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PROPOSAL FOR AN ERGONOMIC CONFORMITY INDEX FOR EVALUATION OF HARVESTERS AND FORWARDERS¹

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ABSTRACT – Context: In mechanized forestry work, the ergonomic conditions of the workplace affects operator's health, performance and productivity. Originality: A comparison of different forest machines becomes complex in case where it is required analysis of several ergonomic factors simultaneously. There are several methods of ergonomic analysis however, a more complete methodology that considers several ergonomic factors and produces an index that represent the ergonomic condition of the machine is needed. Objective: Propose a methodology to determining an Ergonomic Conformity Index to evaluate Harvesters and Forwarders of different brands. Methodology: The ECI was determined initially basing in four relevant ergonomic factors: noise, vibration, thermal environment and air quality. These factors were evaluated utilizing four Harvesters and two Forwarders in eucalyptus timber harvesting operations. For each factor, a score was given according to its compliance with the established parameters. The ECI was obtained from an average of the scores given to each factor. The index ranges from zero to one, so that lower values indicate worse ergonomic conditions. Results: All the analyzed machines had continuous noise between 75.0 and 82.6 dB (A) and whole-body vibration between 0.27 and 0.70 m s⁻². HV1 and HV2 presented thermal environment in accordance with the established criteria, other machines showed deficiencies in this regard. All the machines presented non-conformities in the air quality, except HV2. The ECI of Harvesters HV1, HV2, HV3 and HV4, were 0.83; 0.88; 0.71; 0.63. The ECI of Forwarders FW1 and FW2 were 0.58 and 0.79. Conclusion: The determination of the ECI allowed an evaluation and comparison between analyzed forest machines. The machine with the higher ECI had only one non-conformity, and it was related to noise inside the cab. The machine that got the lower ECI presented non-conformities for all the factors.

Keywords: Forest harvesting; Forest mechanization; Occupational hygiene.

ÍNDICE DE CONFORMIDADE ERGONÔMICA PARA MÁQUINAS FLORESTAIS

RESUMO – **Contexto:** No trabalho florestal mecanizado, as características ergonômicas do posto de trabalho influenciam a saúde, o desempenho e a produtividade dos trabalhadores. **originalidade:** A comparação entre diferentes máquinas florestais se torna complexa quando se deseja analisar diversos fatores ergonômicos simultaneamente. O Índice de Conformidade Ergonômica (ICE) proposto neste trabalho considera diversos fatores ergonômicos e permite uma comparação simples e objetiva entre máquinas florestais. **Objetivo:** Desenvolver metodologia para determinação do ICE e estabelecer uma comparação entre Harvesters e Forwarders de diferentes marcas com o uso do ICE. **Metodologia:** O ICE foi determinado a partir da média de ICE parciais para ruído, vibração, ambiente térmico e qualidade do ar. Foi realizada avaliação desses fatores em quatro Harvesters e dois Forwarders. **Resultados:** Todas as máquinas analisadas apresentaram ruído contínuo entre 75,0 e 82,6 dB(A) e vibração de corpo inteiro entre 0,27 e 0,70 m s⁻². Dois Harvesters apresentaram ambiente térmico em conformidade com os critérios estabelecidos, as demais máquinas apresentaram deficiências neste aspecto. Os ICE dos Harvesters HV1, HV2, HV3 e HV4 foram, respectivamente: 0,83; 0,88; 0,71 e 0,63. Os ICE dos Forwarders FW1 e FW2 foram 0,58 e 0,79. **Conclusão:** A metodologia proposta se mostrou viável



para a comparação de máquinas florestais. A única não conformidade da máquina de maior ICE foi em relação ao ruído. A máquina que obteve menor ICE apresentou não conformidades para todos os fatores analisados.

Palavras-chave: Colheita florestal; Mecanização florestal; Higiene ocupacional.

1. INTRODUCTION

In the search for increased competitiveness in the global market, the mechanization of forest harvesting activities became a reality in Brazil. Forest machine operators remain exposed to adverse conditions such as noise, vibration and unfavorable thermal environment throughout the working day. Workers involved in these activities tend to extend their working hours or to compromise rest periods due to the constant need of machines maintenance and due to pressure for higher levels of production (Lilley et al., 2002).

The comfort of workers during the operation of forestry machines may have an important contribution to performance and productivity on work (Häggström and Lindroos O, 2016). In this sense, ergonomics has an important contribution to the sustainable development of work and of the corporations themselves (Bolis et al., 2014). Compliance with ergonomic principles in the development of modern forestry machinery should contribute to the reduction of mental and physical stress and other constraints imposed to the operator. In addition, it should contribute to reduce the probability of errors and the under-utilization of machines, with regard to their technical capabilities (Goscianska and Radniecki, 2009).

According to Gerasimov and Sokolov (2014), in terms of ergonomics, the best working conditions are offered by Harvesters and Forwarders. However, this system does not exempt workers from risks such as exposure to noise and vibration, poor thermal environment and poor air quality.

Noise is a complex mixture of several vibrations capable of sensitizing the human ear, understood as an auditory stimulus that does not contain useful information for the running task (Iida, 2005). The main effect related to excessive noise exposure is Noise-Induced Hearing Loss (NIHL). Mechanisms involved in the development of this disease are not fully understood yet, but it is known that exposure to high doses of noise causes decreased blood flow and formation of free radicals in the cochlea (Le Prell et al., 2007). According

to Fernandes and Morata (2002), even using Individual Protection Equipment, tractor operators presented PAIR, in addition to extra-auditory effects such as nervousness, anxiety, headache, tinnitus and stomach problems.

The use of adapted agricultural tractors is a reality in the forestry sector. Since most of these machines do not have a closed booth, the risks of exposure to noise and other environmental factors become even greater. According to Sumer et al. (2006), sound pressure levels in 4000 Hz range are up to 28 dB(A) lower on closed cabin tractors when compared to tractors without cabs where noise has reached up to 90 dB(A).

Vibration is an irregular movement that a body executes around a fixed point, being defined by frequency, acceleration and direction of the movement (Iida, 2005). Exposure to full body vibration results from the presence of machines or vibrating agents in the work environment. This mechanical disturbance affects the physiological processes of the human body (Savage et al., 2016). The vibration and the adoption of inappropriate postures lead to a higher incidence of lumbar disorders among agricultural tractor operators than among unexposed workers (Bovenzi and Betta, 1994).

In the long term the exposed individuals can suffer adverse effects in the gastrointestinal and urogenital systems, in addition to the lumbar disorders (Wikstrom et al., 1994).

One of the intrinsic characteristics of forestry work is that workers are constantly exposed to climatic conditions. In the operation of forestry machines with enclosed cabins, the operator is more protected from external factors, however the work is not free of risks. Cabins that have large glass area can have a thermal behavior similar to greenhouses and concentrate the heat inside (Ruzic and Casnji, 2012). The consequences of the incidence of solar radiation on the skin can be acute, such as erythema or burn, thickening, elevation of temperature, tanning and immediate pigmentation; or chronic diseases such as photoaging or cancer (Schalka et al., 2014).

The presence of gases, dust and microorganisms in the air may be a source of illness for forest machine

operators, as well as affect comfort conditions during operation.

In a study of the exposure of forest machine operators to these risk factors, Kallunki et al. (2004) have concluded that exposure under normal operating conditions is low as long as the cabin is kept closed and the filters are cleaned and replaced periodically.

The indexes are used as a way of comparison in the most diverse sectors, and its main advantage is the capacity of synthesis in comparisons involving several elements of a set, allowing even the monitoring of indicators over time. Indexes do not replace more detailed investigations and analyzes of reality, on the contrary, they are dependent on them in the aim of translate numerically certain phenomena by means of values that express a relative position with respect to a given point taken as a parameter (Vaitsman et al., 2003).

Ergonomic factors that influence the work in the forest sector have been analyzed by several authors (Bovenzi and Betta, 1994; Kallunki et al., 2004; Minette et al., 2007). However, studies contemplate each factor in isolation. The main objective of this work was to propose a methodology for the determination of an Ergonomic Conformity Index (ECI) for forest machines, considering the aspects related to exposure to noise, vibration, thermal environment and air quality. In addition, the secondary objective was to apply the proposed methodology in the ergonomic evaluation of Harvesters and Forwarders of different brands and models.

2. MATERIAL AND METHODS

2.1 Evaluated Forest Machines

The methodology proposed in this work was applied in the evaluation of Harvesters and Forwarders. Harvesters from four different brands were evaluated, identified as HV1, HV2, HV3 and HV4 in this work. Forwarders from two different brands, identified as FW1 and FW2, were also evaluated.

HV1 had 23,500 kg of weight, standard width of 3,180 mm, with fuel tank volume of 550 l, 6x6 tires with 650/65 x 26.5 front tires and 700/70 x 34 rear tires. Engine was 6-cylinder with power of 210 kW (285 hp), torque of 1300 Nm (1500 rpm) and 190 kN traction force.

HV2 had an approximate weight of 20,000 kg, a standard width of 3,085 mm, with a fuel tank volume

of 380 l rotated from 6x6 tires with 600 / 65-, 710 / 55-34" front tires and rear tires of 800 / 40-26.5 ". The engine was 6-cylinders with power of 205 kW (275 hp), torque of 1,100 Nm (1200 to 1500 rpm) and 160 kN traction force.

HV3 had an approximate weight of 21,000 kg, standard width 3,090 mm, with fuel tank volume of 350 l and track system. The engine was 6-cylinder with power of 123 kW (165 hp), torque of 730 Nm (1350 rpm) and 183 kN traction force.

HV4 had an approximate weight of 21,000 kg, a standard width of 2,900 mm and a track system with a maximum speed of 5.5 km / h. The engine was 6-cylinder with power of 155 hp at 2000 rpm, and 178 kN traction force.

FW1 had an approximate weight of 21,800 kg, maximum load capacity of 18,000 kg, standard width from 2,990 to 3,300 mm, with fuel tank volume of 270 l, 8x8 tires, 750 / 55x26,5 tires. The engine was 6-cylinders with power of 205 kW (275 hp), torque of 1,100 Nm (1200 to 1600 rpm) and 220 kN of traction force.

FW2 had an approximate weight of 19,100 kg, a maximum load capacity of 18,000 kg, a standard width of 3,170 mm, a fuel tank volume of 210 liters, 8x8 tires, 750 / 45x30,5 tires. The engine was the CTA 74 CTA, 6-cylinder, turbocharged with Commonrail, with power of 170 kW (231 hp), torque of 100 Nm at 1500 rpm and 207 kN of traction force.

2.2 Ergonomic factors

2.2.1 Noise

Continuous noise evaluation was done using a 01dB-Metravib Wed007 noise dosimeter brand operating in the "A" compensation circuit and slow response circuit. The measures were performed with the instrument fixed close to the workers ear, during the whole work shift. NR15 regulates the level of noise exposure for unhealthy purposes. For an 8-hour working day, the maximum set is 85 dB(A) and the maximum allowed exposure time decreases progressively with increasing noise level. NR 17 regulates the level of noise exposure for the purpose of comfort in the workplace. In this case the maximum noise level for activities requiring intellectual solicitation and constant attention is 65 dB(A).

Machines with equivalent noise levels equal to or greater than 65 dB (A) received a non-compliance for this factor, so that the nonconformity value of 1 (NC = 1) was assigned. For all machines that had

equivalent noise levels between 65 dB (A) and 85 dB (A), the value attributed to the Non-Conformity Weight was 0.5 (NCW = 0.5). For machines that had an equivalent noise level of 85 dB (A), the value attributed to the Non-Conformity Weight was equal to 1 (NCW = 1).

2.2.2 Vibration

The regulatory standard dealing with vibration in Brazil is NR15, Annex 8, which specifies that if the daily occupational exposure limit of 1.1 m s^{-2} is exceeded work is considered unhealthy. In this case, preventive and corrective measures should be taken to preserve the health and safety of workers. According to Directive 2002/44 / EC of the European Community, the tolerance limit is equal to 1.15 m s^{-2} and the action level is equal to 0.5 m s^{-2} .

The machines that presented an acceleration value resulting from normalized exposure (aren) equal to or greater than 0.5 m s^{-2} received a non-conformity for this factor, so that a non-conformity value of 1 (NC = 1) was assigned. For all machines that presented an acceleration value resulting from normalized exposure (aren) between 0.5 m s^{-2} and 1.1 m s^{-2} the value attributed to the Non-Conformity Weight was equal to 0.5 (NCW = 0.5). For machines that had a standardized exposure (aren) acceleration value greater than or equal to 1.1 m s^{-2} , the value attributed to the Non-Conformity Weight was equal to 1 (NCW = 1).

The vibration evaluation was done using an 01dB-Stell Maestro accelerometer, in accordance with technical procedures established by the Occupational Hygiene Standard 09 (FUNDACENTRO, 2013). Whole body vibration levels were measured and in each case the resulting normalized exposure acceleration (aren) was obtained.

2.2.3 Thermal environment

The thermal environment inside the cabin was evaluated according to the parameters of the Ergonomic Checklist for Forest Machines (Almqvist R, Gellerstedt S, Tobish R, 2006). The item "Cabins climate" was composed of 3 qualitative parameters.

The following aspects were analyzed: the ability to maintain adequate internal temperature even on hotter days; Uniform distribution of temperature and percentage of operator's body reached by incident sunlight. For each unattended parameter, a non-conformance value of 1/3 (NC = 1) was assigned, and the value assigned for the Non-

Conformity Weight was equal to 1 when it was a more severe non-compliance and 1/2 when it is a mild non-compliance. The qualitative parameters for the evaluation of the thermal environment are shown in Table 1:

2.2.4 Air quality

The air quality inside the cabin was evaluated according to the parameters of the Ergonomic Checklist for Forest Machines (Almqvist et al., 2006). Three qualitative parameters were considered. For each unattended parameter, a non-conformance value of 1/3 (NC = 1) was assigned. The value assigned for the Non-Conformity Weight was equal to 1 when it was a more severe non-compliance and 1/2 when it is a mild non-compliance. The qualitative parameters for air quality evaluation are shown in Table 2:

2.3 Ergonomic Conformity Index (ECI)

The ergonomic factors considered in the determination of the Ergonomic Conformity Index (ECI) were the following: noise, vibration, thermal environment and air quality. All factors had the same weight in determining the Index. A Partial Ergonomics Conformity Index (ECIp) was calculated for each factor according to Equation 1, developed by the authors for this work.

$$ECIp = 1 - (NC \times NCW) \quad (\text{Eq.1})$$

Where:

ECIp = Partial Ergonomics Conformity Index

NC = Non-Compliance Assigned Value

NCW = Non-Compliance Weight

The Ergonomic Conformity Index (ECI) was obtained from an arithmetic mean of the ECIp of all factors considered, according to Equation 2.

$$ECI = \frac{ECIr + ECIV + ECIt + ECIqa}{4} \quad (\text{Eq.2})$$

Where:

ECIr = Partial Ergonomic Conformity Index for noise

ECIV = Partial Ergonomic Conformity Index for vibration

ECIat = Partial Ergonomic Conformity Index for

Table 1 – Qualitative parameters for forest machines thermal environment evaluation.

Tabela 1 – Parâmetros qualitativos para avaliação de ambiente térmico em máquinas florestais.

| Cabin temperature | |
|---------------------------|--|
| C | Suitable temperature. In winter, adjustable between 15 and 33 ° C and in summer between 20 and 25 ° C. These temperatures can be maintained in any weather or weather conditions. |
| NCW = 1/2 | Difficulty on maintaining proper temperature on hot summer days or cold winter days. |
| NCW = 1 | Difficulty on maintaining proper temperature in most situations |
| Uniformity of temperature | |
| C | Temperature Uniformly distributed from head to feet of the operators. The airflow is well distributed and does not cause discomfort. |
| NCW = 1/2 | Temperature differences in various parts of the body causing mild discomfort. |
| NCW = 1 | Clear differences in temperature between the various parts of the body. Inconvenient with drafts. |
| Sun protection | |
| C | Sunlight affecting a small area of the operator (up to 10% of the body, eg arms and hands). |
| NCW = 1/2 | Sunlight affecting to 40% of the body (eg chest, abdomen and thighs) |
| NCW = 1 | Sunlight on more than 40% of the operator's body. |

Source: Adapted from Almqvist R; Gellerstedt S; Tobish R (2006).

Table 2 – Qualitative parameters for forest machines air quality evaluation.

Tabela 2 – Parâmetros qualitativos para avaliação da qualidade do ar em máquinas florestais.

| Air filter | |
|----------------------------|--|
| C | Filter system can remove dust, pollen and soot (quality at least F7). There is a clear indication of when to replace the filter |
| NCW = 1/2 | Filter system at least F5. Indication of substitution with deficiencies. |
| NCW = 1 | No filter available or filter with poor function. Missing indication. |
| Replacing the filter | |
| C | Filter easily accessible and can be changed without the use of tools. |
| NCW = 1/2 | Easy access but tools are necessary. |
| NCW = 1 | Difficult to replace and tools are needed. |
| Perception of the operator | |
| C | The operator does not smell any exhaust fumes and has no problem with dust or particles. |
| NCW = 1/2 | Under special conditions there may be momentary influence of exhaust fumes or dust. |
| NCW = 1 | There are obvious problems with exhaust fumes or dust. |

Source: Adapted from Almqvist et al. (2006).

thermal environment

ECI_{qa} – Partial Ergonomic Conformity Index for air quality

A comparison of the ergonomic aspects of the forest machines was made by determining the ECI of each machine. According to the proposed methodology, machines with higher ECI are superior from the ergonomic point of view.

3. RESULTS

3.1 Noise, Vibration, Thermal Environment and Air Quality

The evaluation of the environmental agents during a typical work day allowed the determination of the Equivalent Noise Level (LA_{Eq}), the resulting acceleration of standardized

exposure (a_{ren}) and the qualitative aspects related to the thermal environment and the air quality inside the cabs of the forest machines analyzed. The results of the evaluations and the respective Partial Ergonomic Conformity Indices are presented in Table 3.

3.2 Ergonomic Conformity Index (ECI)

The determination of ECI allowed a comparison between the analyzed forest machines. The ECI of Harvesters HV1, HV2, HV3 and HV4 were, respectively: 0.83; 0.88; 0.71 and 0.63. The ECI of Forwarders FW1 and FW2 were 0.58 and 0.79.

4. DISCUSSION

Continuous noise levels varied between 75.0 and 82.6 dB (A). All the analyzed machines obtained the ECI_r equal

Table 3 – Equivalent noise level (LAEq), resulting acceleration of standard exposure (aren), thermal environment, air quality and partial Ergonomic Compliance Indices of Harvesters and Forwarders.

Tabela 3 – *Nível de ruído equivalente (LAEq), aceleração resultante da exposição normalizada (aren), ambiente térmico, qualidade do ar e Índices de Conformidade Ergonômica parciais de Harvesters e Forwarders.*

| MACHINE | | HV1 | HV2 | HV3 | HV4 | FW1 | FW2 |
|---------------------|-------------------------|------------|------------|------------|------------|------------|------------|
| Noise | dB(A) | 77,4 | 78,6 | 76,2 | 78,9 | 75,0 | 82,6 |
| | NC | 1 | 1 | 1 | 1 | 1 | 1 |
| | NCW | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 | 1/2 |
| | ECI_r | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| Vibration | m s ⁻² | 0,33 | 0,37 | 0,37 | 0,27 | 0,70 | 0,38 |
| | NC | 0 | 0 | 0 | 0 | 1 | 0 |
| | NCW | - | - | - | - | 1/2 | - |
| | ECI_v | 1 | 1 | 1 | 1 | 0,5 | 1 |
| Thermal Environment | NC | 0 | 0 | 1/3 | 2/3 | 1/3 | 1/3 |
| | NCW | - | - | 1/2 | 1/2 | 1/2 | 1/2 |
| | ECI_{at} | 1 | 1 | 5/6 | 4/6 | 5/6 | 5/6 |
| Air quality | NC | 1/3 | 0 | 1 | 1 | 1 | 1 |
| | NCW | 1/2 | - | 3/6 | 4/6 | 3/6 | 1/6 |
| | ECI_{qa} | 5/6 | 1 | 3/6 | 2/6 | 3/6 | 5/6 |

to 0.5. This indicates that the values found are below the limit of exposure allowed by Brazilian legislation, which is 85 dB (A) for an 8-hour daily exposure, but above the comfort threshold, which is 65 dB (A). Similar results are described by other authors in studies carried out with the same types of machines analyzed in this study (Messingerová et al., 2005; Minette et al., 2007). Under these working conditions, the operator may have a reduction on productivity and performance, as well as the risk of hearing loss and extra-auditory effects.

The vibration levels to which workers were exposed ranged from 0.27 to 0.70 m s⁻². All analyzed Harvesters had a lower vibration value than the action level proposed by the European Community Directive 2002/44 / EC and only FW1 showed vibration above 0.50 m s⁻².

These values were similar to those found by Jankovský et al. (2016). The high vibration value caused the FW1 to obtain the lowest ECI between the analyzed machines. Vibration reduction depends on engineering measures, such as the suspensions studied by Fleury e Mistrot (2006).

All factors related to the thermal environment in HV1 and HV2 were in accordance with the determined standards.

In HV3 it was found that there was higher heating in the operator's legs region. In HV4, in addition to the temperature being not uniform throughout the cabin, there was a high incidence of sunlight on the operator's body. In FW1 there was an incidence of sunlight up

to 40% of the body of the operator and in FW2 the cooling system was not able to maintain the proper temperature on the hottest days.

The only machine that was in compliance with all air quality parameters was HV2. In the HV1 the air filtering system had deficiencies. In the HV3 and in the FW1 all the items presented slight nonconformities. In the HV4 it was verified influence of the exhaust gases and dust during part of the operation and in the FW2 the change of the filter was only possible using specific tools.

The forest machines that obtained higher ECI were HV1 and HV2. The differential in these machines was the low vibration level and the favorable thermal environment inside the cab. The machine that obtained the best ECI, the HV1, showed only one nonconformity, related to the noise. To obtain the maximum ECI equal to 1, the noise in this machine should be less than 65 dB (A).

The ECI proposed in this work allowed a simple and direct ergonomic evaluation of forest machines. It was possible to establish a comparison between the forest machines evaluated, by determining the ECI of each one of them.

Although the index represents a simple and direct comparison, a partial indexes analysis can provide more detailed information on the items responsible for the final ECI value. The ECI model may have other variables included. Among these variables, the aspects related to repetitiveness, work posture and cabin dimensions.

On this work, the proposed ECI was applied in the evaluation of Harvesters and Forwarders. However, the same methodology could be applied in the ergonomic evaluation of other forest machines, such as Feller-Bunchers or Skidders.

5. CONCLUSIONS

The methodology proposed on this work to determine the Ergonomic Conformity Index (ECI) was efficient in the ergonomic evaluation of harvesters and forwarders. The determination of the ECI of the evaluated machines allowed the establishment of a comparison between them. The descending ECI order of evaluated harvesters was: HV2, HV1, HV3, HV4. The FW2 forwarder obtained higher ECI than FW1.

All evaluated forest machines had a continuous noise level above 65 dB (A), which is the limit established for comfort purposes, but less than 85 dB (A), occupational exposure limit for unhealthy purposes. Only the FW1 had a full body vibration level above the action level. Only HV1 and HV2 presented thermal environment in accordance with all the qualitative criteria used in the evaluation. Air quality inside the cab was considered unsatisfactory for all evaluated machines, except for HV2.

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