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Ergonomic evaluation and comparison of wood harvesting systems in Northwest Russia

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ABSTRACT

A comparison of 14 currently applicable wood harvesting systems was assessed with respect to ergonomic point of view. For this purpose, the research method, based on the Hodges–Lehmann rule and the integrated work-severity rate of single machinery, was developed for ergonomic evaluation of cut-to-length, tree-length and full-tree harvesting systems. Altogether, about 130 different parameters of 36 units of equipment that impact on the ergonomics and work conditions were measured and estimated in interviews undertaken directly at forestry harvesting workplaces in 15 logging companies in the Republic of Karelia, Northwest Russia. Then the results were compared to the effective norms, and the degree of compliance with the stipulated values was determined. The estimates obtained for the degree of compliance were combined. This permits a direct comparison of the workload on forestry harvesting workers such as operators, lumberjacks and choker setters. In many respects, the current ergonomic standard is standard, except for the operators of cable skidders, chainsaws and choker settings. Visibility and work postures were considered to be the most critical features influencing the operator's performance. Problems still exist, despite the extensive development of cabs. The best working conditions in terms of harvesting systems were provided by "harvester + forwarder" in cut-to-length harvesting, and "feller–buncher + grapple skidder" in full-tree harvesting. The motor-manual tree-length harvesting performed with cable skidders showed the worst results in terms of ergonomics.

1. Introduction

Full-tree (FT), tree-length (TL) and cut-to-length (CTL) methods, and associated harvesting systems usually are applied in wood harvesting. These methods differ in relation to the technology utilised. The FT method is globally the most common method. FT harvesting means that the trees are felled and the stem, intact with branches, is initially transported to the roadside landing using a skidder. Delimbing and, if necessary, bucking are performed at the roadside. In the TL method, trees are delimbed immediately after felling, and then the intact stems are skidded to the roadside landing. The tree-lengths, in both methods, are then transported by tree-length trucks or trains to the central processing yard or wood-processing mill, where they are bucked into timber assortments. If the bucking is performed at the roadside terminal, the assortments are directly transported by short-wood trucks to the wood-processing mill. The third method, cut-to-length, means that the trees are processed (delimbed and bucked) into timber assortments in conjunction with the felling operations. Then the assortments are extracted with forwarders to the roadside where they are piled to await secondary transport by short-wood trucks to the wood-processing mill.

Each of the harvesting methods also has its specific features that depend on natural and production conditions, the technology used, and the share of manual operations in the overall process. Thus, depending on the level of mechanisation and the type of equipment used, all the identified harvesting systems can be divided into the following most typical groups in Russia (Gerasimov and Seliverstov, 2010):

1. Fully mechanised CTL harvesting: felling, processing (delimbing and bucking) with a harvester, and extraction with a forwarder: FM CTL (harvester + forwarder);
2. Motor-manual CTL harvesting: felling, processing with a chainsaw, and extraction with a forwarder: MM CTL (chainsaw + forwarder);

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3. Motor-manual TL harvesting: felling with a chainsaw, delimbing with a chainsaw/axe, and extraction with a cable skidder: MM TL (chainsaw + skidder);
4. Fully mechanised FT harvesting: felling with a feller buncher, extraction with a grapple skidder, and processing with a processor: FM FT (feller buncher + skidder + delimber/processor);
5. Motor-manual FT harvesting: felling with a chainsaw, extraction with a cable skidder, and processing with a delimber: FT (chainsaw + skidder + delimber).

The efficiency and functionality of a particular wood harvesting system depend on a number of characteristics. The economic benefits can be evaluated by such indicators as labour, productivity and cost. Environmental indicators can include soil damage (the rut depth or the degree of soil compaction), damage to undergrowth or remaining trees, etc. The wood quality indicators are determined by evaluating the quality of the timber in accordance with the quality specifications in the customer contracts, as well as other quality requirements. Undoubtedly, work safety and ergonomics cannot be ignored when comparing different technologies. Wood harvesting has been associated with high accident risk due to the low level of mechanisation, especially with a fatal outcome; the latter has been estimated at 1.4 deaths per 1 million m^3 cut in Russia (Gerasimov and Karjalainen, 2008). Recently, special attention has been paid to comfortable and safe working conditions in forest operations (Hanse and Winkel, 2008; Smidt, 2011; Synwoldt and Gellerstedt, 2003). This will make harvesting work more attractive to the young, and employment in a logging company more desirable. Ergonomic indicators describing the work severity (noise and vibration levels, visibility, etc.) can be used to evaluate the safety and comfort of the work (Hansson, 1990; Harstella, 1990). Some studies in ergonomics of logging operations have been conducted in Russia during the Soviet time (Byzov, 1985; Oblivin et al., 1988; Vasekin et al., 1991) and are still conducting today in Russia at Voronezh Forest Engineering Academy (e.g., Kondrashova, 2010; Posharnikov et al., 2012), Petrozavodsk State University (e.g., Kukelev and Ustinov, 2005; Sokolov, 2008; Sokolov et al., 2008, 2012; Syunev et al., 2009; Gerasimov et al., 2008) and some others (e.g., Korenevsky et al., 2009).

A positive result of the mechanisation of harvesting work is the drastic reduction in serious accidents and injuries (Axelsson, 1998; Lefort et al., 2003; Potočnik et al., 2009; Sokolov et al., 2008). However, increasing mechanisation is posing new problems. Operators of harvesting machinery are being afflicted by overload injuries to the neck, arms and cervical spine. The main causes of these injuries are probably excessive periods of sitting, excessive work intensity during work in fixed, ergonomically-inappropriate positions, and repetitive, short-cycle movement patterns. Moreover, the motor-manual harvesting systems, using chainsaws, choker settings and primitive cable skidders, still continue to be widely used in forest operations due to steep and wet terrains and the difficult social-economic conditions in many countries, such as Russia. Due to the ergonomic feasibility of harvesting operations being a critical element for the development of wood harvesting, using a number of different harvesting systems, such as MM FT, FM FT, MM CTL, FM CTL and MM TL, the main objective of the study was to evaluate and compare the most applicable currently used harvesting systems in terms of ergonomics.

2. Material and methods

There is a need for a comprehensive approach towards the evaluation of ergonomic performance of harvesting operations and the selection of the most appropriate technology for local conditions. To evaluate the efficiency of the harvesting methods currently used, a comprehensive field study (measurements) and personnel surveys (interviews) were performed in Northwest Russia. The region was selected as the study region because its territory is very representative in terms of the wide range of harvesting machinery used and the fact that nearly all harvesting technologies employed in different natural conditions are typical for boreal forests. Harvested forest stands had not been thinned before the final felling. A typical study stand was of mixed tree age and species. The tree species included spruce (31% on average), pine (35%), birch (28%), and aspen (6%). The average stem volumes of the harvesting sites varied between 0.13 m^3 and 0.64 m^3 under bark with the average value 0.29 m^3. The average growing stock of harvested stands was 150 m^3/ha with tree density 520 trees/ha. Typical soils in the test areas were loam, clay loam, and sandy loam. The harvesting sites were on flat terrain (Gerasimov et al., 2012; Gerasimov and Seliverstov, 2010).

The study was performed in 2007–2009 and involved 15 logging companies, which harvest 0.866 million m^3/yr of wood with CTL, 0.935 million m^3/yr with TL, and 0.385 million m^3/yr with FT harvesting systems. The companies selected performed harvesting operations, applying all the harvesting systems mentioned using both Russian and foreign machinery. The following machinery was used in the wood harvesting systems studied (Fig. 1): track feller buncher (Timberjack 850), wheel purpose-built harvester (Timberjack 1270D, John Deere 1070D, John Deere 1270D, Valmet 901.3, Valmet 911.3), excavator-based harvester (Volvo EC210BLC), track cable skidder (TDT-55A, TLT-100), track grapple skidder (ML-136), wheel forwarder (Timberjack 1410D, Timberjack 1010D, John Deere 1110D, John Deere 1410D, Valmet 840.3), wheel grapple skidder (Timberjack 460D), and track stroke delimber (LP-30B), chainsaw (Husqvarna 254XP, Husqvarna 262), choker setting. Field research was carried out at 23 harvesting sites, the locations of which are shown in Fig. 2. The study involved field measurements and a personnel survey, with questionnaires for the staff and managers of the logging companies (Fig. 3).

2.1. Field study

A common approach was used for the field data collection and processing. Different parameters that impact on the ergonomics and working conditions were directly measured at workplaces under actual working conditions: 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; the force needed to operate machine controls, etc. A measuring tape was used to measure a distance, a protractor – angles, a dynamometer – forces, a sound level meter – noise, a vibrometer – vibration, video recording – time. Altogether, about 130 different parameters were measured for 27 machines and 9 chainsaws (Table 1) according to valid national state ergonomic standards and international and Russian ergonomic guidelines (Frumkin et al., 1999; Gellerstedt et al., 1999; Peskov, 2004).

The measured ergonomic parameters of harvesting machines are resulted in Annex 1. In order to evaluate individual harvesting machines, six ergonomic groups were considered with 2–4 indicators in each group (Table 2). The measured ergonomic parameters from Annex 1 were participated in forming of ergonomic indicators and groups depending on which factor of the working conditions they were used to evaluate). "Controls" group (total of 56 measured parameters) consisted of four indicators: location and stroke of controls; force required to operate controls; hand-operated controls; foot-operated

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