
9	CTL (cs+f)	0.4	124	0.300	pine 20%, spruce 20%, birch 40%, alder 20%	96 200
10	TL (cs+s)	0.5	20	0.641	pine 20%, spruce 30%, birch 30%, alder 20%	197 900
11	TL (cs+s)	0.6	58	0.267	pine 10%, spruce 40%, birch 30%, alder 20%	70 100
12	TL (cs+s)	0.4	60	0.230	pine 30%, spruce 10%, birch 60%	75 200
13	TL (cs+s)	0.6	36	0.300	pine 10%, spruce 30%, birch 40%, alder 10%	122 000
14	a) TL (cs+s)	0.3	13	0.211	pine 60%, spruce 30%, birch 10%	218 400
	b) FT (fb+s)	0.15	70	0.234	pine 40%, spruce 50%, birch 10%	214 900
15	FT (cs+s)	0.5	35	0.254	spruce 50%, birch 30%, alder 20%, pine <5%	67 100

The total harvesting volumes and volumes by individual harvesting methods for the studied companies for 2006 are shown in Fig. 1.1.

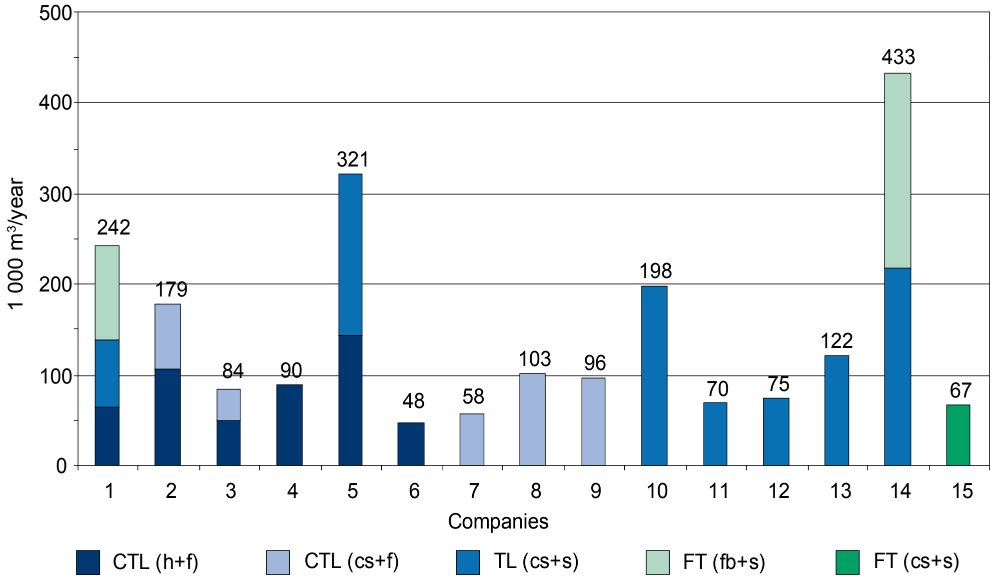

Fig. 1.1. Harvesting volumes by studied companies

Altogether, in terms of harvesting volumes by technology, the distribution is as follows: tree-length 42%; cut-to-length 40%; full-tree 18% (Fig. 1.2).

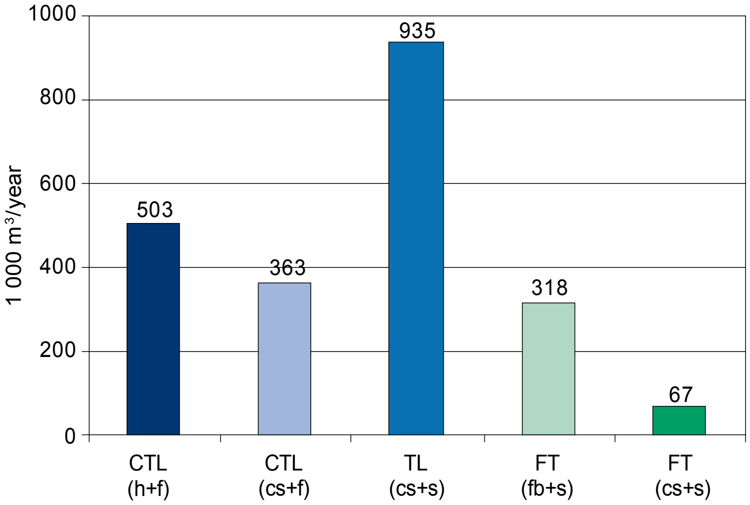

Fig. 1.2. Harvesting volumes by technologies

The following machinery was used in the studied logging processes: feller bunchers (Timberjack 850), wheeled and tracked harvesters (Timberjack 1270D, John Deere 1070D, John Deere 1270D, Volvo EC210BLC, Valmet 901.3, Valmet 911.3), tracked skidders (TDT-55A, TLT-100A, TB-1-16, ML-136), wheeled forwarders (Timberjack 1410D, Timberjack 1010D, John Deere 1110D, John Deere 1410D, Valmet 840.3), wheeled skidders (Timberjack 460D), delimbers (LP-30B) and processors (Hitachi Zaxis 230). The study involved field measurements and a personnel survey with questionnaires for staff and managers of the harvesting companies. Field research was carried out at 23 harvesting sites, the locations of which are shown in Fig. 1.3.

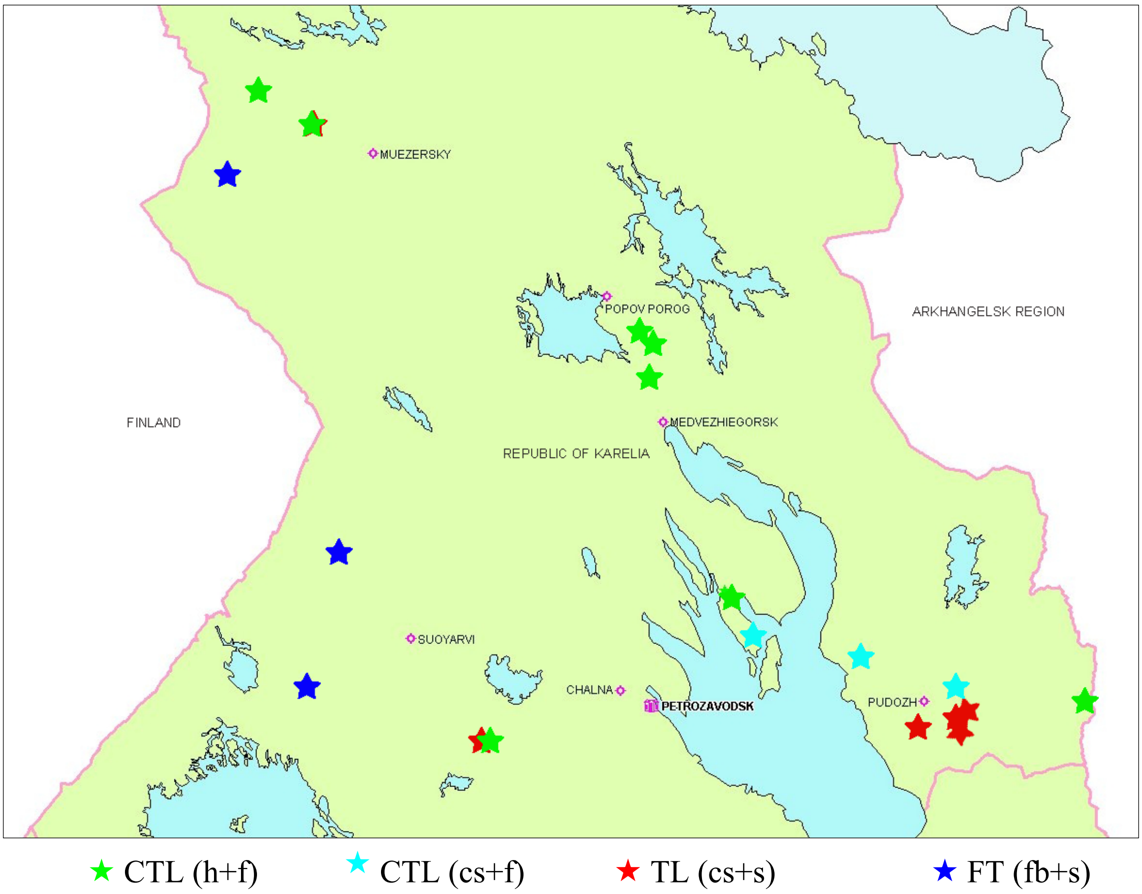

Fig. 1.3. Field survey sites

2 Economic efficiency of wood harvesting

2.1 Methods and data

2.1.1 Productivity

The main evaluated parameters were shift and hourly output for basic harvesting operations, both per machine system and per single machine or mechanism.

1. *Output per one machine-shift for a machine system (m^3)* was determined based on the average operational data of the machines used at the felling site. The output per one machine-shift was obtained using the actual data of the company and was calculated as a ratio of the annual amount of work done to the number of completed shifts. The final average output per shift was defined as the averaged value of all the work done. Internal reporting of the companies served as the main source for productivity estimation. The reporting included both standard forms and forms that are typical only for the given company.[1] The number of companies included in the evaluation of the output per machine-shift is shown in Table 2.1.

Table 2.1. Data used to evaluate the output per machine-shift

Technology	Number of companies	Number of machine-chains	Completed machine-shifts (year)
CTL (h+f)	6	12	9 342
CTL (cs+f)	5	5	8 853
TL (cs+s)	7	7	24 360
FT (fb+s)	2	2	3 093
FT (cs+s)	1	1	1 118

When evaluating the output, it is very important to consider not only the current output level, but also the change dynamics of the production. During the evaluation, a relation between the output and the experience of harvester operators was detected by using the Timbermatic data accounting system installed on John Deere harvesters. The work of 20 harvester operators was evaluated during their first 16 months of work experience. The total change in the output was defined as an average for all the work performed.

2. *Output per hour for a single machine or mechanism (m^3)* was defined as an average during the shift for the given machines and mechanisms, including the time spent on pre- and after-harvesting operations, time for rest, as well as downtime. It was defined as the ratio between the total amount of work done at each of the operations of the process and the shift duration. The actual output per hour was calculated based on the following data:

a) company data: time-study data provided by the staff of the planning and economics departments of the studied companies;

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[1] The study has shown that harvesting companies use standard forms only for decision-making at the top-level management and typically only for substantial business operations. Non-standard forms usually appear when there is a need to evaluate certain business processes or their components. For example, companies that use more than one type of harvesting system manage their operative reporting for each of the technologies employed without taking into account factors such as mechanization level, type of machinery or machine systems, seasonality, etc. Hence, it is evident that, in order to perform a complete evaluation of the current situation in harvesting, formalization of business processes is needed, which means the developing and applying of documentation forms for investigating harvesting operations.

b) field study: a time study (photographing, videotaping) carried out by the executors of this study. The duration of different phases of the harvesting process was recorded (time elements of the operation), e.g. forwarder unloading and also the beginning and the end of individual phases such as skidding and transportation to the loading site.

The time study was carried out by using observation forms (Appendix 1). All working time was recorded by registration points, which defined the end of the previous operation and the beginning of the following operation, according to the methodology [2, 6]. The number of measurements per technology and per company is shown in Table 2.2.

Table 2.2. Data for output per hour

N	Technology	Number of measurements (source)			
		Data of Timbermatic system	Company data	Field study	
				Time-study photographing	Time-study videotaping
1	CTL (h+f): companies 1, 2, 3, 4, 5 and 6; 17 felling sites				
	Harvester	258	10	7	6
	Forwarder	-	4	10	5
2	CTL (cs+f): companies 2, 3 , 7, 8 and 9; 10 felling sites				
	Chainsaw: felling, delimbing	-	9	7	6
	Forwarder	-	14	2	2
3	TL (cs+s): companies 1, 5, 10, 11, 12, 13 and 14; 7 felling sites				
	Chainsaw: felling	-	4	3	1
	Chainsaw: delimbing and topping	-	5	3	1
	Skidder (TDT)	-	4	3	1
4	FT (fb+s): companies 1 and 14; 3 felling sites				
	Feller buncher (TJ 850)	-	1	2	3
	Skidder (TJ 460 D)	-	1	2	3
	Hitachi 230 (LC)	-	1	2	2
5	FT (cs+s): company 15; 2 felling sites				
	Chainsaw: felling	-	-	2	1
	Skidder (TDT)	-	-	2	3
	Delimber (LP -30B)	-	-	2	1

2.1.2 Direct operating costs

Only direct harvesting costs were taken into account in the study. Other associated costs, which are usually attributed to direct costs, such as stumpage price, as well as general and administrative costs, were excluded. In other words, only a limited number of direct costs per work unit (RUB/m^3) originating between "stump" and upper landing (loading site) were considered. These costs were evaluated by economic components and factors [4, 5, 7].

When evaluating economic components, the costs were grouped according to their economic content:

- Salaries for workers employed in harvesting operations;
- Social-security charges;
- Machine and mechanism amortization;
- Material costs (including fuel and lubricants, equipment maintenance and repair)
- Other costs, including leasing payments and also depreciations of chainsaws, rubber, cables, blocks, etc.

For an assessment of technical and economic factors, the costs were grouped according to harvesting volumes and were divided as follows:

- *Fixed costs*: the cost of auxiliary materials used for repairs; lubricating and wiping materials, tools; leasing payments for equipment and machinery; mandatory property insurance payments, bank loan repayments at the interest rate set by relevant authorities, amortization deductions for fixed assets (machinery and equipment); leasing and other payments are also taken into account;
- *Variable* costs: fuel and energy costs, salaries, social-security charges, etc.

Cost evaluation was based on the following data (Table 2.3):

- Economic reporting documents and operational reporting data used in the studied companies;
- Available summary reports, prices for purchased resources during relevant time periods, cost standards, work rates and other documents.

Table 2.3. Used cost data

Technology	Companies	
	Actual data	Estimation
CTL (h+f)	1, 2, 3, 4, 5, 6	
CTL (cs+f)	2, 3, 8	7, 9
TL (cs+s)	1, 5, 12, 13, 14	10, 11
FT (fb+s)	1, 14	
FT (cs+s)	1	

Costs were calculated using the above-mentioned cost elements per work unit (RUB/m^3),[2] taking into account the amount of work done. Further, the average costs were calculated for each technology, machine and mechanism, both in aggregated form and for each technical and economic factor. The results obtained were compared with the Finnish cost calculation method [1], which provides a simplified tool for decision-making outside the bookkeeping system.

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[2] Harvesting companies frequently use non-standard, self-composed templates for economic reporting and internal standards (norms, rates, etc.) for internal use.

2.2 Results

2.2.1 Productivity

Output per machine-shift based on the actual company data is shown in Fig. 2.1.

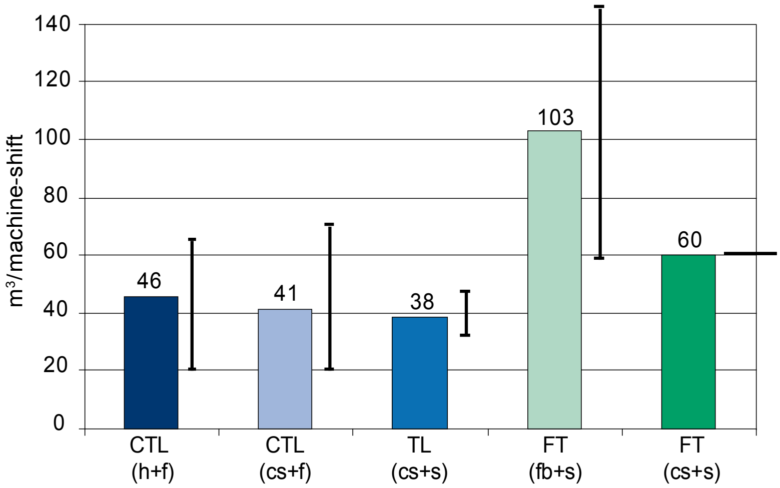

Fig. 2.1. Output per machine-shift

The fully mechanized full-tree harvesting system provided the highest output and the partially mechanized tree-length harvesting system provided the lowest output. At the same time, the greatest variation of the results was also found in full-tree harvesting, this being due to a number of factors. Predominant factors were: inefficient planning of harvesting operations, idle periods when machinery is transferred from one site to another, and long repair periods due to lack of a developed service system for the machines used in this technology. The narrow variation range for the tree-length system shows that this traditional technology has no potential to increase its productivity. The average output for the fully mechanized cut-to-length system was higher than for the partially mechanized cut-to-length system, yet the maximum peak values were observed with the latter technology. In general, the actual output was also dependent upon other natural and technical factors (size of harvesting site, tree species, etc.).

The influence of the operator's work experience on productivity was evaluated.[3] It was found that, in general, a harvester operator reaches the level of 90% of the average output only after nine months of work experience; the 100% level was attained after 13 months (Fig. 2.2). Thereby, it is obvious that, in the harvesting companies of the Republic of Karelia, the professionalism and experience of harvesting-machine operators have a substantial impact on the increase of output. Also proper training is essential.

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[3] Data registered in the Timbermatic time-accounting system were used. The data is averaged because operators working by work shifts (12 hours each) have differing work experience. It should be noted that even by the sixteenth month, the output level was not very high, i.e., there is potential to increase the output.

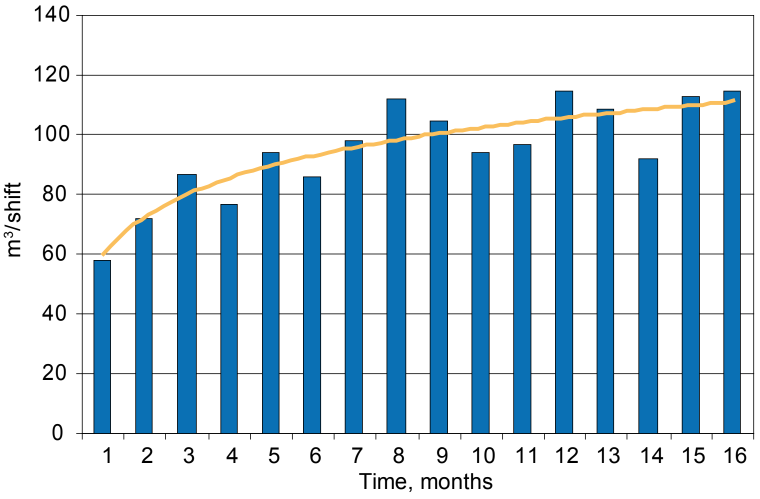

Fig. 2.2. The relation between average output and work experience of harvester operators (line: regression trend)

Output per hour is shown in Fig. 2.3. The hourly output by machines and mechanisms was characterized by a great range of data variation, due to the same reasons as for output data per machine-shift. Table 2.4 presents the average values of the hourly output for the cut-to-length harvesting system.

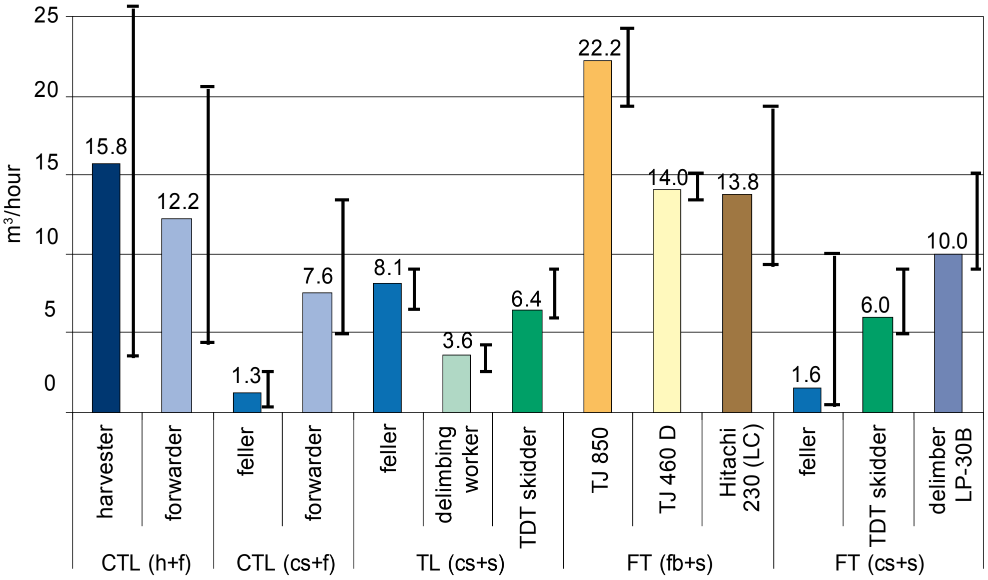

Fig. 2.3. Output per hour

Table 2.4. Output per hour (minimum and maximum values), m³/hour

Technology	Data of Timbermatic system	Company data	Field study	
			Time-study photographing	Time-study videotaping
CTL (h+f)				
Harvester	16.5 (4.0 – 26.0)	9.6 (6.8 – 14.3)	15.9 (3.1 – 21.6)	17.1 (6.0 – 19.9)
Forwarder	–	8.2 (4.7 – 11.1)	13.7 (10.0 – 20.1)	11.5 (11.0 – 12.0)
CTL (cs+f)				
Chainsaw	–	1.2 (0.6 – 1.5)	1.5 (1.0 – 2.0)	1.2 (0.85 – 1.6)
Forwarder	–	7.0 (5.0 – 13.0)	8.5 (7.5 – 9.5)	7.5 (7.1 – 7.9)

The output data taken from company documents were, on the average, lower than the results of the field study. This is explained by the fact that companies have conducted time studies mainly when introducing new machinery into practice. That is when the operators' productivity is usually at its lowest. The minimum data variation was observed for partially mechanized felling and the maximum for fully mechanized, which is connected to the variation in harvester operators' work experience and professional skills.

2.2.2 Direct operating costs

Total direct costs per 1 m^3 of harvested wood are shown in Fig. 2.4 (by company) and in Fig. 2.5 (by harvesting method). The costs varied from one company to another, due to different conditions and harvesting volumes.

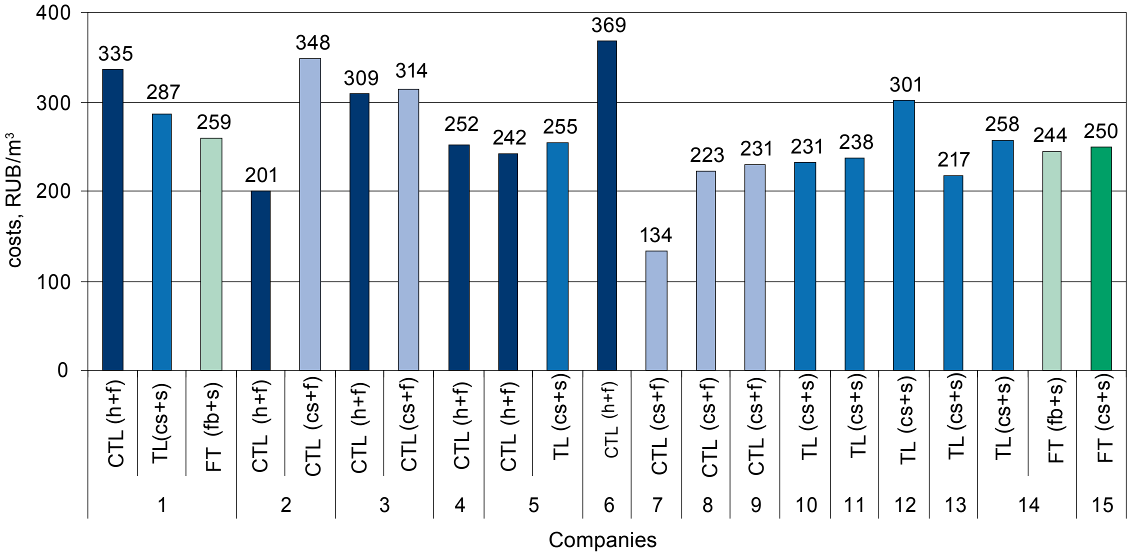

Fig. 2.4. Direct operating costs by studied companies

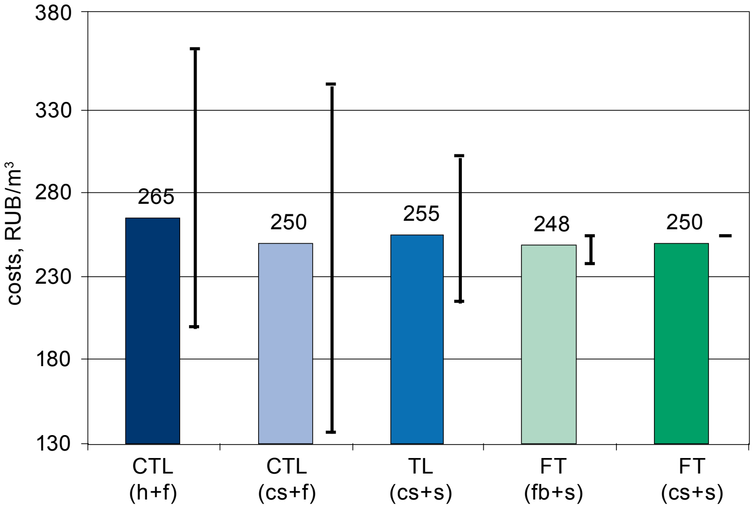

Fig. 2.5. Average direct operating costs by technologies

As seen from the Fig. 2.5, the direct operating costs did not differ significantly. The lowest unit costs were observed in the fully mechanized full-tree system. The range of costs was, in this case, quite narrow, caused by the limited amount of observations made for this technology. At the same time, the widest range of costs was typical for the partially and fully mechanized cut-to-length systems. It can be concluded from the results that, with good organization of harvesting operations and a high level of machinery productivity, the partially and fully mechanized cut-to-length technologies could have lower costs than the other technologies.

Low direct operating costs were observed when felling was performed with chainsaws, costs being mainly the fellers' salaries and materials spent (fuel and lubricants, saws, etc.) (Fig. 2.6). In the case of forwarders, costs differed when a forwarder was used with the partially and fully mechanized cut-to-length systems, due to the difference in wear and tear of machinery, average output and operational conditions. For similar reasons, there was also a difference in costs for tracked skidders (TDT) used in tree-length harvesting and partially mechanized full-tree harvesting.

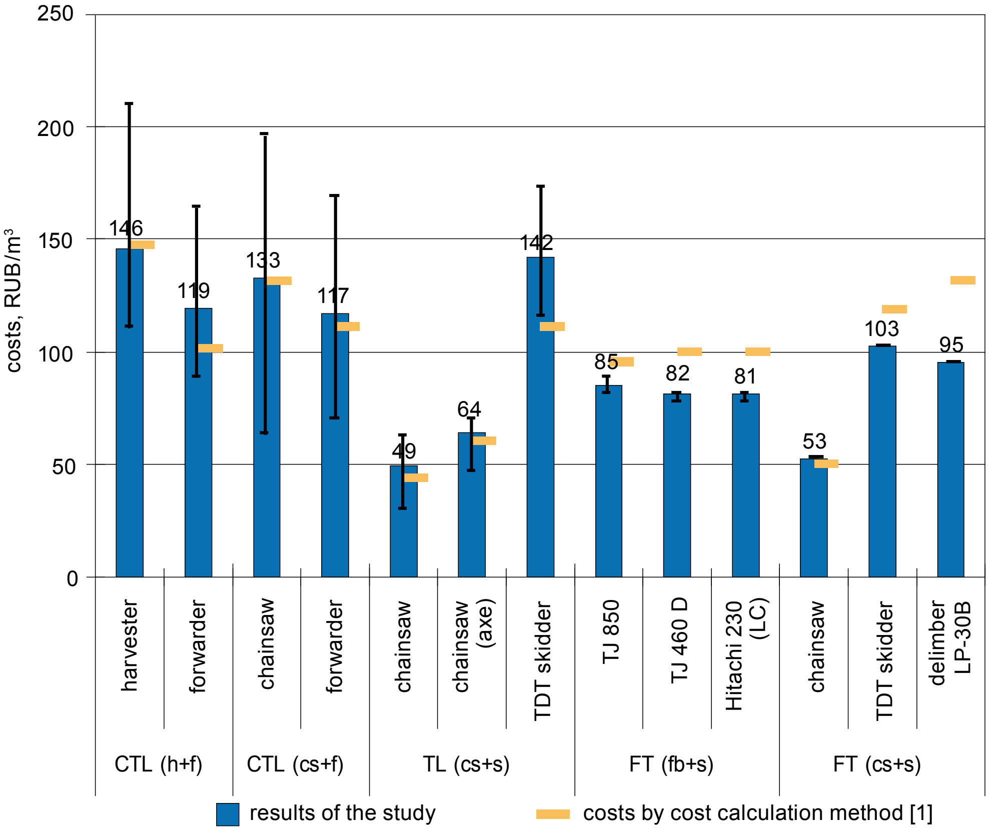

Fig. 2.6. Average operating costs for machines and mechanisms[4]

The Finnish cost calculation method also demonstrated similar values for different technologies, compared to the data from the field study. The difference in the obtained results was very slight and was explained by the simplified approach used. Examples are presented in Appendix 2.

The cost structure of the studied harvesting methods was evaluated by cost elements (Fig. 2.7), as well as by technical and economic factors (Fig. 2.8). As seen in Fig. 2.7, the maximum data-variation range by cost elements was observed for the partially and fully mechanized cut-to-length harvesting systems, which was explained mainly by the higher number of observations compared to the tree-length and full-tree systems. Other costs may include the leasing of harvesting machines and mechanisms; wear and tear of machines; work-clothing costs; property tax; transport tax, etc.

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[4] The range of data in the figure reflects the minimum and maximum value of the parameter; the actual average value was calculated as a weighted-average.

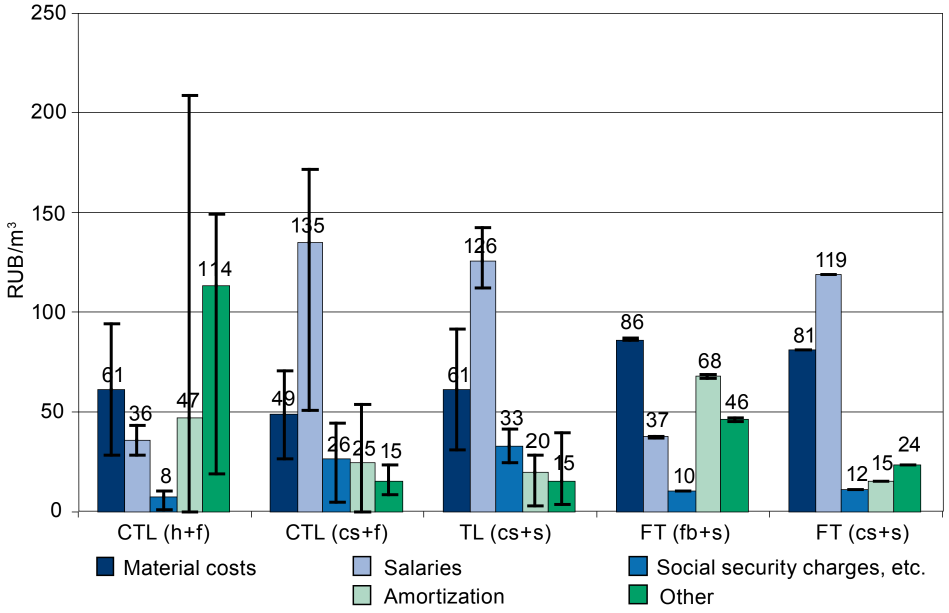

Fig. 2.7. Average costs by elements

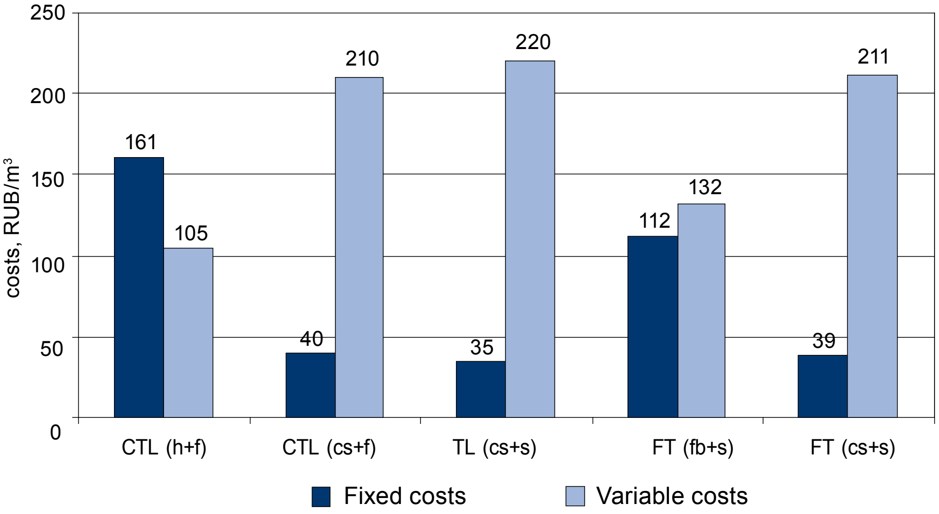

Fig. 2.8. Average direct operating costs by technologies

Based on the cost structure evaluation by technical and economic factors, it can be concluded that the fully mechanized cut-to-length system had the highest fixed costs. The reason for this is the short time that the machines have been in use. In most cases, machines were purchased under a leasing agreement, which increases costs substantially during the first 3–5 years of the machine's service time, due to higher amortization expenses (up to 40% in the cost structure). The partially mechanized cut-to-length method also showed reasonable cost levels. The share of fixed costs was 16%, due to fewer machines needed in this harvesting method. Variable costs mainly consisted of salaries, social-security charges and other salary-related deductibles (over 50% of the total costs) and material costs (about 20%). For partially mechanized full-tree harvesting fixed costs represented 16% and variable costs 84% in the cost structure. Labour costs (over 50%) and material costs (over 30%) were the most significant elements. Costs for the traditional tree-length method (14% fixed, 86% variable) were generated mainly by salaries (over 60%) and material costs (25%). In this case, because of the heavy wear and tear of the machinery used, the share of amortization payments was lower compared to other technologies (less than 7%).

2.3 Analysis of the results

2.3.1 Productivity

Fully mechanized full-tree harvesting had the highest productivity. In general, the average output for this technology was 1.8 times higher than the average output provided by any other technology in similar natural and operational conditions. With proper work management (no idle periods caused by organizational reasons, well-timed delivery of materials, etc.), the output for this technology could be increased by 20–50%.

Partially mechanized full-tree harvesting also demonstrated a reasonable output. On average, in order to ensure continuous and smooth work without interruptions, a team of six fellers, two skidding tractors and one delimber is needed. In general, the output of this technology was 4% higher than the average. Since work with this technology is traditionally performed in one shift (sometimes in summer in two shifts) and outdated equipment is used, prospects to increase the output are limited. In addition, in the full-tree system, there is a need to perform another set of operations at the central processing yard, which substantially decreases the productivity of this technology.

The fully mechanized cut-to-length system indicated an output of 20% lower than the average, but still higher than the partially mechanized cut-to-length or traditional tree-length harvesting systems (11% and 20% respectively). It is important to notice that these low output figures were mainly caused by the low level of the operators' proficiency and by insufficient training. For example, during the time study, skilled harvester operators demonstrated an hourly output of up to 26 m^3. At the same time, unskilled operators produced from 3 to 15 m^3 – although, if the work is properly organized and managed and the operators properly trained, the average output could be increased by two times. Considering the productivity of a machine system, it can be noticed that the productivity of harvesters is, on average, 30% higher than that of forwarders. For this reason, a machine system of two harvesters and three forwarders can be recommended in order to provide a high level of machine system productivity.

the partially mechanized cut-to-length harvesting system provided an 8% higher productivity than the traditional tree-length harvesting. The optimum team for this technology, with one work shift of fellers and a round-the-clock shift of forwarders, should, on average, consist of 16 fellers and one forwarder. Partially mechanized tree-length technology had the lowest productivity. The average output of a feller was 12% higher than a person delimbing (on average, two persons delimbing with axe or chainsaw) and 27% higher than the productivity of a tracked skidder (TDT-55, TLT-100). This technology has almost no further potential for productivity increase. In addition, work is usually performed only in one shift (sometimes in summer in two shifts). Hence, if the traditional tree-length harvesting system is given up, the fully mechanized harvesting systems seem to be more promising in terms of productivity.

2.3.2 Direct operating costs

Comparing the technologies studied by direct operating costs per unit, it can be concluded that there was no significant difference. It should be noted that the use of traditional technology (tree-length) had a negative impact on the costs. This method includes not only the felling operations and transportation of stems, but also the work performed at the central processing yard. Considering the high price of the equipment used, the high level of its wear and tear and low utilization level, it can be stated that this technology is more costly than the other studied technologies. In cut-to-length harvesting, the logs produced are ready for transportation at the upper landing (loading site), while tree-length as well as full-tree harvestings include operations at the processing yard. Therefore, methods requiring operations at the processing yard can have a rather negative influence on companies' economy compared to methods providing logs ready for delivery to customers.

When the full cost structure was analyzed, taking into account work at the processing yard, timber transportation, etc., the following distribution of technologies was observed (Fig. 2.9):

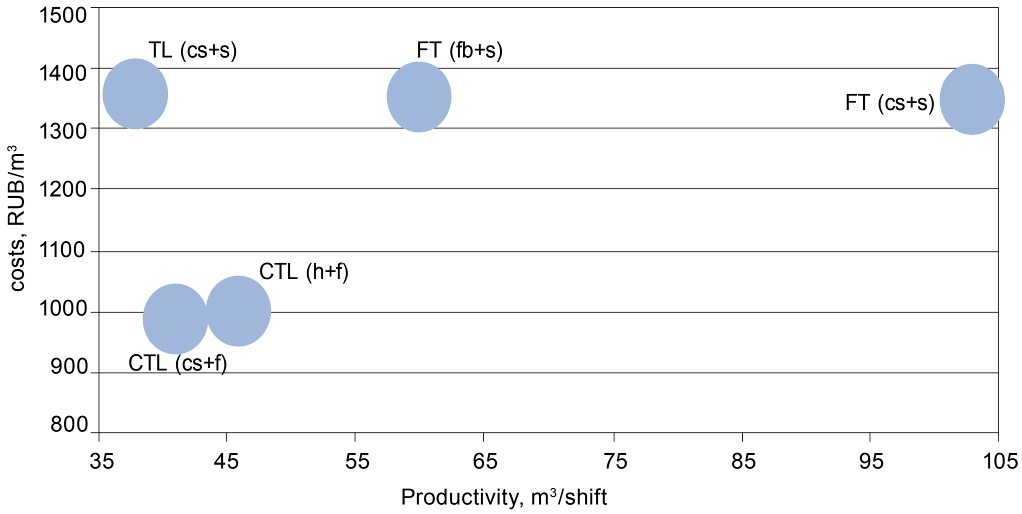

Fig. 2.9. Distribution of technologies by average costs and output

Thus, considering not only the direct operating costs for felling operations, but all the costs that form the total (commercial) production costs, it can be said that the fully mechanized cut-to-length harvesting system may allow companies to significantly reduce their losses and improve the harvesting efficiency.

Comparing the average actual harvesting costs of the companies studied with the Finnish cost calculation method [1], it can be stated that there is no significant difference. The existing slight difference is explained by the simplified approach used in the Finnish method and the averaged values used in calculations. In general, the results obtained with this method stay within the ranges of actual company data. This proves the applicability of this method for preliminary estimation of harvesting efficiency.

2.4 Alternatives for utilizing new machinery in harvesting

When purchasing harvesting machines, it is necessary to estimate the economic implications of the decisions made, i.e., to analyze the future cash flows for different types of funding. The main funding sources to purchase machinery are own capital, bank loans and leasing.

Let us look at how the average harvesting costs change in cases in which the new machinery is purchased to be used in traditional tree-length harvesting, fully and partially mechanized cut-to-length harvesting and fully mechanized full-tree harvesting, by different funding sources [8]. The initial conditions are: a three-year period for both loan repayment and leasing contract with an annual interest rate of 18%, inflation for variable costs of 12%, with other conditions being equal (size of felling site, stem volume, etc.). In practice, there is a great multitude of lending and leasing schemes used for purchasing harvesting equipment. It is up to the company to choose the leasing company, bank or equipment supplier based on many external factors that influence the decision-making process.

As Fig. 2.10 shows, the lowest cost alternative is for the company to purchase machines using their own funds as the source of funding. This, however, requires the maximum cash outflow at the start, and therefore companies very often do not have enough funds for this type of investment. Moreover, net profit is mostly used for this purpose, which might have a negative impact on the company's economy.

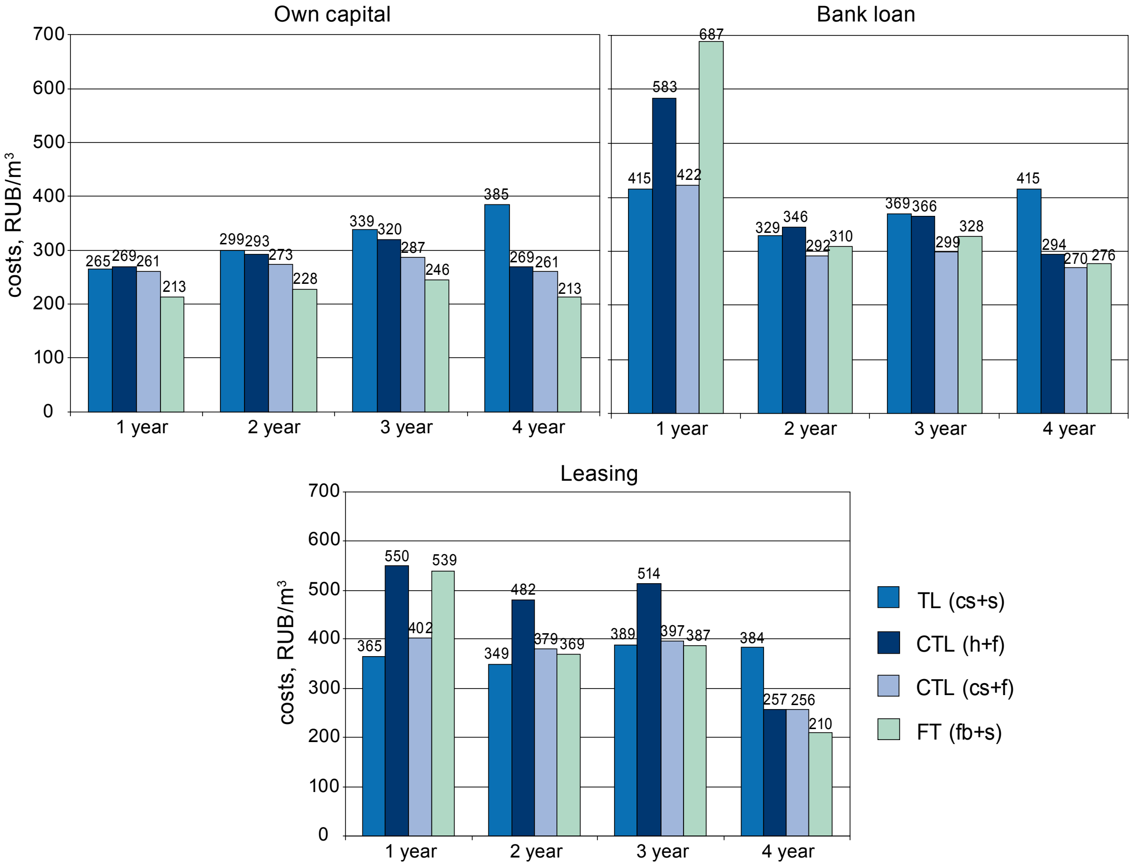

Fig. 2.10. Changes in costs by financing sources

When credit is used to purchase machinery, large initial investments from the company's budget are not required. Moreover, after the loan is paid, the machines that are on the company's balance sheet have a substantial residual value. This means that even after the loan period expires, the company will still be saving on the income tax (amortization deductions and property tax). The cost of funding during the loan period is a little lower than in the case of leasing. However, in the long-term, it is leasing that has the best prospects, due to the following reasons:

- leasing gives an opportunity to use accelerated amortization (with the maximum coefficient 3). This makes the payback period shorter and the company can replace outdated machines with new ones more quickly;
- by the fourth year (in the examined case), the level of harvesting costs gets lower compared to the case when bank loans were used;
- leasing payments are 100% allocated to the costs of roundwood (the "Other costs" element);
- other reasons such as right of VAT deduction, easy access to leasing, etc.

Comparing different harvesting methods by the level of harvesting costs, it is seen that, during the first years of machine operation, it is the tree-length harvesting that has the lowest costs. But in the longer term, this technology shows a swift increase in costs, due to the high level of variable costs (86%). By the fourth year of operation, the tree-length technology has the highest level of costs compared to all other technologies. The partially mechanized cut-to-length technology demonstrates the lowest level of costs when either a bank loan or leasing approach is used. By the fourth year of operation, the cost level for fully and partially mechanized cut-to-length technology draw closer. In this case, the cut-to-length technology is advantageous for the company because less funding is required in the first year of operation. The full-tree harvesting method requires substantial funds during the first year (when leasing is used), but by the fourth year the method shows the lowest costs.

2.5 Conclusions and recommendations

The results of the study show that, in the course of decision-making, managers of harvesting companies often pay insufficient attention to the tools of controlling business processes and are using only financial and tax accounting reports as supporting material. The “all-in-one-pot” method of cost calculation is quite frequently used by harvesting companies. Yet, this method does not provide proper cost evaluation and controlling of costs by the place of origin and by operational phases of harvesting. This often leads to the lack of actual data about consumption, overconsumption or saving of resources. Besides that, companies do not fully use the capacities of management accounting. Therefore, they cannot differentiate cost information by types of harvesting operations and end products. Meanwhile, the cost estimation data sheets prepared in the process of harvesting can be used as a tool for quick evaluation of the work and the existing management approach allows the measurement of the harvesting costs by each work phase and operation.

Looking at the harvesting methods, it can be stated that both the fully and partially mechanized cut-to-length systems, as well as the fully mechanized full-tree system, all have significant potential for productivity improvement. An analysis of the harvesting methods by direct operating costs did not reveal any significant difference between the technologies. However, considering that the tree-length and full-tree technologies require further work at the central processing yard, the cut-to-length system proves to be the most preferable in terms of costs, because the final product of harvesting (logs) is available directly at the upper landing (loading site).

Currently, varying combinations of different harvesting technologies are used by companies (traditional tree-length transportation with subsequent work at the central processing yard or various modifications of the cut-to-length method). These methods should be evaluated across the whole spectrum of technical and economical indicators. Transition to a new technology requires substantial financial investments. Therefore, evaluation should be performed for different financial approaches: using their own funds, loans or leasing. Altogether, it may be concluded that transition to the cut-to-length method allows in the long term a decrease in production costs, an increase in productivity and, consequently, an improvement in the financial situation of the company and the competitiveness of its products.

3 Harvesting methods and their impact on the forest environment

3.1 Methods and data

3.1.1 Field study

The impacts of harvesting technology on soil were studied by evaluating the following parameters:

- reduction of soil porosity along the machine trails, in % of the porosity of soil with intact structure;
- average trail depth, cm;
- mineralization of the upper soil layer, in % of the harvesting-site area.

The soil is mainly damaged along strip roads, at loading sites or along other machine trails. To measure the above-mentioned indicators, linear measurement lines were laid across the trail in the starting, middle and end zones of the trail. On each line, measurement points were set as follows: left rail, middle part of trail, right rail, and cutting strips (monitoring of natural properties). In every zone of the trail, three measurement lines were laid out after every 0.5 m (Fig. 3.1) in accordance with earlier proven methodology [16].

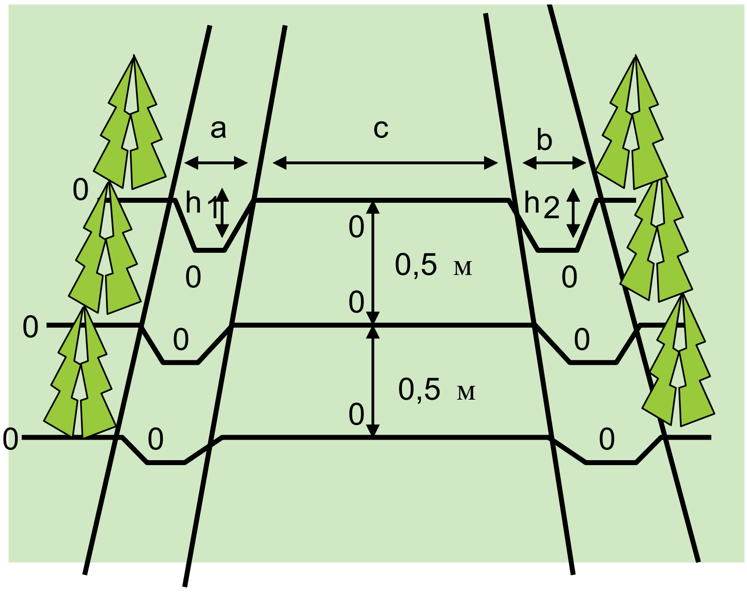

Fig. 3.1. Layout of measurement lines

The percentage of mineralization of the upper soil layer was calculated using the formula:
$M = M_V + M_P + M_{VS}$
where M_V is the mineralization of strip roads, %;
M_P is the mineralization of cutting strips, %;
M_{VS} is the mineralization of the upper landing, %.

The trail depth was measured in both right (h_1) and left (h_2) rails (Fig. 3.2) and the average value of the trail depth was calculated. This indicator was then averaged across all the measured sites, thus obtaining the final average value of trail depth. To determine the percentage of porosity reduction, organic layer was removed in each measurement point and soil samples were taken using soil samplers. Soil samples were taken in measurement points according to a standardized methodology [9] from the surface layer of 0 – 5 cm and from the deep layer of 15 – 20 cm in the starting, middle and end zones of the skid trails and main strip roads (points 0, see Fig. 3.1). the soil samples were delivered to the soil laboratory in airtight packaging (Fig. 3.3) and weighed with electronic scales with a resolution of 0.01 g. As well, the density of the soil samples was determined. Soil types were named according to the state soil-classification standard [11]. Soil porosity and its reduction percentage were determined.

Fig. 3.2. Measurement of trail depth

Fig. 3.3. Soil sample cups

The impacts of harvesting technology on soil were studied only during the summer season. At the harvesting sites that were cut in winter, test soil samples were taken and the results demonstrated that, with established snow cover and sufficient frost depth, no significant changes occurred in the soil. Test samples taken from the middle part of the trail after the passing of harvesters and forwarders demonstrated that the soil between rails (C, see Fig. 3.1) stays almost intact. Therefore, no further samples were taken from the middle part of the trail at the sites harvested using cut-to-length machinery. Table 3.1 shows the number of measurements for each technology.

Table 3.1. Distribution of harvesting sites and soil samples by technologies and soil types

Technology	Number of sites (soil samples)	
	Sand or sandy loam[5]	Clay loam
Clearcuts		
CTL (h+f)	2(216)	2(216)
CTL (cs+f)	1(108)	1(108)
TL (cs+s)	1(144)	1(144)
FT (fb+s)	1(144)	1(144)
FT (cs+s)	-	1(144)
Total	5(612)	6(756)
Thinnings		
CTL (h+f)	-	1(108)
TL (cs+s)	-	1(144)
Total	-	2(252)

Impacts on remaining trees. In selection cuttings and thinnings, a key indicator is the damage percentage of the remaining trees. During the study, rectangle-shaped sample plots of a size of 100 x 50 m were established. They were divided into 10-metre-wide measurement strips parallel to the shorter side of the sample plot (Fig. 3.4). The strips were positioned with regular spacing and their total area was at least 8% of the harvesting site's area, in accordance with the Russian harvesting-site guidelines [12].

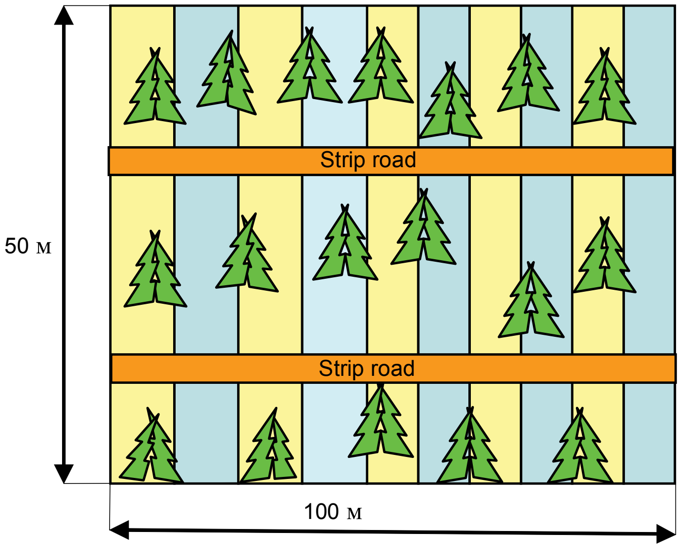

Fig. 3.4. Layout of the sample plots for determining the degree of impact on the remaining trees and undergrowth

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[5] Data shown here and below are for sands and sandy loams.

Damaged trees were examined and counted along the strips. According to harvesting and silvicultural guidelines [13 and 14], the following trees were considered as damaged:

- with a broken top (stem);
- tilted by 10 degrees or more;
- with a damaged crown of 1/3 of its surface or more;
- with bark loss of 10% of the stem circumference or more;
- with broken main roots.

Three reporting forms were compiled (Appendix 3) and used to record the percentage of damaged trees. The number of harvesting sites, sample plots and the number of measurements are shown in Table 3.2.

Table 3.2. Number of harvesting sites, sample plots and number of measurements for counting undergrowth and growing stock

Technology	Number of harvesting sites (sample plots)		Number of measure-ments
	Winter	Summer	
Clearcuts			
CTL (h+f)	2(5)	4(5)	2426
CTL (cs+f))	1(3)	2(5)	1472
TL (cs+s)	2(3)	2(5)	1594
FT (fb+s)	1(3)	2(5)	1602
FT (cs+s)	1(3)	1(3)	1116
Total	7(17)	11(23)	8210
Thinnings			
CTL (h+f)	-	2(2)	817
TL (cs+s)	-	2(2)	790
Total	-	4(4)	1607

Impacts on undergrowth and young stands. According to the instructions for preserving undergrowth and young stands [15], undergrowth is the growth that has regenerated under the main canopy cover, but has not reached the merchantable dimensions as described in the Russian guidelines for planning harvestings [12], i.e., the diameter at chest height is less than 8 cm and the tree height is below 2.5 m. Undergrowth is defined as a viable generation of the main tree species that ensures natural reforestration in the given conditions. A young stand consists of viable and well-rooted trees of the main tree species with heights more than 2.5 m and diameters of less than 8 cm that are capable of forming a part of the tree stand.

During the study, rectangle-shaped sample plots of a size of 100 x 50 m were established. They were divided into 10-metre-wide measurement strips parallel to the shorter side of the sample plot, using the same scheme that was used for the measurement of the remaining trees (see Fig. 3.4). Undergrowth was counted according to the instructions for preserving undergrowth [15] and the data was recorded on a reporting form (Appendix 4). The amount of survived viable undergrowth and young trees, as well as the survival rate, were determined for cutting-strip areas without skid trails and main strip roads, haulage roads, landing sites or storage areas located at the given site with undergrowth. The number of measurements is shown in Table 3.2.

Area occupied by trails and landings. Some parts of the harvesting area are allocated for technical purposes. This category includes areas occupied by trails, loading sites, production or auxiliary facilities. Changes appear in the forest environment of these areas. During the study, measurements of actual areas for technical purposes were conducted. Based on the measurements, the area occupied by upper landing sites and trails was determined and compared with the harvesting-site area indicated in the harvesting plan. The area allocated for technical purposes was determined, thus obtaining its share from the total harvesting-site area.

3.1.2 Expert evaluations

To determine the degree of negative impact of different harvesting methods on the forest environment, a questionnaire was developed and harvesting experts from the Republic of Karelia were interviewed. Both managers and operators of harvesting machines participated in the survey. Those interviewed were asked to evaluate the level of negative impact on forest environment using a five-score system, “5” standing for the maximum negative impact and “0” signifying the minimum negative impact. The scores were then summed up and averaged. In total, 21 persons were interviewed. The questionnaire data gives a subjective dimension to the evaluation of different harvesting methods.

3.2 Results

3.2.1 Impact on soil

Analysis of the soil samples showed a reduction of porosity along main strip roads and skid trails regardless of the technology employed (Figs. 3.5 and 3.6). The tree-length technology caused the greatest soil compaction (especially in the upper horizon). The minimum reduction of porosity was observed with the full-tree technology.

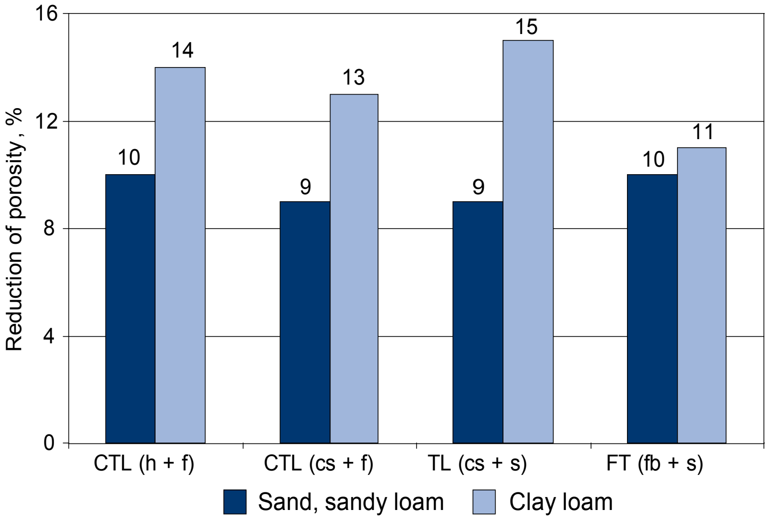

Fig. 3.5. Reduction of soil porosity along main strip roads

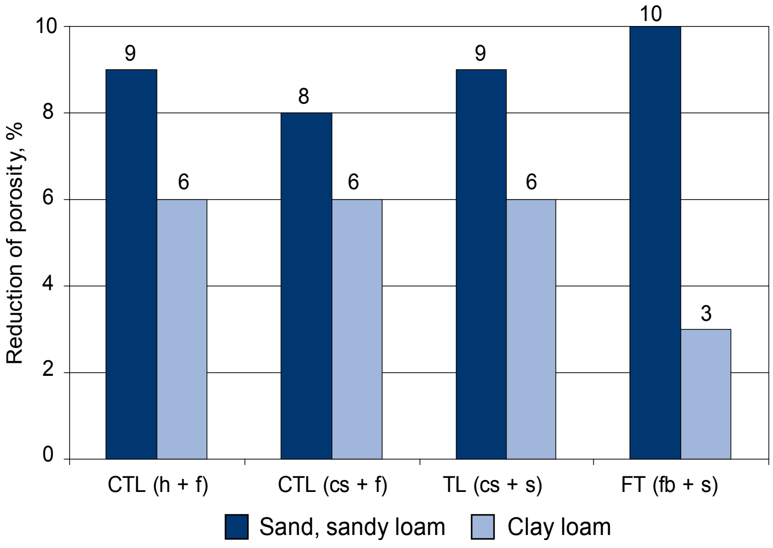

Fig. 3.6. Reduction of soil porosity along skid trails

The full-tree harvesting was performed with Russian machines in specific conditions of peaty clays with low bearing capacity. Porosity in these conditions was reduced about 23% along main strip roads and 17% along skid trails. It should be noted, that the tree-length harvesting caused some compaction (up to 5%) in the middle part of the strip road as well. The full-tree harvesting, on the contrary, was found to increase porosity up to 3% between the tracks. The cut-to-length harvesting technology was shown to keep the area between the tracks almost intact.

Fig. 3.7 shows averaged track depth values. The data indicated that on sandy soils the track depth is more or less the same, regardless of the technology used. On clay soils, significant track formation is typical for fully and partially mechanized cut-to-length technologies. For full-tree harvesting in peaty clays the average track depth was 41 cm.

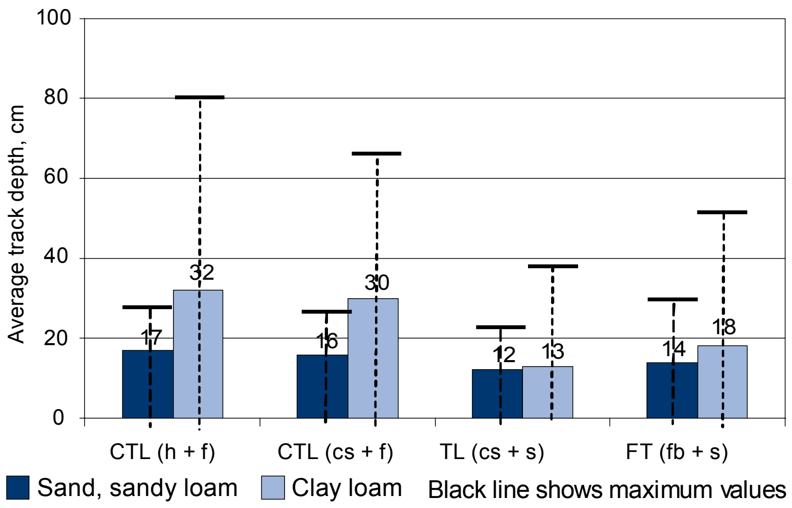

Fig. 3.7. Average depth of tracks made by machinery

The mineralization degree of the harvesting site was also determined during the experiment (see Fig. 3.8). As the diagrams show, the cut-to-length technology tends to cause less upper soil mineralization than the full-tree or tree-length technology.

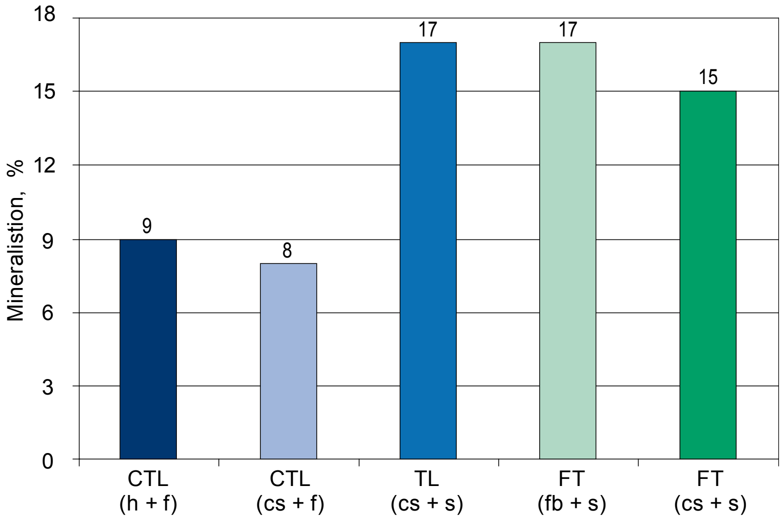

Fig. 3.8. Mineralization of the site in percentage

3.2.2 Impact on undergrowth and young stands

The results of undergrowth measurements made on sample plots on 18 harvesting sites are presented in Fig. 3.9. Each of the above-mentioned technologies, except for fully mechanized full-tree harvesting, provided the undergrowth preservation at the level stipulated in the Russian wood-harvesting norms [13]. It should be noted that the cut-to-length technology enabled some undergrowth preservation even in the trail area between rails, which was almost never observed for the full-tree and tree-length technology during the summer season.

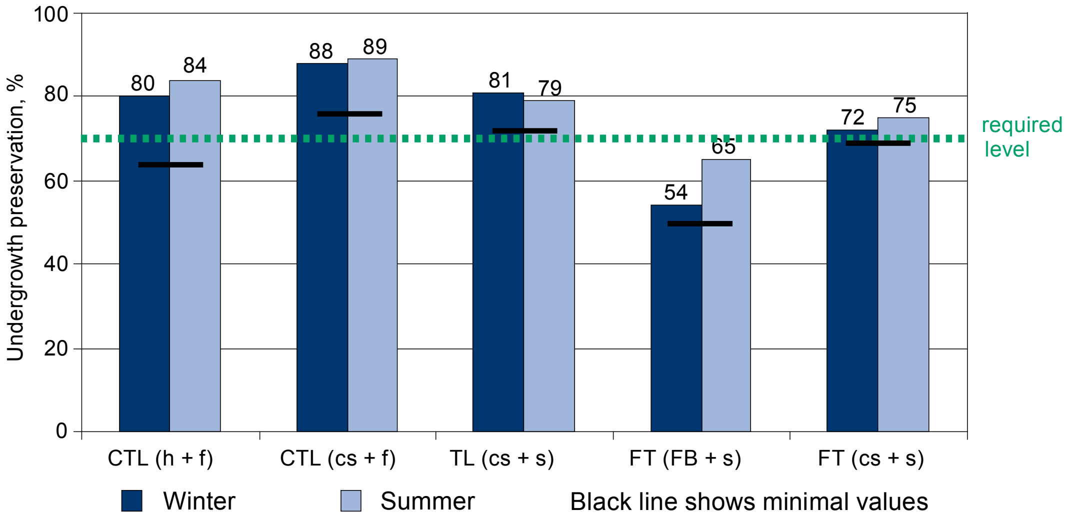

Fig. 3.9. Undergrowth preservation on cutting strips

3.2.3 Area occupied by trails and landings

The harvesting-site area occupied by landings and trails is shown in Figs. 3.10 and 3.11. It is clearly seen that the cut-to-length technology took a 2.3 times smaller area than traditional Russian technologies. Strip roads occupied an almost equal portion of the site area (about 22%), with either the fully or partially mechanized cut-to-length technology. This parameter reached its maximum (32 to 36%) when the fully mechanized full-tree technology was used.

The use of the partially mechanized full-tree harvesting system on soils with low bearing capacity becomes more efficient in terms of the required area in the winter season.

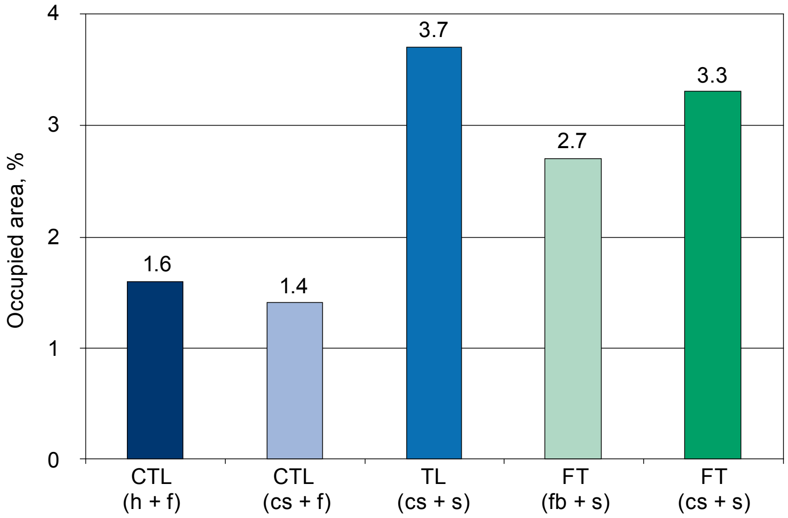

Fig. 3.10. Upper landing area in percentage of the harvesting-site area

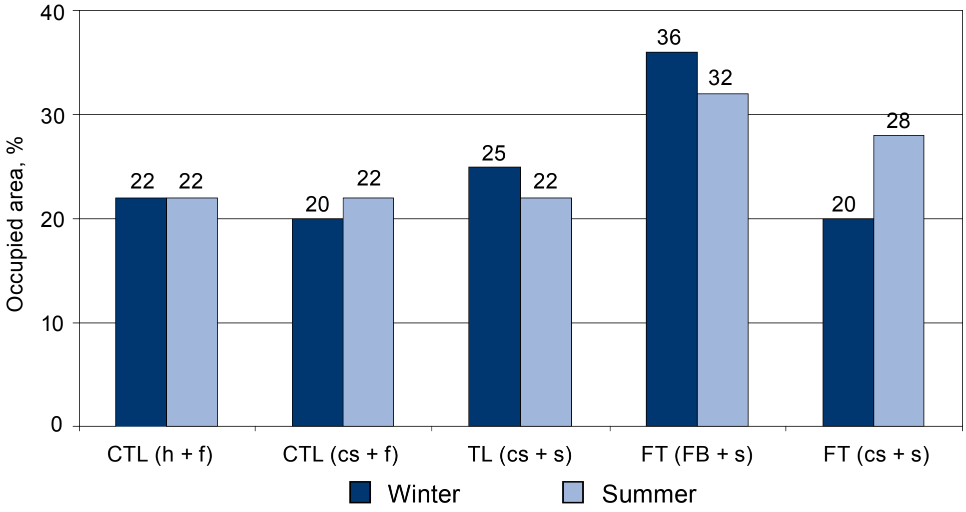

Fig. 3.11. Trail and strip-road area in percentage of the harvesting-site area in winter and summer

3.2.4 Damage to forest environment in thinnings

Similar conditions (stand composition 40% spruce, 30% birch, 30% aspen; light clay loam) were selected to compare environmental impacts of the tree-length and fully mechanized cut-to-length technologies in thinnings. Results are presented in Table 3.3.

Table 3.3. Comparison of impacts of tree-length and fully mechanized cut-to-length technologies on the forest environment

Indicator	Measurement unit	Technology	
		CTL (h+f)	TL (cs+s)
Damage to trees	%	2	3
Reduction of porosity	%	6	5
Soil mineralization	%	7	6
Average track depth	m	0.14	0.07
Undergrowth preservation	%	85	81
Area of landing	ha	0. 036	0.11
Average trail width of strip road	m	3.8	4.5
Average width of cutting strip	m	19.5	26
Area occupied by skid trails	%	19	17

In thinnings, the fully mechanized cut-to-length technology proved superior to the tree-length technology in terms of tree damage, compaction of landing site, undergrowth preservation and skid trail width. However, the harvester + forwarder system resulted in deeper tracks and more narrow cutting strips.

3.2.5 Expert evaluation

Each of the studied harvesting methods was evaluated on the basis of completed questionnaires. The subjective personal evaluation derived from the questionnaires shows that most experts believed that the partially mechanized cut-to-length technology causes the least negative impact on the forest environment (Fig. 3.12).

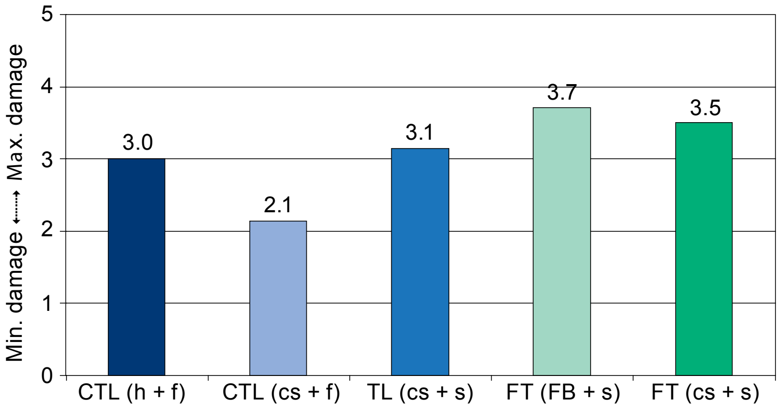

Fig. 3.12. Negative impact of the selected technologies on the forest environment (opinion of questionnaire respondents)

3.3 Analysis of the results

3.3.1 Impact on forest soil

Sandy soils compacted to a constant level after two or three machine trips. Along the main strip roads, porosity reduction was limited to 10% (compared to the intact soil structure) for all types of harvesting systems included in the study. Along skid trails, compaction was about 8–10% on sandy soils, as soils of this type compacted as early as after 2–3 machine trips and maintained a relatively constant bearing capacity further on. The 10% porosity reduction did not cause any significant deterioration of soil properties. Therefore, all harvesting methods are equally applicable on sandy soils. For all technologies, the average track depth on sandy soils was within 12 –17 cm; the lower levels resulting from full-tree and tree-length harvesting and higher readings produced by the cut-to-length technology.

For clay soils, some differences were identified between harvesting methods. Along skid trails, tree-length and cut-to-length technologies proved to reduce porosity by 6%. When a “feller buncher + wheeled skidder” combination was used, porosity was reduced only by 3%, which is explained by the loosening of the upper soil layer caused by a tree bunch. Along the main skid roads, porosity was reduced by 15, 14 and 13% respectively, with the tree-length, fully mechanized cut-to-length and partially mechanized cut-to-length technologies. It should be noted that tracked skidders caused compaction without any significant track formation (average track depth 13 cm), whereas wheeled machines caused a minor porosity reduction, but a significant track depth (30 – 32 cm) (Fig. 3.13). Wheeled skidders proved to be an exception, with porosity reduction of as low as 11% and average track depth of 18 cm.

“Harvester + forwarder” and “chainsaw + forwarder” systems caused less soil mineralization (8–9% of mineralized area) in topsoil. Tree-length and full-tree harvesting resulted in a mineralized area of up to 17%, which makes them less environmentally friendly for dry sandy soils and wet clay soils. Traditional tree-length and fully mechanized cut-to-length technologies used in thinnings did not cause a significant mineralization (5–7%) and proved to be almost equal. However, on clay soils, wheeled machines produced a 10 – 15 cm deep track, on average.

Fig. 3.13. A main strip-road track formed after multiple forwarder trips

3.3.2 Impact on remaining trees and undergrowth

In the hands of qualified operators, the fully mechanized cut-to-length technology ensured low levels of damage to the remaining trees (less than 2%). The tree-length technology also ensured less than 3% damage to trees in the course of thinnings.

According to the data provided by the interviewed companies, harvesting sites where undergrowth should be preserved form approximately 70% of all the sites intended for clear cutting, which makes the survival of undergrowth an important factor in harvesting. This factor should be taken into account in the course of tree-stand inventory and harvesting technology selection. According to the interviewed specialists, forest authorities primarily allocate for cutting forest areas with a substantial amount of undergrowth.

In winter time, cut-to-length harvesting with the “chainsaw + forwarder” system provided for high undergrowth preservation (90%). About 80% of the undergrowth was preserved on the site during tree-length and fully mechanized cut-to-length harvesting, while the fully mechanized full-tree technology did not permit the achievement of the level (70%) stipulated in the norms [15]. Only half of the undergrowth was preserved (Fig. 3.14) and, compared to the other technologies, the cutting strips themselves were smallest in area.

Fig. 3.14. Young trees damaged with a bunch of harvested trees

During the snowless season, the cut-to-length and tree-length technologies indicated a good undergrowth preservation from 80% to 90%, which exceeds the stipulated norms (70%). Feller buncher + skidder-based harvesting, as the field data demonstrated, did not provide for compliance with the stipulated levels of undergrowth preservation. During thinnings, both the tree-length and fully mechanized cut-to-length technology ensured good undergrowth preservation.

3.3.3 Required area for trails and landings

The area required for trails and landings differs from the used harvesting technology to other technology. There are also factors within each technology, which further impact the area requirements. For example, one unforeseeable factor is the need to expand the upper landing area (loading site) due to delays in timber transportation.

Upper landings (loading sites) occupy the largest area with regard to the site area (4%), when the traditional tree-length harvesting technology is used. This is mainly explained by the cross-cutting of the tree-lengths with chainsaws, which requires the unloading of the tree-length bunches. Tracked skidders make relatively low piles (2 to 2.5 m) and they have to pass the same trail multiple times, which results in an almost total destruction of the topsoil.

When feller bunchers, skidders and processors are used during full-tree harvesting, the area occupied with upper landings becomes smaller compared to tree-length harvesting, because delimbers and processors are capable of building compact piles of 3 to 3.5 m high. As well, these machines ensure a reduced impact on topsoil, since they travel on the harvesting residue layer generated in the course of their operation. Nevertheless, reforestation of the upper landing becomes problematic when the harvesting residue layer gets too thick and wide.

Cut-to-length harvesting ensures the most compact layout of landings (about 2%). This is due to the following factors: the possibility of forming piles up to 4 m high; a wide range of choices for placing piles at the landing; and a smaller area required for piling and loading operations. Since forwarders impact the soil mainly in access skid roads only, this technology can be considered less damaging to the soil than the traditional tree-length technology.

Compared to full-tree harvesting (25–36%), a logging trail and strip-road network takes a smaller area when the tree-length and cut-to-length technologies are used (20–25%). According to harvesting instructions [13], the normative maximal strip-road area is 30% for clear cuttings with multifunction machines. In thinnings, the normative maximal strip-road area is as low as 15%. This should be kept in mind when designing the strip-road network. An optimal strip-road network layout helps to avoid excessive formation of skidding trails.

During thinnings, the traditional tree-length technology requires a somewhat smaller strip-road area (17%) than the “harvester + forwarder”-based system (19%). This indicator should be less than 15% according to the harvesting instructions. However, the upper landing (loading site) is more compact in size when the cut-to-length technology is used.

3.3.4 Results of expert evaluation

Experts have estimated mechanized cut-to-length harvesting to be the most environmentally-friendly harvesting method (negative impact rating 2). The traditional tree-length and fully mechanized cut-to-length harvesting methods got more or less similar opinion-based scores (negative impact rating 3). Full-tree harvesting is considered to be the least environmentally friendly (negative impact rating 4).

3.4 Conclusions and recommendations

1. Each of the reviewed machine systems changed the soil porosity (within 9–10%) equally on sandy and loam soils.
2. “Harvester + forwarder” and “chainsaw + forwarder” systems in cut-to-length harvesting were less damaging to sandy and loam soils which promotes natural regeneration in coniferous stands and hilly landscape conditions.
3. Full-tree harvesting can promote natural regeneration in stands with a thicker humus layer.
4. On clay loams, the traditional tree-length technology, unlike the cut-to-length technology, results in a significant compaction of topsoil, but at the same time forms almost no track. Therefore, for large harvesting sites (more than 20 ha), the tree-length technology can be recommended. On small harvesting sites, the cut-to-length technology works better, because it reduces the necessity for multiple trips along the same strip road, thus reducing track formation and providing for less compaction of topsoil.
5. “Feller buncher + wheeled skidder”-based full-tree harvesting is only acceptable for sites where no undergrowth preservation is needed. Mechanized cut-to-length harvesting ensures high undergrowth preservation.

6. For thinnings, both the tree-length and fully mechanized cut-to-length methods can be used, the latter providing for a lower percentage of damaged trees (down to 2% with an operator having more than five years of work experience, as compared with the stipulated norm of 3%).
7. Based on the experimental data and interviews among harvester operators (40% of harvester operators have less than one year of work experience), it can be stated that the fully mechanized cut-to-length method can become more environmentally sound if the qualification of the workforce improves.

4 Workplace ergonomics and working conditions at harvesting sites

4.1 Methods and data

4.1.1 Field study

A standardized method was used for the field data 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. (Fig. 4.1). Altogether, more than 150 different parameters were measured for 28 machines (Table 4.1).

Fig. 4.1. Measurements

Table 4.1. Number of measured machines by models

Model	Number of machines measured
Harvesters	
John Deere 1070D	2
John Deere 1270D	2
Valmet 901.3	1
Valmet 911.3	1
Volvo EC210BLC	1
Forwarders	
John Deere/Timberjack 1010	3
Timberjack 1110D	3
John Deere 1410D	2
Valmet 840.3	1
Skidders	
Timberjack 460D	3
ML-136	1
TLT-100	2
TDT-55A	3
TB-1-16	1
Other	
Timberjack 850 feller buncher	1
LP-30B delimber	1
Chainsaws	
Husqvarna 254XP	8
Husqvarna 262	1

The measured parameters were grouped depending on which factor of the working conditions they were used to evaluate:

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 (Appendix 5), 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 (0-6). 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 4.2).

Table 4.2. 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

4.1.2 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. The workers were asked to give their evaluation of their working conditions (Fig. 4.2). Each of the 51 interviewed workers was asked to evaluate 46 working conditions by a 6-score scale (Table 4.3). Similar to the field measurements, factors were combined into groups. For each group, the integrated indicator was derived. A work-severity rate at each of the reviewed workplaces was the result of the interview data.

Fig. 4.2. Personnel opinion survey

Table 4.3. Interviewed operators by machine models

Model	Interviewed operators
Harvesters	
John Deere 1070D	1
John Deere 1270D	8
Valmet 901.3	1
Valmet 911.3	1
Volvo EC210BLC	1
Forwarders	
John Deere/Timberjack 1010	1
Timberjack 1110D	1
John Deere 1410D	7
Valmet 840.3	1
Skidders	
Timberjack 460D	3
ML-136	1
TLT-100	2
TDT-55A	4
Chokersetters (TDT-55A, TLT-100)	5
TB-1-16	1
Other machines	
Timberjack 850 feller buncher	3
LP-30B delimber	1
Chainsaw	
Chainsaw Husqvarna 254XP	9

4.1.3 Comparison of machine systems and harvesting methods

The main objective of this study was to compare different harvesting methods and machine systems rather than individual work phases. Each method 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. Wald’s minimax criterion was used to resolve this problem. According to the 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 the 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.

4.1.4 Injuries during harvesting operations

Along with field measurements and the personnel opinion survey, statistical data about frequency and types of injuries by different harvesting methods was gathered. Accident investigation reports and reports issued by health authorities and investigation commissions served as information sources.

4.2 Results

4.2.1 Harvesters and feller bunchers

Five harvester models were studied during the field measurements (Fig. 4.3).

Fig. 4.3. Analyzed models of harvesters

Observations on the work cycle of harvesters, video filming and a time study showed the following distribution of harvester's operation time by main work elements (Fig. 4.4).

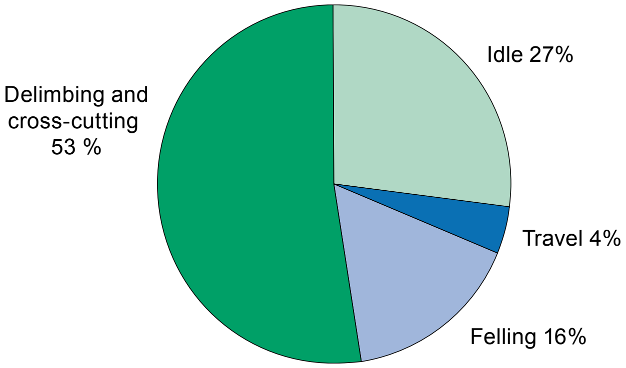

Fig. 4.4. Time distribution during the work cycle of a harvester

It was necessary to find out the time required for each operation, because some factors that determine the 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, whereas moving and delimbing/cross-cutting cause the highest noise load. This had to be taken into account when calculating the work-severity rate.

The average share of working time during which the operator has to be in an uncomfortable body position is another important factor that affects the overall comfort of operating the machine. In this regard, the harvester is a very comfortable machine. Valmet and Volvo harvester operators were working almost completely without uncomfortable body positions in standard conditions. This is because these harvester models have a rotating cabin and the operator can always observe the operation process by looking directly ahead and not having to turn his head at great angles. John Deere harvester cabins were not rotating and, therefore, the time spent in uncomfortable working positions was about 8%. The uncomfortable position mainly meant that the operator had to turn his head at significantly great angles in order to monitor the cross-cutting and delimbing process (Fig. 4.5).

Fig. 4.5. Uncomfortable body positions when operating a harvester without a rotating cabin

Figures 4.6 and 4.8 to 4.11 show comparative diagrams by the main 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.

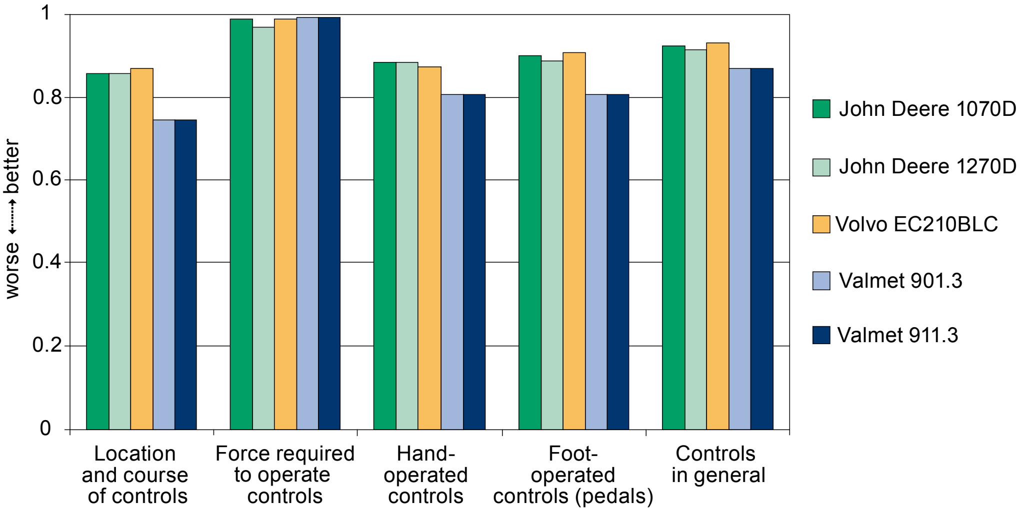

Fig. 4.6. Integrated indicators for the group "Controls"

As Figure 4.6 shows, Valmet harvesters got lower scores in "Location and course of controls", which further impacted the three latter indicators. This is mainly because Valmet harvester controls did not comply with three requirements of Russian norms and standards, namely: the diameter of the control handle falls outside the recommended range (49 mm against the norm of 20…40 mm, Fig. 4.7); the distance between pedals operated with the same foot was too small (40 mm against the norm of >50 mm) equally to the pedal stroke distance (50 mm against the norm of 70…100 mm). On the other hand, operators who had worked with both John Deere and Valmet harvesters thought that, altogether, the Valmet controls (handles) are easier to operate thanks to their compact layout with all the buttons and joysticks being placed directly on the handles (Fig. 4.7). This is the very reason for their larger diameter.

John Deere

Valmet

Volvo

Fig. 4.7. Main harvester controls

Lower scores in “Body position” and “Seat” indicators for Valmet (Fig. 4.8) were caused by the fact that Valmet’s cabins were considered to be relatively more cramped compared to John Deere’s cabins. This resulted in non-compliance with the Russian norms set for the longitudinal and vertical seat adjustment range and, consequently, in a less comfortable body position (angles at body joints). Volvo’s seat had too narrow armrests and no adjustable backing in the seat backrest.

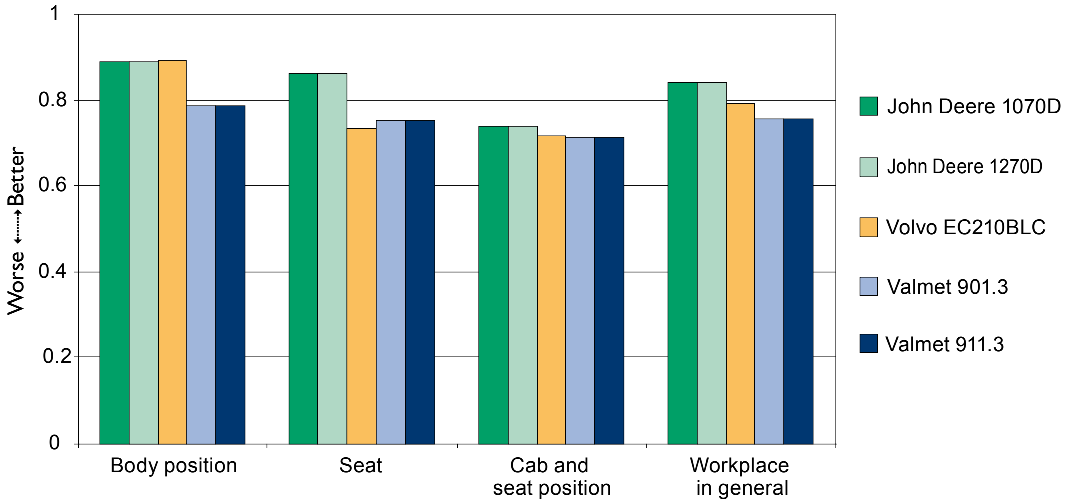

Fig. 4.8. Integrated indicators of the group "Workplace"

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

Comparatively low visibility angle values for Valmet machines (Fig. 4.9) 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. Figure 4.10 shows the integrated indicator values based on the results of the interviews of harvester operators. The operators were asked to evaluate the technical perfection of machines and working environment by a 6-score scale. The higher the indicator, the better the conditions were.

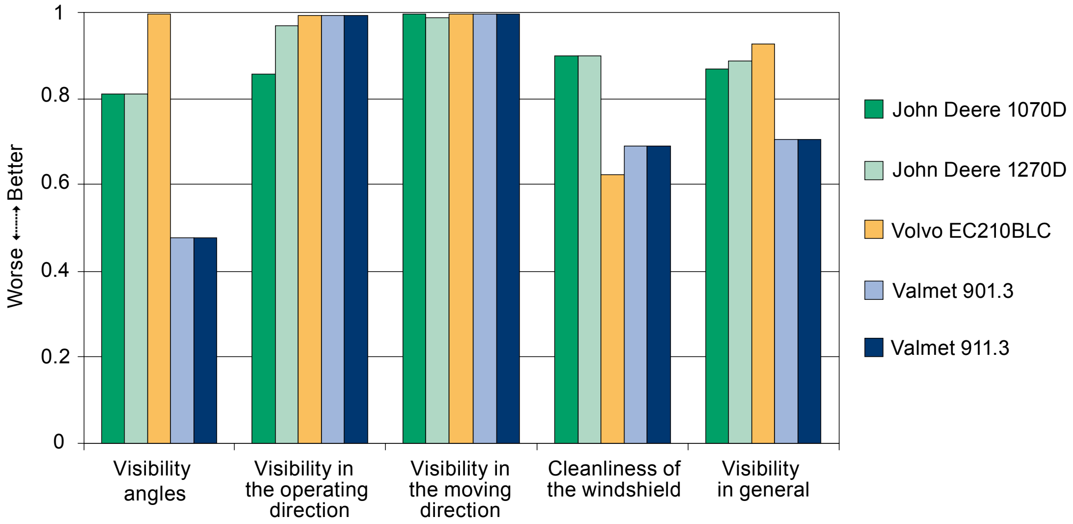

Fig. 4.9. Integrated indicators of the group "Visibility"

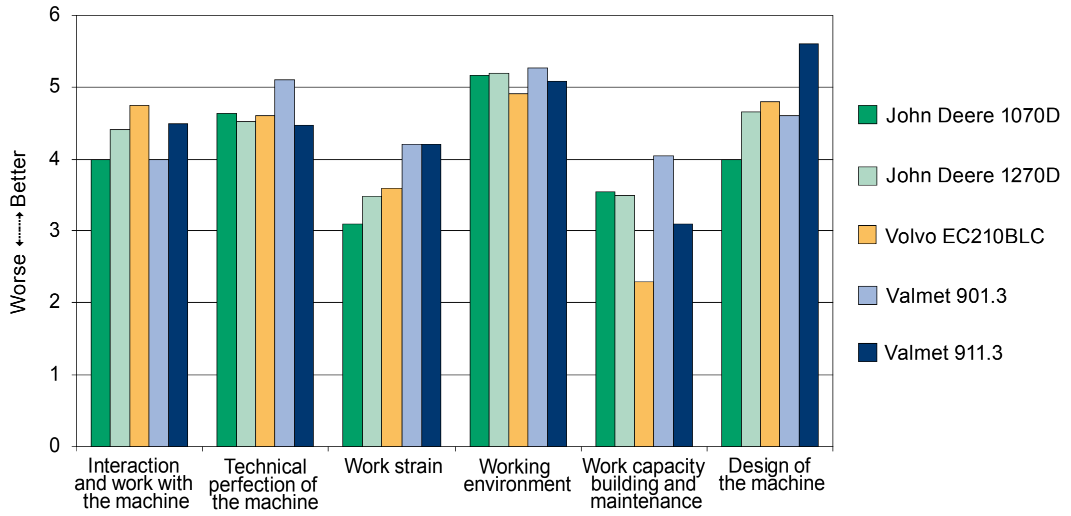

Fig. 4.10. Integrated indicators based on the personnel survey data

Figure 4.11 shows the 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 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.

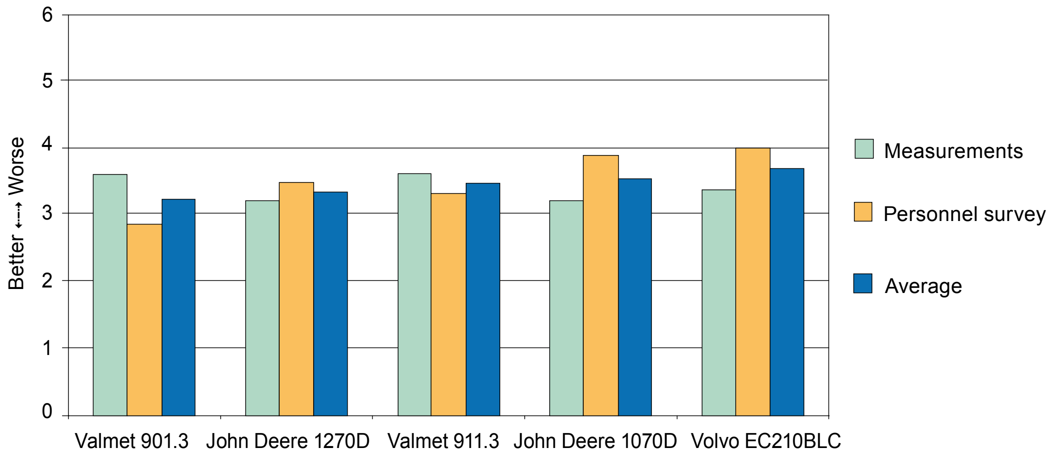

Fig. 4.11. Harvester operator’s work-severity rate

Only one feller buncher model was analyzed in the course of the study: Timberjack 850 (Fig. 4.12). Figure 4.13 shows the time distribution by operations. This machine proved to be the best by the majority of the evaluation indicators. Figures 4.14 and 4.15 show the results of measurements and the personnel survey.

Fig. 4.12. Timberjack 850 feller buncher

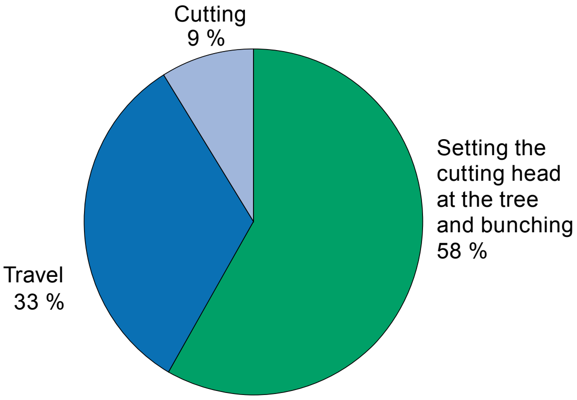

Fig. 4.13. Time distribution during the work cycle of a feller buncher

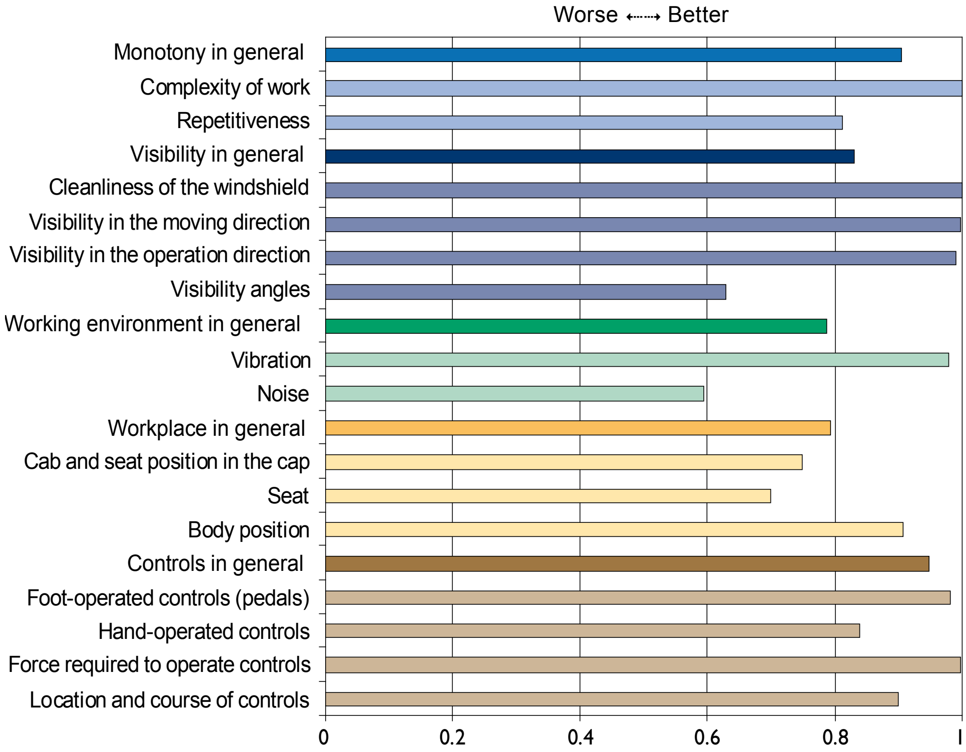

Fig. 4.14. Integrated indicators for the Timberjack 850 feller buncher based on measurements

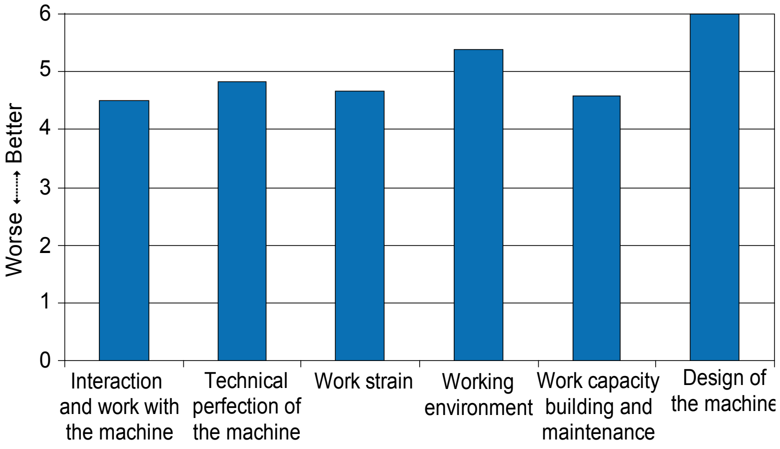

Fig. 4.15. Integrated indicators for the Timberjack 850 feller buncher based on personnel survey

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”.

4.2.2 Skidding machines

Four forwarder models were analyzed in the course of the field study (Fig. 4.16).

Fig. 4.16. Analyzed forwarder models

Time distribution of forwarder operations is shown in Figure 4.17.

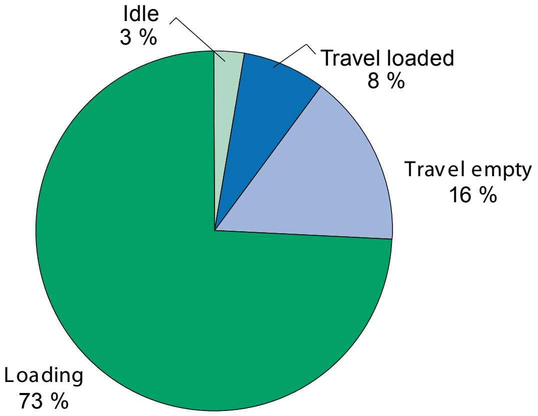

Fig. 4.17. Time distribution during the work cycle of a forwarder

According to the time study, forwarder operators spent a considerable amount of time in uncomfortable body positions; 23% of the total working time on average. Uncomfortable positions involved turning the head and body at great angles during loading and movement of the machine (Fig. 4.18).

Fig. 4.18. Uncomfortable positions during forwarder operation

Figures 4.19 to 4.23 show comparison diagrams by main indicators describing working conditions for the analyzed forwarder models. As Figure 4.19 shows, 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 (Fig. 4.20) 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 (Fig. 4.22), because it has a much shorter front (a more compact engine room, Fig. 4.16). 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. 4.24).

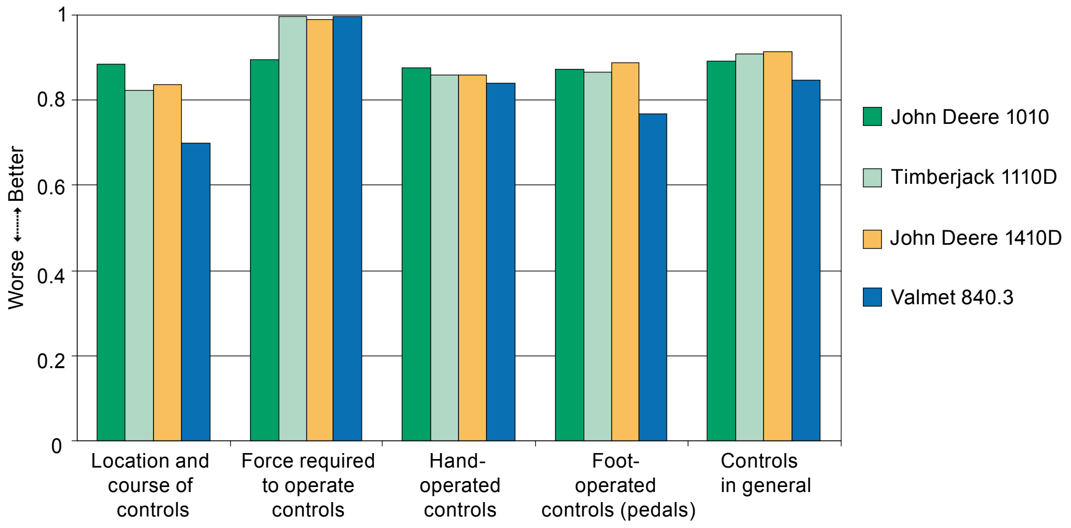

Fig. 4.19. Integrated indicators of the group "Controls"

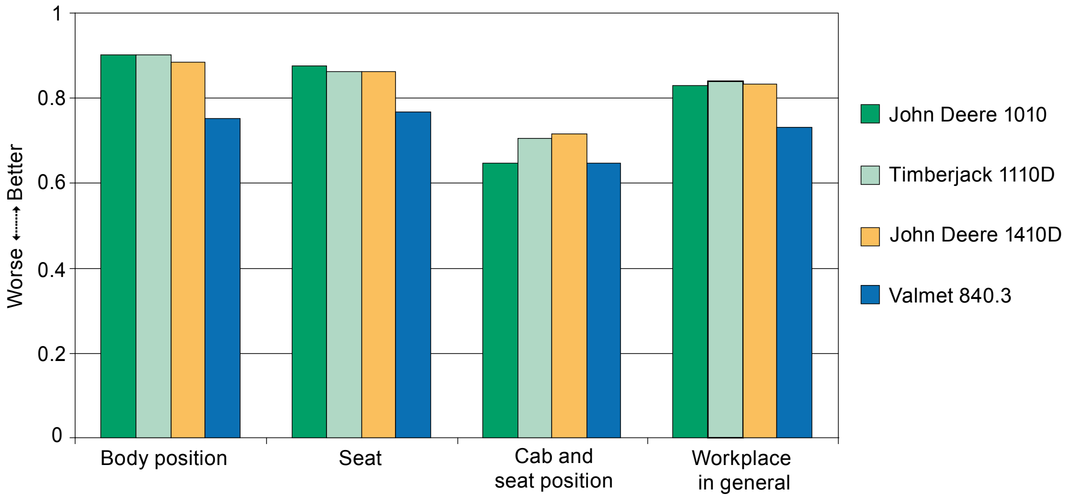

Fig. 4.20. Integrated indicators of the group "Workplace"

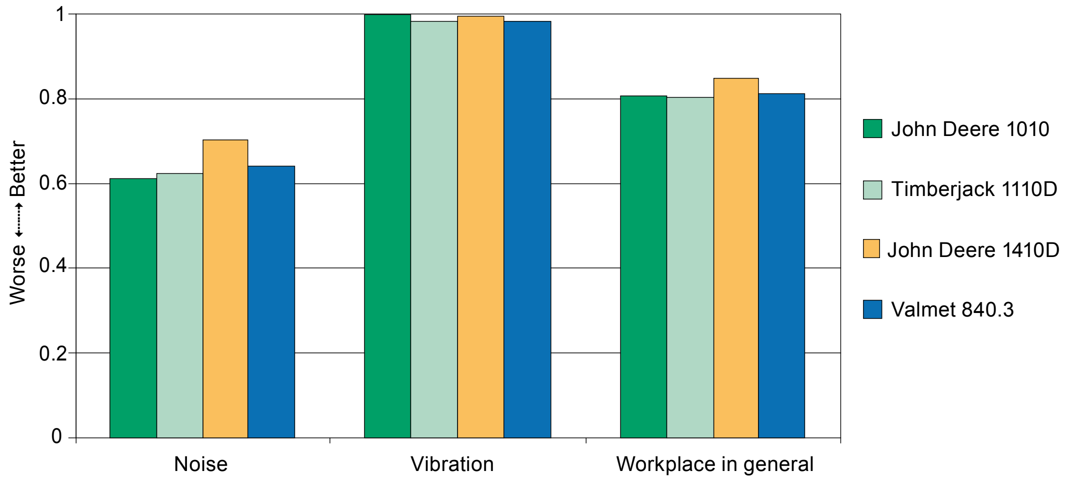

Fig. 4.21. Integrated indicators of the group “Working environment”

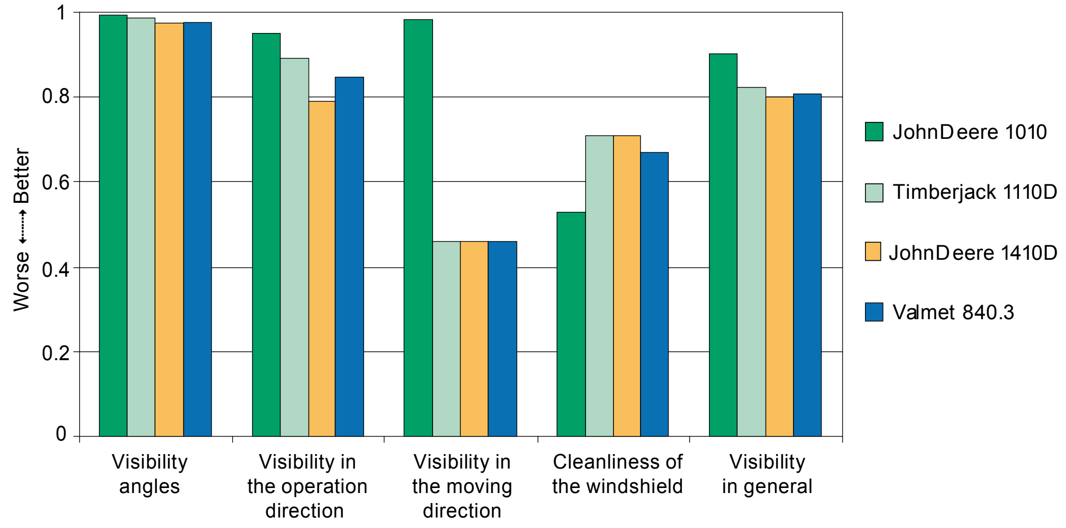

Fig. 4.22. Integrated indicators of the group “Visibility”

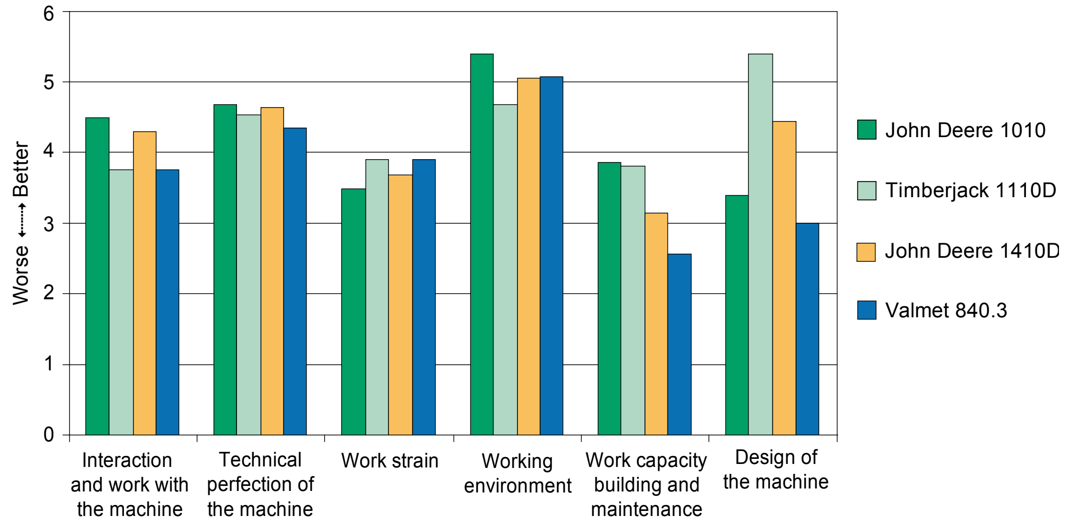

Fig. 4.23. Integrated indicators based on the personnel survey

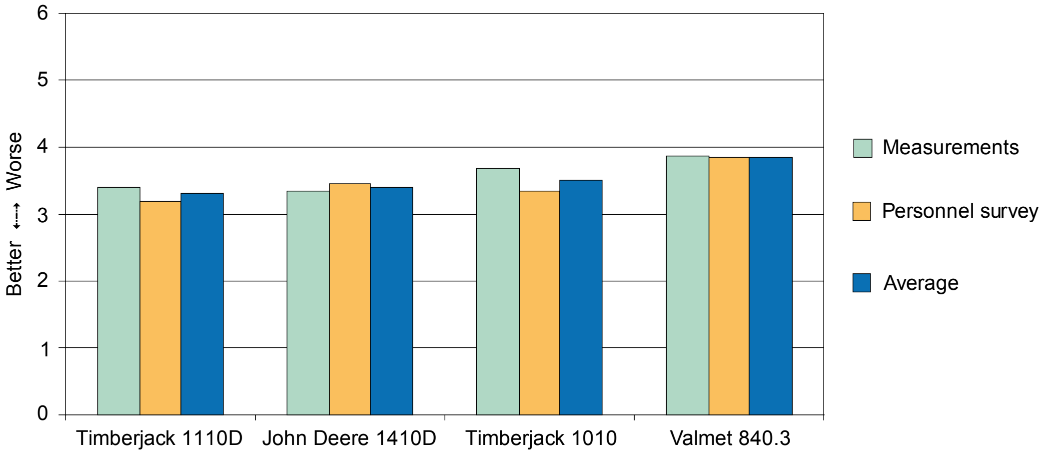

Fig. 4.24. Work-severity rate for forwarder operators

Later, two models of Russian-made tracked skidders, the TDT-55A and the TLT-100 manufactured by the Onezhsky Tractor Plant were analyzed (Fig. 4.25).

TDT-55A

TLT-100

Fig. 4.25. Analyzed models of tracked Russian skidders

Based on the time-study data, a diagram was built to illustrate the time distribution by operations (Fig. 4.26). The average time during which the operator had to be in uncomfortable body positions was 25% of the total working time. Uncomfortable positions here were more diverse than in the case of western machinery (Fig. 4.27).

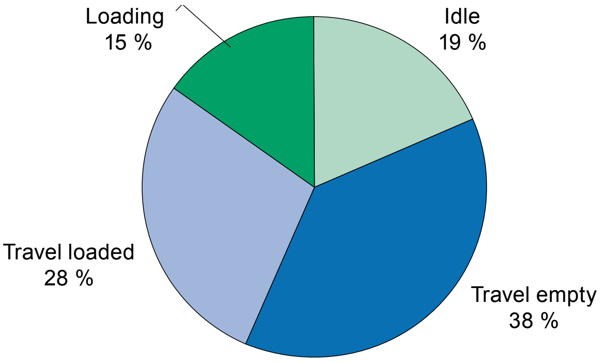

Fig. 4.26. Time distribution during the work cycle of a skidder

Fig. 4.27. Uncomfortable body positions during operations with a cable skidder

Results for the skidders are shown in Figures 4.28 to 4.30. For the TLT-100 skidder, most indicators were better than for the TDT-55A skidder. This is because TLT-100 is a later model equipped with a more comfortable and spacious cabin, a more comfortable spring-mounted seat, etc. This is why working environment indicators are two to three times better for the TLT-100 tractor.

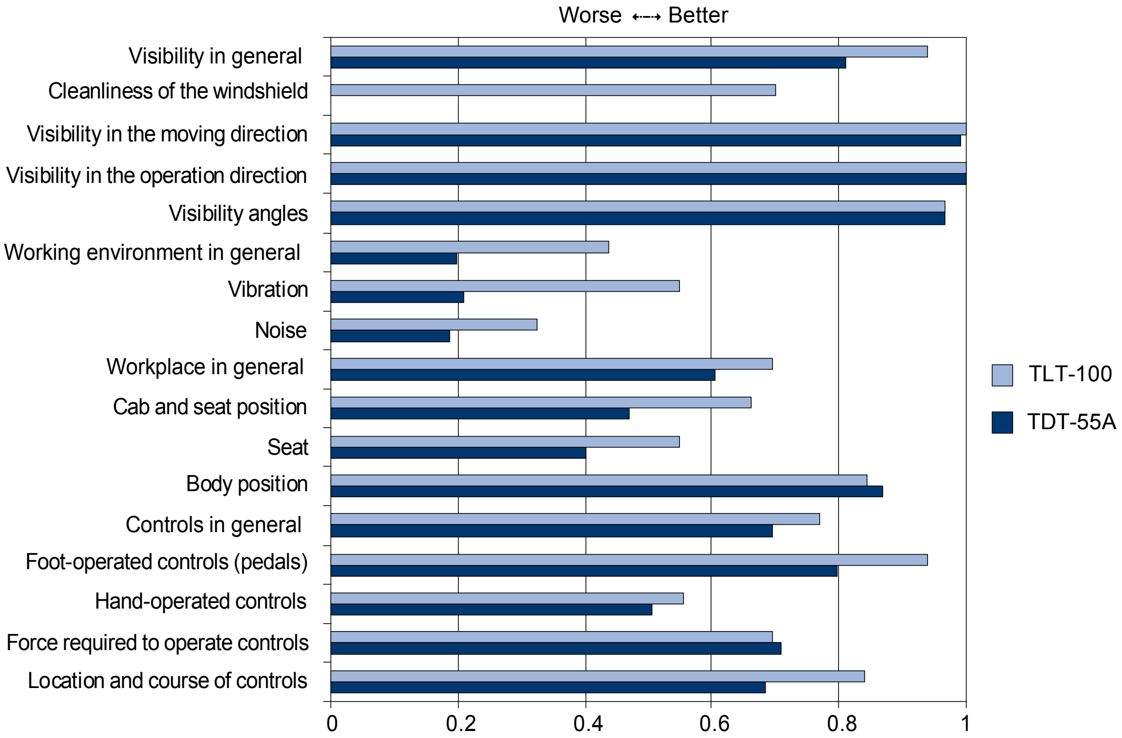

Fig. 4.28. Integrated indicators based on field measurements

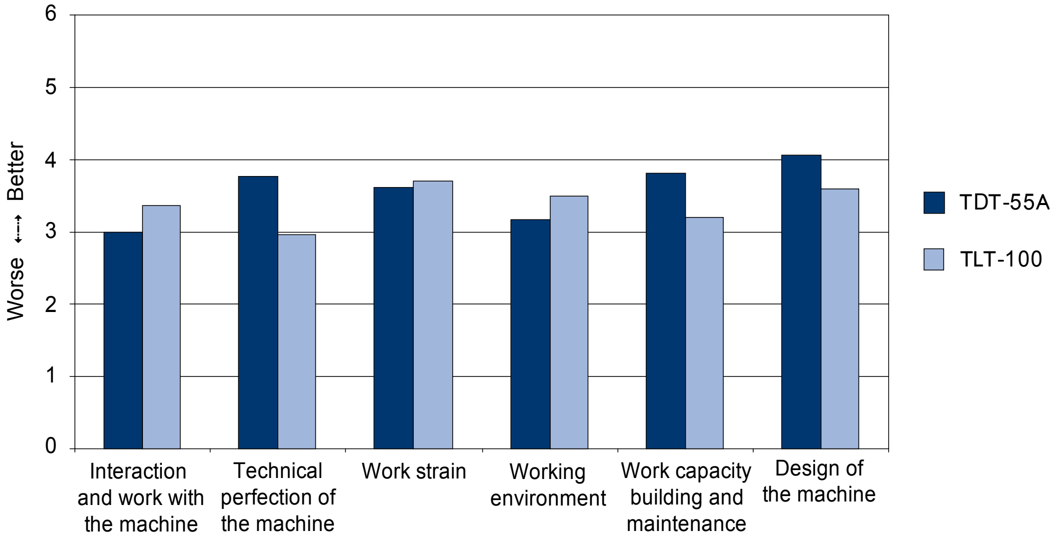

Fig. 4.29. Integrated indicators based on the personnel survey

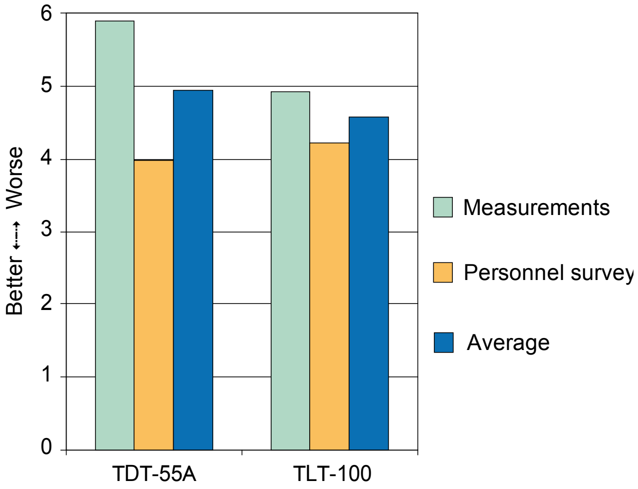

Fig. 4.30. Work-severity rate for operators of tracked cable skidders

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. 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 wheeled grapple skidder was analyzed: Timberjack 460D (Fig. 4.31). The work-cycle parameters are shown in Figure 4.32.

Fig. 4.31. Timberjack 460D skidder

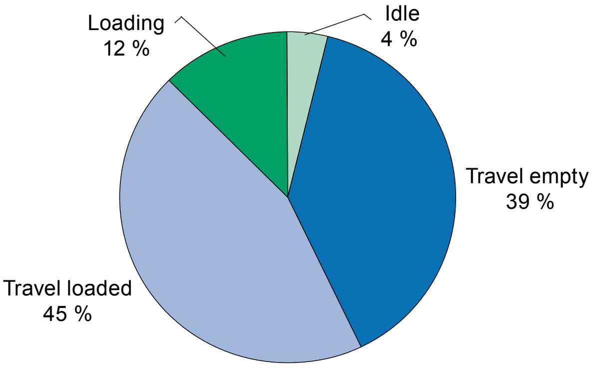

Fig. 4.32. Time distribution during the work cycle of the Timberjack 460D skidder

Due to the working methods used with the wheeled grapple skidders and the cabin design of the analyzed skidder, the operator had to spend a considerable time in uncomfortable body positions, a total of 31% of the working time. A typical uncomfortable body position occurred when the operator had to turn his head and body at great angles to monitor the loading and unloading processes, and also when moving the machine in order to monitor and adjust the grapple and bunch positions (Fig. 4.33).

Fig. 4.33. Uncomfortable body positions in operating the Timberjack 460D

The results of the measurements and personnel surveys are presented in diagrams (Figs. 4.34 and 4.35). 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.

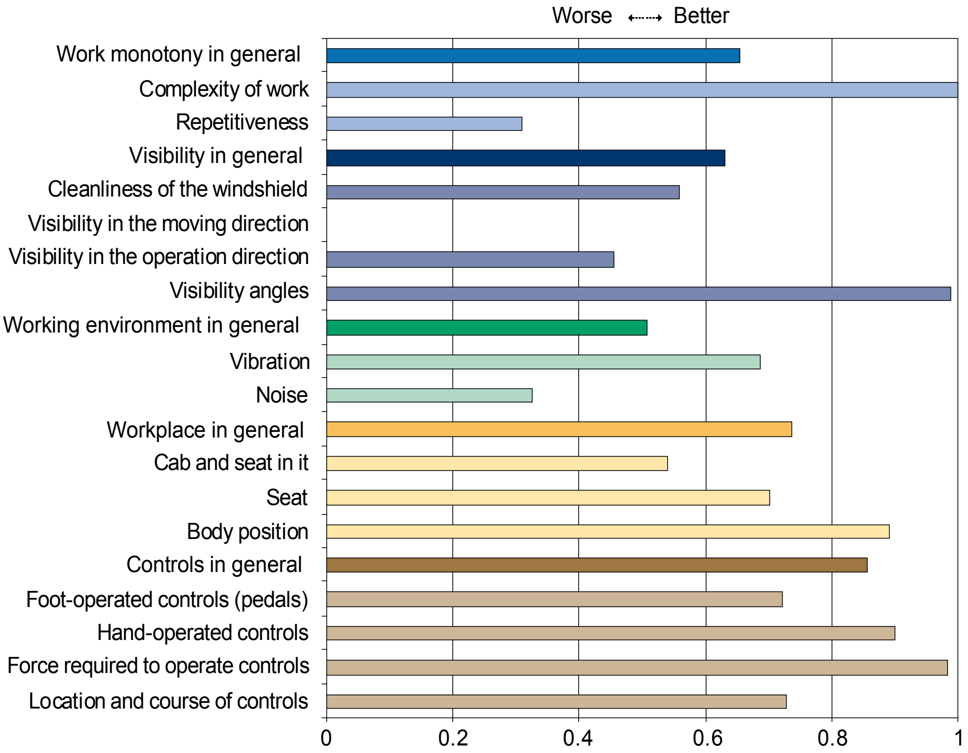

Fig. 4.34. Integrated indicators of the Timberjack 460D skidder based on the field measurements

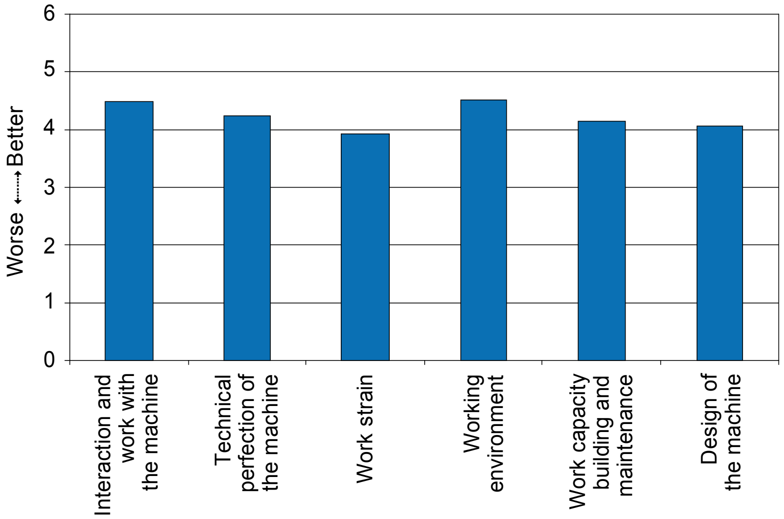

Fig. 4.35. Integrated indicators of the Timberjack 460D skidder based on the personnel survey

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.

4.2.3 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. The results are shown in Table 4.4.

Table 4.4. Results of ergonomic measurements for different work phases with chainsaw

Work phase	Time, when the chain-saw is running, %	Time spent in uncom-fortable positions, %	Weighted average acoustic pressure, dB	Weighted average vibration acceleration, m/s^2		Average vibration per shift, minutes	Allowable vibration per shift, minutes
				Right hand	Left hand		
Felling with Husqvarna 54XP	53	55	83	7.6	10.7	264	197
Felling with Husqvarna 262	53	14	73	4.5	8.1	264	240
Delimbing	66	31	92	10.1	11.9	264	184
Felling – delimbing – cross-cutting (chainsaw+forwarder)	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 4.4), it can be concluded that the GOST 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 tracked 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 upper landing site much 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.

4.2.4 Choker attaching

Figure 4.36 shows the results of the personnel survey among the chokersetters who worked with tracked skidders TDT-55A and TLT-100. Similar to the fellers, all the values were close to 3, except for technical perfection of the machine, which was 1.82. This means that chokersetters often considered the machines, as well as the equipment used (cable, choker), as highly imperfect. 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.

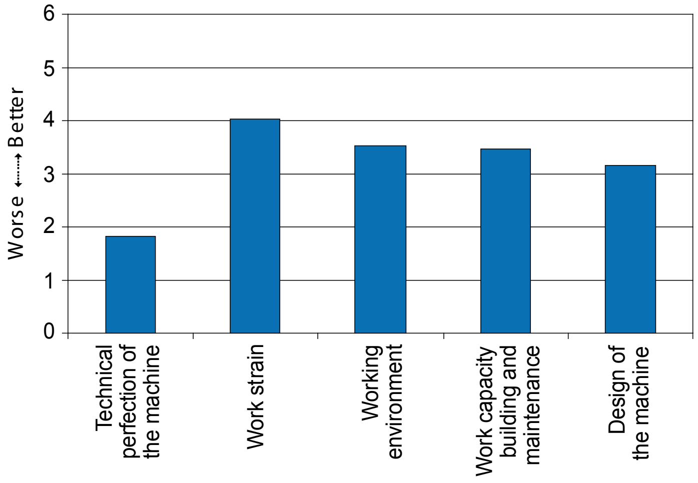

Fig. 4.36. Integrated indicators for chokersetters based on a personnel survey

4.2.5 Accidents during harvesting operations

Statistical information about accidents at harvesting sites was collected together with field measurements and personnel surveys. For each accident, the technology used and the work phase, as well as the type of injury, were recorded. Altogether, 49 accidents were registered: 29 of them happened with tree-length technology and 20 occurred when cut-to-length technology was used. Of the 49 accidents, only one occurred when using a harvester in the cut-to-length method. All the other accidents happened in tree-length or partially mechanized cut-to-length harvesting with felling, delimbing and cross-cutting done by chainsaws. Therefore, it could be concluded that fully mechanized cut-to-length technology (harvester + forwarder) was the safest technology from the accident-rate viewpoint.

Almost three-quarters of the accidents in tree-length technology happened during operations done with chainsaws or axes. These were delimbing (with axe or chainsaw) and felling (Fig. 4.37). Of the registered accidents 14% occurred when attaching chokers. With the “chainsaw + forwarder” cut-to-length system, felling and cross-cutting were the most dangerous operations (35% of accidents) (Fig. 4.38) and the second most dangerous was delimbing with a chainsaw (25%).

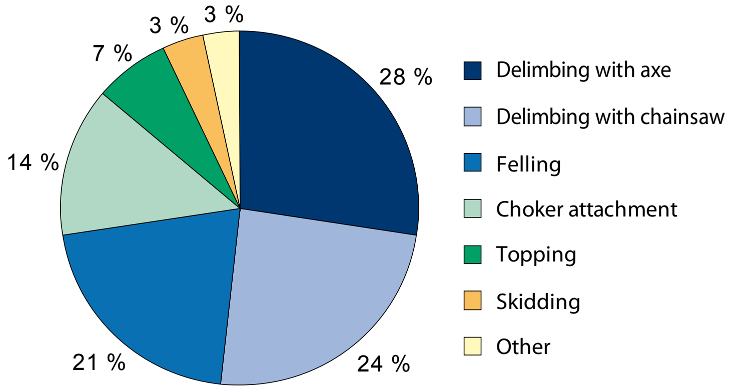

Fig. 4.37. Accident rate for operations with tree-length technology

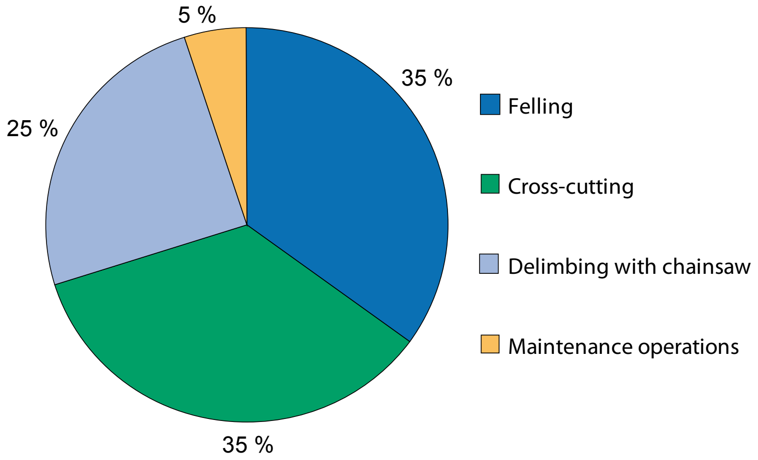

Fig. 4.38. Accident rate for operations with cut-to-length technology

As Figure 4.39 shows, leg injury by saw chain was the most common type of trauma at harvesting sites with a share of 38%. Leg injury by axe was the second common accident type (14%). Generally, various leg traumas altogether made up 68%, while arm traumas were only 12%. Head injuries from a falling tree or tree part were less frequent (8%). Other types of injuries were relatively rare.

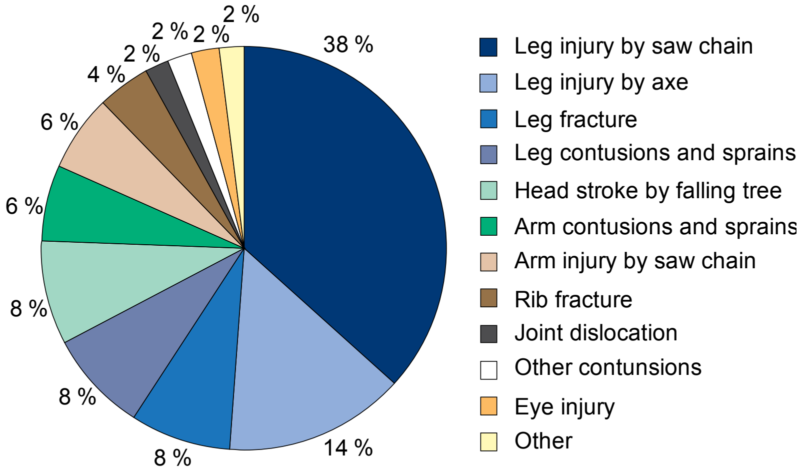

Fig. 4.39. Distribution of injury types

4.3 Analysis of the results

4.3.1 Comparison of machines by measurement data

Diagrams illustrating the work-severity rate and main integrated indicators are presented to compare different models of machines. The Timberjack 850 feller buncher (Fig. 4.40) provided the best ergonomics of controls. 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 tracked skidders, especially TDT-55A, demonstrated substantially lower levels of this indicator.

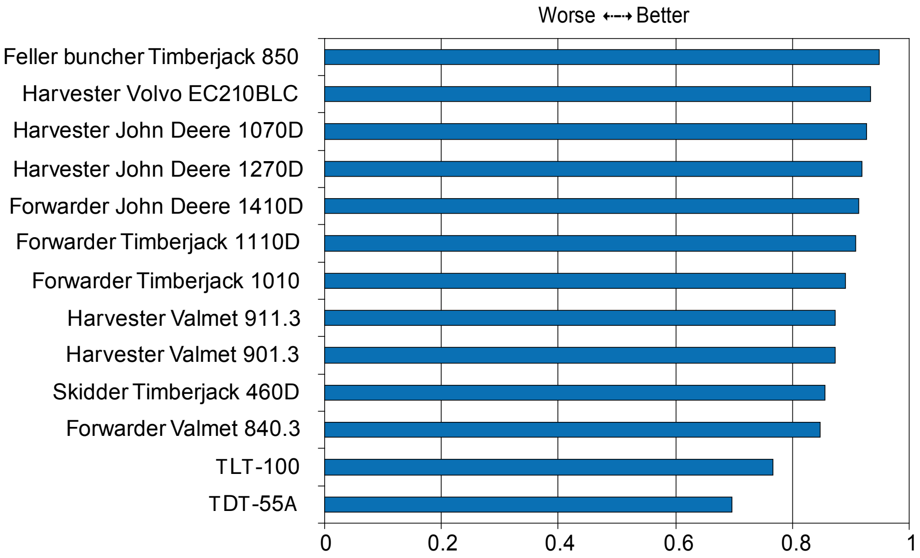

Fig. 4.40. Integrated indicator “Controls”

John Deere cut-to-length harvesting machines were the best on the “Workplace” indicator (Fig. 4.41). 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.

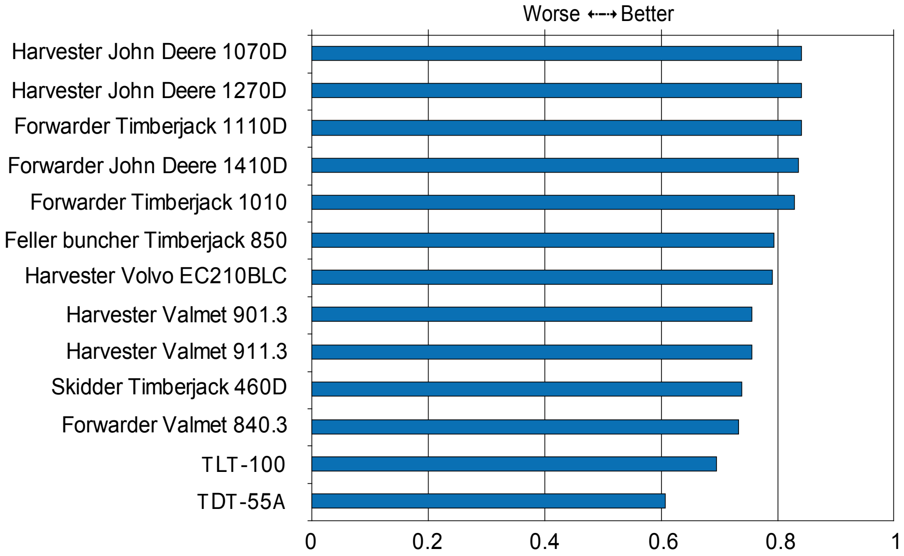

Fig. 4.41. Integrated indicator “Workplace”

Diagrams for the “Monotony” indicator are presented by machine types (Fig. 4.42). Harvesters, forwarders and tracked skidders showed good results. Feller bunchers’ values were slightly lower, and 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.

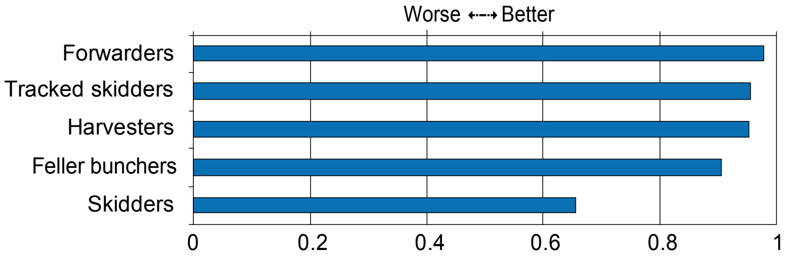

Fig. 4.42. Integrated indicator “Monotony”

“Visibility” was one of the few indicators where Russian machines gained good results (Fig. 4.43). 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.

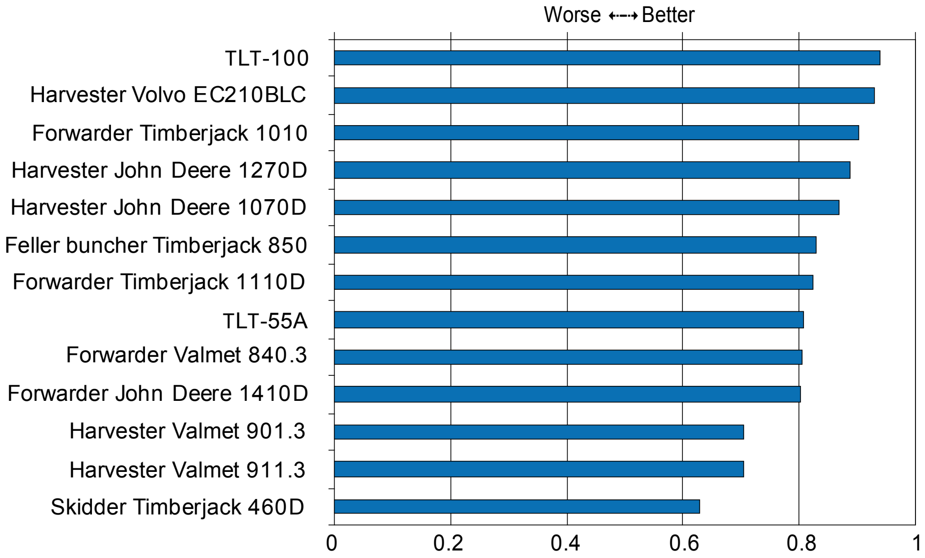

Fig. 4.43. Integrated indicator “Visibility”

In this study “Working environment” indicator was based on noise and vibration characteristics. As a whole, harvesters had better results (Fig. 4.44), 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.

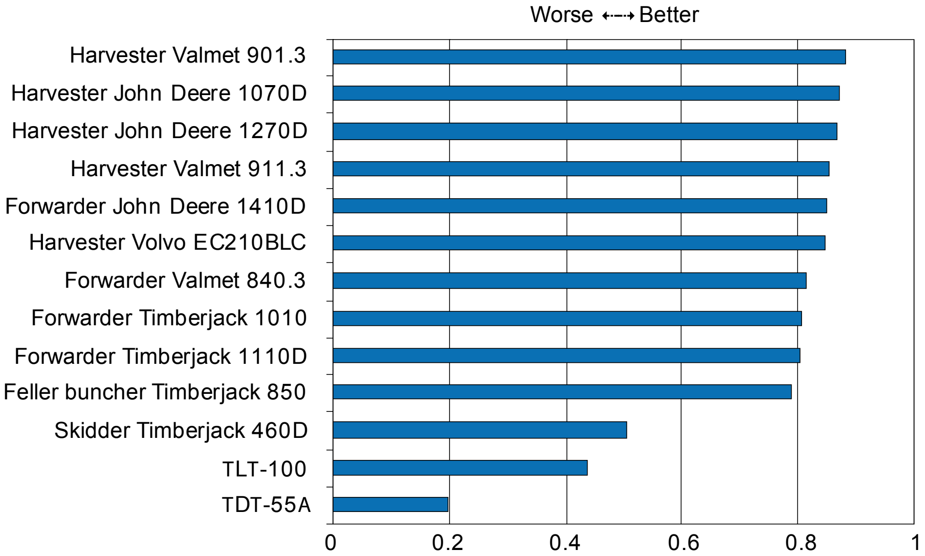

Fig. 4.44. Integrated indicator “Working environment”

The integral ergonomic quality of the machines was evaluated by comparing their work-severity rate calculated using all of the above-mentioned elements of integrated indicators (Fig. 4.45). 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.

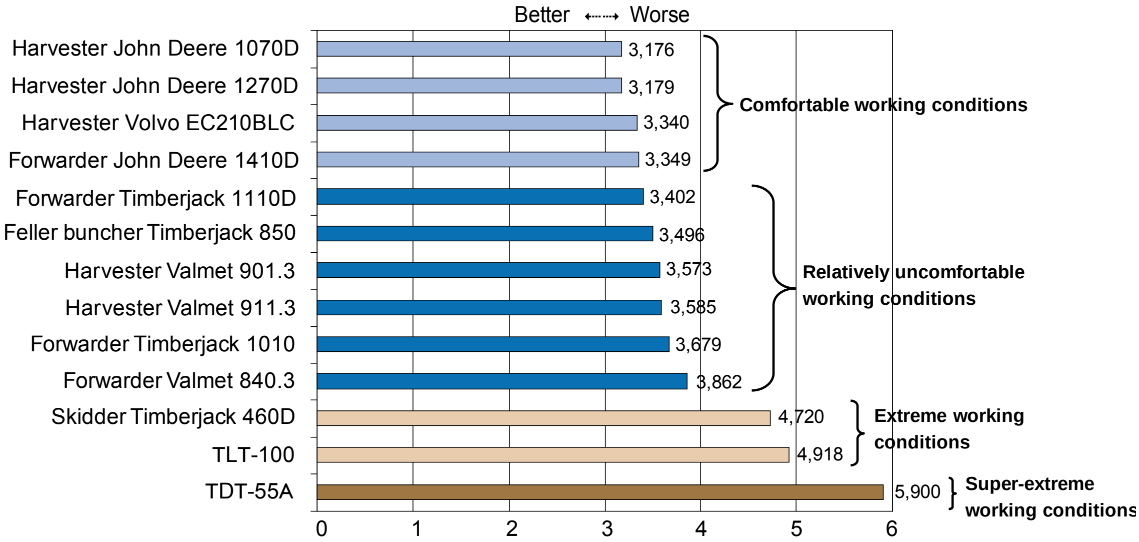

Fig. 4.45. Work-severity rate based on measurements

4.3.2 Comparison of machines by personnel survey data

A number of gross indicators were determined from the data of the personnel survey conducted with the machine operators; the comparative diagrams are shown in Figures 4.46 to 4.49. The diagrams express the subjective views of the operators.

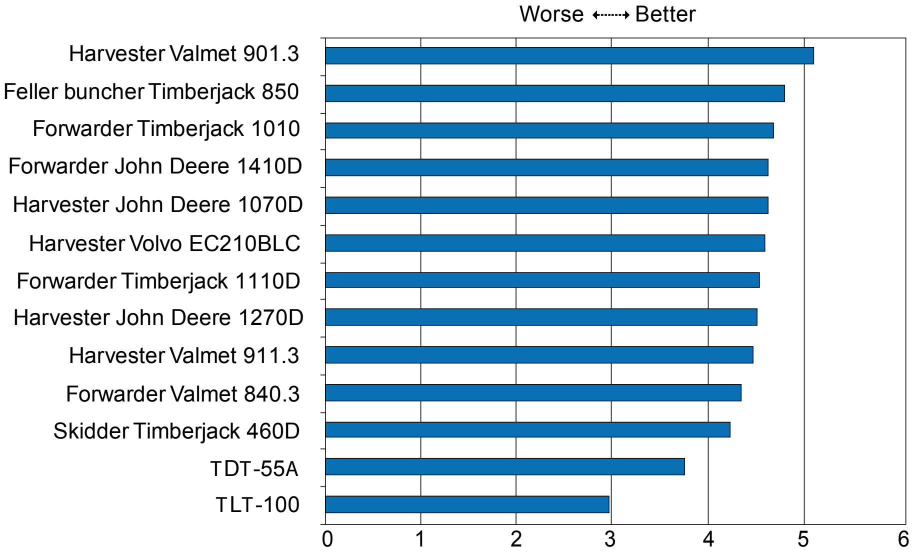

Fig. 4.46. Integrated indicator “Technical perfection of the machine”

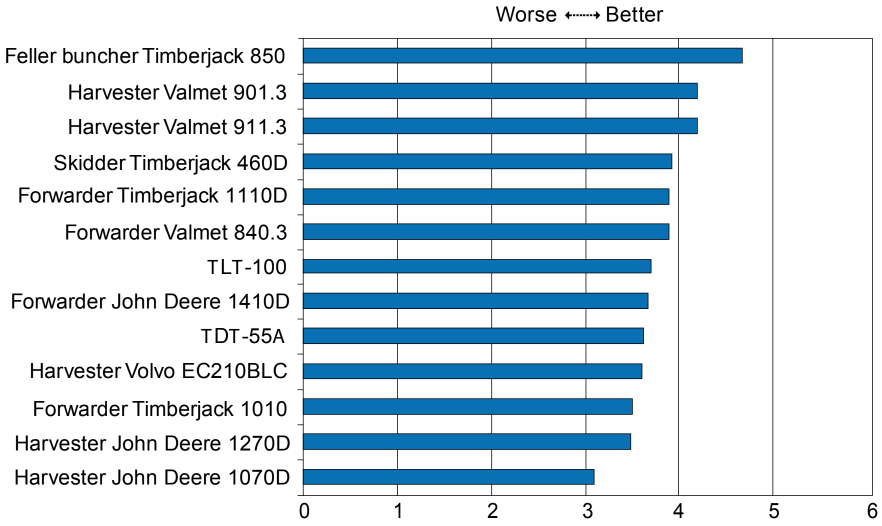

Fig. 4.47. Integrated indicator “Work strain”

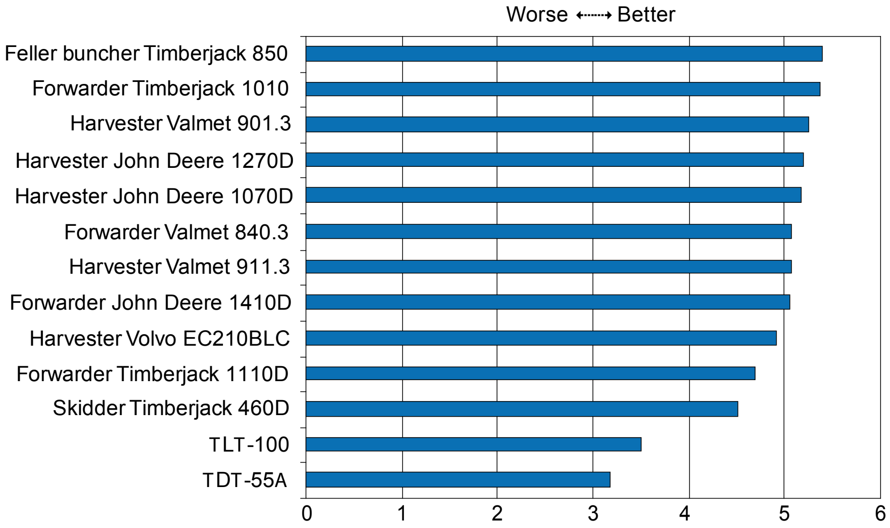

Fig. 4.48. Integrated indicator “Working environment”

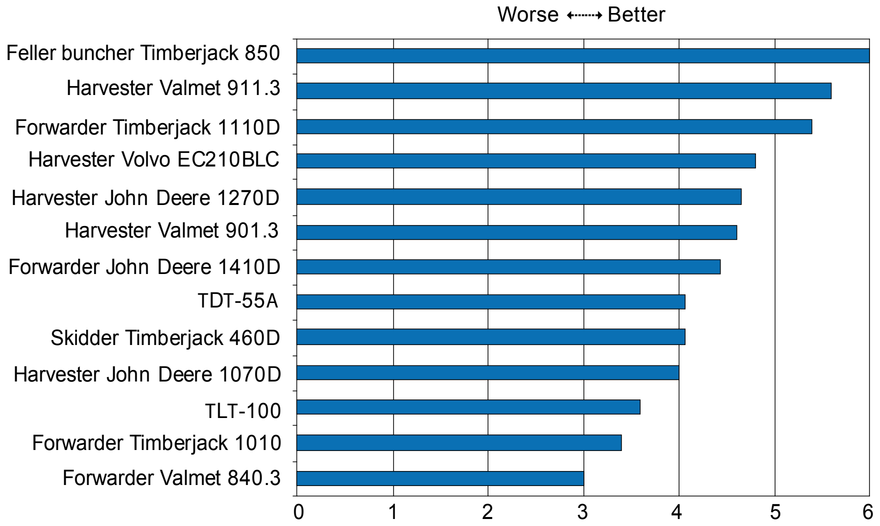

Fig. 4.49. Integrated indicator “Design of the machine”

The Timberjack 850 feller buncher holds either the first or the second position across all the diagrams. This proves that operators were very happy with the working conditions of this machine. This made the Timberjack 850 a clear leader also in terms of the work-severity rate obtained from the personnel survey data (Fig. 4.50). Working conditions of all the machines were graded either as “comfortable” or “relatively uncomfortable”. It should be noted that, in general, forwarder operators were more satisfied with their working conditions compared to harvester operators, despite the fact that the measurement data show that harvesters, in all, offer better working conditions. This is likely due to the higher complexity and higher work-related stress in operating a harvester.

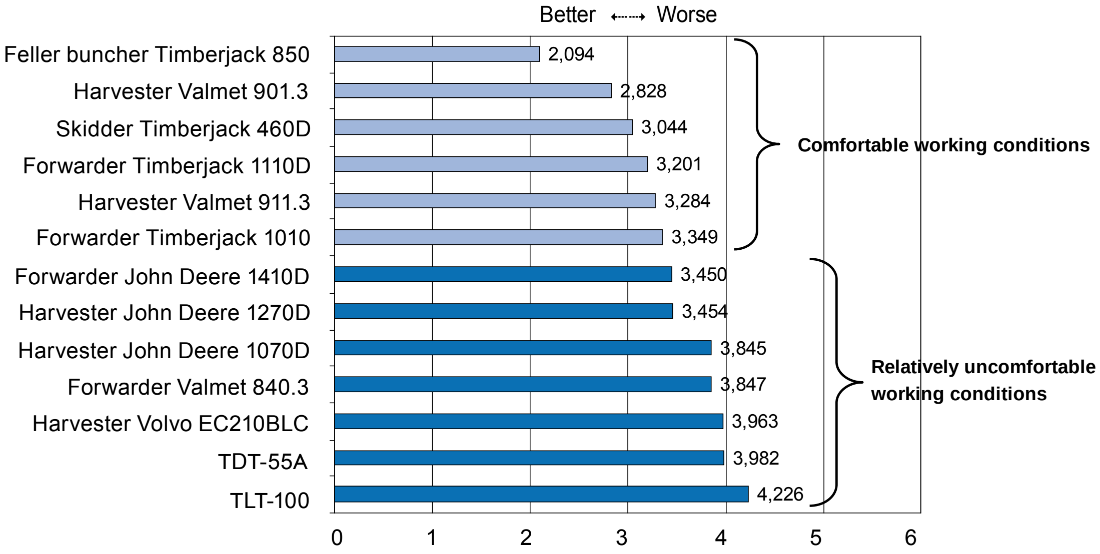

Fig. 4.50. Work-severity rate based on the personnel survey

It is also worth noting that operators of the TDT-55A skidder evaluated their working conditions to be better than the TLT-100 skidder operators did. The reason for this is most probably that these machines are used by experienced operators who have worked with the TDT-55A for most of their life and have grown to like it. The more recent TLT-100 skidder, despite better ergonomics, receives a lot of criticism as many operators are still unaccustomed to it.

4.3.3 Total work severity of harvesting machines

The total work-severity rate was obtained for each of the machines (Fig. 4.51). 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.

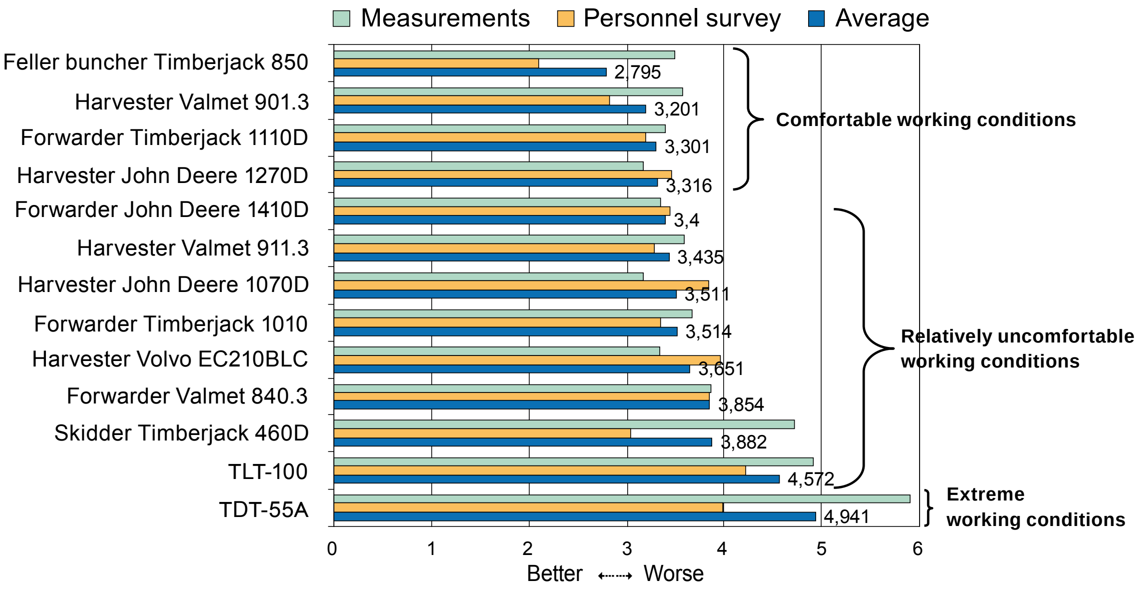

Fig. 4.51. Total work severity

4.3.4 Comparison of operations done with chainsaws

Figures 4.52 and 4.53 show comparative diagrams for noise and vibration loads during different operations. As one can see, both acoustic pressure and vibration acceleration were significantly lower when felling was done with the Husqvarna 262 chainsaw.

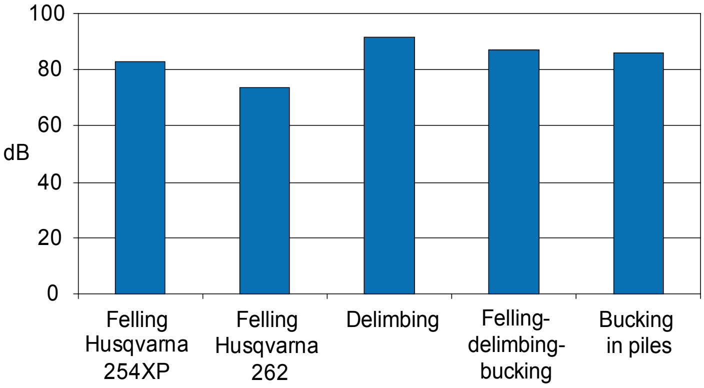

Fig. 4.52. Weighted average acoustic pressure, dB

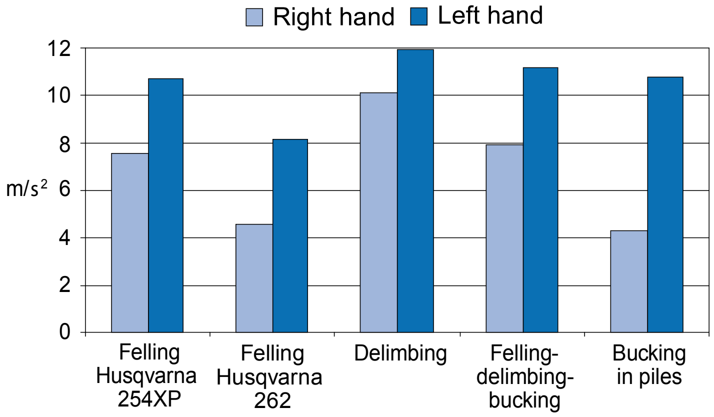

Fig. 4.53. Weighted average vibration acceleration, m/s^2

The diagram shown in Figure 4.54 demonstrates how many minutes the actual (measured) vibration during each of the operations exceeds the allowable limit calculated for the given conditions. For example, a feller with a Husqvarna 254XP chainsaw worked above the defined limit for about one hour per shift, while a feller with a Husqvarna 262 chainsaw exceeded the limit only 20 min. Delimbing with a chainsaw demonstrated the poorest results in every parameter. Delimbing had the greatest negative impact on a worker.

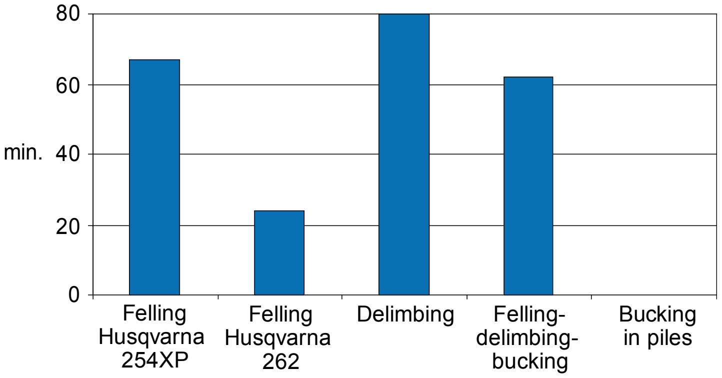

Fig. 4.54. Average measured vibration period exceeding the allowable vibration period, min.

4.3.5 Comparison of different machine systems and technologies

Fourteen different machine systems were analyzed. The Wald's minimax criterion (*W*) was used to compare the machine systems (see point 4.1.3). Comparative results are presented in Table 4.5.

Table 4.5. Comparison of harvesting-machine systems (technologies) by working conditions and workplace ergonomics

	Machine system	*W*				
1	John Deere 1270D → John Deere 1410D	3.4				
2	John Deere 1070D → John Deere 1010	3.514				
3	Volvo EC210BLC → John Deere 1410D	3.651				
4	Valmet 901.3 → Valmet 840.3	3.854	3.2			
5	Valmet 911.3 → Valmet 840.3	3.854	3.435			
6	Timberjack 850 → Timberjack 460D	3.882				
7	20 fellers → John Deere 1410D	4.956				
8	Feller → chokersetter → TLT-100	5.316	4.956	4.572		
9	Feller → chokersetter → TDT-55A	5.316	4.956	4.941		
10	Feller → chokersetter → TLT-100 → delimbing/ cross-cutting worker → John Deere 1410D	5.316	4.956	4.956	4.572	
11	Feller → 2 delimbing workers → chokersetter → TLT-100	5.316	4.956	4.956	4.956	4.572
12	Feller → 2 delimbing workers → chokersetter → TDT-55A	5.316	4.956	4.956	4.956	4.941
13	Timberjack 850 → 2 chokersetters → 3 TLT-100	5.316	5.316	4.572		
14	Timberjack 850 → 2 chokersetters → 3 TDT-55A	5.316	5.316	4.941		

Thus, cut-to-length harvesting performed with a John Deere 1270D harvester and a John Deere 1410D forwarder (machine system 1) appeared to be the one that provides the best working conditions. The worst working conditions were observed in tree-length harvesting with a Timberjack 850 feller buncher and skidding with three TDT-55A skidders (machine system 14). As a whole, the “harvester + forwarder” technology had the best results (machine systems 1 – 5). Full-tree harvesting with feller buncher + wheeled grapple skidder held the second position (machine system 6). Cut-to-length harvesting with chainsaw + forwarder was in third place (machine system 7). The traditional Russian tree-length technology that employs cable skidders and its various modifications had the worst results in terms of ergonomics, work severity and occupational safety (machine systems 8 – 12).

4.4 Conclusions and recommendations

- The “harvester + forwarder”-based cut-to-length harvesting provided the best working conditions in terms of ergonomics and occupational safety, in particular, when John Deere machines were used. Volvo and Valmet-based machine systems got a slightly lower score.
- In second position following the “harvester + forwarder” technology came fully mechanized full-tree harvesting, using a “feller-buncher + wheeled grapple skidder” machine combination. However, this technology did not differ greatly from the leading technology.
- The third position was held by partially mechanized cut-to-length harvesting performed with chainsaw + forwarder. The results, however, were much poorer for this machine combination than for the first two technologies.
- The traditional Russian tree-length harvesting done with cable skidders showed the worst results in terms of ergonomics, work severity and occupational safety.
- Cross-cutting in piles at the intermediate landing showed the best results among operations performed with chainsaws.
- In second place came felling with chainsaws equipped with handles, like the Husqvarna 262 chainsaw.
- Delimbing with chainsaw had the poorest results.
- None of the analyzed operations involving chainsaws, except for cross-cutting in piles, complied with the vibration load standards.

- When selecting a harvesting system where a chainsaw is involved, it is better to avoid having several delimbing workers with chainsaws. Rather, felling should be done with chainsaws equipped with handles, for instance the Husqvarna 262, followed by a fully mechanized delimbing; or alternatively, cut-to-length technology with combined felling/delimbing/cross-cutting should be used, which altogether ensures lower noise and vibration load on the operator.
- When the partially mechanized harvesting system is used, use of the TDT-55A skidder should be as limited as possible, because, as a whole, it does not comply with present ergonomic requirements (the “extreme” working conditions score).

5 Impact of a harvesting technology on wood quality

5.1 Methods and data

5.1.1 Field study of quality indicators

Several quality indicators, regulated by relevant standards and specifications, are used to evaluate the impact of different felling technologies on the quality of roundwood. These include the following [39, 40, 41]: presence of mechanical damage, processing defects, contamination with soil, and deviation of the timber assortment dimensions from the contract specifications or other requirements for timber quality set in a given logging company.

Mechanical damage occurring in the course of harvesting, skidding, sorting, piling and transportation of timber includes the following types of damage: torn and loosened grain, barked stem, cuts (damage by chainsaw, cable, axe) and gouges made by a grapple. Processing defects – one of the main roundwood quality indicators – include: branches (not completely delimbed) and defects caused by improper tree-felling and cross-cutting, namely: log end splits, cracks, log end splinters and miscut log end.

Dimensions of assortments, including log-length allowances and tolerances, as well the grades, are established in relevant standards (for example GOST 9463-88). The maximum diameter of a log end and the minimum top diameter of timber assortments are also limited by contract specifications. Therefore, it is necessary to comply with the size limitations in order to produce high-quality timber.

Table 5.1 shows the method used to measure roundwood quality indicators in summer and in winter time at harvesting sites and central processing yards (lower landings).

Table 5.1. Measurement of roundwood quality

Quality indicator	FS – felling site; L – landing (loading site); PY – processing yard (lower landing)																Measurement tools
	Cut-to-length (cs+f)			Cut-to-length (h+f)		Tree-length (cs+s)				Full-tree (cs+s)				Full-tree (fb+s)			
	saw log	pulp-wood	ve-neer log	saw log	pulp wood	tree-length	saw log	pulp wood	ve-neer log	tree-length	saw log	pulp-wood	ve-neer log	tree-length	saw log	pulp wood	
1 Mechanical damage																	
1) Torn and loosened grain	FS	-	FS	FS	-	-	PY	-	PY	-	PY	-	PY	-	L PY	-	Precision caliper with a depth gauge; measuring tape (2 m)
2) Barked stem	FS	*	FS	FS	*	L	PY	*	PY	L	PY	*	PY	L	L PY	*	Measuring tapes (15 m) and (2 m); Foldable metering rod (3.5 m)
3) Cuts in stemwood and gouges made by a grapple:	FS	-	FS	FS	-	-	PY	-	PY	-	PY	-	PY	-	L, PY	-	Precision caliper with a depth gauge
- Damage by chainsaw	-	-	-	-	-	-	PY	-	PY	-	PY	-	PY	-	L, PY	-	
- Damage by cable / grapple																	
- Damage by boom	L	-	L	L	-	-	-	-	-	-	-	-	-	-	-	-	
4) Cut by axe	-	-	-	-	-	-	PY	-	PY	-	-	-	-	-	-	-	Precision caliper with a depth gauge
2 Processing defects																	
1) Branches	FS	FS	FS	FS	FS	FS	PY	PY	PY	L	PY	PY	PY	L	L PY	L PY	Precision caliper with a depth gauge
2) Log end splits, cracks	FS	-	FS	FS	-	-	PY	-	PY	-	PY	-	PY	-	L PY	-	Log end measuring bracket Measuring tape (2 m)
3) Log end splinter	FS	FS	FS	FS	FS	-	PY	PY	PY	-	PY	PY	PY	-	L PY	L PY	Not measured, presence is registered
4) Miscut log end	FS	-	FS	FS	-	-	PY	-	PY	-	PY	-	PY	-	L PY	-	Measuring tape (15 m); Goniometer
3 Contamination with soil	-			-		L	PY			L	PY			L	L, PY		Measuring tapes (15m) and (2 m)
4 Dimension incompliance																	
1) Length	FS			FS		-	PY			-	PY			-	L, PY		Measuring tape (15 m)
2) Log end and top diameter	L			L		-	PY			-	PY			-	L, PY		Log end measuring bracket

Note:
* - the indicator is measured if there was a limiting value stipulated in the contractual specifications.

In cut-to-length harvestings, logs were measured before skidding on the roadside and also at the upper landing (loading site) after forwarding and sorting (see Table 5.1, and Figs. 5.1 and 5.2).

Fig. 5.1. Measurement of logs in partially mechanized cut-to-length harvesting (chainsaw + forwarder): FS – at the felling site, L – at the upper landing

Fig. 5.2. Measurement of logs in fully mechanized cut-to-length harvesting (harvester + forwarder): FS – at the felling site, L – at the upper landing

In tree-length harvesting, the tree-lengths were measured both at the felling site before skidding and at the upper landing (loading site) after skidding and piling. As well, logs were measured at the cross-cutting and sorting line of the central processing yard (lower landing) (see Table 5.1 and Fig. 5.3).

Fig. 5.3. Measurements during tree-length harvesting (chainsaw + skidder):
FS – tree-lengths at the felling site, L – tree-lengths at the upper landing,
PY – logs at the central processing yard

In full-tree harvesting, tree-lengths were measured at the upper landing (loading site) and logs at the cross-cutting and sorting line of the central processing yard (see Table 5.1 and Figs. 5.4 and 5.5).

Fig. 5.4. Measurements during full-tree harvesting (chainsaw + skidder):
L – tree-lengths at the upper landing, PY – logs at the central processing yard

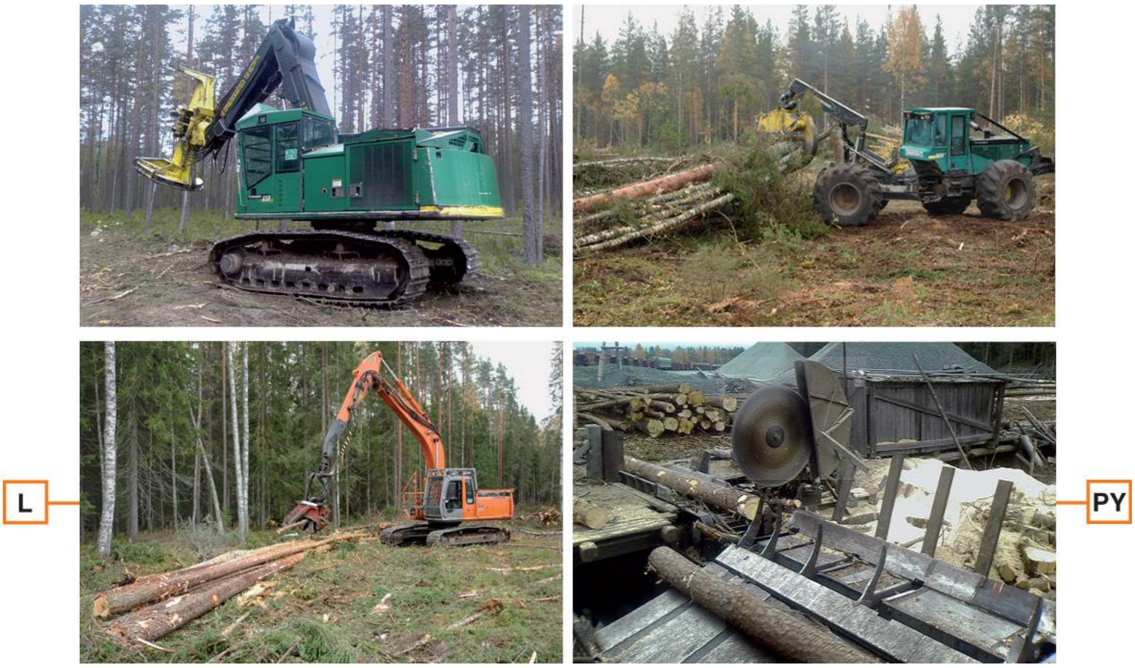

Fig. 5.5. Measurements during fully mechanized full-tree harvesting (feller buncher + skidder): L – tree-lengths at the upper landing, PY – logs at the central processing yard

According to the methodology used, the required number of logs to be measured equals 300 both for each species and each timber assortment. The actual number of logs measured is shown in Table 5.2. All the measurement results were registered in check-lists using a data collector. The state standards GOST 2140-81 [42] and GOST 2292-88 [43] were used during measurement of mechanical damage, processing defects and assortment dimensions. The measurement tools used are shown in Appendix 6. The method defined in Chapter 3 of the reference [39] was used for measuring the degree of barked stem. Contamination of timber with soil was measured based on the width and length of the contaminated area. Contamination is acceptable if the area is not larger than 15% of the total side surface of the log, and not greater than 50% for log ends. Quality requirements of the measured logs of various species and purposes are shown in Tables 5.3 and 5.4.

Table 5.2. Number of measured logs during summer and winter seasons

Technology	**Number of felling sites**		**Number of measured logs, pieces**											
			Pine				**Spruce**				**Birch**			
	winter	summer	winter		summer		winter		summer		winter		summer	
			saw log	pulpwood	saw log	pulpwood	saw log	pulpwood	saw log	pulpwood	veneer log	pulpwood	veneer log	pulpwood
CTL (cs+f)	1	2	300	300	300	300	300	300	300	300	300	300	300	300
CTL (h+f)	3	4	600	600	1 200	900	600	600	1 200	900	-	900	-	900
TL (cs+s)	1	2	600	600	300	300	600	600	300	300	300	300	300	300
FT (cs+s)	1	1	300	300	300	300	300	300	300	300	300	300	300	300
FT (fb+s)	1	1	300	300	300	300	300	300	300	300	-	300	-	300
Total	7	10	2 100	2 100	2 400	2 100	2 100	2 100	2 400	2 100	900	2 100	900	2 100
														Total: 23 400 pcs

Table 5.3. Quality requirements for saw and veneer logs in domestic and export markets

Quality indicator	Saw logs				Birch veneer logs
	Pine		Spruce		
	Export	Domestic	Export	Domestic	Export
1. Mechanical damage					
1) Torn and loosened grain, barked stem, cuts in stemwood and gouges made by a grapple	TU 13-2-12-96 [47]. Not acceptable 🗐.	GOST 22298-76 [46]; GOST 9463-88 [45].	TU 13-2-12-96. Not acceptable 🗐.	GOST 22298-76; GOST 9463-88.	TU 13-2-8-96 [47].
2. Processing defects					
1) Branches	TU 13-2-12-96. Max. acceptable branch length 10/20 mm, diameter below 50/60 mm 🗐.	GOST 22298-76; GOST 9463-88.	TU 13-2-12-96. Max. acceptable branch length 10 mm, diameter below 50 mm🗐.	GOST 22298-76; GOST 9463-88.	TU 13-2-8-96.
2) Log end splits, cracks	Not acceptable 🗐.	GOST 22298-76; GOST 9463-88.	Not acceptable 🗐.	GOST 22298-76; GOST 9463-88.	TU 13-2-8-96.
3) Log end splinters	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.
4) Miscut log end	Not acceptable 🗐.	GOST 22298-76; GOST 9463-88.	Not acceptable 🗐.	GOST 22298-76; GOST 9463-88.	TU 13-2-8-96.
3. Contamination with soil (gravel, sand, mud, clay, etc.)	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.
4. Deviation from the desired dimensions					
1) Length, m (allowance, cm)	4.9; 5.5 (0 /+ 6); 4.0 (0 /+ 6). 4.3; 4.6; 6.1 (+5 / +8)	5.0; 5.5; 6.0; 6.1 (0 /+10) 6.1; 4.0; 3.1 (+3 / +5); additional 4.0; 4.3 (+3 / +10);	5.5 (+3 /+6); 5.5 (0 / +6); 4.05 (0 / +6).	5.0; 5.5; 6.0; 6.1 (0 /+10); additional 4.0; 4.3; 5.2 (+3 /+10).	3.3; 6.0 (0 / +10); 4.4; 5.0 (0 / +5); 3.3 (0 / +5).
2) Maximum diameter of the butt end without bark, cm	55.0*. 34.0	75; 42.0*.	55.0*; 40.0*; 14.9.	75; 52.0*; 36.0; 56.0.	65.0*; 55.0*; 50.0*.
3) Minimum diameter of the butt end without bark, cm	18.0*; 15.0; 15.0*.	16.0; 14.0; 11.0.	18.0*; 17.0*; 16.0*; 12.0.	16.0; 14.0.	25*; 18.0*.

Note: * - diameter over bark; 🗐 - quality requirements in contractual specifications.

Table 5.4. Pulpwood quality requirements for domestic and export markets

Quality indicator	**Pine**		**Spruce**		**Birch**
	Export	**Domestic**	**Export**	**Domestic**	**Export**
1. Processing defects					
1) Branches	GOST 9463-88; TU 13-2-10-96 [48].	GOST 9463-88.	GOST 9463-88; TU 13-2-10-96.	GOST 9463-88; TU 13-2-10-96.	TU 13-2-1-95 [51]; TU 13-2-10-96; TU 13-2-11-96 [50]. Maximum acceptable branch length 20mm🗐.
2) Log end splinters	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.	Not acceptable 🗐.
2. Contamination with soil (gravel, sand, mud, clay, etc.)	Not acceptable 🗐.	GOST 9463-88.	Not acceptable 🗐.	GOST 9463-88; TU 13-2-10-96.	Not acceptable 🗐.
3. Deviation from the desired dimensions					
1) Length, m (allowance, cm)	3.0; 4.0; 6.0 (0 / +10).	3.0 – 6.0 (-20 / +20).	3.0; 4.8. 6.0 (0 / +10)	2.4; 3.6; 4.8; 6.0 (-5 /+15); 4.0; 5.5 (-5/+15); 1.2 (-2 /+ 2); 2.4 (-2 /+ 2); 3.6 and 4.8 (-15 / 15); 4.0 and 5.5 (-10 / +10); 2.4 and 3.6 (+3 / +5).	4.0; 5.5 (0 / +10); 3.0; 4.0; 6.0 (-10 / +10).
2) Maximum diameter in the log end without bark, cm	60.0.	40.0.	40.0	60.0; 50.0; 36.0.	60.0.
3) Minimum diameter in the log end without bark, cm	8.0; 6.0.	6.0.	8.0*	16.0; 6.0.	16.0; 6.0.

Note: * - diameter with bark; 🗐 - quality requirements in contractual specifications.

5.1.2 Determining the reject percentage

The reject percentage was determined based on the results of the study on the logs' quality, i.e., low-quality roundwood was graded and rejected when found not to correspond with the specifications. Mechanical damage, processing defects, contamination with soil and deviations from the desired log dimensions have an impact on the rejection rate, depending on the number of instances of damage, their size and the end use of the logs (for sawmilling, pulp production, etc.). If the logs should correspond with the quality requirements of a certain grade, they should fit into the given range of requirements for quality and dimensions.

The quality requirements for timber assortments of various species, grades and end use are determined in the contract between a logging company and the timber buyer, that is, in the technical specifications. The specifications include the following: tree species, harvesting schedule, dimensions, requirements for processing and quality requirements, such as compliance with standards, e.g. the technical specification TU 13-2-12-96 [47], or the state standards GOST 9462-88 [44] or GOST 9463-88 [45], or other (see Tables 5.3 and 5.4).

Where soil contamination was not acceptable according to the contractual specifications, logs were rejected if more that 15% of the log side surface area or 50% of the log end was contaminated.

Logging companies also develop their own additional specifications for grading and piling of logs, defining the length and diameter of piles, as well as the most preferable log length. If a log does not comply with the above-mentioned requirements, it is rejected or transferred to another grade according to its quality.

During the study, the reject percentage was determined for each measured log according to the technical specifications used in trade contracts or by using internal specifications of the given logging company in the case where the logs were to be used within the company.

5.1.3 Personnel survey

Questionnaires were used in order to gain information about the educational background and work experience of the operators. The survey was conducted at 17 harvesting sites in 11 logging companies in the Republic of Karelia. It included operators of harvesting machines (harvesters, forwarders, delimbers, skidders, skidding tractors and processors), as well as loggers and chokersetters. The results obtained were grouped by harvesting technology (Table 5.5).

Table 5.5. Personnel survey data

Technology	Number of harvesting sites	Number of interviews
CTL (cs+f)	3	12
CTL (h+f)	7	36
TL (cs+s)	3	18
FT (cs+s)	2	13
FT (fb+s)	2	12
Total	**17**	**91**

5.2 Results

5.2.1 Field survey

It was found that mechanical damage (torn and loosened grain, cuts in stemwood and gouges made by a grapple), processing defects (branches, log end splits and cracks) and soil contamination were the most frequent damage (Fig. 5.6).

Fig. 5.6. Indicators reducing roundwood quality

Deviation from the contractual specifications in timber assortment dimensions, maximum log end diameter and minimum top diameter did not have a significant impact on the wood quality. Figure 5.7 presents the results for coniferous logs for all harvesting methods. In tree-length technology, as well as in the partially and fully mechanized full-tree technologies, 2–3% of timber was with mechanical damage. Use of tree-length technology and partially mechanized full-tree technology also resulted in a large share of soil-contaminated timber (5–8%) in summer. When the fully mechanized cut-to-length technology was used, 2% of timber was left with incompletely delimbed branches, both in winter and summer. This was the highest value among all the analyzed harvesting methods.

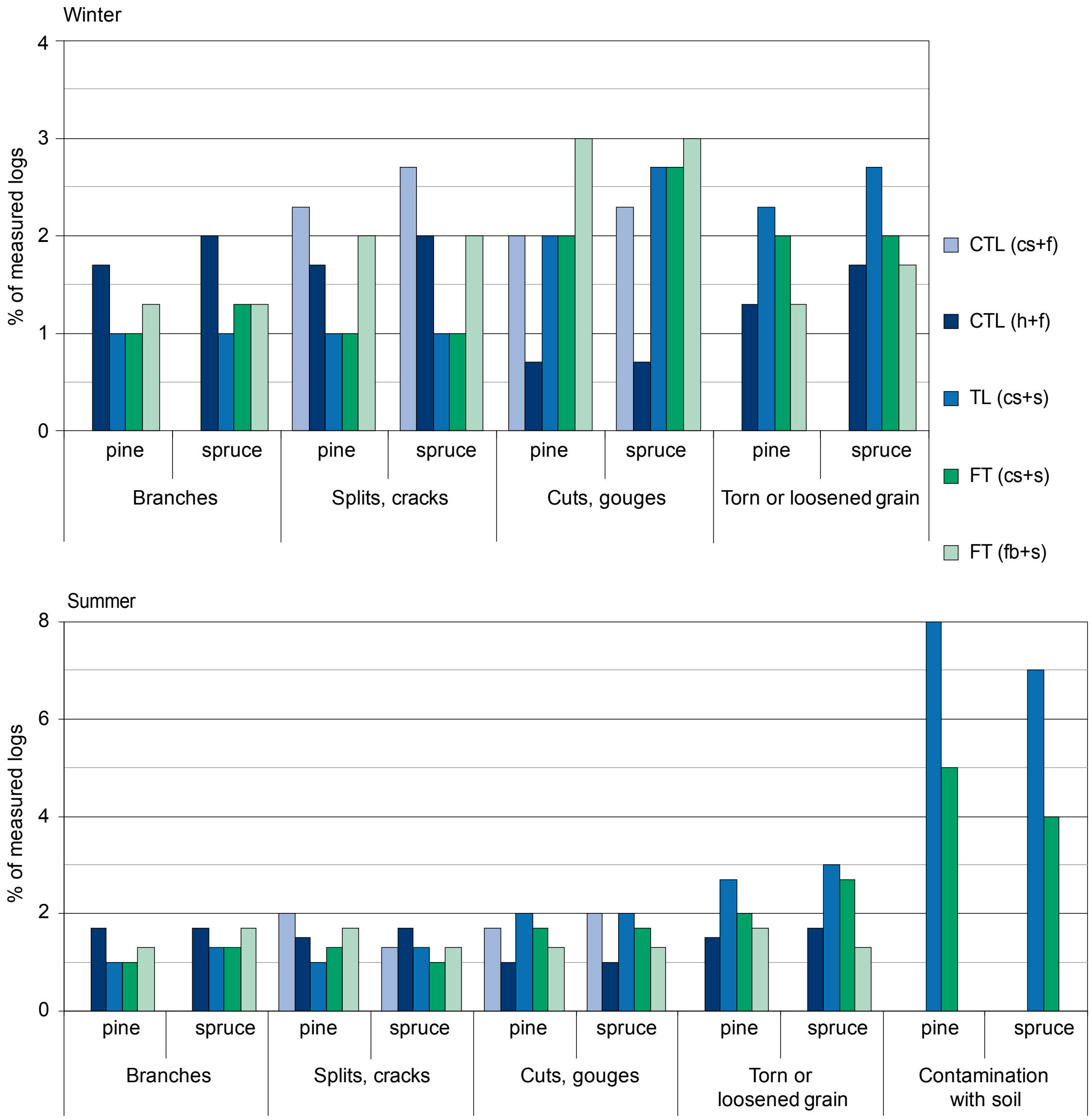

Fig. 5.7. Defects and soil contamination found in saw logs of coniferous species

Figure 5.8 presents the results for birch veneer logs. Here fully mechanized cut-to-length technology and fully mechanized full-tree technology were excluded from the analysis because they were not used for harvesting this type of timber assortment at the analyzed harvesting sites. In summer, the use of tree-length technology resulted in the lowest degree of mechanical damage (3%) and soil contamination (8%).

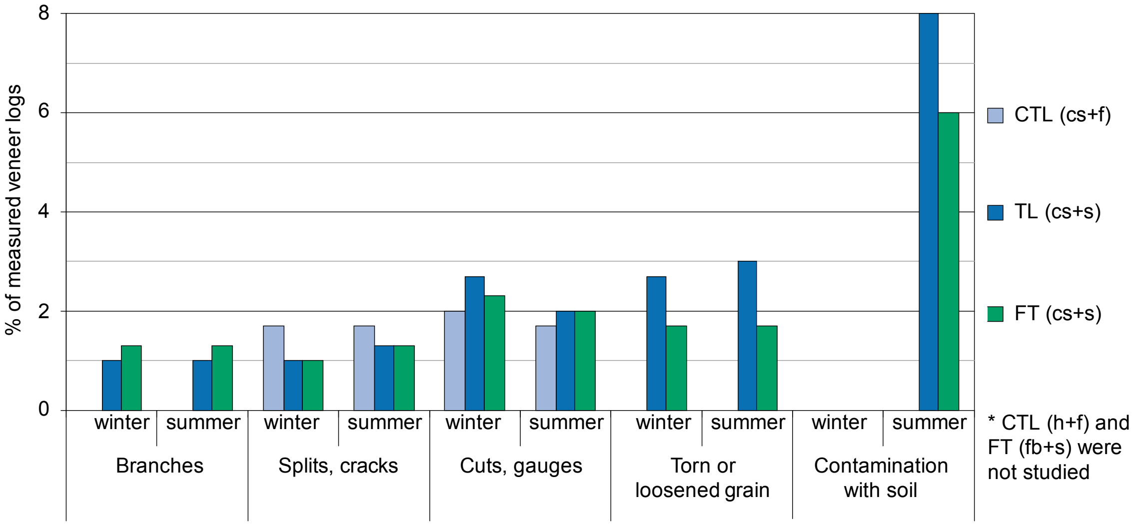

Fig. 5.8. Defects and soil contamination of birch veneer logs in winter and summer

Figure 5.9 shows the results for coniferous and deciduous pulpwood. Incompletely delimbed branches were the most frequent processing defect (2%) of pulpwood for all harvesting methods. The use of tree-length harvesting and partially mechanized full-tree harvesting methods resulted in 6–9% of timber being contaminated with soil in summer.

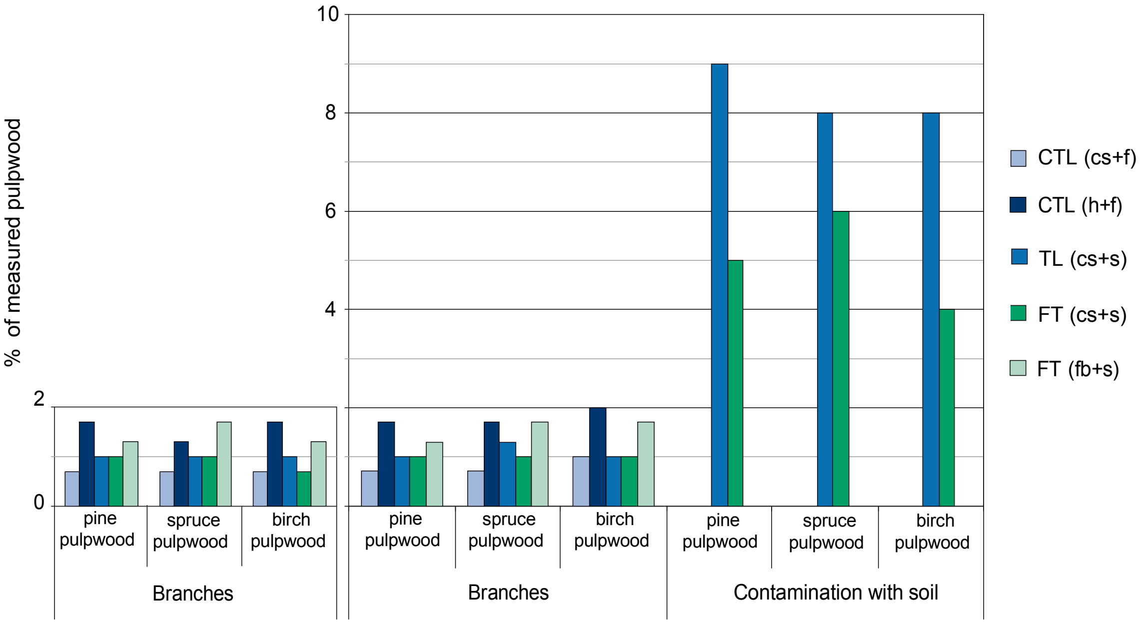

Fig. 5.9. Processing defects and soil contamination of pulpwood in winter (a) and summer (b)

5.2.2 Reject percentage

Figure 5.10 shows the obtained reject percentage for coniferous saw logs and birch pulpwood to be exported to Finland. The results include all the harvesting methods and apply to both the winter and summer seasons. The tree-length technology caused the highest reject percentage for saw logs (7–8%). In summer, this technology also resulted in the highest percentage of birch pulpwood rejection (6%). The lowest reject percentage for saw logs was provided by the fully mechanized cut-to-length technology (3%). The lowest reject percentage for birch pulpwood (1%) was registered with partially mechanized cut-to-length technology.

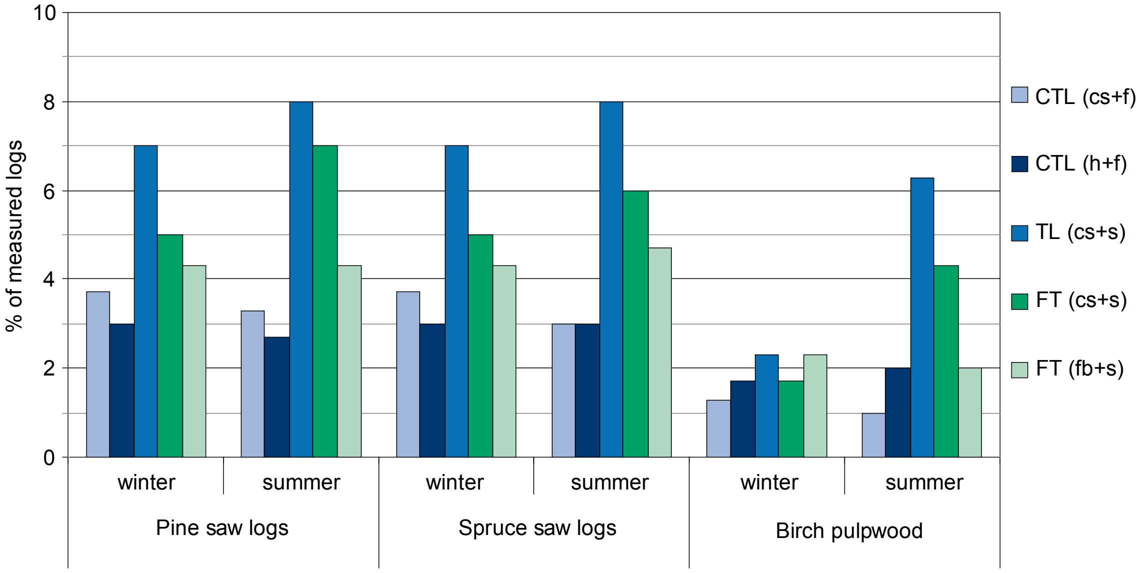

Fig. 5.10. Reject percentage for coniferous saw logs and birch pulpwood exported outside Russia, in accordance with the technical specifications TU 13-2-12-96 and TU 13-2-1-95, respectively

Figure 5.11 presents the reject percentage for coniferous saw logs and pulpwood supplied to the Russian domestic market for all harvesting methods for both the winter and summer seasons. The tree-length technology had the highest reject percentage for saw logs (6–7%), and the fully mechanized cut-to-length technology provided the lowest reject percentage (3%). For pulpwood, the highest reject percentage resulted from the use of tree-length technology (3%), and the lowest was attained with partially and fully mechanized cut-to-length harvesting (1–2%).

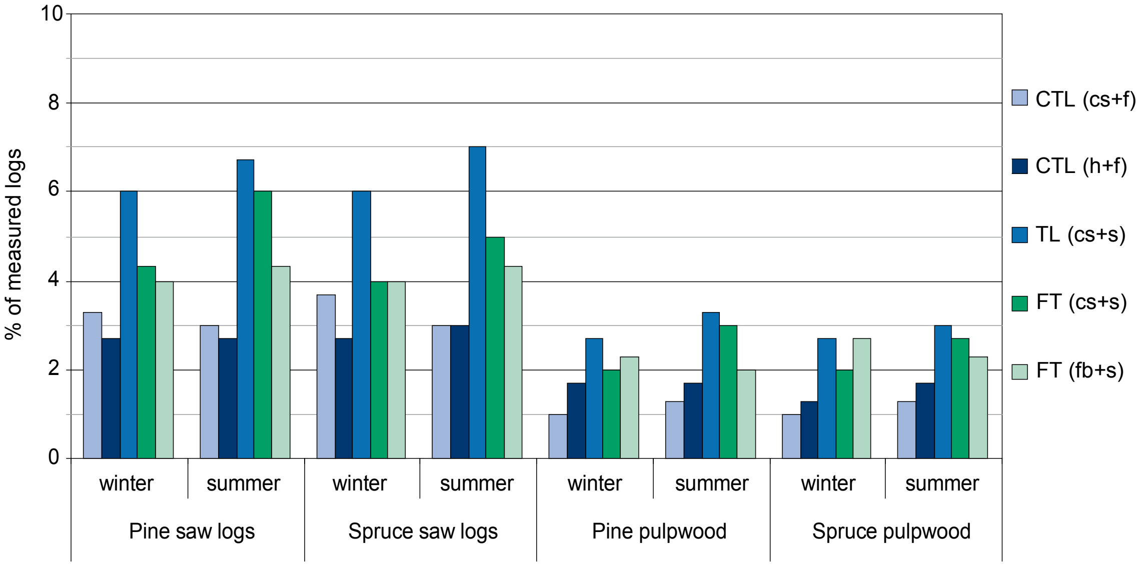

Fig. 5.11. Reject percentage for coniferous saw logs and pulpwood supplied to the Russian domestic market, in accordance with the state standard GOST 9463-88

5.2.3 Personnel survey

Figures 5.12 and 5.13 show the work experience and training of the interviewed operators. Operators employed in partially mechanized full-tree harvesting appeared to have the longest work experience (more than five years), while harvester and forwarder operators had the shortest work experience. All the interviewed harvester and forwarder operators working with partially mechanized cut-to-length technology had relevant intermediate vocational education.

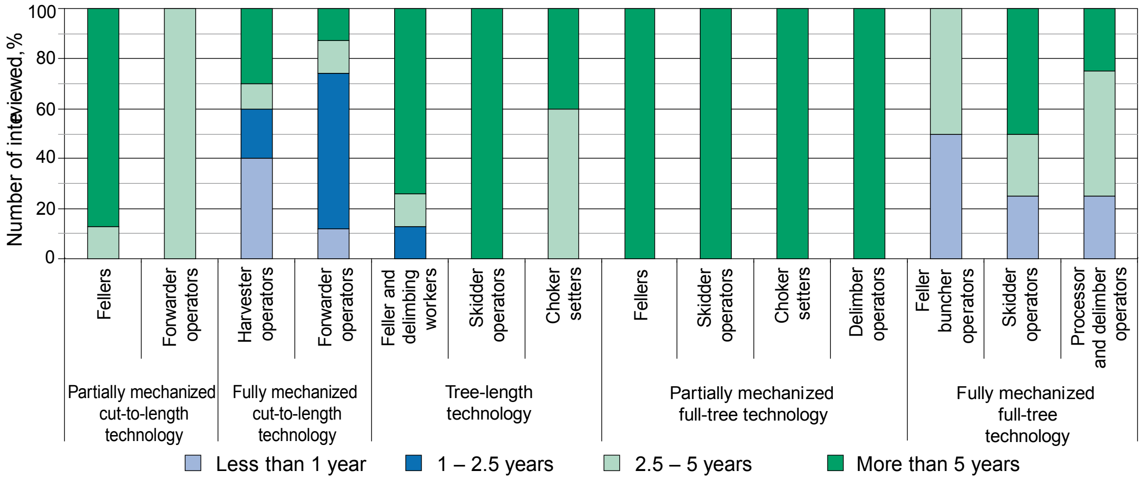

Fig. 5.12. Work experience of the interviewed operators

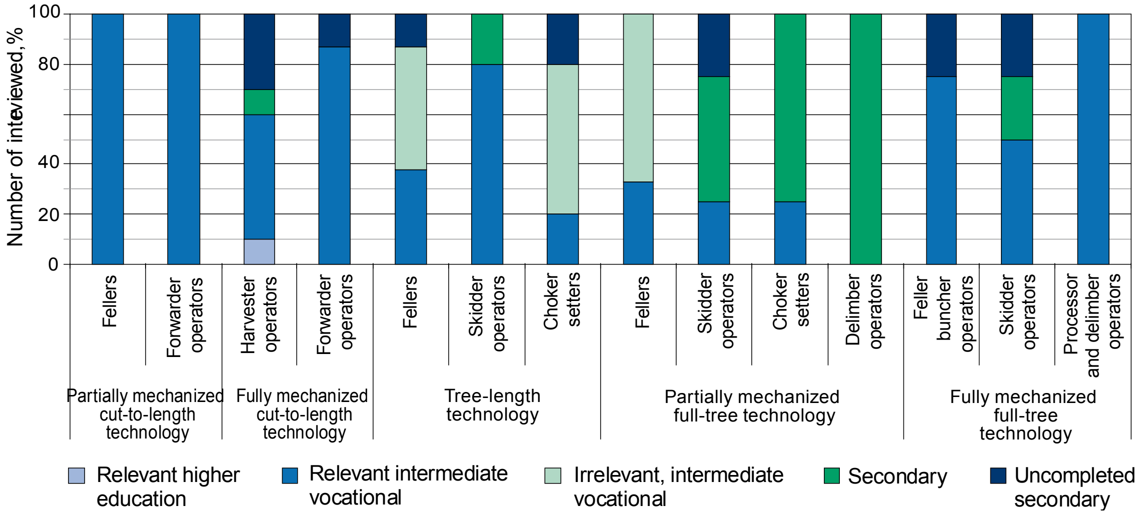

Fig. 5.13. Educational background of the interviewed operators

Figure 5.14 shows the results of the survey conducted among the operators in order to identify their knowledge about wood quality.

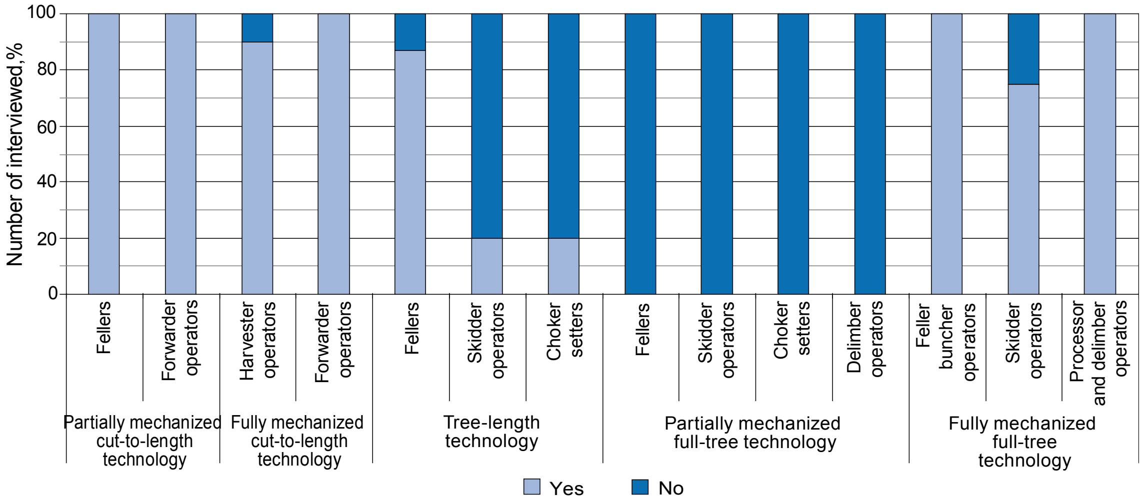

Fig. 5.14. Personnel training in timber quality issues (knowledge of flaws and defects)

Predominantly, operators of harvesting machines (partially and fully mechanized cut-to-length technology and fully mechanized full-tree technology), fellers and delimbing workers (partially mechanized cut-to-length and tree-length technologies) appeared to be the ones who were taught the basics of timber quality assessment during vocational education or further training. Figure 5.15 shows the results illustrating the operators' knowledge about roundwood quality requirements (including roundwood size).

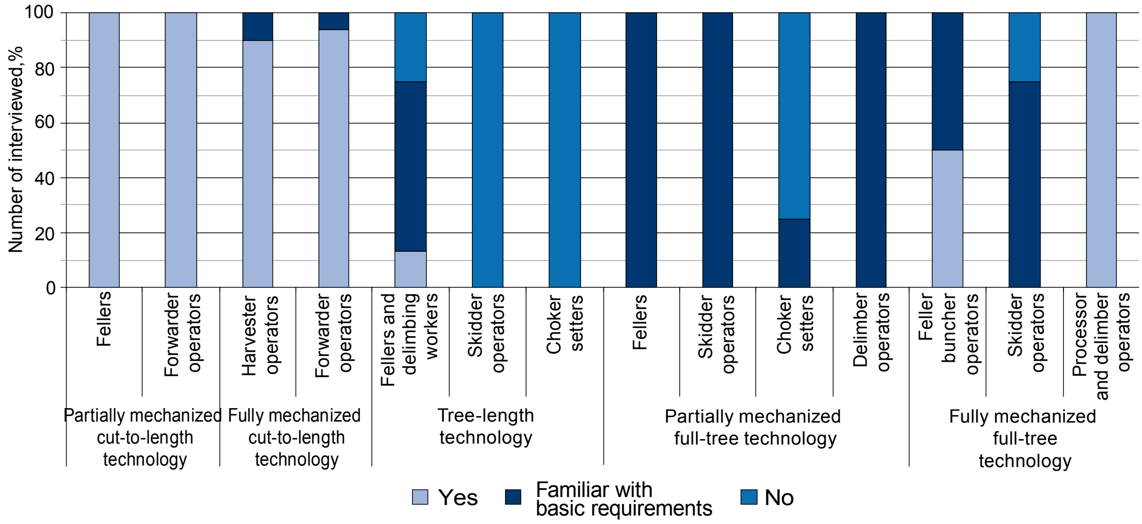

Fig. 5.15. Operators' familiarity with roundwood quality requirements

All of the operators of harvesters, forwarders, feller bunchers, processors and delimbers (both partially and fully mechanized cut-to-length and full-tree technologies), as well as fellers and delimbing workers (partially mechanized cut-to-length and tree-length technology, partially mechanized full-tree harvesting) were familiar with wood quality requirements.

According to the results of the survey among harvester operators, in order to minimize or totally avoid incompletely delimbed branches, it is necessary to use harvester heads with a higher feed force, and to monitor the sharpness of the delimbing blades (Fig. 5.16).

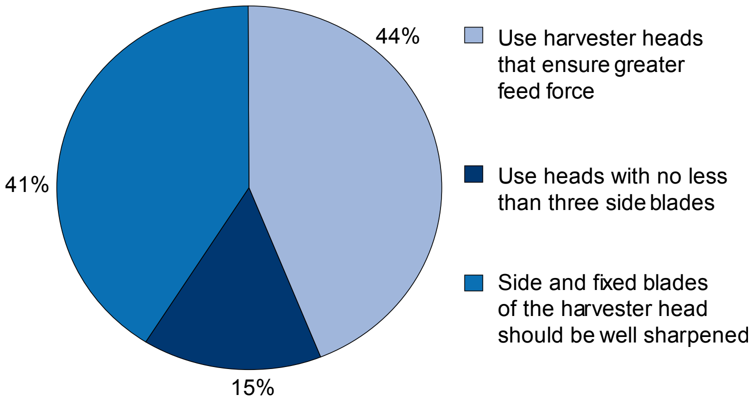

Fig. 5.16. Ways to reduce or totally avoid incompletely delimbed branches

To avoid formation of cracks in log ends, the operator should regularly check the harvester head cutting chain during cross-cutting (Fig. 5.17).

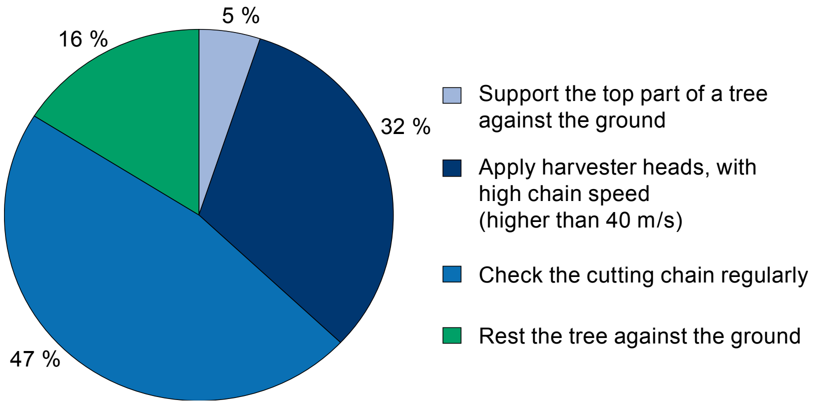

Fig. 5.17. Ways to avoid shake formation on log ends during cross-cutting with a harvester

It should also be noted that all the interviewed skidder operators and chokersetters considered damage to logs by cable (or choker) not to have any negative impact on wood quality. Half of the interviewed skidder operators thought that mechanical stemwood damage by grapple can reduce wood quality.

5.3 Analysis of the results

5.3.1 Comparison of harvesting methods by wood quality

The study of the quality of wood harvested with partially mechanized cut-to-length technology demonstrated that log end splits and cracks (3%), as well as cuts by chainsaw and gouges by forwarder's grapple during loading/unloading operations (2%), were the most common types of processing defects. The reject percentage was about 4% in winter and 3% in summer for coniferous saw logs; and about 1% for birch, pine and spruce pulpwood regardless of the harvesting season.

Fully mechanized cut-to-length technology, both in winter and summer, was mostly associated with the following types of defects: incompletely delimbed branches (2%), log end splits and cracks during felling and cross-cutting (2%), and log surface damage. The latter appeared in the form of damage by the delimbing and feeding mechanisms of the harvester head during delimbing, i.e., torn and loosened grain (2%). This damage was accompanied with barked stem or even a lost layer of stemwood. Logs damaged by a harvester head saw (cuts) or forwarder's grapple were more infrequent (less than 1%).

When harvester operators were following all work requirements and instructions, the reject rate for coniferous saw logs harvested with fully mechanized cut-to-length technology was less than 3%, and less than 2% for coniferous pulpwood, regardless of the season. The fully mechanized cut-to-length technology also ensured efficient cross-cutting of the stems with the required length allowance, normally +(0–4) cm, which maximized the amount of received timber assortments, contrary to the partially mechanized cut-to-length technology, where the allowance was mostly +(5–10) cm.

For the tree-length harvesting and partially mechanized full-tree harvesting, regardless of the season, the following types of damage were typical: torn and loosened grain (3%) and cuts in stemwood and gouges made by a grapple (3%). Less frequent were: incompletely delimbed branches (1%) and log end splits and cracks (1%). In summer, contamination with soil was also found (9% for the tree-length method and 6% for the partially mechanized full-tree method). For spruce and pine saw logs, the following reject percentages were registered: spruce 6–7% and pine 4–5% in winter; and spruce 7–8% and pine 6–7% in summer. The maximum reject percentage was registered for the saw logs intended for export market. For birch pulpwood, this figure made 2% in winter, and up to 6% for the tree-length method and 4% for the partially mechanized full-tree method in summer. For pine and spruce pulpwood, the reject percentage was up to 3% and 2% in winter, respectively, and 3% in summer.

Fully mechanized full-tree harvesting both in winter and in summer was mostly associated with the following types of timber defects: cuts in stemwood and gouges made by a grapple (3%), log end splits and cracks (2%), torn and loosened grain (2%) and incompletely delimbed branches (2%). The reject percentage for spruce and pine saw logs was about 4%, regardless of the season. For birch, pine and spruce pulpwood, this figure was about 3% in winter and up to 2% in summer.

The seasonality of felling operations has a negative impact on the quality of harvested wood; this pertains to the partially mechanized cut-to-length technology, tree-length technology and partially mechanized full-tree technology.

As well, the insufficient qualification of operators working with tree-length and partially mechanized full-tree technology has a negative impact on wood quality. In particular, failure to comply with the required operational technique was observed in the course of the following operations: skidding (Fig. 5.18), piling at the upper landing (loading site) (Fig. 5.19), fully mechanized delimbing at the upper landing (Fig. 5.20) and bunching of tree-lengths prior to loading onto a timber truck (Fig. 5.21).

Fig. 5.18. Improper operations during skidding

Fig. 5.19. Improper operations during piling of tree-lengths

Fig. 5.20. Improper operations during delimbing

Fig. 5.21. Improper operations during bunching of tree-lengths

Improper technical maintenance (harvester head maintenance) performed by harvester operators and their failure to comply with the required operational technique during felling and cross-cutting had a negative impact on wood quality (along with other factors). In particular, incorrect adjustment of the harvester head's delimbing and feeding mechanism, insufficient sharpening of the delimbing blades, wear of feed roller spikes (Fig. 5.22), etc. contributed to torn and loosened grain and barked stem in logs.

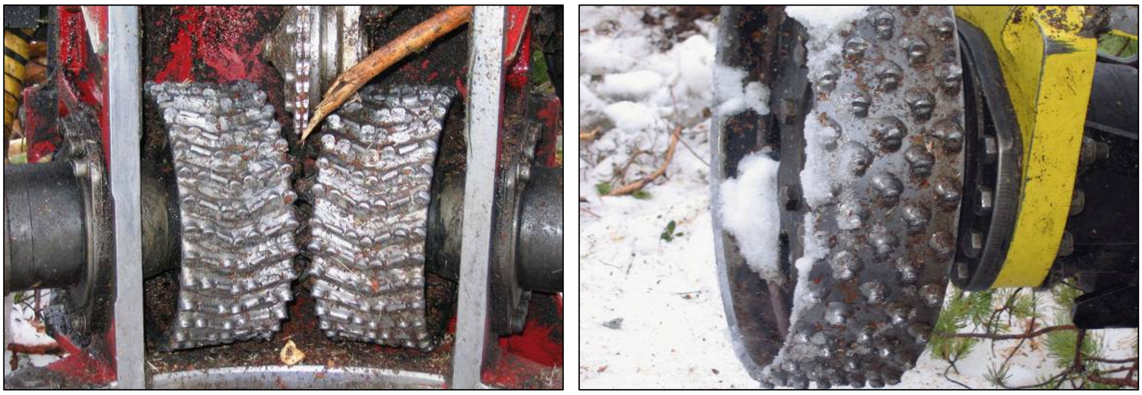

Fig. 5.22. Feed rollers with worn-out spikes

Figure 5.23 shows logs harvested with a harvester that has correctly (a) and incorrectly (b) adjusted delimbing and feeding mechanism of the harvester head. Incorrect adjustment leads to barked stem, so deep that sometimes a layer of timber gets removed.

Fig. 5.23. Logs harvested with correctly (a) and incorrectly (b) adjusted harvester head.

Sometimes forwarder operators failed to comply with the requirements during loading and unloading operations (Fig. 5.24).

Fig. 5.24. Incompliance during loading and unloading operations

During fully mechanized full-tree harvesting, it was observed that skidder operators sometimes did not comply with the required operational technique during piling at the upper landing (Fig. 5.25); and harvester operators, when operating the machine as a processor, did not properly perform the cross-cutting operation. As well, incorrect maintenance of the harvester head's delimbing and feeding mechanism was observed.

Fig. 5.25. Incorrect piling operation

Usually, regardless of the technology employed, bed logs [52] were not laid under the pile before roundwood piling operations (Fig. 5.26). Due to the missing bed logs, timber in the lower part of the pile bottom gets contaminated with sand, clay, etc. During partially-mechanized full-tree harvesting, the missing bed logs hindered bunching of tree-lengths with a loader and contributed to timber damage.

Fig. 5.26. A roundwood pile at the upper landing (loading site) without underlaying bed logs

5.3.2 Impact of operator’s qualification on wood quality

First of all, the short work experience of harvesting-machine operators in fully mechanized cut-to-length and tree-length harvesting should be taken into consideration. Two-thirds of harvester operators had not been working earlier with Russian-made harvesting machinery and, predominantly, they had just recently graduated from higher or secondary vocational schools. When it comes to forwarders, feller bunchers, skidders or harvesters operating as a processor or delimber, most of the operators completed a training course on the new machines approximately one to five years previously and had graduated from relevant vocational schools already a fairly long time ago. Most of the harvesting-machine operators had relevant vocational education.

All the interviewed fellers employed at partially mechanized cut-to-length and full-tree harvesting had secondary vocational education. Most of the fellers and delimbing workers employed at tree-length harvesting also had secondary vocational education. On the other hand, a low educational level was observed among skidder operators, chokersetters and delimber operators working with tree-length technology and partially mechanized full-tree technology, although these operators had sufficiently long work experience.

A survey among operators demonstrated that wood-quality issues were covered during vocational education or training courses of harvesting-machine operators as follows: partially mechanized cut-to-length technology – all forwarder operators; fully mechanized cut-to-length technology – most harvester operators and all forwarder operators; fully mechanized full-tree technology – all feller buncher and processor operators and two-thirds of skidder operators. As well, all fellers that work with partially mechanized cut-to-length technology were trained in timber-quality questions, as well as most of the fellers and delimbing workers with tree-length harvesting. However, only one-fifth of skidder operators and chokersetters that work with tree-length technology had received training in wood quality.

The wood-quality specifications were known to all the harvester, forwarder, feller buncher, processor and delimber operators (in both partially and fully mechanized cut-to-length and full-tree harvesting), as well as to fellers and delimbing workers (in partially mechanized cut-to-length and tree-length technology, and partially mechanized full-tree harvesting). On the other hand, one-third of the interviewed fellers and delimbing workers, as well as all the interviewed skidder operators and chokersetters, were not familiar with wood-quality specifications. Two-thirds of the interviewed chokersetters working with partially mechanized full-tree technology and one-quarter of skidder operators working with fully mechanized full-tree technology were not familiar with the specifications for wood quality and timber assortment dimensions.

5.4 Conclusions and recommendations

The analysis of the obtained results indicates that fully mechanized cut-to-length harvesting can ensure the highest quality of harvested timber (reject rate below 3%) in all the studied regions of the Republic of Karelia, with different species composition. Partially mechanized cut-to-length harvesting and fully mechanized full-tree harvesting demonstrated acceptable timber quality (reject rate below 4%). The quality of wood in tree-length harvesting and partially mechanized full-tree harvesting may be low, particularly in summer (reject rate up to 8% and 7%, respectively).

In cut-to-length harvesting, the workers did not observe the required operational techniques in the following work phases: fellers broke the guidelines during cross-cutting; harvester operators during felling and cross-cutting; as well as forwarder operators during loading and unloading operations. Incorrect maintenance of harvester heads by harvester operators (including harvesters operating as processors) was also registered in fully mechanized cut-to-length and full-tree harvesting. In fully mechanized full-tree harvesting, skidder operators broke the guidelines during piling at the upper landing (loading site).

In tree-length technology and partially mechanized full-tree harvesting, the following discrepancies from the required operational technique were observed: skidding tractor operators did not follow the guidelines during tree-length or full-tree skidding and piling at the upper landing; and delimbing workers and delimber operators during delimbing operation at the felling site and at the upper landing, respectively.

The following defects were found to be typical for partially mechanized cut-to-length technology: processing defects, such as log end splits and cracks, and also mechanical damage (cuts) of the timber by a saw or forwarder's grapple. For fully mechanized cut-to-length harvesting, the following defects were typical: processing defects, in particular, incompletely delimbed branches, log end splits, cracks; and mechanical damage caused by the delimbing and feeding mechanism of the harvester head – torn and loosened grain. Tree-length technology and partially mechanized full-tree harvesting were associated with the following damage types: mechanical damage, such as torn and loosened grain, cuts in stemwood and contamination with soil during summer harvesting. Fully mechanized full-tree harvesting had the following defects:

processing defects, such as log end splits, cracks, branches; and mechanical damage – cuts in stemwood, and torn and loosened grain.

As a conclusion, it can be stated that the crookedness of logs should also have been measured when comparing the harvesting systems. Ability to avoid this defect largely depends on the training level of fellers and harvesting-machine operators, and particularly on the capacity to carry out high-quality cross-cutting and sorting operations.

Almost none of the studied harvesting systems used bed logs under piles when piling roundwood at either the intermediate loading site or the upper landing.

To conclude, in order to improve wood quality in the analyzed harvesting technologies, the following deficiencies should be corrected:

- Operators should perform the maintenance of harvesting machines properly (e.g. adjustment of the delimbing and feeding mechanisms of the harvester head; sharpening the delimbing knives; cleaning the rollers to remove bark and timber residue, etc.). On the other hand, the harvester head should match both the base machine and the species and age composition of the forest stand.
- Harvesting-machine operators should comply with the required operational technique. This should be controlled by site foremen and wood-quality inspectors.
- Workers at the felling site should be familiar with the requirements for wood quality.
- Workers' salaries should depend on the quality of the timber produced.
- Prior to further training courses or specializing in operating sophisticated machines, operators are required to have a relevant vocational education; this is of special importance for harvesters, feller bunchers and forwarder operators.
- In harvesting, the seasonality should be taken into account: the reject percentage is higher in winter for partially mechanized cut-to-length technology, and in summer for tree-length technology and partially mechanized full-tree harvesting.
- Bed logs under piles should be used for roundwood piling at the upper landing (loading site), depending on the soil conditions.
- Taking into account natural and production conditions in the Republic of Karelia, it is necessary to improve the design of the harvester head's delimbing and feeding mechanism, in order to ensure their higher efficiency in the processing of trees with crooked trunks and tapering or large branches.

Particular attention should be paid to the training of harvester and forwarder operators. It is necessary to improve curricula, giving more emphasis to the maintenance and adjustment of harvesting machinery, and also to the practical training of students, teaching them how to operate the particular machines that are used in the company where they intend to work in the future. Recommendations on how to improve the roundwood quality should be developed for harvester and forwarder operators in the form of brief quality guidebooks.

If all the requirements and instructions are met, it should be possible to decrease the level of mechanical damage and processing defects, and otherwise to improve the wood quality for each of the analyzed technologies. In actual harvesting conditions, if all the discovered shortcomings typical for fully mechanized cut-to-length and full-tree harvesting are eliminated, it should be possible to decrease the number of harvested assortment logs with mechanical damage and processing defects by approximately 20% and 25%, respectively. It should be noted that cross-cutting optimization of the fully mechanized cut-to-length harvesting system allows an increase in the amount of received timber assortments. Improvements made in the partially mechanized cut-to-length technology would enable a decrease in the number of logs with mechanical damage and processing defects by approximately 15%. In tree-length and partially mechanized full-tree technology, the potential reduction of damaged logs could reach 20% and 15%, respectively.

6 Conclusion

Following conclusions can be made from the performed comprehensive study.

Productivity of the harvesting-machine systems used in the analyzed harvesting processes varied within a relatively wide range, 20 to 150 m^3 per shift. Fully mechanized full-tree harvesting provided the maximum productivity. This was followed by partially mechanized full-tree harvesting, fully mechanized cut-to-length harvesting, partially mechanized cut-to-length harvesting, and partially mechanized tree-length harvesting.

The professionalism and experience of harvesting-machine operators has a significant impact on the productivity. Finnish harvesting-machine operators, after having completed a special training course and obtaining the necessary practical skills, demonstrate productivity levels almost twice as high (over 30 m^3 per hour against 16 m^3) as Russian operators, because the Russian operators are most often only trained internally at the company. Hence, this factor reveals significant reserves for a productivity increase through improvement of the operator training system.

Direct operating costs had insignificant differences. Fully mechanized full-tree harvesting had the lowest costs, which is first of all due to the high productivity of the machines used (almost two times higher than with other technologies). Even though it had the highest productivity, this technology can not be unambiguously recommended for use in Northwest Russia. This is due to a number of reasons. First, fully mechanized full-tree harvesting requires a long machine chain: feller buncher, grapple skidder, delimber, and either a loader if the wood is transported in tree-lengths, or a harvester operating as a processor if the wood is transported in logs. The purchase of all these machines requires a substantial amount of money, which limits the application of this technology. Tree-length technology shows a medium level of felling costs and is comparable with both the cut-to-length and full-tree technologies. However, it involves, similar to full-tree harvesting with tree-length transportation, further additional costs caused by work at the central processing yard, which is not the case with the cut-to-length technology.

The relatively high costs of the fully mechanized cut-to-length technology were related to the fact that, on average, the machines have been introduced into practice a relatively short time ago. As well, nowadays the machines are mainly purchased under leasing agreements which significantly increase the costs during the first years of operation. In addition, the study has revealed that, due to the insufficient level of operators' qualifications, the average monthly productivity can be low and it achieved only 46 m^3 per shift in this study.

At the present, many companies are considering a change to the fully mechanized cut-to-length technology. This change requires substantial financing, and therefore, different financing alternatives should be analyzed: the company's own funds, bank loans or leasing. In summary, it can be stated that, in the long term, a change to cut-to-length technology makes it possible to reduce production costs, increase productivity and, consequently, improve the financial situation of the company and the competitiveness of its products.

All the studied harvesting methods caused different degree of negative **environmental impact**. When applied on sandy or sandy loam soils, all the machine systems of all the technologies demonstrated an almost similar impact on the lower layers of the soil, i.e., porosity reduction within 9–10%. The "harvester + forwarder" and "chainsaw + forwarder" systems used in cut-to-length harvesting were shown to be less damaging to sandy and loam soils. In coniferous stands and hilly landscapes, this works favourably for natural regeneration. The full-tree technology facilitates natural regeneration in stands with a thicker humus layer.

On clay loams, the traditional tree-length technology, unlike the cut-to-length technology, resulted in significant topsoil compaction, but at the same time formed almost no track. Therefore, for large harvesting sites (more than 20 ha), the tree-length technology can be recommended. For small sites, the cut-to-length technology works better because it reduces the probability of multiple trips along the same skid road, which reduces track formation and provides for smaller topsoil compaction.

The “feller buncher + wheeled skidder”-based full-tree technology is only acceptable in harvesting sites where no undergrowth preservation is intended. Partially mechanized cut-to-length technology ensures high undergrowth preservation. For thinnings, either the tree-length or fully mechanized cut-to-length technology can be used. These technologies result in less damage to the remaining trees (2% to 3% with an operator’s work experience of more than five years). The data of the personnel survey revealed that workers in the Karelian forest sector consider the environmental impact to be equally dependant on a harvesting operator’s qualification and the harvesting technology.

In order to reduce the negative impacts on the forest environment and to decrease the regeneration costs, it is necessary to provide comprehensive training for operators of harvesting machines, including training with simulators, no less than six months of practical work in natural conditions, and a familiarization with the harvesting regulations covering environmental and silvicultural requirements (Appendix 5). It should be noted that the work of harvesting machines on soils with low bearing capacity is currently scarcely studied. Meanwhile, having been remote and hardly accessible in the past due to the lack of technology, these regions possess significant forest-stand reserves and have a promising development potential.

The evaluation of 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 + wheeled skidder” in fully mechanized full-tree harvesting, the difference not being significant. Third place was occupied by the “chainsaw + forwarder” system in the partially mechanized cut-to-length technology, but here the value of the evaluation criteria was significantly lower than for the first two technologies. Traditional tree-length harvesting with cable skidders demonstrated the worst results in terms of ergonomics, work severity and occupational safety.

Among operations performed with chainsaws, cross-cutting in piles at the intermediate landing indicated the best results. However, none of the other types of work phases performed with chainsaws complied with the vibration load norms. When harvesting operations are performed by chainsaw, the use of the TDT-55A skidders should be avoided as much as possible because they do not comply with the latest ergonomic standards.

Comparing the harvesting methods by **the quality of roundwood**, it was found that the fully mechanized cut-to-length technology provided the best quality. The partially mechanized cut-to-length technology and fully mechanized full-tree harvesting resulted in somewhat lower but still acceptable quality. The quality of wood harvested with tree-length or partially mechanized full-tree technology turned out to be the lowest, especially in the summer season.

During the study of cut-to-length harvesting, it was found that fellers were not following the required operational techniques during motor-manual cross-cutting and forwarder operators during loading and unloading operations. Harvester operators made mistakes during felling and cross-cutting. In full-tree and tree-length harvesting, mistakes occurred during skidding and piling operations, as well as during delimbing. In fully mechanized cut-to-length and full-tree harvesting, the required equipment maintenance procedures were also not followed, resulting in roundwood defects.

The above-mentioned violations of operational techniques, as a rule, resulted in defects of the roundwood. Log end splits and cracks, as well as cuts in stemwood and gouges made by a grapple, were typical for the partially mechanized cut-to-length technology. Not completely delimbed branches, log end splits and cracks, and torn and loosened grain were typical for fully mechanized cut-to-length harvesting. Tree-length and partially mechanized full-tree harvesting most frequently resulted in the following defects: torn and loosened grain, cuts in stemwood, and contamination with soil in the summer harvesting season. The fully mechanized full-tree technology caused log end splits and cracks, not completely delimbed branches, torn and loosened grain, as well as cuts in stemwood.

The results of the study demonstrated that the fully mechanized cut-to-length technology provided for efficient cross-cutting of stems with a length allowance of +(0–4) cm, which maximizes the amount of received timber assortments, contrary to the partially mechanized cut-to-length harvesting, where the allowance in most cases was +(5–10) cm.

The personnel survey revealed that operators’ training should play an important role in companies’ efforts to improve wood quality. The companies should make sure that operators’ salaries are directly linked with the quality of harvested wood.

In real harvesting conditions, if operators comply with all the requirements and instructions, it is possible to reduce the level of mechanical damage, processing defects and other quality defects for each of the studied technologies. In particular, when using the fully mechanized cut-to-length technology, special attention should be paid to proper tuning and adjustment of the harvester head’s delimbing and feeding mechanisms, sharpening of delimbing knives, cleaning of rollers from bark and timber, etc. As well, technical parameters of the harvester head should be in line with the species and age structure of the forest stand. Speaking about the natural and production conditions in the Republic of Karelia in particular, it is necessary to improve the design of the delimbing and feeding mechanisms of harvester heads to improve their processing efficiency in the case of trees with crooked trunks and tapering or large branches.

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APPENDIX 1

Observation Form No._____

Company ____

Date __________________________________ Work Area (logging unit)___________________________

Observation started _________________________Observation completed______________________________

Worker’s name ____

Age _______________ Work experience__ Experience at the given job ____________________________

Working conditions ____

Mechanisms, instruments and tools used____

Fuel consumption (litres) ______________________Fuel type _____________________________________

Inventory before the work _____________________ Fuelled_______________________________________

Inventory after the work______________________ Amount of fuel spent___________________________

Amount of job done ____

(processed area in hectares, timber skidded in m^3, etc.)

No.	Elements of working time (process operations) and breaks	Designations	Current time			Duration		Production indicators (species, diameter, load, distance, etc.)	Notes
			hour	min	sec	min	sec		

APPENDIX 2

Examples on cost calculation by the Finnish method

Harvester Timberjack 1270		
Scheduled working days	249 days	
Scheduled working hours	3 794 hours	
Machine utilization rate	91%	
Productive working time	3 429 hours	
Delays	230 hours	
Transportation time	135 hours	
Purchase price	11 174 000 roubles	
Depreciation period	3 years	
Depreciation, %	33%	
Hourly productivity	15 m^3/hour	
Salvage, %	15.2%	
Bank interest rate	15%	
Fixed costs	**Roubles/year**	**Roubles/hour**
Interest payments	965 434	297.52
Depreciation	0	0
Administrative costs	0	0
Other payments (leasing, sub-rent, etc.)	3 158 517.33	973.38
Total fixed costs	**4 123 950.93**	**1 270.90**
Variable costs	**Roubles/year**	**Roubles/hour**
Fuel and lubricants	1 420 000	437.61
Repair and maintenance	135 621	41.80
Spare parts	528 936	163.01
Operator's salary	715 000	220.35
Social welfare deductions (29.1%[6])	208 065	64.12
Other	20 000	6.16
Total variable costs	**3 027 622**	**933.04**
TOTAL COSTS	**7 151 572.93**	**2 203.94**
TOTAL COSTS per 1 m^3	**188.20 roubles**	

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[6] Consolidated Social Tax (CST, 26%) and accident insurance deductions (3.1%) are included in this table and in the following ones.

Forwarder John Deere 1410 D		
Scheduled working days	269 days	
Scheduled working hours	3 290 hours	
Machine utilization rate	79%	
Productive working time	2 590 hours	
Delays	500 hours	
Transportation time	200 hours	
Purchase price	8 500 000 roubles	
Depreciation period	3 years	
Depreciation, %	33%	
Hourly productivity	12.2 m³/hour	
Salvage, %	15.2%	
Bank interest rate	15%	
Fixed costs	**Roubles/year**	**Roubles/hour**
Interest payments	734 400	283.55
Depreciation	0	0
Administrative costs	0	0
Other payments (leasing, sub-rent, etc.)	2 402 666.67	927.67
Total fixed costs	**3 137 066.67**	**1 211.22**
Variable costs	**Roubles/year**	**Roubles/hour**
Fuel and lubricants	625 939	241.68
Repair and maintenance	107 300	41.43
Spare parts	324 500	125.29
Operator’s salary	536 500	207.14
Social welfare deductions (29.1%[7])	156 122	60.28
Other	5 000	1.54
Total variable costs	**1 755 361**	**677.35**
TOTAL COSTS	**4 892 427.17**	**1 888.58**
TOTAL COSTS per 1 m³	**154.90 roubles**	

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[7] Consolidated Social Tax (CST, 26%) and accident insurance deductions (3.1%) are included in this table and in the following ones.

Feller-buncher Timberjack 850		
Scheduled working days	269 days	
Scheduled working hours	5 750 hours	
Machine utilization rate	64%	
Productive working time	3 675 hours	
Delays	1 575 hours	
Transportation time	500 hours	
Purchase price	18 500 000 roubles	
Depreciation period	6.9 years	
Depreciation, %	15%	
Hourly productivity	27.2 m³/hour	
Salvage, %	15.2%	
Bank interest rate	15%	
Fixed costs	**Roubles/year**	**Roubles/hour**
Interest payments	1 598 400	434.94
Depreciation	2 273 623.19	618.67
Administrative costs	0	0
Other payments (leasing, sub-rent, etc.)	0	0
Total fixed costs	**3 872 023.19**	**1 053.61**
Variable costs	**Roubles/year**	**Roubles/hour**
Fuel and lubricants	3 015 000	820.41
Repair and maintenance	750 350	204.18
Spare parts	400 000	108.84
Operator's salary	1 090 000	296.60
Social welfare deductions (29.1%[8])	317 190	86.31
Other	30 000	8.16
Total variable costs	5 602 540	**1 524.50**
TOTAL COSTS	**9 474 563.19**	**2 578.11**
TOTAL COSTS per 1 m³	**94.75 roubles**	

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[8] Consolidated Social Tax (CST, 26%) and accident insurance deductions (3.1%) are included in this table and in the following ones.

Skidder Timberjack 460 D		
Scheduled working days	269 days	
Scheduled working hours	4 560 hours	
Machine utilization rate	66%	
Productive working time	3 025 hours	
Delays	500 hours	
Transportation time	200 hours	
Purchase price	9 000 000 roubles	
Depreciation period	4.0 years	
Depreciation, %	25%	
Hourly productivity	27.2 m^3/hour	
Salvage, %	15.2%	
Bank interest rate	15%	
Fixed costs	**Roubles/year**	**Roubles/hour**
Interest payments	777 600	257.06
Depreciation	1 908 000.00	630.74
Administrative costs	0	0
Other payments (leasing, sub-rent, etc.)	0	0
Total fixed costs	**2 685 600.00**	**887.80**
Variable costs	**Roubles/year**	**Roubles/hour**
Fuel and lubricants	1 250 000	413.22
Repair and maintenance	575 000	190.08
Spare parts	425 000	140.50
Operator’s salary	785 000	259.50
Social welfare deductions (29.1%[9])	228 435	75.52
Other	60 000	1.54
Total variable costs	3 323 435	**1 080.36**
TOTAL COSTS	**6 009 035.00**	**1 968.16**
TOTAL COSTS per 1 m^3	**100.15 roubles**	

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[9] Consolidated Social Tax (CST, 26%) and accident insurance deductions (3.1%) are included in this table and in the following ones.

APPENDIX 3

RECORD OF TREE EXAMINATION AT THE SAMPLE PLOT

Test site No.

No.	Species	Diameter at 1.3 m, cm	Distance to the strip road, m	Ripped bark		Barked stem				Damaged crown, % of the crown length	Tree diameter at the damage, cm	Damaged root		Tree tilt angle, degrees
				Length, cm	Level, m	Length of barked area, cm	Area, cm^2	Height, m	Tree diameter at the height of barked area, cm			Root diameter, cm	Distance from the stem, m	
1														
2														
3														
4														
5														
…														

APPENDIX 4

UNDERGROWTH COUNTING SHEET

Sample plot No.

Undergrowth Index	Species	Height grade			Barked stem	Damaged top	Damaged root	Tilted stem
		Large	Medium	Small				
Measurement strip No.								
1								
2								
3								
4								
5								
…								

APPENDIX 5

Norms used in the study of ergonomics and occupational safety (length is given in mm, force in N, angles in degrees)

Table 1, Controls

Parameter	Norm (recommendation)			
	V.I. Peskov's (A.A. Frumkin's) monograph	GOST[1]	SkogForsk	VNIITE
1	2	3	4	5
Steering wheel diameter	630…600			
Force at the steering wheel		No more than 60, recommended value is 50, emergency force for vehicles with hydro-volumetric gear no more than 600		
Angle of the steering wheel	10…40 (40…75 for low seats)	25…40		
Moving range of long steering lever				100…200
Moving range of short steering lever				50…150
Distance between two adjacent steering levers moved by fingers		No less than 25		
Distance between two adjacent steering levers moved with one hand		No less than 50		No less than 50
with two hands				No less than 100
with gloved hands				No less than 130
with no visual control				No less than 150
Diameter and height of steering lever handles				See Table 8
Length of steering lever driven with hand		No less than 150		
Force at the button			2…5	
Force applied to steering levers and toggle switches		No more than 150 for others (see below)	See Table 9	See Table 10

1	2	3	4	5
Force at the steering lever during gear change		Recommended value is 60 without break in transmission, and 160 – with the break		
Force at turning of steering lever without booster		No more than 100 (recommended value is 50)		
with booster		No more than 60 (recommended value is 40)		
Force at the controls of processing equipment, with mechanical transmission		No more than 100 (recommended value is 60)		
with electro-hydraulic transmission		No more than 30 (recommended value is 15, button 1…5)		
with hydraulic transmission		No more than 60 (recommended value is 20)		
Force at the lever of power switching		No more than 200 (recommended value is 160)		
Force at the pedals when the entire leg is moving	700…900	No more than 250, for the rest (see below)	No more than 250 (optimum is 45…90)	No more than 300
when only foot is moving				No more than 100
during breaking	No more than 687	No more than 250, (recommended value is 200)		
during clutch stroke	No more than 147	No more than 250, (recommended value is 120)		
during accelerating	No more than 78	No more than 90	20…30	
Stroke of pedal when only foot is moving (accelerator)	70…100 (accelerator)			No more than 60
when entire leg is moving	120…150			No more than 200
Distance from the side wall to the pedal	No less than 50			

1	2	3	4	5
Distance between pedals used by the same leg	No less than 50	No less than 50…100		
by both legs	No less than 160	No less than 150		
Length of the pedal when used frequently and for long time		No less than 60		280…300
when used rarely and for short time		No less than 60		No less than 75
Width of the pedal		No less than 60		No less than width of the foot with shoe on
Optimum position of pedals		See Fig. 1		
Distance between the seat back and controls (steering wheel)	360…400 no less than 270 along operator's feet with low seating	485±50 from the vertical axis of the seat checkpoint to the steering wheel centre	No less than 300 along horizontal direct line	
Vertical gap between the edge of the seat cushion and controls (steering wheel)	200…240 for low seating	310±50 from the vertical axis of the seat checkpoint to the steering wheel centre	210…250	
Distance between the seat back and pedals		685±20 from the vertical axis of the seat checkpoint with checkpoint 475 cm high (for other see GOST 12.2.120)		
Distance between the floor to the centre of accelerator and brake pedals		100…250		
Distance from the median line of the seat to the centre of brake pedals		No less than 75		
Distance from the median line of the seat to the centre of accelerator pedals		No more than 400		
Evaluation of instruments' position with regard to their importance and frequency of use, by A.A. Frumkin	See Table 11 (by A.A. Frumkin)			
Hands load factor, by A.A. Frumkin	0.1…0.3 (by A.A. Frumkin)			

Table 2. Workplace

Parameter	Norm (recommendation)			
	V.I. Peskov's monograph	GOST[1]	SkogForsk	VNIITE
1	2	3	4	5
Height of the front edge of the seat cushion	350…400 (150…300 for low seating)		450	
Body angle from the vertical	No more than 10…12 (15…25 for low seating)			
Angle of hip joint A2	90…120		105…120	
Angle of knee joint A3	95…135		105…120	110…120
Angle of ankle joint A4	90…100		90…100	90…110
Angle between body and forearm A5	5…50		0…15	
Angle of elbow joint A6	80…160		105…120	
Angle between forearm and steering wheel A7	90…170			
Hip angle from horizontal A8	4			
Distance between the centre of the loaded seat and the cabin ceiling	No less than 1050 (No less than 960 for low seating)	No less than 1010 of the seat check-point		
Cabin ceiling height			No less than 1800	
Distance between the seat back and the back wall of cabin when the seat is in the extreme back position		No less than 365 of the seat checkpoint	No less than 550 (700 if the seat is reclining)	
Distance between the seat back and the front wall of cabin (glass) when the seat is in the extreme front position		No less than 510 of the seat checkpoint	No less than 500	
Distance between the seat back and objects potentially touching knees in extreme front and medium-height seat positions			No less than 700	
Floor distance between the seat back and the front wall of cabin when the seat is in the extreme back position			No less than 1150	
Cabin width at height where armrests (310 to 810 mm of the seat checkpoint) are in reverse position		No less than 900 (1400 for two-seater cabins)	No less than 1150	
for non-reverse position		No less than 850		
Distance between the middle line of seat and the side wall of cabin from the side where seat is turning (for 180 degrees rotating seats)		No less than 450	No less than 650	
Longitudinal seat adjustment	130…150 for low seating	No less than 135	200	
Vertical seat adjustment	No less than 40 for low seating	No less than 80	400…650 Up to the adjustment from the lowest to the highest seat position	

1	2	3	4	5
Adjustment range for the elastic element of spring-suspended seat, N		600…1200	550…1100	
Adjustable armrests			presence	
Rotating seat			presence	
Support to free leg at 90-degrees angle to the leg	presence			
Height of the adjustable backing in the seat back from the cushion surface	220±25		150…230	
Moving range of the adjustable backing in the seat back			50	
More inelastic side surfaces of the seat cushion	presence			
Seat width	No less than 460	No less than 400	No less than 460	
Seat depth	400…450 (450…500 for low seating)	215…265 from the seat checkpoint to the front edge	370…480	
Seat-back height	450…555	150…400 above the seat checkpoint		
Seat-back width		No less than 300		
Armrest width			No less than 100	
Seat-back angle backwards		Till 20	Till 30	
Seat-back angle upwards			Till 8	
Seat-back angle downwards			Till 15	
Angle of transversal seat inclination to ensure horizontal position when working at slopes			±15	
Seat rotation angle, when necessary		No less than 180	No less than 220	
Distance between armrests			470±50	
Armrest rotation angle inwards			30	
outwards			15	
Length of armrest			250±50	
Height of armrest			150…270	
Seat adjustment force		No more than 100		
Safety belts		presence		

Table 3. Visibility

Parameter	Norm (recommendation)		
	V.I. Peskov's monograph	GOST[1]	SkogForsk[2]
1	2	3	4
Zone A, angle up	6		
Zone A, angle down	3		
Zone A, angle left	15		
Zone A, angle right	16		
Zone B, angle up	9		
Zone B, angle down	7		
Zone B, angle left	19		
Zone B, angle right	Symmetrical to the longitudinal axis		
Cleaning degree of Zone A	More than 98% for full glass (97% for compound glass)		
Cleaning degree of Zone B	More than 80% for full glass (70% for compound glass)		
Visibility angle horizontally		No less than 170	
vertically		No less than 30 (No less than 120 for feller buncher)	
Distance between the middle line of machine and the visibility line where ground is seen from the operation side of crane			3500 (A)
Distance at which ground surface is visible in the moving direction of the machine			5000 (A)
Maximum height of the point visible to the operator at a distance of 10 m from the machine			25 m (A (Upwards visibility angle of 65 degrees)) 20 m (B) 15 m
Observation of front wheels in motion			Preferably with the minimum change of the body position

Table 4. Equipment

Parameter	Norm (recommendation) as per V.I. Peskov's monograph
Background colour of equipment	black
Display colour of equipment	white
Regulation of readings	presence

Table 5. Working environment (comfort zone according to Peskov (for other, see the table))

Parameter	Norm (recommendation)			
	V.I. Peskov's monograph	GOST[1]	SkogForsk[2]	A.A. Frumkin's monograph
1	2	3	4	5
Noise (average), dBA	40…78	No more than 80	A no more than 65 B no more than 70 C no more than 75 D no more than 85	
Noise (peak values, for less than 1s), dBA			A no more than 80 B no more than 85 C no more than 90 D no more than 140	
Noise produced by wheeled machine at a distance of 7.5 m from the longitudinal axis, dBA		No more than 85		
Vibration amplitude	0…0.2 mm			
Vibration acceleration, impact on whole body m/s^2		No more than 0.56 along the vertical axis, No more than 0.4 along the horizontal axes	A no more than 0.4 B no more than 0.57 C no more than 0.8 D no more than 1.1	
on hands, m/s^2		No more than 2	A less than 1 B less than 1.4 C less than 2 D less than 2.8	
Vibration safety coefficient				No less than 24.4
Vibration fatigue coefficient				No more than 5
Duration of continuous vibration in vibration cycle where the adjusted norms are exceeded		No more than 50 min (no more than 15 min when the excess indicator Δ is 9 dB and higher		
Discreteness coefficient of vibration cycle for cases when the value for exceeding vibration load Δ is 6 dB and higher		No more than 1		
Acceleration	0…0.1 g			
Temperature	18…24 ºC	14…33 (with outdoor temp. higher than 30) ºC		
Temperature decrease between head and feet		No more than 4 ºC		
Humidity		No more than 60% if air conditioner is present		
Ventilation rate	35…90 m³/hr			
CO2 content	0…0.2 %			
CO content	0…0.01 %			

Table 6. Safety

Parameter	Norm (recommendation)	
	GOST[1]	SkogForsk[2]
1	2	3
Railing	Presence if steps are available	
Distance between ground and railing	No more than 1700	1200(A)
Distance between stair steps and railing		850(A)
Free space around railing	No less than 60	
Railing length	No less than 120	
Railing diameter	15…38	
Distance between ground and first step of the stair	No more than 550 (no more than 650 GOST 51863)	No more than 350(A)…400(B)
Stair slope	Recommendations are: either 30…35, or 75…90; not recommended is 60, 25…75	45(A)…70(B)
Step height	No more than 250 (350 for footboards)	No more than 200(A)…300(B)
Step depth	No less than 20	No less than 100(A)…200(B)
Step width	No less than 150 for one foot and no less than 300 for two feet	No less than 300
Space behind step	No less than 180 minus step depth	No less than 150
Door-opening height	no less than 1300	no less than 1600
Door-opening width at shoulder level	no less than 450	no less than 600
Door-opening width in the lower part	no less than 300	no less than 350
Platform in front of the door	no less than 180x300 if the height above the ground is over 1600	presence
Emergency exit	no less than three, and no less than two for rotating cabins	presence
Emergency exit layout	on different wall and roof of the cabin	
Opening part of 640x440 in the cross-section of the emergency exits	opening	
Entrance and steps lighting		presence
Special place in the cabin for first-aid kit, manuals and personal belongings	presence	presence
Independent emergency brake	presence	presence
Moving at lowest gear with activated brake		not possible (A)
Sharp edges and ribs in the cabin		absence (A)
Special jib positions for transportation and parking	presence	presence
Capsules for moving parts	presence	presence
Protective grid	presence for machines that transport timber in fully loaded state	
Mesh size of protective grid	no more than 100	
"Do not stand under weight" sign on the manipulator	presence	
Same for "Dangerous zone … m" sign	presence	
Location of batteries	outside the cabin	outside the cabin
Efficient fire-extinguishing equipment	presence	presence
Colour	contrast to the background	

Table 7. Monotony indicators of activities

Parameter	Norm (recommendation) as per A.A. Frumkin's monograph
Rate of repetitiveness work	0.2…0.85
Rate of work complexity	No more than 0.2
Number of indicators that require simultaneous remembering	No more than 2

[1] The state standards, listed as [24] – [36] of the references were used.
In addition, the following GOST standards were used: GOST 20062-96, GOST 27258-87, GOST 27254-87, GOST R ISO 11169-95.

[2] A, B, C, and D letters in the SkogForsk recommendations designate the class for which the given norm is shown.

Table 8. Handle sizes of steering levers by VNIITE recommendations

Handle shape	Grip diameter, mm				Grip height, mm			
	With fingers		With hand		With fingers		With hand	
	allowable	optimum	allowable	optimum	allowable	optimum	allowable	optimum
Round, globular, conical, etc.	10…40	30	35…40	40	15…60	40	40…60	50
Elongated (fusiform, cylindrical)	10…30	20	20…40	28	30…90	50…60	80… 130	100

Table 9. Force at controls by SkogForsk recommendations

Type of controls	Force, N	
	For frequent use	Maximum
Button	2	5
Toggle	2…5	40
Lever used by whole arm back and forth	5…15	140
Lever used by whole arm from right to left	5…15	60
Steering wheel	5…20	230
Brake and clutch pedals	45…90	250
Accelerator pedal	20…30	

Table 10. Force at controls by VNIITE recommendations

Method of moving	Maximum force (N) for the given frequency of use (times per shift)				
	More than 960	960–241	240–17	16–5	Less than 5
With fingers	5	10	10	10	30
With hand	5	10	15	20	40
With hand and forearm	15	20	25	30	60
With the whole arm	20	30	40	60 (40)*	150 (70)*
With two arms	45	90	90	90	200 (140)*
* – in brackets – for left-right movement					

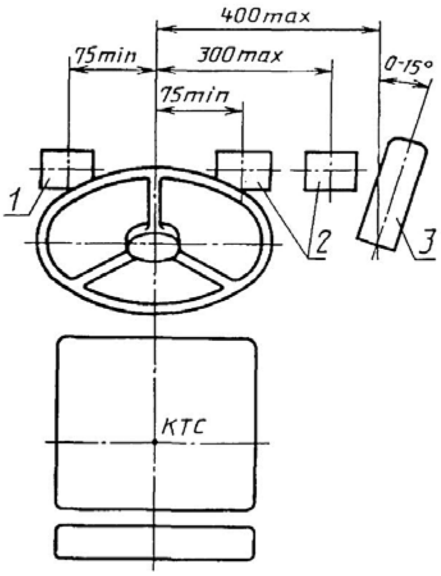


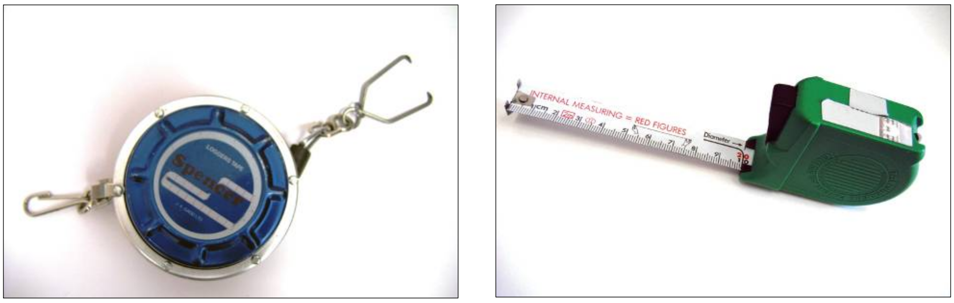
Fig. 1. – Optimum arrangement of pedals according to the GOST 12.2.120-88:
1 — clutch; 2 — brake; 3 — accelerator

Table 11. Weight coefficients to evaluate location of controls by recommendations of A.A. Frumkin

Frequency of use, times/hour	Importance			
	Very important	Important	Less important	Not important
Very often, more than 100	0.28	0.14	0.07	0.04
Often, less than 100	0.14	0.07	0.03	0.025
Rarely, less than 20	0.07	0.03	0.02	0.015
Very rarely, less than 2	0.03	0.02	0.01	0.01
Total	0.52	0.26	0.13	0.09

APPENDIX 6

MEASUREMENT TOOLS



a b

Fig 1. 15 m (a) and 2 m (b) measurement tapes

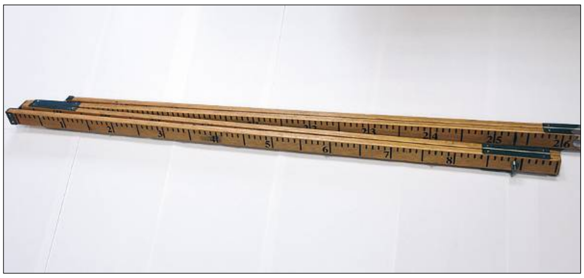


Fig. 2. Foldable measurement rod (3.5 m)

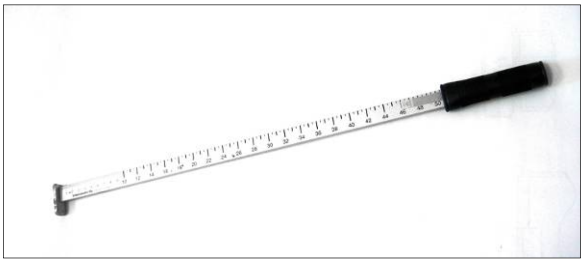


Fig. 3. Log-end measurement bracket (50 cm)

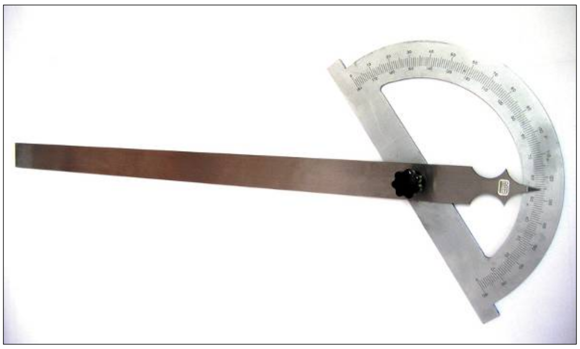


Fig. 4. Goniometer for additional measurement of cuts in stemwood

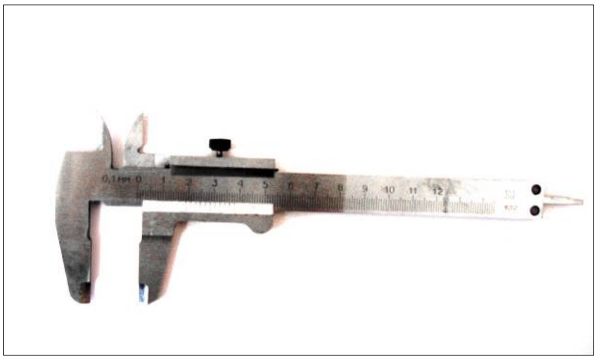


Fig. 5. Precision caliper with depth gauge

Fig. 6. Data collector

APPENDIX 7

Normative silvicultural and environmental requirements for harvesting operations in the territory of the Russian Federation

In accordance with the wood-harvesting regulations [13], the following silvicultural and environmental norms are to be complied with during clear cuttings and selective cuttings:

1. The total area occupied by landings and other production and auxiliary facilities should be as small as possible and have to account for the following percentage of the total harvesting-site area:
   - For harvesting sites of more than 10 hectares: no more than 5% in clear cuttings, and no more than 3% in selective cuttings;
   - For harvesting sites of 10 hectares and smaller: less than 0.40 hectares in clear cuttings with regeneration; 0.30 hectares in clear cuttings with preliminary regeneration and in gradual fellings; 0.25 hectares in selective cuttings;
   - For clear-cutting sites of more than 10 hectares where tree and tree-length skidding is performed, for creation of seasonal wood storages, the total area of loading sites, production and auxiliary sites should be no more than 15% of the harvesting-site area, and the area with damaged soil can be no more than 3%.
2. Process corridors should be arranged along the planned routes in such a way, that the space between remaining trees (including undergrowth) can be used to the maximum possible extent. For this purpose, deviation of the direct line of the corridor is allowed, but the minimum number of trees should be felled. The total area of strip roads and trails should be no more than 20% of the harvesting site in clear cuttings and no more than 15% in selective cuttings. In the case of clear cuttings performed with multi-operational machinery, it can be acceptable to increase the strip-road area up to 30% of the total harvesting-site area.
3. In forests with humid soils of any composition, and also in forests with moist clay loamy soils, in the spring, summer and autumn periods timber skidding should only be performed along the trails strengthened by harvesting residuals. Skidding with tractors along slopes steeper than 20 degrees is not acceptable.
4. At selective cutting sites, the number of damaged trees should not exceed 5% of the number of remaining trees.
5. Cleaning of the harvesting residuals from the harvesting site has to be carried out in parallel with wood harvesting. The following cleaning methods can be used: collection of harvesting residuals in piles or stacks to be used as fuel or for processing; strengthening of trails with harvesting residuals to protect the soil from compaction and damage during skidding; collection of harvesting residues in piles or stacks to be burned during the fire-safe period; collection of harvesting residuals in piles or stacks and leaving them on the spot for decomposition and food for wild animals in the winter season; spreading of chipped harvesting residuals to improve forest growth conditions; stacking and leaving for decomposition at the felling spot (without undergrowth).

In accordance with the forest silvicultural regulations [14], thinnings should be performed in compliance with the following silvicultural and environmental requirements:

1. The total area of process corridors cut in the course of thinnings should not exceed 15% of the harvesting-site area. In middle-aged stands, no more than 5–10% of the trees existing in the stand before the thinning can be cut to accommodate process corridors (strip roads and trails).

2. Loading sites should be located near roads or compartment lines, on openings or other areas not covered with forest vegetation. The size of one loading area should be no more than 0.2 hectares, their total area should not be more than 0.2 hectares for harvesting sites smaller than 10 hectares, no more than 0.3 hectares for harvesting sites of 11–15 hectares, and no more than 2% of the total harvesting-site area for sites larger than 15 hectares and for felling carried out by compartments.
3. The share of damaged trees during thinnings should be limited to the following levels:
    - during clearing of young stands and thinning of thickets – 2% of the remaining trees;
    - during thinning of middle-aged and maturing stands – 3% of the remaining trees;
    - in protective forests, 2% of the remaining trees.
4. The share of protected undergrowth in cutting strips during thinnings in exploitable forests should be no less than 80% of the undergrowth's quantity before cutting; and no less than 90% in protective forests in all types of thinning.