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Application of Data-mining Methods in the Assessment of Excessive Vibrations: Decision Trees, Basket-market Analysis

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Abstract: The article examines the issue of assessing the impact of above-limit vibrations on the health of employees in handling and dispatch warehouses (timber yards). The results are based on the arithmetic mean of multiple measurements of both hands of the chainsaw operator or the hands/whole body of the machinist, while taking care to maintain consistency. The measurement locations, measurement duration and selection of samples were chosen so that the result represented and described the employee's personal exposure. The main objective was to identify the relationship between the working activity of the studied forest administration employees, exposure to vibrations, and the actual accurately identified harm to the health status of the assessed persons. Basic methods of statistics and probability theory and methods of in-depth analysis (decision tree, association rules) were used in the evaluation. From the results, significant exceeding of the action and limit values of exposure to vibrations transmitted to the hands at the work position (chainsaw operator) was found. The decision tree showed that the age and experience in the employee's field have a major impact on the development of traumatic vasoneurosis (part of vibration disease occurring because of long-term local exposure to excessive vibrations). Through the analysis of association rules, dependencies were found between selected attributes that described each employee (age, experience, exposure, vibration acceleration, medical history). From the association rules, we obtained significant associations, for example, between a high value of vibration acceleration and numbness of the fingers, or back pain, tinnitus, etc. Also based on the analysis of the association rules, it was confirmed that old age or long experience in the field and exposure to vibrations over 4 hours/day significantly affect the occurrence of vascular changes in the fingers of the studied subjects.

Keywords: employees; decision tree; health; wood harvesting; market-basket analysis; decision trees; forestry; exposure to vibration

1. Introduction

A health condition caused by vibrations manifests itself slowly. Initially, it usually starts with pain. The assessment of workers exposed to the risk of vibration has been studied by a large number of domestic and foreign authors.

Raynaud's phenomenon was first described by the son of a Paris university professor, M.A.G. Raynaud in 1862. Later, this phenomenon was also called vibrating white finger and is currently referred to as hand-shoulder vibration syndrome. At the beginning of the 20th century, Loriga [1] first described the appearance of tingling, numbness and whitening of the fingers in stonemasons and carvers who used a pneumatic hammer without a handle. Wasserman et al. [2] stated that approximately 8 million workers in the United States are exposed to some form of industrial vibration. The prevalence of

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coronary heart disease depending on occupational exposure to vibration was studied on a sample of 150 miners [3]. They concluded that the presence of Raynaud's syndrome did not affect coronary heart disease in the vibration-exposed group. Solecki [4] examined disorders of the lower spine in his work, which is related to the whole-body transmission of vibrations to the employee. In the study, he included 98 men aged 53.3±10.1 from seven municipalities in the Lublin region who worked in the agricultural production sector. In Slovakia, the assessment of vascular disease due to vibration has been studied in depth [5–9]. Hůzl et al. [10] studied the most severe stages of vibration vascular disease in engineering and metallurgical plants. From 16 cases of vascular disease from vibration, they showed that the third most advanced stage of this disease will certainly manifest itself with several hours of exposure during a work shift and with insufficient hygienic and medical prevention. The correlation between health symptoms and EMG findings in (n=451) workers who worked at risk of vibration was investigated [11]. All the assessed employees worked at risk of above-limit vibrations (risk group = 3).

Employees who are exposed to vibrations acting on the hands and arms are also exposed to high levels of noise. Pyykkö et al. was the first to suggest that chainsaw operators who were indicated for Vibration White Finger disease (VWF) may develop greater hearing loss than men without a VWF indication [12]. A similar result was reported in a study conducted on a sample of 499 sawfish [13]. Hrušková et al. [8] tried to objectify the level of noise and vibration risk in a selected group of employees (n=36). Their aim was to determine a set of measures to protect the health of workers who are exposed to these physical factors repeatedly or over a long period of time. Palmer et al. [14], on a sample of 8193 respondents, investigated the relationship between VWF and NIHL. He concluded that Noise-Induced Hearing Loss (NIHL) was about twice as common in women and men who reported VWF. Iki M., et al. [15], Bovenzi M. [16], House R.A., et al. [17], Pettersson H., et al. [18], Turcot A., et al. [19], supported the hypothesis that VWF increases the risk of hearing loss in those workers who use manual vibration tools.

Data mining techniques are used to make effective use of data. According to Witten et al. [20] and Kantardzic [21] data mining is an analytical methodology for extracting non-trivial hidden and potentially useful information from data. Important methods of data mining include classification trees and association rules. Decision trees: an overview and their use in medicine/healthcare was written by [22,23]. The term "association rules" was popularized in the early 90s by Agrawal Rakesh in connection with market-basket analysis [24]. Market-Basket analysis is one of the main methods used to find frequently occurring patterns of behaviour. The most well-known algorithm for finding association rules is the APRIORI algorithm [25]. A priori is also used in medical research to reduce the manual effort of healthcare professionals in analysing data related to the medical field. For example, to detect schistosomiasis disease [26] and to detect common diseases [27–29]. A novel approach to predicting diseases using weighted association rules was proposed by Lakshmi and Vadivu [30].

The presented work monitors the attributes that describe individual employees and the presence of selected medical histories, while trying to relate these attributes to the diagnosis of vascular changes in the fingers. Based on these scientifically grounded facts, it is necessary to continue seeking and developing new methods of investigating, measuring, objectifying, and evaluating the exposure of employees to vibration from the tools they use during their work activities.

2. Materials and Methods

It is important to realize that vibration is one of the factors that is significantly involved in the development of occupational diseases [9,16,31–34]. Vibration hazards occur in various industries, especially at manual mechanized workstations or in industrial operations where workers handle forklifts and encounter heavy machinery, such as trucks. Manual power tools used in manufacturing, quarrying, mining and construction, agriculture and forestry [16] lead to the development of disorders of peripheral nerves, muscles, bones and joints.

2.1. Objective and methods of research evaluation

In our case, employees in handling and dispatch warehouses, in timber yards in the roles of chainsaw operator and front loader machinist are exposed to the greatest exposure to vibrations. This significant impact manifests itself for two main reasons. The first is that the work tools used, such as a chainsaw, are one of the most significant sources of vibration in forestry. Secondly, the exposure time to vibration is in the range of 4–6 hours for a working shift.

Some work tools and equipment are known to produce such vibrations that, over time, cause cumulative traumatic disorders that eventually lead to conditions such as vibrating white fingers and toes [35–37], Raynaud's disease [38,39], finger tingling [36], carpal tunnel syndrome [40,41], back and neck pain [42,43], headaches and dizziness [31], and other problems.

Chainsaw operators are rarely permanent employees, they are usually self-employed persons. For that reason, it must be argued that the actual time of exposure to vibration may thereby differ significantly from the time indicated by the employer, since they also carry out that activity after working hours or on weekends. Despite the significant increase in protection for chainsaw operators in recent years, this profession remains one of the riskiest in terms of developing an occupational disease. For front loader machinists, the risk primarily arises from prolonged exposure, often lasting an entire work shift. In the case of chainsaw operators, an associated negative factor is the cold, especially when working in the winter months.

Our experimental research was conducted to identify the relationship between the working activity of the studied employees, exposure to vibration, and the actual accurately identified harm to their health. As part of the research, we conducted a series of measurements. The results on which we based our evaluation are the arithmetic mean of numerous measurements of both hands of the chainsaw operator or the hands/whole body of the machinist, with care taken to maintain consistency.

2.2. Preparation and implementation of measurements

In view of the fact that an occupational disease cannot be recognised without an assessment of objective conditions in the workplace, it was necessary to assess the overall situation in the selected jobs. This means assessing all the vibration data obtained for a specific mechanized tool, or work machine or vehicle. It was equally important to find out the course of the operations performed and assess their possible health risks.

The basis for the implementation of the research were not only the results of measurements, but also the medical records of employees for whom these measurements were performed. After each measurement, a personal interview was conducted with each employee. The basis of the interview was to obtain information about their subjective perception of their health condition (Table 7), the basic characteristics of their work activities and an overview of the machines and equipment used. The questionnaire was formulated in the form of closed questions with predefined answer options, namely "yes" or "no". The analysis of the equipment used for logging and processing of wood was carried out in order to identify them more closely, because, despite indisputable technical developments, they are a significant source of negative effects on human health.

The protection of the health and safety of employees in connection with exposure to vibration at work is stipulated in the Slovak Republic in:

– *Act no 124/2006 on Occupational Health and Safety;*

– *Act no 355/2007 on the Protection, Promotion and Development of Public Health;*

– *Approximation Regulation of the Government of the Slovak Republic No. 416/2005 on Minimum Health and Safety Requirements for the Protection of Employees against Risks Related to Exposure to Vibration, as amended by Government Regulation No. 629/2005 Coll.*

According to Section 33 of Act no. 355/2007, employers who use or operate equipment that are a source of vibration are obliged to ensure, in accordance with Regulation of the Government of the Slovak Republic No. 416/2005, technical, organizational and other measures that will exclude or reduce to the lowest possible and achievable level the exposure of employees to vibrations and thereby ensure the protection of health and safety of employees. In the Official Gazette of the Slovak Republic No. 416/2005, which transposed Directive 2002/44/EC of the European Parliament and of the Council of 25 June 2002, additional requirements are laid down, which apply to all activities in which employees are exposed to vibration risks due to their work during working hours. In accordance with this directive, the determining quantities of vibration at workplaces have been introduced into the legislation of the Slovak Republic, which are the resulting normalized vibration acceleration, continuous weighted acceleration, equivalent acceleration and normalized acceleration in the third-octave band. Limit and action values for exposure to vibration are specified in the Government Decree of the Slovak Republic No. 416/2005, Annex No. 2.

As part of the research, the determining quantities of vibration acceleration were measured at the monitored workplaces, namely vibrations transmitted to the hands and to the whole body. Instruments under metrological control and accredited measurement procedures were used to measure and calculate vibration exposure and their subsequent evaluation. An indirect measurement method was chosen to measure vibration. A Crystal Instrument CoCo80 vibration analyser, a Dytran 5313A three-axis acceleration sensor, and a Piezotronics 35621 PCB were used to measure the vibration exposure. During the measurement, the vibration acceleration sensors were placed at the points where the vibration enters the body. The measured data were processed in EDM (Engineering Data Management) software. Due to the measurement method used, the measuring devices, the measurement conditions and the experience of the measurers, the measurement was subject to a measurement error of U = 22%. The calculation of the uncertainty of the vibration measurement result was performed on the basis of valid norms. The calculation took into account all sources of error that affect the determination of the uncertainty of the results. The evaluation of the results of the vibration acceleration measurement consisted of a comparison of the measured values with the required values, according to Annex No. 2 of the Government of the Slovak Republic No. 416/2005 The measurements were carried out in accordance with the standards STN EN ISO 5349-1: 2001, STN EN ISO 5349-2: 2015/A1 and STN ISO 2631-1: 1997. The measurement locations, measurement duration and selection of samples were chosen so that the result represented and described the employee's personal exposure.

Figure 1: Vibration measurement locations in dispatch and handling warehouses

On the basis of Directive 2002/44/EC, we proceeded to implement vibration measurements in dispatch and handling warehouses (timber yards), which are used for storage, handling, treatment and preparation of wood logs for dispatch. The measurements were carried out under normal operating conditions in several places in eastern Slovakia (Michalovce, Sečovce, Slanec, Haniska, Mníšek nad Hnilcom and Stará voda – Fig. 1).

The vibration acceleration measurement was carried out during work using the hand tool or devices specified (Table 1). In the case of grasping the hand tool with both hands, vibration acceleration measurements were taken for both hands. The evaluated workplaces are single-shift,

Table 1: Description of the professions assessed.

Job classification	*Machinery and equipment*	*Description of work activity*	*Exposure time*	*Stress factors*	*Transmission Source*
Chainsaw operator	STIHL [3] Husqvarna [4]	Measuring and processing wood logs into shorter pieces, which are then prepared for export.	150 – 420 min.	Noise	saw motor and drive mechanism
				HTV [1]	front and rear saw handle
Front loader operator	Caterpillar [5]	Handling of wood logs: carrying the wood logs to the place designated for their treatment, aligning the wood logs and preparing them for cutting, loading the wood logs into wagons ready for export.	300 min.	Noise	from the drive mechani-sm and hydraulic system
				HTV [1]	through the steering wheel and gear lever
				WBV [2]	through the seat and floor

1 – Hand-Transmitted Vibration (HTV); 2 – Whole Body Vibration (WBV); 3 – STIHL MS 440/460/650; 4 – Husqvarna 254/266; 5 – Caterpillar IT14G employees work from 7:00 a.m. to 3:00 p.m., with a 30-minute break. The evaluated professions were front loader machinist and chainsaw operator. These professions are most exposed to the influence of vibrations when performing their work activities. The job description of the assessed professions and the assessed risk factors are listed in Table 1.

2.3. Statistical assessment methods

Basic methods from statistics and probability theory were used in the evaluation. Decision trees and association rules are among the important methods of data analysis.

2.3.1. Decision trees

Decision trees are an important tool for classification and prediction and for facilitating decision-making with various decision-making problems. They are among basic data mining methods. The task of classification is to create a classification model that would enable the appropriate value of the target attribute to be assigned to the values of the input attributes of an object. The goal of the decision tree is to classify objects into classes (categories) of the target attribute. According to the type of target attribute, they are divided into classification and regression decision trees. Due to the discrete nature of the output attribute in the thesis, a classification tree will be used.

The algorithm for creating a classification tree starts on a training set that is made up of n objects. Each object is described by input attributes (properties), and the input attributes can be discrete or continuous. For each object, the value of the target attribute Y is also known, which can take m different values, classes. The key task of classification is to select an attribute suitable for branching the tree. In the work, we will use the C5.0 algorithm, which is suitable for all types of attributes, but the output variable is categorical. The criterion for branching is information gain and entropy [44,45].

2.3.2. Association rules

Association rules are important methods of data mining. Originally, they are derived from basket-market analysis, where they express which goods the customer has bought or buys together in the store, i.e. they usually put them together in the shopping basket. Today, however, this technique is also applied in other areas: financial analysis, customer relationship management, medicine, social network analysis, etc.

The association rule is defined as the implication of $A \Rightarrow B$, where A, B are the disjoint items from the set I, i.e. $A \cap B = \varnothing$. Thus, every rule of association consists of two parts, condition A (assumption) and result B (consequence), and usually can be represented by the statement: ***If assumption A, then consequence B, i.e. $A \Rightarrow B$. Association rules can also be more complex and contain more items. For example, the three-element rules (items A, B, C) include the statement: If the assumption A and B, then the consequence C, i.e. $A \propto B \Rightarrow C$.***

The quality of the association rule $A \Rightarrow B$ is assessed by three indicators: ***Support, Confidence and Lift.***

The most well-known method of searching for association rules is the APRIORI algorithm [25]. The A priori algorithm gradually generates sets of frequent (frequent) items (sets), progressing from single-item sets to multi-item sets. When frequent item sets are found, rules are created that meet the required minimum support conditions. The output of the algorithm is all strong n-item sets from which association rules can be generated. The task of the A priori algorithm is to find, with respect to a given set of transactions D, all such association rules the support of which is greater than the specified minimum mins support and the reliability greater than the minimum specified reliability of minc. The disadvantage of analysing the rules of association is that even with a small number of items, the potential number of rules can be huge, and many of them may not be useful. Not all discovered rules are useful or applicable. Some may be trivial or require further investigation to understand their practical implications [46,47].

In this article, the R program (library C50) is used to create a classification model and establish association rules.

3. Results and Discussion

3.1. Evaluation of measurement results

The results show that the action and limit values for chainsaw operators' exposure to vibrations have been exceeded to a high degree. These results can be influenced by several factors, namely the brand and type of single-man chainsaw used and its technical condition, the method of cutting (i.e. the individual approach of the chainsaw operator), the hardness and diameter of the sawn logs, the length of the cutting part of the bar and the grip force. In the case of the results of exposure measurements to vibrations transmitted to the hands (through the steering wheel) for the profession of front loader machinist, the action values were exceeded only in two cases. In the assessment of normalized vibration accelerations transmitted to the whole body, in no case does it exceed the action or limit values.

Both professions, namely the front loader machinist and the chainsaw operator, are burdened by vibrations transmitted to the hands when performing their work. In the case of the chainsaw operator, it is an enormous burden. For this reason, in the next part of this research, we focused on evaluating the impact of vibrations transmitted to the hands of employees, with a focus on the chainsaw operator profession. During measurements for this profession, information on the type of sawn wood logs (poplar and beech) was also obtained. The aim was to find out whether the type of wood mass processed has a significant impact on the magnitude of vibration acceleration or whether it can be neglected in practical conditions. The measurement was carried out with several single-man chainsaws of the STIHL and Husqvarna brands. Currently, these are the most common types of chainsaws used in forestry. The experiment was carried out on two types of wood, namely beech, which is classified as a medium-heavy, hard and not very flexible wood, and poplar, which, on the other hand, is a light, very soft and not very strong woods.

When comparing the results of equivalent vibration acceleration on the front and rear handles, it was found that on the front handle, the type of sawn wood mass does not have a significant effect on the amount of vibrations transmitted to the hands. On the other hand, higher vibration acceleration values were measured on the rear handle when sawing beech wood than when sawing poplar.

Based on the above results, we can state the following:

– *The front handle is designed in such a way that its suspension is greater than that of the rear handle.*

– *From the engine, vibrations are transmitted more to the rear handle than to the front handle.*

– *The type of wood mass was visible only on the rear handle, where measurements showed a significant difference in range (2.92–13.57 m.s^{-2}).*

– *The measurement results have a large variance.*

– *To achieve more relevant measurement results, it is necessary to carry out repeated measurements on a larger scale, based on which it would be possible to more objectively assess the effect of the type of sawn wood on the magnitude of the acceleration of vibrations transmitted to the hands.*

3.2. Basic data on employees

The pilot study involved 35 employees (men) aged between 35 and 60 who had been exposed to hand-transmitted vibration as part of their profession. From the medical records, we obtained information about the age of the employees, years of service, average daily exposure time to vibration, BMI index and other factors. The assessed value of normalized vibration acceleration was obtained by objectifying the vibrations transmitted to the hands. Basic data and characteristics are in Table 2.

3.3. Creating a classification model based on decision tree theory

The group of 35 employees was divided into 2 groups: a training group (25 employees) and a test group (10 employees). Each employee is described by 4 input attributes: age (Age), number of years worked (Experience, years), exposure time (Time, hr./day) and the assessed value of normalized vibration acceleration (Acceleration, m.s^{-2}).

Using the training set, a decision tree was created. The output attribute is the occurrence of vascular changes of the fingers (Changes) with two categories: Yes (occurrence of vascular changes) and No (no occurrence of vascular changes). Only two attributes are used for branching: the number of years worked (Experience, 100%), which is used

Table 2: Basic data on employees (n=35).

Characteristics	*Age (years)*	*BMI (%)*	*Exposure time (hr./day)*	*Work experience (years)*	*Vibration exposure (m.s^{-2})*		
					Selection form RH/LH	*HTV*	*WBV*
Arithmetic mean	48.86	28.17	4.27	20.63	7.72	1.79	0.32
Deviation	6.60	4.06	0.67	6.30	3.20	1.28	0.20
Maximum	60.00	36.88	5.00	32.00	14.57	4.92	0.73
Minimum	35.00	21.00	2.50	8.00	4.28	0.53	0.08

RH – right hand; LH – left hand; HTV – Hand-Transmitted Vibration; WBV – Whole Body Vibration; BMI – body mass index at the first level, and the age of the employees (Age, 76%). The result of the decision tree is in Figure 2.

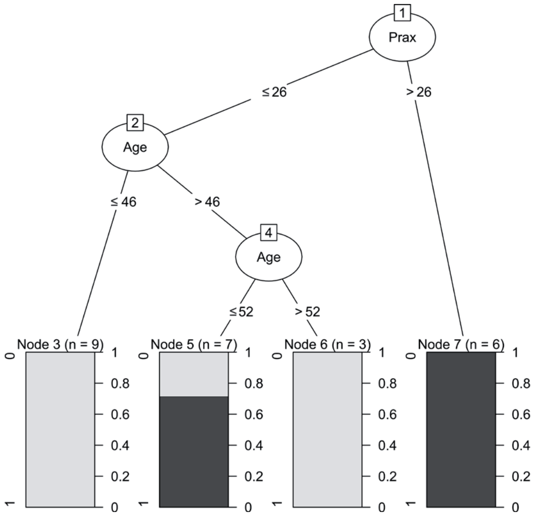

Figure 2: Classification tree

Simple decision-making rules follow from the decision tree:

```
IF (Prax>26) THEN (Changes=Yes)
IF (Prax<=26) AND (Age<=46) THEN (Changes=No)
IF (Prax<=26) AND (46<Age<=52) THEN (Changes=Yes)
IF (Prax<=26) AND (Age>=52) THEN (Changes=No)
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It turns out that if an employee has experience in the field for 26 years or more, he or she has a high risk of diagnosing vascular changes in the fingers. On the other hand, an employee whose age is at most 46 years and has not worked for more than 26 years in the field is not diagnosed with this disease. The situation is similar for an employee who is older than 52 years and has worked for less than 26 years.

An interesting finding is that employees between the ages of 46 and 52, despite less than 26 years of experience in the field, have a high risk of a positive diagnosis of vascular changes in the fingers. This may be due, for example, to the fact that in employees in the age category of 46–52 years, the same associated accompanying factors (smoking, BMI) contributed to the development or susceptibility to the development of traumatic vasoneurosis, which were manifested in all the aforementioned persons who were diagnosed with vibration disease of the fingers (Raynaud's syndrome). It was also found that these employees used mostly older machines and equipment in the performance of their work, i.e. age of machine > 10 years and at the same time operating hours > 10,000 hours. Furthermore, it was found that these persons belonged to the group of self-employed persons, i.e. they also performed this work outside direct working hours. During a personal interview, they confirmed to us that outside of this work (timber yards of the Slovak Republic) they do not always use personal protective equipment.

To describe the correspondence between the classification obtained from the experiment and the classification determined by the classification tree, we will use a matrix of pronouns. The substitution matrix for the training group shows that 23 out of a total of 25 employees were correctly classified (Table 3). The created model incorrectly classified only 2 employees. Overall accuracy of Ac=92% (overall accuracy) means that the created classification tree has excellent classification ability.

Table 3: Basic data on employees (n=35).

Vascular changes observed	*Classification determined by the decision tree*	
	yes	*not*
yes	12	2
not	0	11

We verified the predictive ability of the classification model using a test group of 10 employees (Table 4). A comparison of the results of the occurrence of vascular changes in the fingers obtained on the basis of medical examinations (plethysmography of the hands and water cold test) and the results obtained by the model show that a total of 8 employees from the test group were successfully classified. The overall accuracy of the classification is Ac=80%.

Table 4: Confusion matrix (test group; n=10).

Vascular changes observed	*Classification determined by the decision tree*	
	yes	*not*
yes	4	2
not	0	4

3.4. Application of Association Rules (Basket-market analysis)

For the purposes of creating association rules, we divided each variable (Age, Experience, Exposure and Acceleration) into two categories (Table 5).

Let I be the set of items that represents a group of all monitored parameters (Table 6): basic data on employees, medical history, plethysmography and water cold test result – by diagnosing the occurrence of vascular changes in the fingers, i.e.

Table 5: Categorize basic employee data.

Variables	*Description*
Age	Age I (45 years and under), Age II (46 years and above)
Experience in the field	Experience I (20 years and less), Experience II (21 years and above)
Vibration exposure	Exposure I (max. 4 hr./day), Exposure II (over 4 hr./day)
Vibration acceleration	Acceleration I (up to 3.75 m.s^{-2}) , Acceleration II (over 3.75 m.s^{-2})

Table 6: Overview of basic items in the analysis of association rules

Item	*Variable*	*Description*
Basic data on monitored employees		
I1	Age category 46 years and over	I1=1 (yes), I1=0 (no)
I2	Experience in the field over 21 years	I2=1 (yes), I2=0 (no)
I3	Exposure over 4 hr./day	I3=1 (yes), I3=0 (no)
I4	Vibration acceleration above 3.75 m.s^{-2}	I4=1 (yes), I4=0 (no)
Research area of subjective/objective evaluation		
I5	Smoking	I5=1 (yes), I5=0 (no)
I6	High blood pressure	I6=1 (yes), I6=0 (no)
I7	Hearing impairment	I7=1 (yes), I7=0 (no)
I8	Headaches	I8=1 (yes), I8=0 (no)
I9	Excessive sweating	I9=1 (yes), I9=0 (no)
I10	Pain in the spine	I10=1 (yes), I10=0 (no)
I11	Hip pain	I11=1 (yes), I11=0 (no)
I12	Left elbow pain	I12=1 (yes), I12=0 (no)
I13	Pain in the right elbow	I13=1 (yes), I13=0 (no)
I14	Tinnitus	I14=1 (yes), I14=0 (no)
I15	Pain in the upper limbs	I15=1 (yes), I15=0 (no)
I16	Pain in the lower limbs	I16=1 (yes), I16=0 (no)
I17	Swelling of the upper limbs	I17=1 (yes), I17=0 (no)
I18	Swelling of the lower limbs	I18=1 (yes), I18=0 (no)
I19	Numbness of the fingers	I19=1 (yes), I19=0 (no)
I20	Colour change of the fingers	I20=1 (yes), I20=0 (no)
I21	Diagnosed vascular changes	I21=1 (yes), I21=0 (no)

I={I1,I2,...,I20,I21}.

Based on the information obtained, we concluded that out of the total number of studied employees, 19 actively smoke (I5:54.29%), smoking increases the heart rate and causes narrowing of the arteries, together with the action of vibrations, it can have an even more serious impact on the health of employees, and also obesity. 9 employees (25.71%) suffer from a medium to high health risk in terms of body mass index. 24 employees (I10:68.57%) experience back pain and 23 (I15:65.71%) upper limb pain. Finger tingling reports 14 (I19:40.00%) employees and only 7 (I20:20.00%) also their colour changes. Elbow pain is experienced by 11 (I12:31.43%) and 13 (I13:37.14%) employees. Nine employees report problems with high blood pressure (I6:25.71%). Hearing impairment is experienced by eight (I7:22.86%) and related tinnitus by ten (I14:28.57%) employees. All the answers of the interviewed employees were subsequently verified by an extract from their health cards.

The occurrence of vascular changes in

employees was obtained from the results of finger plethysmography (decay >97%) and the results of a water cold test of 10°C/10 min. (lividity, redness, whitening, marbling, cyanosis). We divided the severity of harm in the studied sample of employees into two categories: complete/partial, or none. Nine employees had vascular changes in the fingers before cooling (25.71%) and in nineteen vascular changes manifested themselves only after cooling (54.28%). The incidence of monitored medical histories is shown in Figure 3.

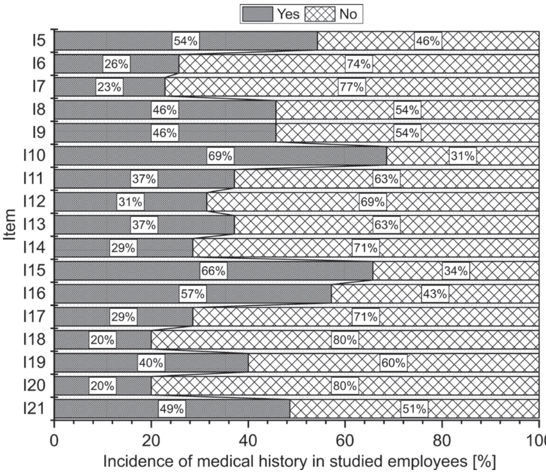

Figure 3: Incidence of medical history in studied employees

Let D be the set of transactions T, D={T1,T2,...,T35}, where Ti represents the i-th employee and all his recorded items, i=1,2,...,35. Table 7 lists the first 5 employees from the database. If the employee has a given item, there is 1 in the column of that item, otherwise it is 0. For example, an employee with ID number ID3 has items T3={I1,I3,I4,I5,I8,I10}, i.e. He is 46 years old or over, the exposure is over 4 hr./day, vibration acceleration is above 3.75 ms^{-2}, smokes, reports headaches and spinal pain.

Before performing the association analysis, we set the minimum support mins =0.25, which means that a set of items must appear in at least 25% of all transactions to be considered frequent. We were interested in cases with a minimum reliability of the minc =0.50 rules and a maximum of four-element rules. From such settings, we obtained 273 association rules, 15 of which we organized according to the Support value (Table 8). We only took into account the association rules with a Lift higher than 1. If the Lift value is greater than 1, it means that the association is significant and the degree of association between the assumption and the effect is higher than if they were independent.

Support for the first rule is 51.4% (18/35 = 0.314), which means that the number of employees who also have items (I4 – acceleration of vibration above 3.75 $m.s^{-2}$, I15 – pain in the upper limbs) is 51.4% in the database. The confidence for this rule is 81.8% and expresses the probability that if the vibration acceleration is above 3.75 $m.s^{-2}$, then the employee also has upper limb pain at 81.7%. Lift = 1.245 means that an employee with a vibration acceleration above 3.75 $m.s^{-2}$ has a 1.245 to 1 chance of also having upper limb pain compared to a randomly selected other employee. Other rules of association can also be interpreted by analogy.

For example, it turns out that there is an 86.7% probability that an employee who has upper limb pain (I15) and back pain (I10) is over the age of 46 (I1) (Rule: I15&I10=> I1, Confidence=0.867, Lift=1.379, Support=0.371). The rules state that if an employee's exposure lasts longer than 4 hr./day (or the employee reports numbness in the fingers of his hands), he also has back pain. (Rule I3 => I10, or I19 => I10).

In the next step, we will focus on item I21 (vascular changes of the fingers). We are interested in what items employees have so that they can also be diagnosed with an I21 item. The result of the analysis is 9 association rules arranged according to the value of Support (Table 9).

Support for the first rule is 40.0%, which means that the number of employees who have at the

Table 7: Table of transactions and items (for the first 5 employees).

ID	*I1*	*I2*	*I3*	*I4*	*I5*	*I6*	*I7*	*I8*	*I9*	*I10*	*I11*	*I12*	*I13*	*I14*	*I15*	*I16*	*I17*	*I18*	*I19*	*I20*	*I21*
1	0	0	0	1	1	0	1	0	1	1	0	1	0	1	1	1	1	0	1	1	0
2	1	1	0	1	1	0	0	0	0	1	1	1	0	1	1	0	1	0	1	1	1
3	1	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
5	0	0	1	1	0	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0

Table 8: Table of association rules (mins=0.25, minc=0.50).

Index	*Support*	*Confidence*	*Lift*	*Count*	*Rule*
1	0.514	0.818	1.245	18	I4 => I15
2	0.457	0.727	1.107	16	I1 => I15
3	0.457	0.727	1.061	16	I4 =>I10
4	0.400	0.824	1.311	14	I21 => I1
5	0.371	0.929	1.477	13	I14 =>I4
6	0.371	0.867	1.379	13	I15&I10 => I1
7	0.371	0.929	1.354	13	I3 => I10
8	0.371	0.929	1.354	13	I19 => I10
9	0.371	0.867	1.319	13	I1&I4 => I15
10	0.371	0.722	1.053	13	I15&I4 => I10
11	0.343	0.857	1.304	12	I19 => I15
12	0.314	1.000	2.500	11	I12 => I19
13	0.314	0.846	1.234	11	I13 => I10
14	0.314	0.917	1.337	11	I15&I9 => I10
15	0.286	0.714	1.923	10	I13 => I19

I1 – age category 46 years and over; I3 – exposure over 4 hr./day; I4 – vibration acceleration above 3.75 m.s-2; I9 – excessive sweating; I10 – back pain; I12 – pain in the left elbow; I13 – pain in the right elbow; I14 – tinnitus; I15 – pain in the upper limbs; I19 – numbness of the fingers; I21 – diagnosed vascular changes

Table 9: Table of Association Rules for Item I21 (mins=0.25, minc=0.50).

Index	Support	Confidence	Lift	Count	Rule
1	0.400	0.636	1.310	14	I1 => I21
2	0.343	0.750	1.544	12	I2 => I21
3	0.343	0.500	1.029	12	I10 => I21
4	0.314	0.733	1.510	11	I2&I1 => I21
5	0.286	0.625	1.287	10	I1&I15 => I21
6	0.257	0.643	1.324	9	I3 => I21
7	0.257	0.643	1.324	9	I19 => I21
8	0.257	0.692	1.425	9	I19&I4 => I21
9	0.257	0.692	1.425	9	I10&I1 => I21

I1 – age category 46 years and over; I2 – experience in the field over 20 years; I3 – exposure over 4 hours/day; I4 – vibration acceleration above 3.75 m.s-2; I10 – back pain; I14 – tinnitus; I15 – pain in the upper limbs; I19 – numbness of the fingers; I21 – diagnosed vascular changes

same time items (I1 – age over 46 and I21 – vascular changes of the fingers) is 40.0% in the database. The confidence for this rule is 63.6% and expresses the probability that if the employee is over 46 years old, then he certainly has vascular changes in the fingers at 63.6%. There is a 73.3% probability that an employee who is over 46 years old (I1) and has experience in the field over 20 years (I2) is also diagnosed with vascular changes in the fingers (I21) (Rule: I2&I1 => I21, Confidence=0.733, Lift=1.029, Support=0.286).

A graphical representation of the rules of association organized by the value of Confidence is shown in Figure 4.

If we only monitor the occurrence of anamnesis, regardless of age, experience, exposure and acceleration, we will obtain 105 association rules. If we focus only on item I21 (we are interested in what items employees have to be diagnosed with vascular change of the fingers), then the result is only 3 association rules (Figure 5) under the set conditions (min_s =0.25, min_c =0.50).

The rules show that if an employee reports numbness in the fingers, then 64.3% of them are also diagnosed with vascular changes in the fingers (Rule1: I19 => I21, Confidence=0.643, Lift=1.324, Support=0.257). According to another rule, if an employee reports back pain, 50.0% of them are diagnosed with vascular changes (Rule3: I10 => I21, Confidence=0.500, Lift=1.029, Support=0.343). Rule I16 => I21 (if he has pain in his lower limbs, he also has vascular changes in his fingers) is one of the rules that may not be applicable to practice (Rule2: I16 => I21, Confidence=0.500, Lift=1.059, Support=0.286).

Not all discovered rules are useful or applicable. Some may be trivial or require further investigation to understand their practical implications.

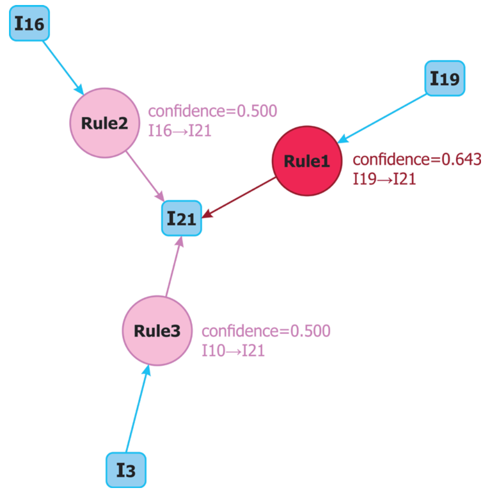

Figure 4: Graphical representation of the association rules (arranged by Confidence value)

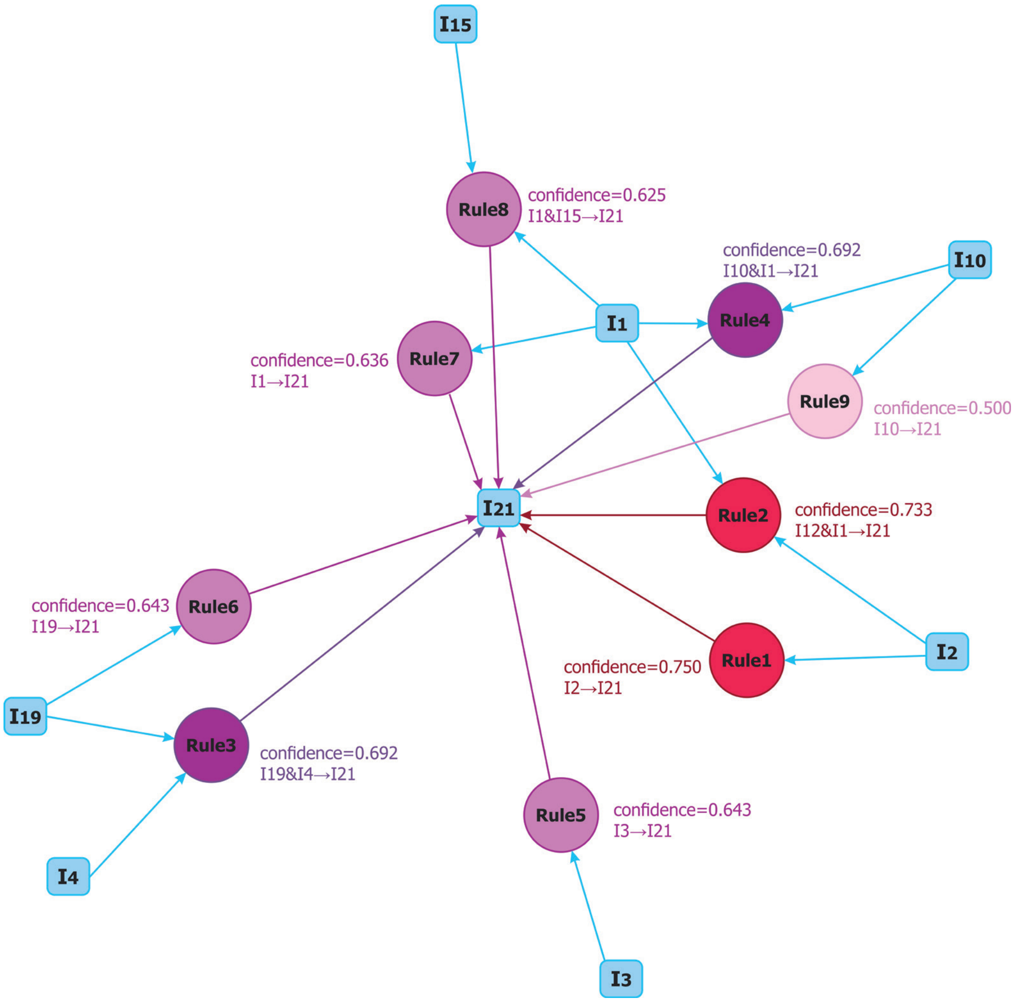

Figure 5: Graphical representation of the rules of association for item I21 (arranged by Confidence value)

4. Conclusions

This experimental research was focused on the issue of vibrations transmitted to the whole body, but especially to the hands of a selected group of employees in the work environment. For the purposes of this research, the forestry sector was selected as the working environment, which is one of the riskiest in terms of the occurrence and impact of risk factors on the health of employees. The article presents the results of an extensive number of measurements of noise and vibration exposure performed in both laboratory and real conditions of practice for the professions of front loader machinist and chainsaw operator. The measurements presented in this research were carried out based on the methodology for assessing the impact of noise and vibrations on health in the working environment created at the workplace of the SOEF (Section of Objectification of Environmental Factors) – accreditation certificate No. S-292.

In this research, procedures and methods of objective evaluation of the physical factor (vibration) in the working environment of handling and dispatch warehouses (timber yards) were used in the professions of front loader machinist and chainsaw operator in eastern Slovakia. The basis for the implementation of the research were also the medical records of the studied persons in whom vibration measurements were performed. From the results of the presented findings, and several other measurements and observations, it is clear that the chainsaw operator profession is one of the professions that is enormously exposed to hand vibrations. The findings so far have confirmed the authors' assumptions about the extremely intensive exposure of chainsaw operators. The evaluation also revealed an uncertainty factor, which often consisted of a problematic determination of the exposure time. Employees often performed the work of a chainsaw operator even after working hours, sometimes for various reasons it was not possible to determine the actual exposure time in the long term. Also, the calculations were based on measurements of current single-man chainsaws and not those that were used in sawing wood years ago in one case even 28 years ago.

The above results showed the action and limit values of exposure to vibrations transmitted to the hands had been exceeded to a high degree in the job of chainsaw operator. Both professions are burdened by vibrations transmitted to the hands when performing their work, but in the case of the chainsaw operator, it is an enormous load (3.40–14.22 m.s-2). When assessing the normalized values of vibration acceleration for the whole body, these values were not exceeded. At the same time, an experiment was carried out as part of the research, the aim of which was to find out whether the type of processed wood mass has a significant impact on the magnitude of vibration acceleration or whether it can be neglected in practical conditions. Part of the experiment was to identify dependencies between work activity, described by employee exposure to vibration, and actual, precisely identified harm to the employee's health. Based on the identified dependencies, some interesting claims can be formulated, the justification of which, however, would need to be proven by more extensive research. The aim of this study was also to outline one of the possibilities of how to proceed in the evaluation of above-limit vibrations in the lumber industry, in our case in handling and dispatch warehouses (timber yards).

In-depth analysis of data is one of the useful methods in examining the relationships between variables. Through the decision tree, a simple classification model has been created, which will help to classify and at the same time predict the occurrence of vascular changes in the fingers based on basic data on employees working in the professions of chainsaw operator and front loader machinist.

The decision tree shows that the age and experience in the employee's field play a large role in diagnosing vascular changes in the fingers. Through the analysis of association rules, dependencies were found between selected attributes that described each employee (age, experience, exposure, vibration acceleration, medical history). From the association rules, we obtained significant associations, for example, between a high value of vibration acceleration and numbness of the fingers, or back pain, tinnitus, etc. (Table 8). Based on the analysis of the association rules, it has been confirmed that old age or long experience in the field and increased exposure significantly affect the occurrence of vascular changes in the fingers. At the same time, it has been found that the presence of back pain, or pain in the upper limbs, or numbness of the fingers also implies the occurrence of vascular changes in the fingers. It should be remembered that not all rules obtained are applicable and may be useless in practice or their meaning is confusing. Therefore, it is important to subject the individual rules of association to further examination.

We would like to highlight the fact that a very small number of respondents participated in the pilot study, which can significantly influence the results of the evaluation, and the claims and conclusions made. It is clear to us that extensive research still needs to be done for any far-reaching claims about the health risks of vibration.

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