Open Access

International journal of Rural Development, Environment and Health Research (IJREH)
[Vol-4, Issue-5, Sep-Oct, 2020]
ISSN: 2456-8678
https://dx.doi.org/10.22161/ijreh.4.5.2

Statistical Analysis to Audiometric Evaluation with Internal Collaborators in a Brazilian Sugar and Alcohol Industry

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Abstract — *Since the Industrial Revolution period, workers have been exposed to noisy work environments that are detrimental to their hearing health. However, in Brazil, mandatory audiometric testing occurred late, and were implemented in the end of 1970s. Noise-induced hearing loss (NIHL) occurs when there is continuous exposure to loud noise, which causes hearing damage, and it is quite common in industry environments, being, then, the center of this work study: the influence of the working are of a sugar and alcohol industry located in the interior of the State of São Paulo in which the hearing of analyzed employees in a period of one year. I´d been used a sample of twenty-eight employees, half of whom were located in the transportation sector and the other half from machine operators. The analysis was performed, comparatively, in 2017 and 2018, considering frequency analysis between 500 and 8000 Hz. As a result for the right ear, there was a reduction in the percentage of NIHL in the transportation sector from 2017 to 2018, while the left ear remained stable. For the machine operators sector, the relationship was inverse, in which an increase in NIHL value checked for the right ear was obtained, so that the left ear remained constant.*

Keywords* — *ANOVA, Audiometry analysis, Hearing health of employees, NIHL, Sugar and alcohol industry.

I. INTRODUCTION

Studies related to the safety and health of workers are increasingly evident in Brazil. One of the reasons for this increase was the Consolidation of Labor Laws (CLT), which raised great concerns about the condition of workers. Within this context, a recurring disturbance in many companies is the noise generated by machines in the product processing stages. Aiming at preserving the health of workers, one of the annexes of the CLT provides for the mandatory audiometric monitoring, by specialists, of employees working in companies with working conditions with high levels of sound pressure, and, in the case of hearing damage, specific treatments of preservation of hearing health (Assunção, Abreu, and Souza, 2019; Boger, Sampaio and De Oliveira, 2013; Meira, Santana and Ferreti, 2015).

In such cases, it is important, on the part of the employees, the correct and constant manipulation of the instruments intended for hearing protection. For this reason, in addition to monitoring hearing health, the National Committee for Hearing Noise and Conservation organized basic guidelines for the Hearing Conservation Program (PCA), covering the following steps: recognition and risk assessment for hearing, audiometric management, measures collective protection, individual protection measure, education and motivation, data management and program evaluation (Assunção, Abreu, and Souza, 2019; Meira, Santana and Ferreti, 2015).

Daily, workers in the sugar and alcohol industry transportation sector are exposed to noise, dust and heat from sunlight. Those working in the machinery operating sectors are exposed to noise pollution with high noise levels. That is why it is necessary to apply statistical tools, which provide a systematic study in order to identify problems through their symptoms to modify the variables that are proven to benefit the employees' hearing health (Cavalcanti, 2014).

According to Feltre and Paulillo (2013, p.663) “The Brazilian sugar and alcohol sector has a long historical trajectory that was characterized, at times, by the strong intervention of the State in production and commercialization and, at other times, by the untying of the government many activities ”.

Previous studies such as Cavalcanti (2014, p.15) that refer to the auditory effects of post-exposure workers, to the most diverse types of noise found in a sugar and alcohol industry, have already shown the importance and interest of work developments in relation to audiometry, occupational audiology allied to PAIR, so that actions could be anticipated, not only in terms of workers' health, but also in the work environment to which they were being submitted, which is related to areas related to work safety, in order to comply with labor laws and determinations of regulatory bodies.

The objective of this study is to evaluate the hearing health of employees of a sugar and alcohol company through the use of the ANOVA statistical tool, evaluating the sectors of machinery and transport operators based on tests carried out in the frequencies of 500, 1000, 2000, 3000, 4000 , 6000 and 8000 Hertz, differentiating the results obtained from the left and right ears.

II. THEORECTICAL BACKGROUND

Sound is defined as any vibratory disturbance in an elastic medium, which produces the auditory sensation. The noise, which is already part of everyday life, is an acoustic and aperiodic signal, originated from the superposition of various vibration movements with different frequencies that are not related to each other. Therefore, from the point of view of Physical Acoustics, it can be said that the definition of noise is encompassed by the definition of sound (Kim, et al., 2017; Meira, Santana and Ferreti, 2015; Silva, 2008; Miranda et al., 1998).

The contact with noisy work environments has been intensifying since the industrial revolution, however, the concern with the damage to the health of the exposed worker is relatively recent. In the USA and Europe, this concern goes back to the 1940s, even so, in response to the high social and economic cost that fell on industries due to heavy labor indemnities (Meira, Santana and Ferreti, 2015; Assunção, Abreu, and Souza, 2019).

In Brazil, however, legislation on the subject only began to be implemented in the late 1970s with Ordinance 3214 of 1978 establishing the mandatory admission, periodic, dismissal audiometric tests, whenever the work environment has sound pressure levels greater than 85 dB in eight hours of exposure. This ordinance also establishes the limits of exposure and differentiates continuous noise from impulsive noise. Finally, Regulatory Standard (NR) 15 of Ordinance 3214/78 defines the environmental criteria that characterize work considered unhealthy by exposure to noise (Assunção, Abreu, and Souza, 2019; Guerra et al., 2005; Kwitko, 2001).

When the noise is intense and the exposure to it is continued, on average 85 dB for eight hours a day, structural changes occur in the inner ear, a hearing deterioration, slowly progressive, with neuro-sensory characteristics, not very deep, almost always similar bilaterally and absolutely irreversible, which determine the occurrence of NIHL - Hearing loss induced by noise - focus of study of this work within the industry, through statistical methods to verify if, among the functions attributed to the employees of a sugar and alcohol company (transport sector and machine operator), the sector in which the employee is inserted interferes in his hearing (Silva, 2008; Dias et al., 2006).

Noise-induced hearing loss (NIHL) is a highly prevalent occupational disease in the manufacturing environment, occurring in numerous branches of activity. Ordinance 19/1998 establishes the definition of occupational NIHL, guidelines and minimum parameters for the assessment and monitoring of the hearing health of workers exposed to noise and, finally, provides subsidies for the prevention of occupational NIHL cases in companies where this risk exists (Kim et al., 2017; Bernardi, 2003; Kwitko, 2006; Cavalcanti, 2014).

NIHL is the most characteristic form of hearing damage due to noise. Those affected begin to have difficulties to perceive high-pitched sounds, such as those of telephone, whistles, clock ticking, bells, etc. And soon the deficiency extends to the middle area of the audiometric field, compromising frequencies in the so-called conversation zone and, consequently, affecting speech recognition. In short, the definition of work-related noise-induced loss, unlike acoustic trauma, is a gradual decrease in hearing acuity, resulting from continued exposure to high noise levels; this hearing impairment can lead to important changes that lead to quality of life, whether in hearing impairment or disadvantage (Kim et al., 2017; Meira, Santana and Ferreti, 2015; Kwitko, 2004; Miranda et al., 1998).

When studying occupational hearing loss, it should be taken into account that there are other causal agents that, not only can generate hearing loss, regardless of exposure

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to noise, but also interact with it, potentiate its effects on noise. hearing (Giustina, 2001; Kwitko, 2001).

One-way analysis of variance allows you to check for differences between the means of three or more groups or conditions. For this, the variance between the compared groups is analyzed, and the variance within each group. This test is applied based on Fisher's F, given by Equation (1), where S2b is the dispersion between groups, and S2w is the dispersion within groups (Cordeiro, Melo, and Fernandes, 2018).

$$F = \frac{S_b^2}{S_w^2} \quad (1)$$

$$S_b^2 = \frac{\sum n_i\,(\bar{x}_i - \bar{\bar{x}})^2}{k-1} \quad (2)$$

Where K are the groups to be compared, $\bar{x}_i$ is the mean of the sample, e $\bar{\bar{x}}$ is the mean of the global sample (Giustina, 2001).

$$S_w^2 = \frac{\sum (n_i - 1) S_i^2}{\sum (n_i - 1)} \quad (3)$$

Where S_i^2 is the estimate of the variance of sample i (Cordeiro, Melo, and Fernandes, 2018).

For the application of this parametric model, some requirements are necessary, such as the normality of the sample distribution and the homogeneity of the variances. The ANOVA basically divides the variability between groups and within groups, comparing the two (Cordeiro Melo, and Fernandes, 2018).

III. MATERIAL AND METHODS

To carry out such a statistical experiment, we rely on data collection from 28 employees, belonging to the transport sector (drivers) - 14 - and machine operators - 14 - from a sugar and alcohol industry, located in the interior of the State of São Paulo. Paulo, in order to carry out a case study. The collected population is 100% male, and the data evaluated refer to the years 2017 and 2018, so that there are no differences between the calibrations of the device that performs the audiometry (audiometer).

All the findings, made by the professionals in conducting the audiometry, and the discussion of the data collected for statistical analysis were based on Regulatory Standard 7 of the current labor legislation, Ordinance No. 19 (Regulatory Standard No. 15, 1978; Regulatory Standard No. 7, 1994).

In audiometry, the frequencies of 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hertz were tested, and the tests, performed by a qualified professional (speech therapist), were performed after an acoustic rest of more than 14 hours.

Based on information provided by the company, the database was created using Microsoft Excel 2013 ® and MINITAB 2016 ®, with the following variables: employee code, exam date, function, frequencies and hearing thresholds (in decibels), in left and right ears.

In principle, the employees' data regarding the Current P19 Classification (NR 15) (Regulatory Norm No. 15, 1978; Regulatory Norm No. 7, 1994) were treated, in this way, we obtained how the different employees and functions are distributed according to the classification cited (Fig. 1 and Fig. 2). An observation to be made is that NORMAL hearing thresholds up to 25 dB were considered (Silva, 2008; Giustina, 2001; Kwitko, 2006).

IV. RESULTS AND DISCUSSION

Fig. 1 and Fig. 2 illustrate the audiometric data collected regarding the distribution of the different employees, according to their work sector, in relation to the analyzed parameters of NIHL and Normal, of the right (RE) and left (LE) ears.

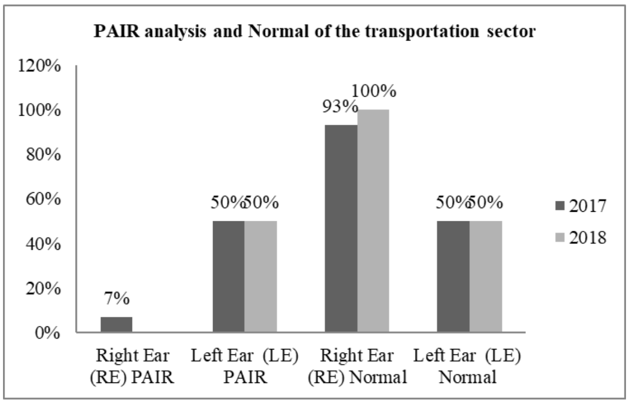

Fig. 1: Comparison of the PAIR analysis and employees Normal in the transportation sector between the years 2017 and 2018

Through the data collected and analyzed, for the years 2017 and 2018, it can be seen that, in relation to the transport sector, the percentage of employees with NIHL in the right ear was 7%, in 2017, to 0%, in 2018 ; in the left ear, it remained stable, at 50%, as shown in Fig. 1.

In the case of machine operators, the percentage of employees with NIHL in the right ear, which was 0% in 2017, increased to 14% in 2018; in the left ear, the value remained stable at 43%. In general, in 2017, the transport sector had a higher percentage of employees with NIHL, a

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result that was reversed in 2018, with machine operators presenting higher values, as shown in Fig. 2.

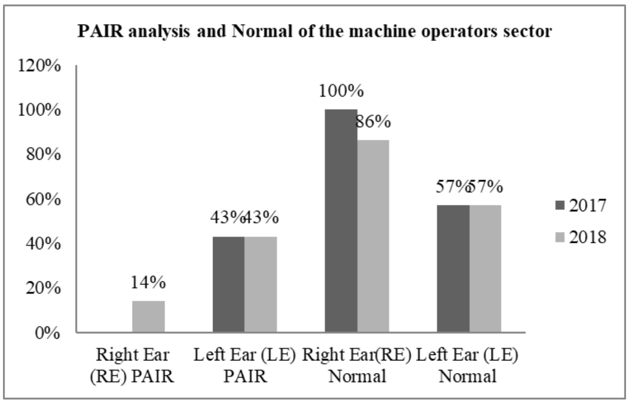

Fig. 2: Comparison of the PAIR analysis and Normal of the machine operators sector between years 2017 and 2018

It is worth mentioning that the improvement in NIHL for the transport sector is due to the use of individual safety equipment, such as hearing protection and hearing protection. It is also appropriate in this explanation that when the employee has a hearing loss - detected by audiometry - and suggestive of NIHL, this audiometry becomes a reference in the acquisition system and database used, therefore, as the NIHL is slow and progressive in the over the years, it takes a long time to detect a new loss. Thus, the improvement in PAIR for the years 2017 and 2018 in the transport sector is also justified.

Fig. 3 and Fig. 4 illustrate the general result of the audiometry test carried out with company employees, in relation to the transport and machine operator sectors in the years 2017 and 2018.

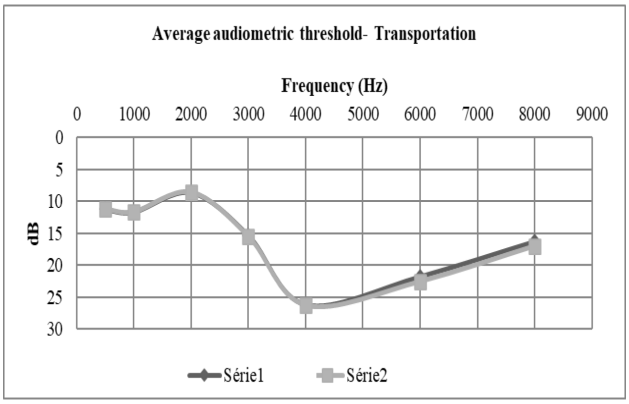

Fig. 3: Average audiometric thresholds in sound field (a) of the transport sector

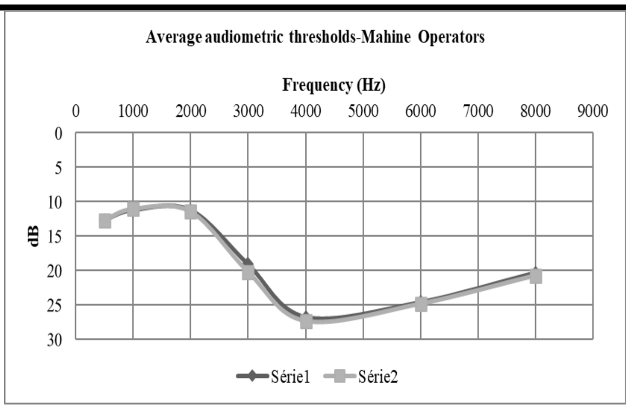

Fig. 4: Average audiometric thresholds in sound field (a) of the machine operators sector

In Tables 1 and 2, the result of the audiometric test of workers in the transport sector and in the machinery operation sector is presented.

Table 1: Audibility test for the transportation

Transportation sector						
	BF			**AF**		
	RE	**LE**	**Mean**	**RE**	**LE**	**Mean**
1	11,25	13,75	12,5	21,67	30	25,83
2	8,75	8,75	8,75	6,67	5	5,83
3	8,75	10	9,375	20	23,33	21,67
4	15	17,5	16,25	51,67	45	48,33
5	17,5	12,5	15	40	25	32,50
6	10	10	10	18,33	20	19,17
7	8,75	8,75	8,75	16,67	15	15,83
8	10	16,25	13,125	13,33	16,67	15
9	10	8,75	9,375	16,67	13,33	15
10	8,75	8,75	8,75	23,33	16,67	20
11	8,75	10	9,375	10	8,33	9,17
12	13,75	11,25	12,5	21,67	20	20,83
13	18,75	12,5	15,625	38,33	35	36,67
14	15	15	15	21,67	20	20,83

Through the data presented in Table 1 and Table 2, it is possible to observe the average audibility for the lowest frequencies of 500, 1000, 2000 and 3000 Hz (BF), and for the high frequencies of 4000, 6000 and 8000 Hz (AF) in the year 2018.

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Table 2: Audibility test for the Machine Operation

	Machine Operation Sector					
	BF			**AF**		
	RE	**LE**	**Mean**	**RE**	**LE**	**Mean**
1	11,25	11,25	11,25	21,67	21,67	21,67
2	10	10	10	16,67	18,33	17,5
3	15	12,5	13,75	21,67	18,33	20
4	20	18,75	19,37	35	45	40
5	8,75	11,25	10	16,67	18,33	17,50
6	10	15	12,5	20	16,67	18,33
7	7,5	8,75	8,12	10	15	12,50
8	18,75	18,75	18,75	28,33	28,33	28,33
9	15	20	17,5	53,33	51,67	52,50
10	12,5	12,5	12,5	16,67	20	18,33
11	10	10	10	13,33	13,33	13,33
12	8,75	8,75	8,75	16,67	15	15,83
13	18,75	22,5	20,62	23,33	25	24,17
14	25	16,25	20,62	51,67	28,33	40

Table 3 shows a summary of the descriptive statistics of the audiometry test for the transportation sector and machine operator.

Table 3: Descriptive statistics of sector audibility

	Transportation			
	BF		**AF**	
	RE	**LE**	**RE**	**LE**
Mean	11,786	11,696	22,857	20,952
Maximum	18,75	17,50	51,667	45,00
Minimum	8,75	8,75	6,667	5,00
P-value	0,008	0,088	0,029	0,453
	Machine Operation			
	BF		**AF**	
	RE	**LE**	**RE**	**LE**
Mean	13,661	14,018	24,643	23,928
Maximum	25,00	22,500	53,333	51,667
Minimum	7,50	8,750	10,000	13,333
P-value	0,116	0,175	0,005	0,005

For the audibility equality test, the average of the employees' right and left ears at low frequencies (500, 1000, 2000 and 3000 Hz), and at high frequencies (4000, 5000 and 6000 Hz) was considered. Analysis of these results showed that there is no significant difference in employee audibility between the company's work sectors (p-value 0.158 and p-value 0.588 for low and high frequencies, respectively). In Fig. 5 and Fig.6, the BloxPlot of the averages is illustrated for comparison purposes.

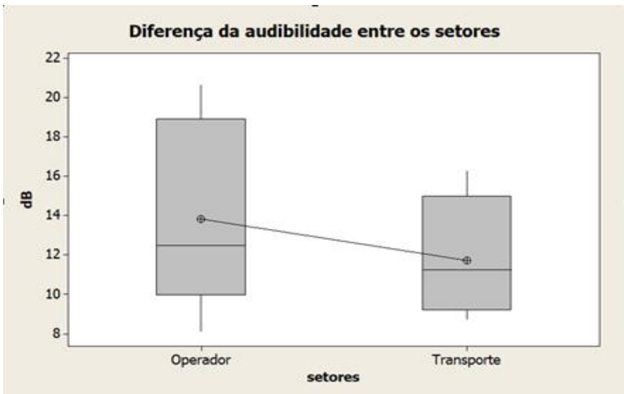

Fig. 5: Boxplot of audibility by sector in low frequencies

ISSN: 2456-8678
https://dx.doi.org/10.22161/ijreh.4.5.2

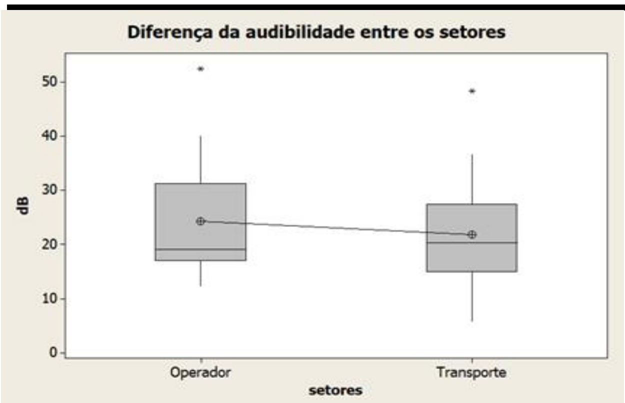

Fig. 6: Boxplot of audibility by sector in high frequencies

The same procedure was used to compare the year of work, but now, considering two consecutive years of work, to determine whether there is a difference in audibility between the years.

The analysis of the audiometry of the years showed that there is no significant difference between the two consecutive years analyzed, for low frequencies, in both sectors (p-value 0.967 for both sectors). The test for high frequencies also showed no significant difference (p-value 0.937 and 0.910 for the transport sector and for the machine operation, respectively). In Fig.7 and Fig.8, the BloxPlot of hearing averages per year is illustrated.

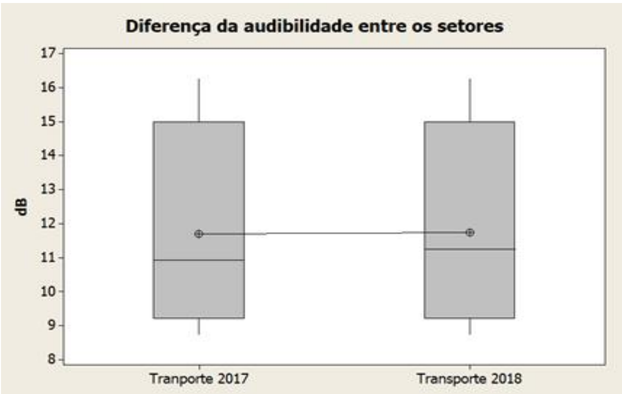

Fig.7: Boxplot of audibility per year at low frequencies for the transport sector

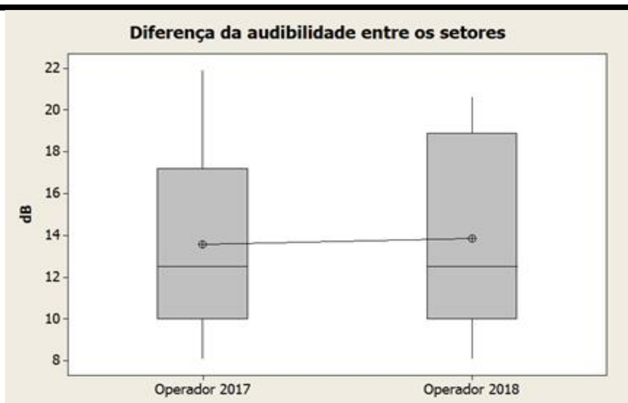

Fig.8: Boxplot of audibility per year at low frequencies for the operating sector

An important and key point in the qualitative analysis conducted by this research work, shows that regardless of the position that employees occupy, as well as the statistical tests showed, that the well-being of a company's workforce is of paramount attention, since losses hearing aids and increased NIHL are, in most cases, irreversible, and can last for years, until deleterious occurrences are detected.

Given what was presented in this research, it can be shown in a statistical way how to interpret results originated from a simple periodic examination, and how to proceed in the detection of sound accuracy in productive sectors, as well as, in the clinical evaluation of the staff. In addition to the results presented, the identification of the importance of Individual Safety Equipment (PPE), coupled with awareness programs for their use, negatively impacting the worsening of already identified NIHL situations, reducing their frequency, which justifies the constant stimulus to research works in this area, who approach themes both in the clinical / audiometric scope in a qualitative way, consolidated with quantitative statistical approaches, aiming, thus, to validate, in a scientific way, the findings presented clinically.

V. CONCLUSION

The present research work fulfilled the proposed objective, since it presented results of the hearing health evaluation of employees of a sugar and alcohol company using the ANOVA tool.

The importance of statistical tools for both analysis and validation of the diverse database was evidenced, giving reliability to the results found.

As a contribution, this work presents the applicability of statistical tools, in this case ANOVA, as a support for occupational health areas, which can be extended to the area of occupational safety and medicine.

The work presents ANOVA as a statistical tool, which proved to be of great applicability also to other segments of companies, so that they can monitor the health of their employees and adapt to the results obtained.

As a limitation for this research, the collected sample size can be scored. Since there were no variations between sectors, the monitoring and collection of more data should be continued, preserving employees, since the percentage of people with NIHL is considerable. Another limitation is based on the fact that only one statistical tool, ANOVA, was used, and the results could be impacted, if another tool was applied for data analysis and treatment.

With the presentation of this work, it is also clear that the use of Protective Equipment is very relevant for the preservation of the health of employees.

VI. RECOMMENDATIONS

It is suggested for future work, approaches analogous to this research work, to be conducted in companies from different segments, and combined with a quali-quanti comparison of the results. It is also suggested the application of other statistical tools in the analysis and treatment of data, with the objective of providing a critical analysis of their applicability not only in the sugar-alcohol segment, but also in others of importance and representativeness for the national economy.

ACKNOWLEDGEMENTS

Authors wish to acknowledge the University of the State of São Paulo, Faculty of Engineering of Guaratinguetá, for its assistance during the research period.

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