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# THE EFFECT OF COMPONENTS IN A WORK DAY ON WHOLE-BODY VIBRATION EXPOSURE: THE STUDY OF A SCHOOL BUS DRIVER.

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**Abstract:** Concern about occupational health led to the development of research relating the exposure to physical agents and the time of daily exposure with health problems commonly presented by a population of workers. Vibration is a physical agent that can cause harm to the health of the worker when exposed to long periods. Studies are developed in order to characterize and evaluate exposure to Whole-Body Vibration (WBV) through components, that is, by decomposing daily exposure into parts. The standard responsible for the parameterization of exposure to WBV is NHO - 09 Avaliação da Exposição Ocupacional por Vibração de Corpo Inteiro (2013) based on the International Organization for Standardization (ISO) - 2631: Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration. Part 1: General Requirements (1997). Although the NHO - 09 presents detailing to obtain the evaluation parameters and VDVR, there is no standardization in obtaining the exposure components needed to obtain them. The NHO - 09 indicates a professional analysis of the evaluator responsible for the study regarding the amounts and duration of the exposure components used, which may present divergence from evaluator to evaluator as a result of the amount of data obtained. This study consisted of a comparison on the interference of the quantity and the measurement time of the components used for evaluations to exposure to WBV. By means of four analyzes with different amounts of components and having or not repetitions, the coherence between the four results obtained in relation to the exposure to the WBV of a school bus driver of the University of Brasília (UnB) was evaluated. It could be concluded that for this study that has fixed daily paths, it is possible to evaluate the exposure to WBV through the use of exposure components.

**Keywords:** Vibração de Corpo Inteiro, Componente de Exposição, Ônibus.

## 1. INTRODUCTION

According to Mansfield (2005), vibrations are mechanical waves, which need a means to propagate. They can propagate in gaseous medium, such as air, liquid, such as water or solid, like the human body. Vibrations transmitted to body parts occur when in direct contact with an object that emits acceleration from the vibration to that particular part of the body. Whole Body Vibrations (WBV) occur when the human body is in contact with a vibrating surface and transmits acceleration throughout the body; such as vehicle seats, mobile platforms, etc.

The exposure to WBV for long periods can be considered a health hazard. The most common effects of exposure to this type of vibration are lumbar pain, digestive disorders, thickening of the heart structures, neurological diseases and vascular disorders, as mentioned by Mansfield (2005) and Griffin (1990).

Due to the variety of situations that contribute to the exposure to WBV and the varied ergonomic characteristics of workers, it is necessary to develop studies for the investigation of the threat to health and well-being of workers in the workplace. Studies such as those of Zanatta (2013), Ciloglu et al. (2015), Jonsson et al. (2014) and Vallone (2016) exemplify the variety of means of exposure to whole body vibration as in: airplanes, buses, cars and tractors.

In order to preserve the health and safety of the worker, Normas Regulamentadoras (NR) have elaborated, where minimum requirements and general provisions for prevention in health and safety at work are found. They are required by all companies, public and private institutions that have employees governed by the Constituição das Leis do Trabalho (CLT).

In view of the variety of exposure to physical, chemical and biological agents and the need for control parameters, a number of standards known as Normas de Higiene Ocupacional (NHO) were published. These parameters were the results of concepts and information from the research carried out by Fundacentro, a governmental institution responsible for promoting studies, assessing and pointing possible solutions to worker exposure. In particular, the parameter imposed by the NHO - 09 is based on the International Organization for Standardization (ISO - 2631).

The limits of exposure to whole-body vibration are defined by the NR – 15 - Atividade e Operações Insalubres (Anexo - VIII) and NR - 09 - Programa de Prevenção de Riscos Ambientais (Anexo I) and numerical parameterizations are elaborated by NHO - 09 Avaliação da Exposição Ocupacional por Vibração de Corpo Inteiro.

According to NHO - 09, the evaluation of the worker 's exposure to WBV should, in principle, be based on the evaluator' s technical convictions. The professional should judge the working conditions and how such exposure should be measured.

It should be emphasized that the procedures for the evaluation of exposure should be performed with the least possible interference in the work routine under study. The daily exposure may be evaluated by the use of one or more components, with or without repetitions, long or short durations, using the whole day work or only part of it. Bibhuti and Mansfield (2016) divided the daily exposure to WBV into eight exposure components, aiming to analyze and evaluate different characteristics of the processes performed by the worker. If the daily exposure comprises more than one component, the assessment may be performed by combining the data obtained from each component.

Due to the non-parameterization of the measurement time and / or the unavailability of the integral follow-up of the worker by the evaluator, different durations of components are found in the existing bibliography about exposure to WBV. Researchers such as Silva (2005), Tiemessen (2008), Costa (2014) and Weddington (2014) use measurement time for the component around 30 minutes, representing part of the daily exposure. Nunes and Silva (2015), use in their study components of exposure ranging from 2.32 to 8.8 hours, continuously considering all daily exposure to WBV.

Among the variety of studies related to WBV exposures, Tamrin et al. (2014) classifies professional drivers as the group of workers who present higher risk of exposure. The author defines a professional driver as the worker whose main function is to drive an automotive vehicle in traffic conditions. In his study, Kompier (1996) assesses occupational health in bus drivers and stands out as a group of workers who occupy high risk due to time and working conditions.

This study consisted of a comparison on the interference of the quantity and the measurement time of the components used for evaluations to exposure to WBV. By means of four analyzes with different amounts of components and having or not repetitions, the coherence between the results obtained in relation to exposure to the WBV in a school bus driver of the University of Brasília (UnB) was evaluated.

## 2. MATERIALS AND METHODS

### 2.1 Methodology

Initially, the worker was submitted to a questionnaire aiming at a better characterization of the interviewee, which covers anthropometric characteristics, occupational history and health problems.

Subsequently, his job cycle was analyzed and thus defined the cases of study of this work, where in these cases will be considered different components of exposure and the necessity, or not, of repetitions of the same. “Table 1” shows the routes considered for each case.

Table 1. Considerations about routes in different cases.

Routes	Case 1	Case 2	Case 3	Case 4
A	FGA – Fórum – Galpão – FGA	FGA – Fórum – Galpão – FGA	-	-
B	FGA – Galpão – Fórum – Galpão – FGA	FGA – Galpão – Fórum – Galpão – FGA	FGA – Galpão – Fórum – Galpão – FGA	-
C	FGA – Galpão - Fórum	-	-	-
D	Fórum – Galpão - FGA	-	-	Fórum – Galpão - FGA
E	FGA – Galpão – Fórum – Galpão - FGA	-	-	-
F	FGA – Galpão – Fórum - FGA	FGA – Galpão – Fórum – FGA	-	-

In the first case, the exposure to vibration was measured considering only one Exposure Component (EC) without repetitions, that is, the integration of the vibration signal was maintained continuously throughout the work day. The data collected and analyzed for whole time exposure will be used as reference in this study for the other cases.

In the second case, the daily exposure was measured considering three components of exposure, but with repetition of three times only for the second component. Three different routes of the total daily route were used, where each exposure component represents a route.

For the third case, the largest route during the job cycle was used, that is, only one exposure component. However, 5 repetition was considered for this component.

The fourth case considered the smallest route during the job cycle. Thus, we have 1 exposure component with 10 repetitions.

In summary, for the analysis of the first case, all routes and their respective vibration exposure were considered. For the second case, routes A, B and F will be considered, adopting three repetitions for path B, since this is equal to path E and consequently equivalent to path C + D. For the third case, only path B, adopting five repetitions for the same. Route B was chosen because it is characterized as the most complete of all routes. The last case had as its choice the component referring to route D, because it represents one of the routes with the shortest exposure time and a ten-fold repetition of this component was adopted. The “Table 2” below shows the information of the components used in this study

Table 2. Summary of components used in the study.

Components Information	Case 1	Case 2	Case 3	Case 4
Routes	A+B+C+D+E+F	A, B (=C+D=E) e F	B	D
Amount of components	1	3	1	1
Repetitions adopted	Continuous Integration	EC 1 (route A) = there is not repetition EC 2 (route B) = 3 EC 3 (route F) = there is not repetition	5	10

The measurement process was initiated when it came into contact with the WBV exposure and paused at the end of each route, considering only the exposure time. After obtaining and processing the exposure accelerations, the values obtained for exposure to vibration were compared to each other, verifying the consistency between the different cases. All procedures for obtaining exposure values are described by NHO - 09.

## 2.2 Route

The daily route is 12.48km a total. The complete route can be seen in Fig. 1, where the bus departs from the parking lot of the UnB Gama College (FGA) (identified by point 1 in Fig. 1), passes through the Galpão (point 2) and heads to the old city Forum (point 3). After this, the driver will return to the parking lot of the UnB (FGA) (1), which depending of the route, the driver will be able to go through point 2 again before to go to Gama College.

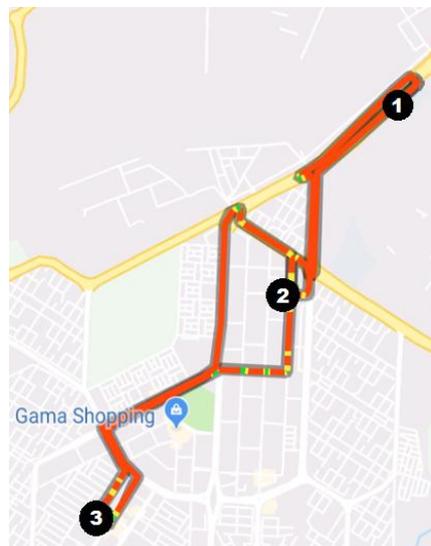


Figure 1. Daily route made by the school bus driver.

The route taken by the driver is fixed for all working days, established by UnB, and has the objective of transporting students and staff of the UnB (FGA) based in the city of Gama - DF.

The six daily routes were settled and established by UnB, as show on “Table 3”.

Table 3. Daily route established by UnB.

Component	Time	Routes	Exposure ( <i>T<sub>exp</sub></i> )
A	07h:30min (am)	FGA – Fórum – Galpão – FGA	30 min
B	09h:40min (am)	FGA – Galpão – Fórum – Galpão – FGA	40 min
C	00h:10min (pm)	FGA – Galpão - Fórum	27 min
D	01h:35min (pm)	Fórum – Galpão - FGA	17 min
E	04h:10min (pm)	FGA – Galpão – Fórum – Galpão - FGA	38 min
F	06h:10min (pm)	FGA – Galpão – Fórum - FGA	40 min

During the entire course of the route, the driver is exposed to WBV because the vehicle is not turned off. The average duration of the routes may vary in relation to traffic conditions. The routes are divided during their job cycle of 08:40 hours daily. In the interval of each route, the driver turns off the bus, that is, is not exposed to WBV.

### 2.3 Vehicle

The vehicle used to transport students and staff is an urban bus, as shown in “Figure 2”.



Figure 2. Bus used to transport students and staff.

According to information obtained by the manufacturer, the vehicle has a gross total weight of 10,710 kg, carrying capacity of up to 44 passengers, type traction, chassis model Volvo B270F, length 11 meters, diesel engine MWM 7B270 EUV, with power of 201 kW and torque of 950 Nm. It has metal suspension on both axles, double acting shock absorbers and stabilizer bars on all axles.

### 2.4 Measurement of Exposure to Acceleration

The equipment to be used for measuring the WBV exposure in drivers is a portable vibration analyzer composed of a triaxial accelerometer type seat pad which meets the ISO-2631 and NHO -. 09, as shown in “Figure 3”. The model equipment is the HVM100 from manufacturer Larson Davis.



Figure 3. Instrumentation used to measure WBV.

Each seat was equipped with seat pad, as shown in “Figure 4”. The driver sat on the seat as usual without altering anything in his ergonomics and the equipment carried out the measurements during the journey with the vehicle. According to ISO - 2631, the Z direction is always along the main axis of the body, the X direction is related to the front to back movement of the body and the Y direction is related to the side - by - side movement.



Figure 4. Coupling triaxial accelerometer, seat pad type.

It is emphasized that the equipment does not generate any discomfort since it has been designed by the manufacturer in such a way as to interfere as little as possible in the habitual activities of the individual. It is composed of a rubber in the shape of a flat disc. The measurement process must start when the activity that corresponds to the exposure component to be evaluated start and stop the measurement after the exposure component is completed.

## 2.5 Parameters estimate for WBV

NHO 09 stipulates two parameters for WBV exposure measurements; the Aceleração Resultante da Exposição Normalizada (aren), which converts the Aceleração Resultante de Exposição Normalizada (aren) to an 8-hour working day; and the Valor da Dose de Vibração Resultante (VDVR), which represents the exposure peaks related to the path traveled and works as a complementary parameter to the "aren".

Regarding the analysis of results, the NHO - 09 establishes limit values regarding exposure to WBV, as shown in “Table 4”.

Table 4. Judgment criteria to WBV exposure. Adapted from NHO - 09.

AREN (m/s <sup>2</sup> )	VDVR (m/s <sup>1,75</sup> )	Technical Consideration	Recommended Actions
0 - 0,5	0 - 9,1	Acceptabel	Maintenance of existing condition.
> 0,5 - < 0,9	> 9,1 - < 16,4	Above action level	Adoption of preventive measures.
0,9 - 1,1	16,4 - 21	Region of uncertainty	Adoption of preventive and corrective measures aimed at reducing daily exposure.
Above 1,1	Above 21	Above the exposure limit	Immediate adoption of corrective measures.

From the exposure levels obtained, if necessary, preventive measures and corrective measures are adopted, as indicated by NHO - 09.

### 2.4.1 Aren estimate

There is an order of five processing steps regarding the use of parameters to obtain the aren. The procedures will be detailed below as well as the mode of procurement.

- The first stage refers to the aceleração média (am), is obtained by integrating the frequency-weighted acceleration values at time t in m / s<sup>2</sup>, according to a given orthogonal axis "j", according to Equation (1).

$$am_j = \left\{ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a_j^2(t) dt \right\}^{\frac{1}{2}} \quad [\text{m/s}^2] \quad (1)$$

Where; " $a_j$ " corresponds to the frequency-weighted instantaneous accelerations on the axes "x", "y" and "z" and " $t_2 - t_1$ " represents the measurement range.

- The second step is to obtain the Aceleração Média Resultante (amr), according to Eq. (2), which corresponds to the square root of the sum of the squares of the average accelerations " $am_j$ " obtained in the three orthogonal axes.

$$amr = \sqrt{(f_x \times am_x)^2 + (f_y \times am_y)^2 + (f_z \times am_z)^2} \quad [\text{m/s}^2] \quad (2)$$

At where; " $am_j$ " represents the mean acceleration on the axis considered " $j$ " and " $f_j$ " corresponds to the multiplication constant represented for the application of the Whole Body Vibration curve, according to NHO - 09 and ISO - 2631 For the "x" and "y" axes, consider the multiplication factor of 1.4 and for the "z" axis consider the multiplication factor of 1.0. According to NHO - 09, the parameter "amr" can be obtain directly from an integrating meter next to a triaxial accelerometer.

- From Equation (3), we can obtain the third calculation step: the Aceleração Resultante de Exposição Parcial (Arep<sub>i</sub>). Corresponds to the resulting mean average acceleration for each " $i$ " exposure component. The criteria for definition of amount of exposure components are describe by NHO - 09.

$$arep_{ik} = \frac{1}{s} \sum_{k=1}^s amr_{ik} \quad [\text{m/s}^2] \quad (3)$$

The parameter " $amrik$ " represents the mean acceleration resulting from the kth sample for the exposure component " $i$ " and " $s$ " is the number of samples relating to the exposures that have been established.

- The fourth step when the Aceleração Resultante de Exposição (are), represents the average daily acceleration, considering the three orthogonal axes "x", "y" and "z" applying the different exposure components, according to Equation (4).

$$are = \sqrt{\frac{1}{T} \sum_{i=1}^m n_i arep_i^2 T_i} \quad [\text{m/s}^2] \quad (4)$$

The parameter " $arepi$ " already obtained previously will be used in this new procedure. The duration of the job cycle is denote by " $T$ ", " $n_i$ " is the number of repetitions composed of exposures established, " $T_i$ " is the duration time of the component and " $m$ " is the number of components.

- Finally, the last step is obtained by Eq. (5), which is the Aceleração Resultante de Exposição Normalizada (aren). It is intended to convert the (are) to a standard daily journey of 08:00:

$$aren = are \sqrt{\frac{T}{T_0}} \quad [\text{m/s}^2] \quad (5)$$

Measurement of the time of the job cycle " $T$ " can be expressed in hours or minutes, as well as the standardization of the job cycle " $T_0$ " = 08 hours or 480 minutes.

#### 2.4.2 VDVR estimate

VDVR, as well as aren, is obtained through the five-step process of data processing.

- The first step, related to the Valor Dose de Vibração (VDV<sub>j</sub>), is obtained from the vibration dose method to the fourth power, where " $j$ " represents the orthogonal axes "x", "y" and "z". As shown in Equation (6).

$$VDV_j = \sqrt[4]{\int_0^t [a_j(t)]^4 dt} \quad [\text{m/s}^{1.75}] \quad (6)$$

The frequency-weighted instantaneous acceleration is called " $a_j(t)$ " and " $t$ " is the measurement duration time.

- The second processing step is performed through Eq. (7), it is possible to obtain the Valor Dose de Vibração corresponding to the "x", "y" and "z" axes considering the possible exposure components ( $VDV_{ji}$ ).

$$VDV_{ji} = [\sum_{k=1}^s (VDV_{jik})^4]^{\frac{1}{4}} \text{ [m/s}^{1,75}\text{]} \quad (7)$$

The Valor de Dose de Vibração " $VDV_{jik}$ " is the selection of the  $k$ th sample among the repetitions of the " $i$ " components. The " $s$ " parameter indicates the number of samples for the exposure component. It can be extract directly from an integrating meter next to a triaxial accelerometer.

- The Valor de Dose de Vibração de Exposição Parcial is obtained by the third stage of the process. Corresponds to the representative vibration value of daily occupational exposure in the orthogonal axes " $j$ ", relative to exposure components " $i$ ", obtained by applying Equation (8).

$$VDV_{exp_{ji}} = f_i \times VDV_{ji} \times \left(\frac{T_{exp}}{T_{amos}}\right)^{\frac{1}{4}} \text{ [m/s}^{1,75}\text{]} \quad (8)$$

" $VDV_{ji}$ " is the value of the exposure component measured at the " $j$ " axis relative to the exposure component " $i$ ", " $T_{exp}$ " is the total vibration exposure time from the " $i$ " component.

It corresponds to the number of repetitions of the component times the duration time of the component. " $T_{amos}$ " is the total time used for the measurement of all " $i$ " exposure components under study. The parameter " $f_i$ " corresponds to the multiplication constant represented for the application of the WBV curve, according to NHO - 09 and ISO - 2631. For the "x" and "y" axes, consider the multiplication factor of 1.4 and for the "z" axis considers the multiplication factor of 1.0.

- The Valor de Dose de Vibração de Exposição obtained by the fourth step, represented by Eq. (9), corresponds to the representative value of each axis of measured daily occupational exposure.

$$VDV_{exp_j} = [\sum_{i=1}^m (VDV_{exp_{ji}})^4]^{\frac{1}{4}} \text{ [m/s}^{1,75}\text{]} \quad (9)$$

The number of exposure components resulted from the daily exposure is represented by " $m$ " and " $VDV_{exp_{ji}}$ ", is the value of the vibration dose of daily occupational exposure on axis " $j$ ", relative to component " $i$ ".

- Finally, to represent the dose of vibration the daily occupational exposure considering the resultant of the three measuring axes, Equation (10) is used to obtain the Valor de Dose de Vibração de Exposição Resultante.

$$VDVR = [\sum_j (VDV_{exp_j})^4]^{\frac{1}{4}} \text{ [m/s}^{1,75}\text{]} \quad (10)$$

" $VDV_{exp_j}$ " is the dose value, representative of the occupational exposure on the " $j$ " axis, where " $j$ " is equal to "x", "y" or "z".

### 3. RESULTS AND DISCUSSION

The volunteer participant is male, is 51 years old, 98 kg, 187 cm tall and Body Mass Index (BMI) corresponding to 28 Kg/m<sup>2</sup>, according to (OMS, 2017).

It presents pain in the lower back and works as a driver for 33 years, 02 years driver of UNB. The volunteer participant has no addictions and health problems. The data described above were informed by the participant himself.

In the HVM100 the values of " $amr$ ", " $VDV_x$ ", " $VDV_y$ " and " $VDV_z$ " are obtained for the certain exposure components required to quantify the values of " $VDVR$ " and " $aren$ " as shown in items 2.4.1 and 2.4.2. The integrator stores the data every two minutes of measurement. The interface between the equipment and the computer regarding WBV measurement is performed by Blaze ® software.

After the measurements were taken, the values referring to the routes covered during the daily working day of the driver were integrated. With the help of the Matlab software, a graphic representation of the worker's daily life was drawn up. The graph contains the acceleration values " $amr$ " for each second of measurement, as shown in "Figure 5".

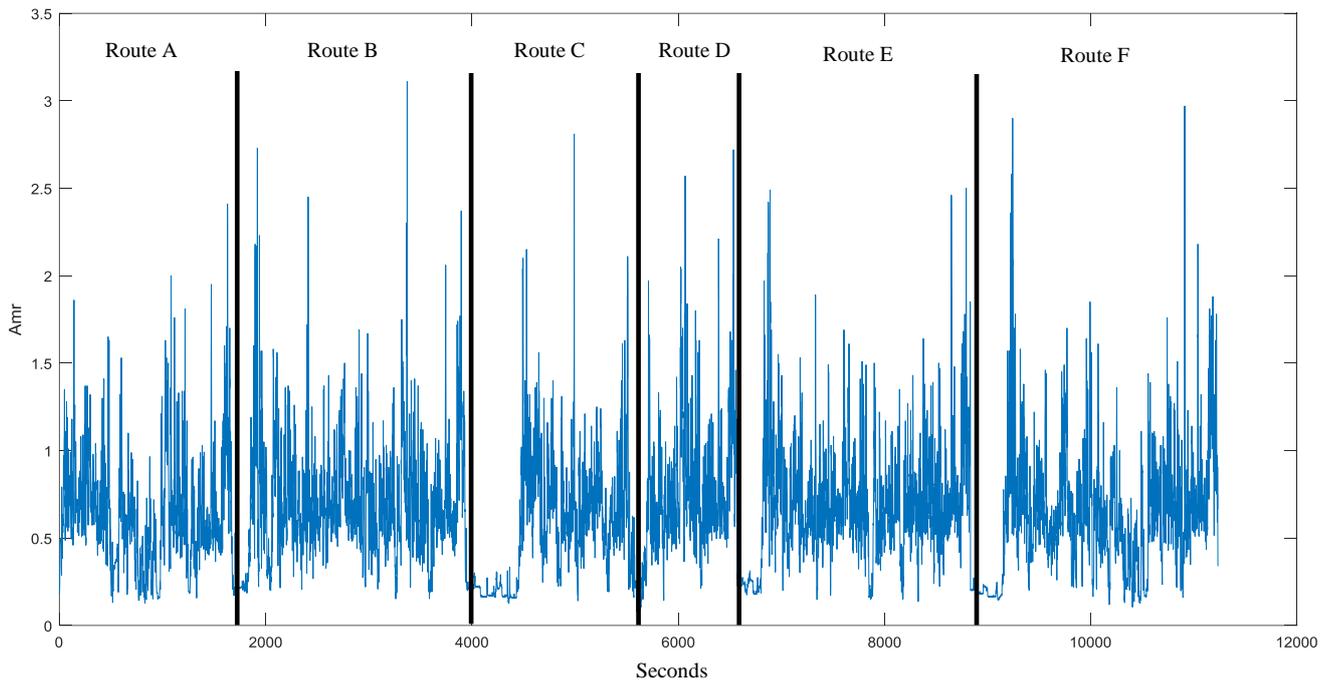


Figure 5. Representation of daily exposure by routes.

The low acceleration values at the beginning of the routes correspond to the time when the bus stays on but stops waiting for students and staff to board and disembark. The unevenness of the UnB – Gama College parking pavements, which corresponds to a distance of 411 meters, may also have contributed to the appearance of peaks at the beginning of paths B, C, E and F “Figure 6 (a)”. The rest of the route has regular pavement as shown in “Figure 6 (b)”, but with random irregularities along the route.



(a)



(b)

Figure 6. Different floors found during the study.

In “Table 5”, we can verify the results obtained for the different cases, by applying the parameters “aren” and “VDVR” through items 2.4.1 and 2.4.2.

Table 5. Summary of parameters obtained.

Cases	Case 1	Case 2	Case 3	Case 4
Amount of data obtained (Amr)	11.231	6.344	2.241	1.002
Time exposure ( <i>Texp</i> ) (min:s)	188:00	105:00	37:70	16:42
aren (m/s <sup>2</sup> )	0,400	0,405	0,428	0,425
VDVR (m/s <sup>1,75</sup> )	10,78	10,92	11,27	11,33
Quantity of data used (%)	100	56	19	8,9
Exposure time (%)	100	55	20	8,8

The Case 1 was use as reference for the other Cases because it is the integral follow-up of the worker, considering then 100% of the time and data obtained. For Case 2, 56% of the data used in relation to Case 1 and 55% of the exposure time was use; the same comparative relation was adopt for the other Cases. The standard deviation of the four cases under study was 1.4% for the aren parameter and 26.7% for “VDVR”. The highest value found for “aren” was obtain in Case 3. For “VDVR” the highest value was obtain in Case 4. The lowest values of “aren” and “VDVR” were find in Case 1. According to the NHO-09 Adapted Judgment Criteria described in “Tab 4”, it can be verified that the values obtained in all cases regarding the exposure are in the same range referring to the Technical Consideration to be adopted.

All four cases under study obtained acceptable “aren” and “VDVR” considered above the action level according to NHO - 09 by means of Technical Considerations, as already explained in “Table 4”. The standard deviation of the results obtained in the four cases for “aren” was 1.4% and 26.7% for “VDVR”. The Case 2 presented an increase of 1.2% in the value of “aren” and 1.29% in relation to the reference “VDVR” value. In Case 3, we can observe an increase of 7% in the parameter “aren” and 4.54% in the parameter “VDVR” when compared to the Reference case. The Case 4 presented an increase in 6.25% of the “aren” and 5.10% of the “VDVR” than the reference case.

It can be observed from the four cases under study that the increase in the number of repetitions of the component results in an increase of the “VDVR” parameter obtained. The increase in “VDVR” was directly proportional to the number of repetitions used in the different Cases.

#### 4. CONCLUSION

It is concluded that for this study that has fixed routes, it is satisfactory to carry out the evaluation regarding exposure to WBV through the method of components repetition. Despite the standard deviation of 1.4% and 26.7% for the “aren” and “VDVR” parameters, respectively, obtained in the four Cases, all results are in the same range of Technical Considerations indicated by the NHO - 09, thus possessing the same Recommended Actions regarding exposure level.

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