A Case Study of the Impact of Skidding Distance on Tractor Operator Exposure to Noise

ANTON POJE [1], IGOR POTOČNIK [1], MILORAD DANILOVIĆ [2] AND SLAVICA ANTONIĆ *[2]

**Corresponding author; Department of Forestry, Faculty of Forestry, University of Belgrade, Kneza Viseslava 1, 11 000 Belgrade, Serbia; slavica.karic@sfb.bg.ac.rs; tel. +381 11 30 53 833*

[1]Department of Forestry, Biotechnical Faculty, University of Ljubljana, Vecna pot 83, 1000 Ljubljana, Slovenia; anton.poje@bf.uni-lj.si; tel. + 386 1 320 35 16

[2] Department of Forestry, Faculty of Forestry, University of Belgrade, Kneza Viseslava 1, 11 000 Belgrade, Serbia; milorad.danilovic@sfb.bg.ac.rs; tel. +381 11 30 53 834

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Abstract

The exposure of a tractor operator to noise does not depend solely on the noise produced by the machine, but also on the working conditions, which are constantly changing in forestry. This research was conducted with an adapted IMT 565 DV agricultural tractor in a mixed stand of beech and fir in southwestern Serbia. The results show that the structure of working time changes with increased skidding distance. When the skidding distance is increased from 150 m to 450 m, the share of empty and loaded travel grows from 38% to 50%, resulting in higher noise exposure of a tractor operator. In addition, it was estimated that an increase in the skidding distance from 50 m to 1000 m results in a noise exposure increase of 2 dB(A). The contribution of the operations of empty and loaded travel and landing work to the total noise level exceeds 90% at 450 meters long skidding distances. However, when assessing worker exposure to noise, it is possible to disregard the major impact factors and inadequately plan the study, which can result in an underestimation or overestimation of exposure to noise. Finally, the results of this study are important for a) a broader understanding of the relationship between the level of noise and exposure time and b) proper planning and performance of measurements characterized by essential and active involvement of forestry professionals.

Key words: Ergonomics, Forest Operations, Exposure to Noise, Skidding Distance, Time Study.

Introduction

Unlike industrial production, forestry production takes place under constantly changing conditions. Given the changing weather conditions and variable terrain and stand characteristics, working conditions are subject to constant change. In addition, the object of labor is also variable (trees of various types, sizes, shapes and quality). The exposure of workers to different impacts is the result of working outdoors, use of equipment and various working practices. For the above-mentioned reasons, forestry activities are classified into the “hard work category” by the International Labour Organisation (ILO 1998). High psycho-physiological levels of worker exposure (Gallis 2006) affect health and safety at work. In addition, due to the difficulty of the work and the variability of working conditions and practices, it is difficult to predict risks and plan and preventive measures against injuries (Potočnik et al. 2009). Therefore, the field of forestry is characterized by a high frequency of injuries (Sullman et al. 1999, Lilley et al. 2002, Tsioras et al. 2014).

In addition to the difficulty of the work itself, forestry workers are subject to exposure to noise, vibration, exhaust gases and dust particles. The eight-hour exposure of a feller to vibration exceeds 2.5 m/s^2 (Goglia et al. 2011), while noise exposure (Malinowska-Borowska et al. 2012) reaches 99.1 dB(A). The recorded average daily level of exposure to carbon monoxide is 8.6 ppm (Lipoglavšek 2000), while the exposure of fellers to other gases reaches the following values: 20 mg/m^3 HC, 0.6 mg/m^3 benzene and 0.1 mg/m^3 formaldehyde (Van Netten et al. 1987). The mean value of mass concentration of respirable particles collected during fuel wood processing is 0.62 ± 0.22 mg/m^3 and of 0.29 ± 0.19 mg/m^3 during final cut (Horvat et al. 2007).

Tractor operators are generally subjected to lower levels of exposure than fellers, i.e. noise exposure 77.5 dB(A) (Melemez and Tunay 2010) and occasionally over 80 dB(A) (Seixas et al. 1999). However, the highest level of worker exposure to vibration was recorded in a tractor with a springless seat (1.51 m/s^2), while in a tractor with a new four-spring seat, acceleration reached 0.76 m/s^2 (Melemez et al. 2013). The average daily level of exposure to carbon monoxide during skidding with a Woody 110 skidder is equal to 0 ppm (Lipoglavšek 2005).

Minimum levels of worker exposure were recorded, when the CTL (cut-to-length) method was applied, i.e. when using harvesters and forwarders. Operator exposure to noise ranged from 60 dB(A) to 77 dB(A) (Seixas et al. 1999, Messingerová et al. 2005, Gerasimov and Sokolov 2013).

Physiological workloads are also influenced by exposure time, i.e. the time of worker exposure to harmful factors. In research of productivity and efficiency, exposure time equals work time (Zečić et al. 2010, Spinelli and Magagnotti 2012, Sowa and Szewczyk 2013). In productivity studies, the structure of time is usually only roughly presented or disregarded. Therefore, in most cases only the overall effect on productive or work time is important. However, research on productivity is usually intended for the purpose of economic (Spinelli et al. 2002, Ozturk and Senturk 2010, Mousavi 2012, Spinelli et al. 2014) rather than ergonomic analyses of working processes.

A detailed fragmentation of working time into smaller units is necessary for a better understanding of working processes. By studying the structure of time, we are able to define the factors that have an effect on the process of work or its individual parts. A detailed structure of time is commonly used for standard time settings (Nadler 1955, Ireland 2009, Marčeta et al. 2014). In addition, accounting for the time structure enables experimental control and productivity modeling and serves as the basis for calculating psycho-physiological workloads.

The crucial factor in the determination of worker exposure to noise according to ISO 9612:2009 standard is knowledge of the structure of exposure time and the factors that have an impact on it. This is especially true if one of the three possible methods of measurement (task, job or day) is used, i.e. the task-based measurement method, whereby noise measurement is assessed for individual work operations. The common feature of all measurement methods is the fact that the number of required measurements grows with an increase in data variability, thereby reducing the uncertainty in the assessment of worker exposure to noise. In addition, the variability of measurements within individual operations, work places or days is affected by the working conditions. Hence, it is necessary to make a proper assessment of exposure at different levels of the impact factors.

As previously mentioned, working conditions in forestry are very inhomogeneous and variable over time. Therefore, this paper is intended to show that the crucial elements of proper assessment of worker exposure to negative effects from work environment are as follows a) determination of the exposure level and b) knowledge of the factors affecting the structure of time. Therefore, this paper provides an example of the impact of skidding distance on tractor operator exposure to noise. It is assumed that, due to changes in the structure of work time, noise exposure increases with skidding distance.

Methods

This research was conducted in mixed stands of beech and fir located in southwestern Serbia and managed by the Faculty of Forestry, University of Belgrade. The skidding of wood assortments was conducted with an IMT 565 DV adapted agricultural tractor, which is commonly used in the first phase of transport in Serbian forestry due to its low purchase price and maintenance costs. The five-year-old tractor had four-wheel drive and a double-drum winch type LIV with 80 kN capacity. During measurement the tractor used no chains on the tires.

The task of the tractor operator was to operate the tractor and winch, while the assistant choked and unchoked the load. At the time of the study, the tractor operator was 51 years old man with 27 years of work experience, being far more experienced than his younger assistant (23 years old man with one year of work experience).

All 10 skidding cycles were performed on the same skid trail in the downhill direction and at skidding distances ranging from 169 m to 425 m. The measurements were performed during regular work, without any additional adjustments. Skid trail slopes ranged from 2 % to 30 % and their conditions did not change in terms of soil moisture due to the stable weather conditions during measurement. Load size ranged between 2.21 m^3 and 4.46 m^3, while the average number of logs per load was 4.6.

The cumulative timing method of recording was used to determine the time structure and duration of the work operations. Work time was divided into productive and non-productive time. The productive time was additionally divided into seven work operations that are significant for skidding using a tractor: empty travel, pulling out the cable and choking the load, winching, moving during loading, loaded travel, unchoking the load and landing work (i.e. sorting and piling the logs at the roadside). The non-productive time, which includes operational delays (7.5%), was assumed to occur randomly and independently from skidding distance and was therefore omitted from the study.

A Bruel & Kjaer 2250 sound meter and a Bruel & Kjear 4189 microphone were used to record the exposure of the tractor operator to noise. The microphone was mounted on the helmet of the tractor operator at a 10-cm distance from his right ear (in accordance with the ISO 9612:2009 standard), while the sound meter was placed in a backpack on the operator's back. The meter was set to the fast time weightings, with time constants of 125 ms, and to one-second data logging.

The exposure of workers to noise by work operation and cycles was calculated as an A-weighted equivalent continuous sound pressure level (Equation 1), and the average exposure per operation as an energy average (Equation 2):

$$LA_{eq} = 10 \cdot \log\left(\frac{\sum 10^{0.1 \cdot LA_{eqi}} \cdot t_i}{\sum t_i}\right) \quad \text{(Eq 1)}$$

$$LA_{eq} = 10 \cdot \log\left(\frac{\sum 10^{0.1 \cdot LA_{eq}}}{10}\right) \quad \text{(Eq 2)}$$

where:

LA_{eq} is the exposure to noise in operation or cycle in dB(A);

LA_{eqi} is the exposure to noise during a stated time interval (t_i) in dB(A);

t_i is the duration of time interval within operation (1s) or cycle in units of time;

$\sum t_i$ is the sum of time within operation or cycle in units of time.

The calculation of the contribution of individual work operations to the total noise exposure was performed using Equation 3 according to ISO standard 9612:2009, as follows:

$$LA_{eq.con} = LA_{eq} + 10 \cdot \log\left(\frac{t_i}{\sum t_i}\right) \quad \text{(Eq. 3)}$$

where:

$LA_{eq,con}$ is the noise contribution from operation in dB(A);

LA_{eq} is the exposure to noise in operation in dB(A);

t_i is the duration of operation in units of time;

$\sum t_i$ is the sum of time within cycle in units of time.

The Utility Software for Hand-held Analyzers BZ-5503 was used to transfer the data from the sound meter. MS Excel 2010 and IBM SPSS Statistics Version 20 were used for statistical calculations.

Results

The exposure of a tractor operator to noise increases with skidding distance. Because of relatively high variability in noise exposure levels a marginally statistically significant regression coefficient between skidding distance and noise exposure was indicated (F (1.9) = 3.791, p = 0.087, R^2 = 0.322) (Figure 1).

The time structure analysis of individual cycles (Figure 2) revealed that parts of certain work operations change in terms of exposure time within a cycle. On average, in a single cycle the largest shares of exposure time were recorded during the operations of pulling out the cable (27%) and empty (25%) and loaded (21%) travel. There is no visible trend of increase or decrease in exposure time, when skidding distance is increased, except in the case of the operation of landing work.

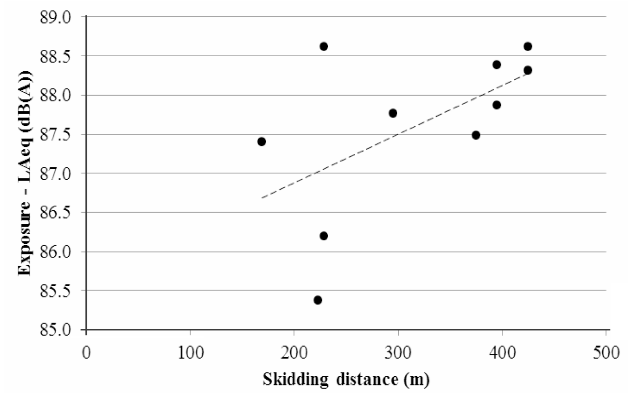

Figure 1. Exposure to noise by skidding distance

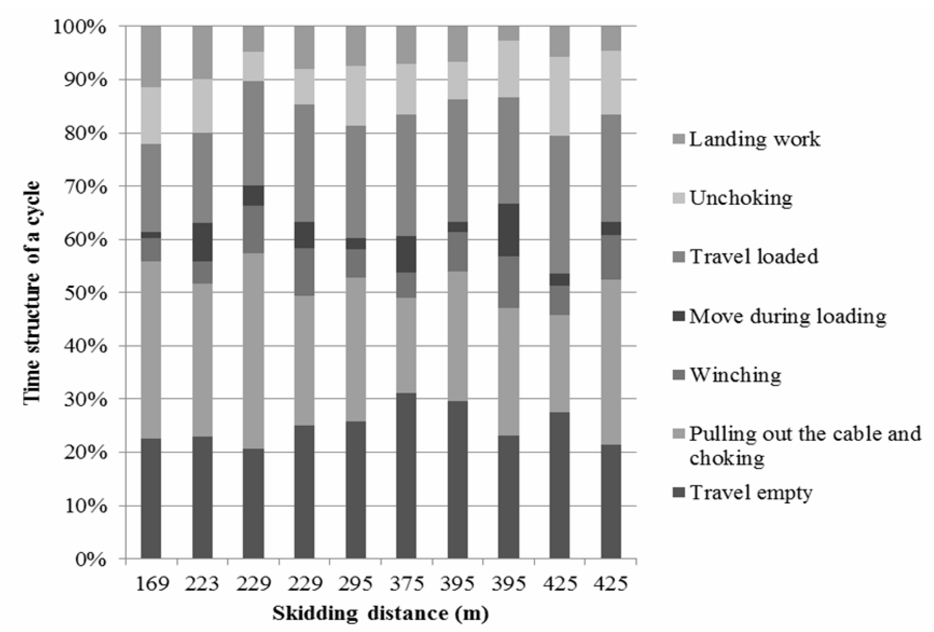

Figure 2. Measured exposure time structure by cycles

Given that parts of the operations in the structure of time are mutually dependent, an increase in the share of one work operation means a decrease in the share of another one. Linear regressions were calculated in order to determine the dependence of exposure time on skidding distance for individual work operations (Table 1). The results show that skidding distance statistically significantly increases the exposure time during empty and loaded travel, as well as unexpectedly during unchoking of the load. Since the increase in skidding distance results in a statistically insignificant increase in a total load volume (F (1,8) = 2.034, p = 0.192, R^2 = 0.203), average size of a piece in the load (F (1,8) = 2.050, p = 0.190, R^2 = 0.204), and decrease in a number of pieces in the load (F (1,8) = 0.131, p = 0.727, R^2 = 0.016), the assumption that the individual characteristics of the load could be the cause of this unexpected result was rejected.

Modeled exposure times by work operations (Figure 3) were calculated from the linear regressions. As in the research on the productivity of the Timberjack 240C skidder (Zečić et al. 2011), in the cases without statistically significant correlation, the average values of exposure time were used instead of the equations (Table 1).

From the modeled structure of noise exposure time, it was found that the structure of time considerably varies with changes in skidding distance. At 150 meter distance, tractor operator exposure time during the work operations of pulling out the cable and unchoking of the load accounts for one third of the total exposure time, whereas at long distances it accounts for less than a quarter of that time. The share of empty and loaded travel increases from 38% at a skidding distance of 150 m to 50% at a skidding distance of 450 m.

The noise levels were on average the highest during the operations of empty and loaded travel and landing work (Table 2). During these work operations, the load on the machine, i.e. rpm of the engine, was the highest. Slightly lower exposure levels were recorded in the work operations of winching and moving during loading. However, the lowest exposure levels were recorded during the operations of pulling out the cable and choking and unchoking of the load, when the tractor operator was out of the vehicle and the engine was running at idle.

The variability of exposure levels (Table 2) among different work operations was the lowest during empty travel, slightly higher during the work operations of landing work, pulling out the cable and loaded travel, and the highest during the operations of winching, moving during loading and unchoking of the load.

The modeled exposure time (Figure 3) and average noise levels measured during individual work operations (Table 2) were used to calculate the contribution of each work operation to the total noise exposure relative to the skidding distance (Figure 4). It was found that the contributions of the operations of empty and loaded travel and landing work were much higher than the others. These three work operations accounted for 86% of the total noise exposure at a skidding distance of 150 m, i.e. 91% at a distance of 450 m.

The reason for the different contributions of work operations to the total noise exposure lies in both components

Table 1. Results of linear regressions with skidding distance as a predictor

Work operation	Equation	R^2	p	Average (min)
Travel empty	t (min) = 0,0103 × DIST (m) + 2,0502	0,671	0,004	5,29
Pulling out the cable and choking	t (min) = 0,0001 × DIST (m) + 5,6010	0,000	0,991	5,63
Winching	t (min) = 0,0029 × DIST (m) + 0,5615	0,197	0,199	1,47
Move during loading	t (min) = 0,0013 × DIST (m) + 0,5356	0,031	0,622	0,94
Travel loaded	t (min) = 0,0097 × DIST (m) + 1,3748	0,727	0,002	4,44
Unchoking	t (min) = 0,0058 × DIST (m) + 0,2457	0,573	0,018	2,09
Landing work	t (min) = -0,0014 × DIST (m) + 1,8163	0,150	0,269	1,37

Table 2. Exposure to noise at skidding operations

Work operation	Travel empty	Pulling out the cable and choking	Winching	Move during loading	Travel loaded	Unchoking	Landing work
	Exposure to noise (dB(A))						
Max	91.9	76.4	88.3	86.3	91.6	80.2	90.3
Min	89.2	73.0	79.0	78.4	86.1	71.3	86.6
Max - Min	2.7	3.4	9.3	7.9	5.5	8.9	3.6
Average	90.9	74.8	84.3	83.9	89.6	76.2	88.8
SD	0.9	1.5	3.2	3.1	1.5	2.7	1.3

affecting calculation, i.e. noise level and exposure time. As follows from equation 3, the contribution of an operation to total noise exposure depends more on the noise levels of an operation or several operations and less on exposure time. This is especially true in the case of high noise levels. Thus, as it seen from Figure 5, which shows noise contributions and the structure of noise exposure time at a distance of 300 m, it is obvious that long exposure time does not automatically mean a greater contribution to the total noise exposure. If the work operation of empty travel is compared to the operations of pulling out the cable and load choking, the difference between the exposure times is only 2.3%, but the difference in noise contribution is 50.4%. The reason for this difference lies in the large difference between the noise levels of the operations. Generally, contributions of the operations to the total exposure are the highest, when the noise level and exposure time are high (e.g. at empty and loaded travel) and lower, when both of these values are low (e.g. during unchoking of the load).

Modeled values of tractor operator exposure to noise (Figure 6) were calculated using the modeled exposure times (Figure 3) and noise levels measured during individual work operations (Table 2). Using the minimum and maximum noise levels by operations, the theoretically lowest and highest values of worker exposure to noise relative to skidding distance were obtained. The relatively

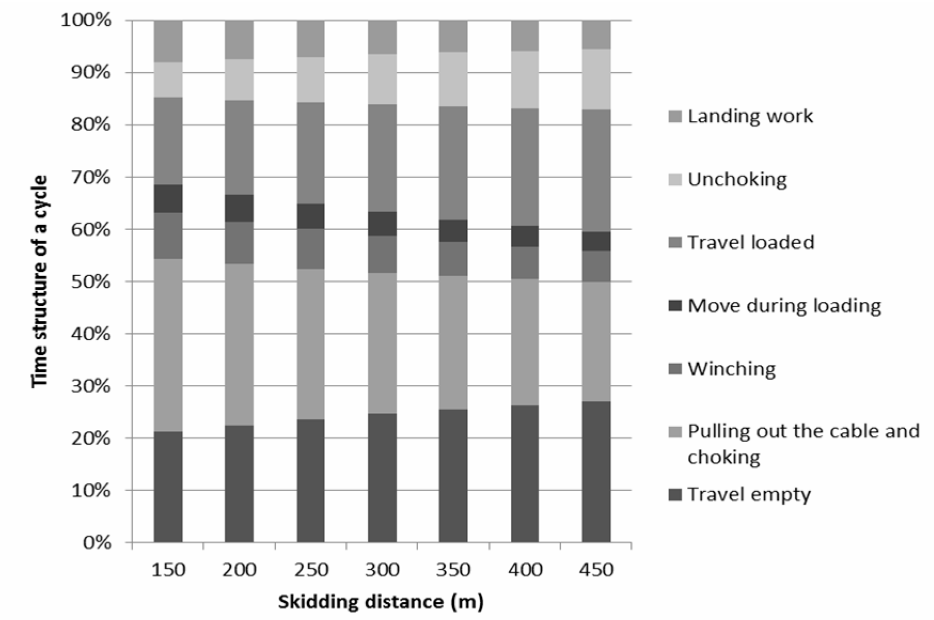

Figure 3. Modeled exposure time structure by skidding distance

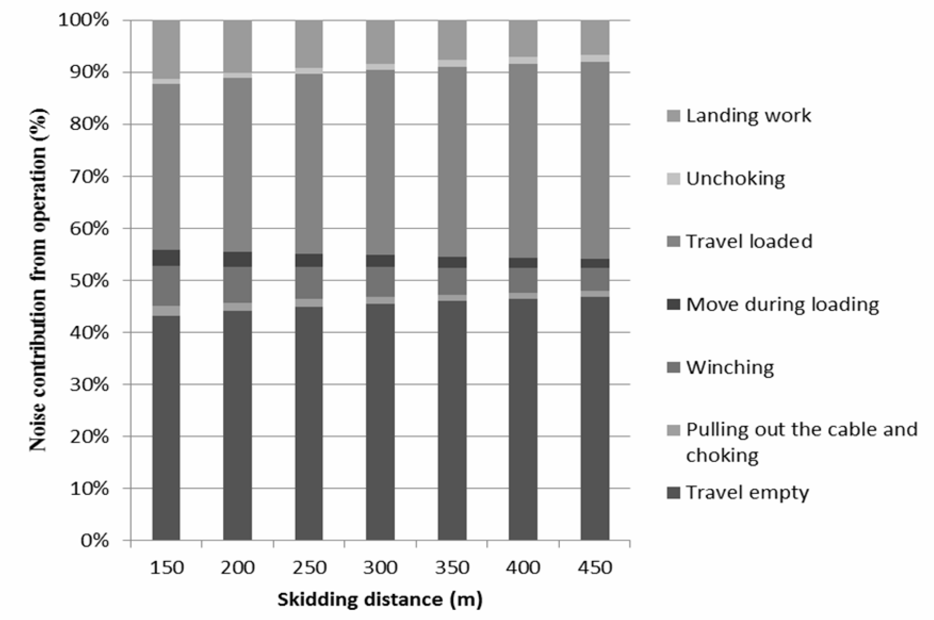

Figure 4. The contribution of work operations to the total noise exposure level by skidding distance

high variability of noise levels within individual work operations (Table 2) is reflected in a large difference between the minimum and maximum modeled exposures, which reaches approximately 4 dB(A) (Figure 6). In the case of minimum noise levels and skidding distances shorter than 200 m the operator exposure to noise could be less than 85 dB(A) using the examined skidding equipment. In contrast, possible exposure to noise at the same skidding distances and maximum noise levels could be higher than 88 dB(A).

For the purpose of displaying the possible extent of the variability, the exposures were extrapolated at distances ranging from 50 m to 150 m, as well as from 450 m to 1,000 m (Figure 6). The difference in exposure to noise during productive time estimated by extrapolation between 50 m and 1000 m skidding distance was 2 dB(A). This fact does not change even if the detected non-productive time with 7.4% of work time and exposure level equal to 83.0 dB(A) is included in exposure evaluations. In this case the total exposure to noise in all three cases drops by 0.3 dB(A) maximum.

Discussion and conclusions

Measuring and evaluating worker exposure to noise and other physical factors that affect workloads requires consideration of all factors that affect the structure of exposure time and working conditions for individual operations. This study focuses on only one of those factors: skidding distance. Previous studies indicated that tractor operator exposure increases not only with increasing skidding distance, but also with increasing skidding and engine speed, whereas it decreases as the number of pieces in a load increases (Marsili et al. 1998, Dewangan et al. 2005, Lipoglavšek and Koren 1982). Other factors that might be relevant are the average volume of a piece in a load and skidding method (e.g. the tree-length method, the assortment method), which affect the size and number of pieces

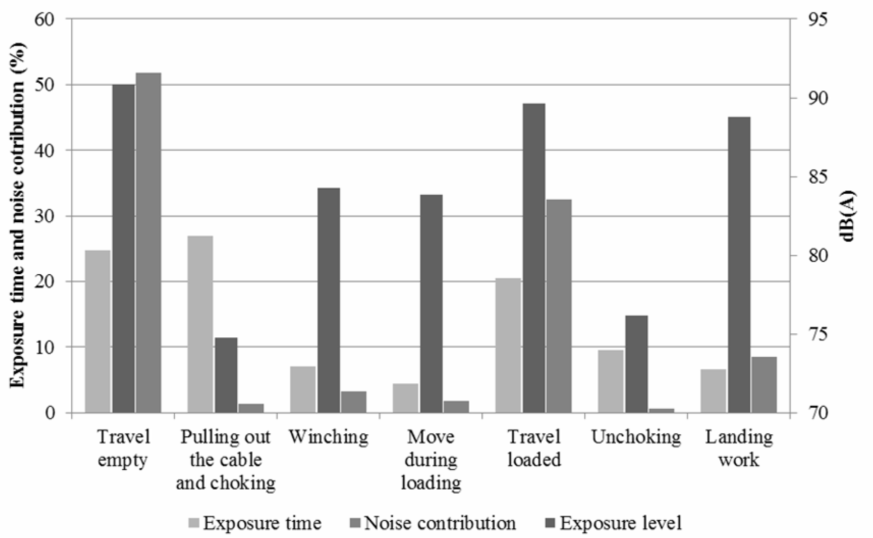

Figure 5. Exposure time, noise contribution and exposure level at a 300-meter skidding distance

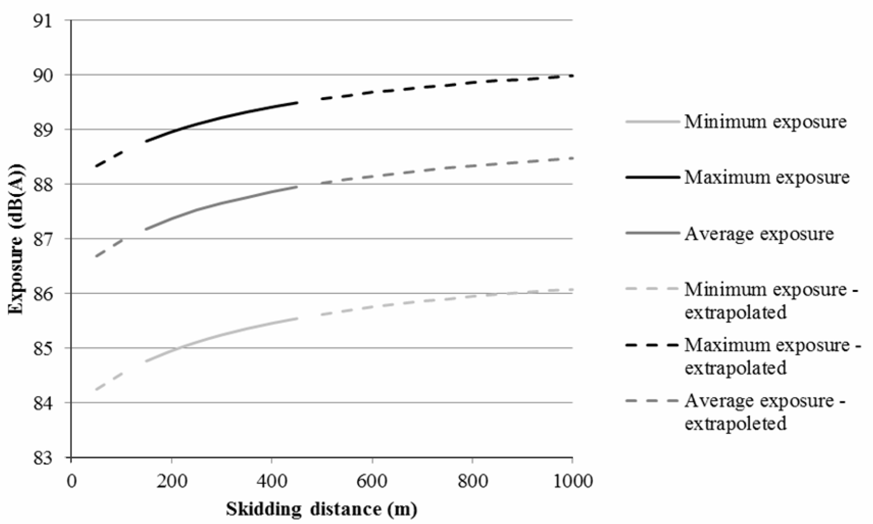

Figure 6. Minimum, average and maximum modeled exposure during productive time in relation to skidding distance

in a load, openness of forests with skid trails, which affects the winching distance from the stump area to the skid trail, the slope of the skid trail and power of the engine.

The results of this study indicated that noise exposure increases with skidding distance and that there is relatively high variability in exposure levels at the same skidding distance. The measured noise exposure difference reached 2.4 dB(A) at the same skidding distance and approximately 4 dB(A) between the minimum and maximum modeled noise exposures. The difference in exposure to noise estimated by extrapolation between 50 m and 1000 m skidding distance was approximately 2 dB(A).

From results from the study is obvious that high noise exposure variability is directly dependent on working conditions, e.g. skidding distance, but also on the behavior of the operators, such as adaptation of speed to the type of groundwork (Wegscheid 1994). The main causes of exposure variability among work operations are the level of performance of the engine (e.g. skidding, moving during loading), the position of the operator (e.g. inside or outside of the tractor) and the distance between the operator and the vehicle (e.g. during the work operation of unchoking the load). At using the examined skidding equipment on a short skidding distance, with a small volume loads and reduced pressure on the engine combined with working at a moderate tempo, noise exposure levels could be lower than 85 dB(A) or less than the upper warning limit (85 dB(A)) defined by Directive 2003/10/EC. In contrast, if the machine is overloaded, possible exposure at the same skidding distances could be higher than 88 dB(A) and in case of non-use none of a hearing protectors is more than the exposure limit value (87 dB(A)).

The noise exposure increases with skidding distance also due to changes of the structure of exposure time. The share of empty and loaded travel increases from 38% at a skidding distance of 150 m to 50% at a skidding distance of 450 m. These results were compared with those obtained in a study of productivity of the Timberjack 240C skidder (Zečić at al. 2011). The comparison revealed that at skidding distances between 150 m and 450 m, the shares of exposure time during empty and loaded travel are almost exactly the same for both skidding means despite the fact that skidder is better suited to the skidding of assortments and despite the different size of work group (tractor operator, two fellers – choker setters, unhooker).

The noise levels were on average the highest during the operations of empty and loaded travel and landing work. The measured values can be compared with the values measured for a tractor of the same manufacturer (Lipoglavšek and Koren 1982) and are much higher than in some other technologically and ergonomically more advanced tractors (Melemez and Tunay 2010). Empty and loaded travel in addition to landing work are the main “culprits” for the high exposure of workers to noise, as the contribution of these work operations to the total noise exposure at long skidding distances exceeds 90%.

From the study it can be concluded that when planning and carrying out measurements, it is necessary to consider the high variability of noise levels within work operations. This indirectly means that a large number of repetitions or detailed fragmentation of work into operations can form a more homogeneous unit from the standpoint of noise level.

A lack of knowledge of the factors that affect the process of skidding and their disregard can lead to an underestimation of noise exposure, which can have a long-term negative impact on the health of workers and consequently on the employer. Similarly, an overestimation of noise exposure means that the employer is financially overburdened due to the unnecessary application of technical and .organisational measures. The main criterion used in the field of occupational risk management and decision making is comparison between the costs of risk prevention and the costs of occupational accidents and diseases (Papadopoulos 2000, Chatzis 2004). The dominant perception regarding the protection of worker health and safety is confined within the scope of the “retention of work ability” with the least cost for companies (Papadopoulosa et al. 2010).

For the purpose of realistic assessment of the exposure of workers in forestry, measurements and risk assessment should be carried out by forestry professionals, or forestry professionals should at least be actively involved in the planning of the measurements. In addition, risks to public safety related to a changing work environment must also be taken into consideration in a holistic view of the overall protection of human health and safety (Papadopoulos et al. 2010). In practice, measurements and assessments of risks are usually performed by people with limited experience in this field of study. The low prices of such services consequently decrease their quality. Due to high competition in the market, costs of services of exposure evaluation are often underestimated. Of course, such evaluations are not useful for workers for whom safety at work is primarily intended. Finally, it is important to note that health must be approached as “the promotion and maintenance of the highest degree of physical, mental and social well-being of workers” (as stated by Who and Ilo, the *World Health.Organization* and the *International Labour Office)* (Papadopoulosa et al. 2010) and not only in relation to the retention of their ability to work.

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