A CORRELATION BETWEEN WHOLE BODY VIBRATION AND LOW BACK PAIN ON LORRY DRIVERS

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To my precious Allah S.W.T
who gave me new life, hope and purpose of life.
To my beloved parent,
Mohd Noor Bin Ismail and Rosanah Binti Musa
For their supports in whole of my life
To my supervisor,
Dr. Musli Nizam Bin Yahya For his advice, support and patience during the completion of this project.
and to all my friends,
For their encouragement, cooperation and motivation in completing this thesis.
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Assalamualaikum w.b.t

*In the name of Allah S.W.T the Most Gracious and the Most Merciful*

Bismillahirrahmanirrahim

*In the holy name of ALLAH*

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Ahmad Fuad Bin Mohd Noor, Kemaman, Terengganu
ABSTRACT

High daily exposure of Whole body vibration (WBV) increases Low back pain (LBP) which identified as the cause of early permanent disability (PT). In Malaysia, accidents on vertebral column cases are reported to have increased since 2009 with 5 cases to 2014 with 13 cases. Due to companies’ confidentiality and high risk industry reinforce the importance of this research. Thus, a prediction model based on WBV towards LBP was developed using vibration and statistical analysis. The 34 drivers with two (2) types of lorry, HINQ and FUSO at off-road and 32 drivers with four (4) types of lorry, NISSAN, HINO, FUSO and ISUZU at on-road were involved. The drivers were able to travel at 20 km/h due to poorly maintained off-road roadway. Besides, at on-road roadway, drivers were able to travel at speed of 110 km/h on good surface. The vibration results found that, higher value of static compression dose ($S_{ed}$) was captured by HINO (1.619 MPa) then FUSO (1.462 MPa) drivers. At the on-road, the higher value of $S_{ed}$ was captured by drivers of NISSAN (1.13 MPa), FUSO (1.06 MPa), HINO (1.00 MPa) and ISUZU (0.86 MPa). According to ISO 2631-5 (2004), drivers was already adverse LBP. Travelling at high speed along irregularities at the roadway without any good vibration insulation seat also has strong relationship towards LBP. Statistical results proved that, all drivers have suffered LBP at off-road; correlation coefficient, $r$ is 0.0774, number of sample, N is 34, significant value, $p$ is 0.001 and at on-road $r$ of 0.536, N of 32, $p$ of 0.001 with long-term effect of year’s exposure at off-road $r$ of 0.425, N of 34, $p$ of 0.001 and at on-road $r$ of 0.542, N of 32, $p$ of 0.001. As a result, Predicted $R/factor = (0.055)$ years exposure + 0.638 was developed with $3.1 \times 10^{-2}$ of Mean square error (MSE). This prediction model can be used to identify the WBV exposure level assessment in an easy and efficient way.
ABSTRAK

Pendedahan harian yang tinggi oleh getaran seluruh badan (WBV) meningkatkan Sakit belakang (LBP) yang dikenalpasti sebagai penyebab kepada hilang keupayaan kekal (HUK). Di Malaysia, merokodkan kes kemalangan yang melibatkan cerebroal column meningkat dari tahun 2009 dengah 5 hingga 2014 dengan 13 kes. Disebabkan oleh maklumat syarikat yang terhad dan industri berisiko tinggi membuatkan lagi kajian ini penting. Sebuah model ramalan berdasarkan WBV terhadap LBP akan dibangunkan menggunakan analisis getaran dan statistik. 34 pemandu dengan dua (2) jenis lori, HINO dan FUSO di jalan lasak dan 32 pemandu dengan empat (4) jenis lori NISSAN, HINO, FUSO dan ISUZU di jalan raya yang terlibat. Di laluan jalan lasak, pemandu hanya mampu memandu pada 20 km/h disebabkan oleh penyelenggaraan yang teruk. Selain itu, di jalan raya, pemandu berupaya untuk memandu pada kelajuan 110 km/h dengan permukaan jalan yang bagus. Dapatkan keputusan getaran jalan lasak menunjukkan, nilai static compression dose (Sec) tinggi dirakamkan pada pemandu HINO (1.619 MPa) seterusnya FUSO (1.462 MPa). Di jalan raya, nilai Sed yang tinggi dirakamkan pada NISSAN (1.13 MPa), FUSO (1.06 MPa), HINO (1.00 MPa) seterusnya ISUZU (0.86 MPa). Menurut ISO 2631-5 (2004), semua pemandu telah mengalami LBP. Memandu pada kelajuan tinggi melalui laluan yang tidak rata tanpa kerusi penebat getaran yang baik juga mempunyai hubungan terhadap LBP. Keputusan statistik membuktikan, semua pemandu telah mengalami LBP di jalan lasak; correlation coefficient, r ialah 0.0774, number of sample, N ialah 34, significant value, p ialah 0.001 dan untuk jalan raya r iaitu 0.536, N iaitu 32, p iaitu 0.001 dengan kesan jangan masa panjang tahun pendedahan di jalan lasak, r iaitu 0.425, N iaitu 34, p iaitu 0.001 dan di jalan raya, r iaitu 0.542, N iaitu 32, p iaitu 0.001. Hasilnya, Predicted R factor= (0.055) years exposure + 0.638 telah dibangunkan dengan 3.1×10^{-2} Mean square error (MSE). Model ramalan ini boleh digunakan untuk menentukan penilaian tahap pendedahan WBV dengan cara lebih mudah dan efisien.
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<td>Permanent Disability</td>
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<td>SEAT</td>
<td>Seat Effective Amplitude Transmissibility</td>
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<td>Statistical Package for Social Science</td>
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CHAPTER 1

INTRODUCTION

1.1 Research Background

In the transportation industry, drivers and passengers are frequently exposed to vibration due to moving vehicles hence producing an uncomfortable situation. (Figure 1.1) presents off-road and on-road lorries which are one of the common transportations used in the industry (Tamrin et al., 2007). These lorries are usually committed to carrying sand, rocks, diesel, water or soil from a spot to another at the construction site. These lorries usually encounter problems such as maintenance and also the route trip condition. Vibration is omnipresent and is a motion caused by forces applied to a structure or a machine (Mansfield, 2004). For example, the human body also has resonance frequencies where the body will adapt maximum mechanical response produced by any external mechanical structure.

(a) Off-road lorry  (b) On-road lorry

Figure 1.1: The example of lorries
The response produced could not be explained in single resonance frequency because every individual has a different resonance frequency which is dependent on the posture (Griffin, 1990). Basically, there are two types of human vibration which are hand-arm vibration (HAV) and whole body vibration (WBV) (Griffin, 1990; Mansfield, 2004). However, WBV is the main focus of this research. WBV is a vibration that affects the whole body of the exposed individual. It is normally transmitted through seat surface, backrest and foot, and is usually experienced by individuals who travel using moving vehicles (ISO 2631-1, 1997). Most WBV exposures are associated with transportation where vehicle passengers or drivers are exposed to mechanical shock and disturbance while travelling (ISO 2631-5, 2004).

According to ISO 2631-5 (2004), the adverse health effects of prolonged exposure to vibration include multiple shocks which are related to dose measures and affect the health of lumbar spine. There are epidemiological studies in the literature which indicate that exposure to WBV contributes to the development of Low Back Pain (LBP) since 1986 to 1997 (Bovenzi & Hulshof, 1999). Basically, WBV principally occurs in vehicles and wheeled working machines such as car, lorry, truck and others (Tamrin et al., 2007). The important high-risk groups include off-road vehicles, drivers of forklift trucks, lorries, and buses, crane operators and helicopters pilots (Ismail et al., 2010). In addition, it was also explained that high intensity of WBV is usually induced by the heavy vehicle (Hashim & Taha, 2014). On top of that, this situation usually happens to those who work for a long period such as lorry drivers, who lift heavy burdens and also do not practice ergonomics health in their daily activities (Rasyada, 2010). Thus, there are evidence that the exposure of WBV from heavy vehicles will contributes to the health effects especially LBP problems.

1.2 Background of the Study

Others researchers have concluded that WBV can cause postural stress which can cause LBP. According to Kumar et al. (2014), the occurrence of lower back symptoms increases with whole body vibration exposure expressed in terms of cumulative vibration dose, equivalent vibration magnitude, and duration of exposure (years and service). Other influencing factors which affect the drivers’ back are newer and older vehicles (Mayton et al., 2008), travelling speed and roadway condition (Granlund & Brandt, 2008), increasing duration of working day (Monaghan & van Twest, 2004), rest period (ISO 2631-1, 1997) and years of exposure (Wolfgang & Burgess-Limerick, 2014).

Exposure to WBV, particularly to large shocks and joints, is a back-pain health
risk for employees who drive mobile machines or other work vehicles over poor surfaces (DOSH, 2003). The drivers find it difficult to know exactly the exposure of WBV to them, and how much they have been exposed as the drivers have insufficient knowledge of ailments that can be caused by WBV (Ismail et al., 2010). Hashim & Tah (2014) stated that high intensity of WBV is induced by a heavy vehicle. The long-term exposure to the WBV has adverse effects on human health. Thus, this research is important and critical to help the drivers during the handling of vehicles by providing detailed knowledge about WBV.

1.3 Problem Statement

Low back pain (LBP) has been identified as the cause of early permanent disability if the drivers are continuously exposed to WBV. It was reported that, truck, buses, heavy construction equipment produce vibration with the frequency of 0.1 – 20Hz within the duration of 8 hours can have an effect on the body of operators (Giramkar & Kale, 2013). High daily exposure increases the risk of long-term health effect, particularly back injury (Wolfgang & Burgess-Limerick, 2014). The high intensity of WBV induced by a lorry will affect the driver’s lower back. This proves that, the interest in occupational exposure to WBV, particularly for heavy equipment operator, has increased over the past two to three decades as a connection has been made between long-term exposure to vibration and certain medical problems (Lundström & Holmlund, 1998). An increased risk of LBP, or back disorder has been reported for machine operators, truck drivers, tractors drivers, earthmoving machine operators, forklift drivers, crane operators, agricultural workers, bus drivers and so on (Shibata & Maeda, 2010).

![Figure 1.2: Number of reported cases on permanent disorder at vertebral column since 2009 until 2014 (PERKESO, 2014)](image-url)
Figure 1.2 shows the increasing numbers of vertebral column cases since 2009 to 2014 experienced by drivers in Malaysia. The figure shows that the lowest cases is in 2010 and 2012 with 3 cases while the highest is in the year 2014 with 13 cases. Although the cases have slightly reduced from 2009 to 2010 and from 2011 to 2012, the case have then increased until 2014. Besides that, limitation happens on basic information about lorries that are involved in heavy industry and coupled with company confidentiality stress the importance of this study. Thus, in order to minimise and prevent negative health outcomes associated with WBV exposure, a risk assessment, which is based on ISO 2631-5 (2004) to estimate the prevalence of LBP must be done. This risky occupational must be studied in order to identify the level of WBV towards LBP.

1.4 Objectives of Study

The main objective of this research is:

i. To determine the prediction model on off-road lorry drivers associated with low back problem.

1.5 Scopes of Study

The scope of study for this research can be explained in detail as follows:

i. Focus more on off-road and on-road lorry drivers which are exposed to vibration during working.

ii. Type of vibration for the study is whole body vibration (WBV) which is related to Low Back Pain (LBP).


iv. The frequency that needs to be collected will be in the range of 1 – 20 Hz according to ISO 2631-1 (1997).
1.6 Expected Outcomes

The data obtained from the research can be used to determine the WBV exposures among off-road and on-road lorry drivers induced LBP due to continuous and impulsive motions in the normal working condition. The effect of WBV towards LBP problem also must be identified with value of transmissibility of the driver's seat. Thus, the additional of prediction model related to LBP problem can be produced for an easy and simple assessment.

1.7 Significant of Study

The details about the WBV require further attention in order to obtain a more detailed set of data in order to fulfil the objectives of this research. These data obtained can be used to determine the correct and the safe operating conditions for many lorry drivers. This research can also provide guidelines to off-road and on-road drivers to help them further understand the effects of WBV and LBP on the human body especially from long-term exposure.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The past decades have shown a rapid development in Malaysia’s automobile and transportation industries. Apart from contributing to the economic growth and creating job opportunities, this sector could also create an issue such as work-related musculoskeletal disorder (Ismail et al., 2010). The common issues in these work-related musculoskeletal disorders are usually due to whole-body vibration (Noor et al., 2015). As the industries develop, many workers are exposed to whole body vibration in their workplace every day (Park et al., 2013). Interest in occupational to whole-body vibration (WBV), particularly heavy equipment operators, has increased over the past two to three decades as a connection has been made between long-term exposures to vibration and certain medical problems (Eger et al., 2008).

WBV principally occurs in vehicles and wheeled working machines (Tamrin et al., 2007). Interest in occupational exposure to WBV, particularly for heavy equipment operators, has increased over the past two to three decades as a connection has been made between long-term exposure to vibration and certain medical problems. Human response to WBV is a very complex phenomenon. The combination of effects may occur simultaneously but may promote the onset of another. During exposure to WBV, there are many physiological, psychological and physical factors which are relevant for the development of unwanted effects (Lundström & Holmlund, 1998). Salmoni et al. (2008) explained that there were others effects of vibration on human body including LBP, dysfunction of autonomic nervous system, degraded circulatory functioning, muscular fatigue, headaches, and loss of hearing, eye problems, reduced balance, and nausea. The most frequently cited and research-supported problem/injury is LBP.
The combined effects of body posture, postural fatigue, dietary habits and WBV are also possible for these disorders. East European researchers have noted that exposure can cause an overall ill feeling which they call “vibration sickness”. In this hypothetical cohort, it was estimated that among workers with the highest exposure to WBV, an average of 47 weeks of their working life was lost due to sick leave because of LBP, which accounts to approximately 2.5% of their working life. When all workers on prolonged sick leave for 52 weeks would remain disabled for the rest of their working life, a maximum of 23.4% of their working life could be lost due to high WBV exposure. Among workers without or low exposure to WBV the corresponding losses were 0.8% and 7.8%, respectively (Burdorf & Hulshof, 2006). Thus, WBV already affects the human health. The new ISO standard was established to quantify the health risks specifically to the lumbar spine and the vertebral endplates which are resulted from WBV exposures that contain multiple shocks (Fritz et al., 2005).

2.2 Whole body vibration (WBV)

It is common for people to experience WBV in their daily activities. WBV occurs when a human is supported by a surface that is shaking and the vibration affects body parts remotely from the site of exposure. The vibration is transmitted through the vehicle to the seat and footrest, which are the surfaces that support the driver (Mansfield, 2004). A majority of epidemiological studies on the health effects have focused on the magnitude in the vertical direction.

Therefore, it can be concluded that knowledge about health effects due to WBV in horizontal directions is sparse and lacking. It should also be noted that most knowledge on the relation between WBV exposure and health are of the cross-sectional type. Hence, it is important and essential to identify the characteristics of harmful vibration and this can be done by establishing protocols on accurate description and comparison of the outcome parameters and variables of vibration characteristic such as magnitude, frequency, direction and duration.

1. Magnitude

The extent of the oscillation that determines the magnitude of vibration with is related to displacement, velocity and acceleration. For practical reasons, the magnitude of vibration is usually described by its acceleration (Griffin, 1990).
2. Frequency

The repetition rate of cycles of oscillation determines the frequency of vibration with the unit of hertz (Hz). The human body seems to be most sensitive for WBV within the frequency range of 0.1 to 100 Hz and usually the lower frequency components are attributed to the adverse health effect ISO 2631-1 (1997).

3. Direction

There are three mutual perpendicular axes of a human body in seated, standing and recumbent position. The basicentric coordinate system is described by the axes which originate at a point from which vibration is considered as highlighted in ISO 2631-1 (1997).

4. Duration

The health risk assessments are primarily based on the magnitude of vibration and duration of exposure according to ISO 2631-1 (1997); Nelson & Brereton (2005). Most studies have measurement periods shorter than 8 h as technical difficulties may arise in the storage of large amount of data. Usually, a selected representative period of the work is assessed and then extrapolated. The nature of vibration, the characteristics of the exposed individuals and the effect of the vibration can vary greatly from one environment to another. Those areas of variability contribute to the cause-effect model of human response to vibration as outlined in Figure 2.1.

![Figure 2.1: Outline model of vibration and its effect (Griffin, 1990)]

2.2.1 WBV in heavy industry

WBV refers to the transmittance of vibration from a workplace machine or vehicles to a person’s body. This kind of vibration can affect the health of those exposed in
several ways including aggravating back pain. Vibrations that include large jolts and shocks are believed to cause harm. There are also safety concerns associated with WBV, vibration frequencies which match the resonant frequency of the body. These have been shown to hamper a worker’s ability to perform their job tasks (Paschold & Sergeev, 2009). However, for the occupants in off-road vehicles, such vehicles may cause severe and frequent stress, which then leads to adverse health effects (Griffin, 1990). There are examples to illustrate the exposure values which are likely to be found for the operation of many types of off-road machine.

The examples given are for the use of agricultural tractors for activities known to cause high vibration exposure, and for selection quarrying activities using several types of earth moving machine. The involvements of off-road lorries that are involved in con traction activities are more likely. Thus, those references of exposure level from quarrying are important during data collection. The similarities of activities are identical for off-road lorry and hauling-rigid dump trucks. The details for the exposure level in quarrying activities are shown in Table 2.1. Salmoni et al. (2008) presented three case studies in transportation to highlight the difficulties experienced when accessing WBV exposure within an industrial occupational health setting. Across the three cases and various vehicles, the z-axis was always dominant with acceleration values collected at the seat-operator interface. The long-term vibration stress can contribute to the degenerative changes in the joints of the human body, especially in the lumbar spine. An important factor in the development of these diseases is contributed by the forces transmitted in the joints (Fritz et al., 2005).

Table 2.1: The example in quarrying activities (Paddan & Griffin, 2002)

<table>
<thead>
<tr>
<th>Vehicle type (number of vehicles)</th>
<th>ISO 2631-1 (1997)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r.m.s (m/s²)</td>
</tr>
<tr>
<td>Car (25)</td>
<td>0.39</td>
</tr>
<tr>
<td>Dumper (4)</td>
<td>1.28</td>
</tr>
<tr>
<td>Lift truck (11)</td>
<td>0.74</td>
</tr>
<tr>
<td>Tractor (7)</td>
<td>0.73</td>
</tr>
<tr>
<td>Lorry (16)</td>
<td>0.50</td>
</tr>
<tr>
<td>Mower (3)</td>
<td>0.60</td>
</tr>
<tr>
<td>Van (9)</td>
<td>0.45</td>
</tr>
<tr>
<td>Bus (10)</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Based on Table 2.1, the exposure range of dumper can be referred as the level of exposure for off-road lorry while lorry can be referred for on-road lorry. The exposures are above the exposure action value but are below the exposure limit value. Exposures in a majority of the industry are likely to be much lower than the examples given. Thus,
the given example shows that the vibration exposure at the off-road vehicle is higher than on-road vehicle. The exposure by ISO 2631-1 (1997) accepted the prediction of health problems. This standard acts as a guideline on the qualification of WBV in relation to human health and comfort, the probability of vibration perception, and incidence of motion sickness (Eger et al., 2008). Currently, it is not clear whether the predicted health risk for vibration containing shocks is better assessed using the VDV method or the new method as proposed by the new ISO 2631-5 (2004).

The comparison has indicated that both methods may predict risk differently with the new ISO 2631-5 (2004) standard being more conservative than its predecessor (Wolfgang & Burgess-Limerick, 2014). Although the ISO 2631-1 (1997) is the earlier assessment as compared to ISO 2631-5 (2004) for WBV exposure. However, due to not clear outline, the generally accepted norm is to apply this standard first. If the value of crest factor (CF) is clearly higher than 9 which is considered as a high magnitude transient shocks, then, further assessment by the new standard is recommended. The low shocks are carried in a high shock environment which lead to lower values of $S_{ed}$ and leads to the prediction of lower risk health based on ISO 2631-5 (2004) in such low environment. Therefore, the health risk assessment based on Sed parameter is more conservative than risk assessment based on VDV for the presence of shocks (Aye & Heyns, 2011). To obtain a better assessment method and suitable exposure value for the WBV exposure, this present study is done in order to find the solution for off-road and on-road lorry drivers.

2.2.2 Influence factor of WBV exposure

Previous studies reported that various factors can contribute to WBV exposure such as the speed, route condition and also the seat. Mayton et al. (2008) found that the newer trucks and associated seats may provide lower levels of WBV exposure when considering the mean of r.m.s for drivers/operators as compared to the older trucks and seat previously studied at the quarry. That was due to the fact that newer trucks which have better vehicles suspension and isolated cab as compared to older trucks. It is proven that, although from different manufactures and models, improved wheel suspension design will result in lower exposure of WBV.

It is reported that, excessive exposure of WBV typically occurs when the exposure duration is long and is accompanied with a large vibration magnitude. Among the various modes of transportation, it is found that the car most often produces high magnitude of vibration. Ismail et al. (2010) found that the value of daily exposure to
vibration $A(8)$ and vibration dose value (VDV) for car travel at 60 $Km/h$ was higher than the car travelling at 30 $Km/h$. The comparison from the two experiments conducted in the study concluded that when the speed of the car increase, the exposure of WBV towards the driver is amplified as the magnitude of the vibration generated by car has increased.

Other than that, Smets et al. (2010) stated that the surface haulage truck operators are typically exposed to WBV that exceeds the cautionary boundaries set in place by the ISO 2631-1 standard independent of vehicles size or assessment method. It is important to consider the effect of driver behaviour on exposure, terrain, work site, vehicles maintenance, tire pressure, and many others that may also affect exposure. Trucks performed work phases under various conditions such as laying gravel roadbeds and transporting ore from an open pit a crusher station or dump site and each phase occurred over slightly different terrain. Thus, for the same vehicle, there may be an interaction between speed, path selection, road roughness and the vibration magnitude and also frequency measured. This variation in terrain can lead to a potentially misleading crest factor. The aggressive driving patterns, rough and poorly maintained road and pit floors, along with the occasional bump and poorly placed load from a shovel can create intense and sometimes serious vibration levels hauler (Aye & Heyns, 2011).

Besides that, influence factors caused by environments behaviour and, the condition of seat driver are also related to WBV exposure. Griffin & Erdreich (1991) found that this distribution is determined by the posture of the body and by the vibration at the interfaces between body and environment. When a person is sitting in a rigid seat, the vibration exposure may be determined from measurements made at any convenient location on the seat. Measurement should normally be close to the contact point because any rotational vibration will result in different amounts of translational vibration at different locations. Thus, the condition of the seat and combined with the influence of static and dynamics factors can relate to the vibration exposure intensity experienced by the drivers themselves.

2.2.3 Effect of WBV towards health problems

There are several health effects caused by the exposure of WBV. Gallais & Griffin (2006) found that the effect from who WBV for the human body causes discomfort, adversely affect the performance, increase the potential for low back injuries and increase the health and safety risk. The low-frequency vibration of the body can cause
motion sickness. Previous studies of long-term exposure to WBV have shown evidence for causing risk of health, mainly in the lumbar spine but also in the neck and shoulder. Others factors that also contribute to these problems of low-back pain, neck and shoulder pain are working posture, muscle tone, physical workload, and individual susceptibility.

Other than driving, other factors that can contribute to these pain problems are prolonged sitting in constrained postures, poor postures, frequent twisting of the spine, the need to adopt twisted head postures, frequent lifting and materials handling, traumatic injuries and unexpected movements. WBV exposure, especially when chronic, is suspected to cause adverse health effects such as fatigue, lower back pain, vision problems, interference with or irritation to the lungs, abdomen, or bladder, and adverse to digestive, genital/urinary, and female reproductive system (Picu, 2013). Lumbar spine disease and complaints are perhaps the most common diseases associated with the long-term exposure to WBV when sensitive to 4-12 Hz vibration range (Griffin, 2004). The cardiovascular system effects are result from prolonged exposure to WBV at frequencies $1 - 20 \text{ Hz}$.

The dominant vibration transmitted through the seats of the vehicles is often at frequencies below $20 \text{ Hz}$ (Griffin, 1990). Every part of the human body has its own resonant frequency (Figure 2.2). When vibration occurs at the frequency which is equal to the natural frequency (the unforced vibration of the body), a resonance (vibration occurring at maximum magnitude) occurs, which lead to large internal stresses and strain (Wilder & Pope, 1996). Basically, those outcomes from prolonged exposure of WBV could affect and cause hyperventilation, increase heart rate, oxygen intake is increased, pulmonary ventilation and respiratory rate also increased. Therefore, when exposure periods are sufficiently long, vibration effects might be expected to be more severe. There is a higher possibility to experience the high frequency of vibration and the intensity could affect drivers. Thus, the environment workers such as off-road vehicles drivers will be exposed to this risky injury. Truck, buses, heavy construction equipment produce vibration with the frequency of $0.1 - 20 \text{ Hz}$ with duration of 8 hours which can affect the body of operators (Giramkar & Kale, 2013).
The acceleration and frequency interact to determine the level of discomfort. The duration of exposure will determine the acceptability of vibration in the workplace. Work-related musculoskeletal symptoms were greatest in the lower back (60%), neck (44%), and shoulders (37%). Musculoskeletal symptoms that cause drivers to miss work were most prevalent in the lower back (8%), ankle/feet (3%), wrist/hands (3%), and shoulders (2%). Physician visits due to musculoskeletal symptoms were highest for the lower back (25%), neck (20%), upper back (13%) and shoulders (12%) (Kittusamy & Buchholz, 2004).

2.3 Low back pain (LBP) problem

Low back pain (LBP) is one of the common health problems in the world. Lifetime prevalence has been estimated to be 60% - 80% for industrialised countries, having a large impact on health care utilisation and on sickness absence and disability figures and cost (Hulshof et al., 2002). An increased risk of low back pain, or back disorder has been reported for machine operators, truck drivers, tractor drivers, earthmoving machine operators, forklift drivers, crane operators, agricultural workers, bus drivers and so on (Park et al., 2013). Low back pain can interfere with activities at work and cause a reduction in productivity, an increase in sickness absence and chronic occupational disability (Leelavathy & Raj, 2013). This high daily exposure increase the risk of long-term health effect, particularly back injury (Wolfgang & Burgess-Limerick, 2014). The WBV exposure causes an acceleration of the human body with related dynamic forces acting on the spine.
A clear conceptual framework in Figure 2.3 can help to clarify the factors determining the effects of WBV on spinal health and contributing to the internal stress-strain relationship during WBV exposure. The exposure of WBV is dependent on several factors such as driving speed, seat suspension and type of vehicle. This WBV causes an acceleration of the human body with related dynamic forces acting on the spine. The two aspects of the static internal parameter and dynamic internal parameter are also related to vehicle seating comfort. Thus, total discomfort (static plus dynamic) increases with the vibration magnitude (Mansfield, 2004). Further dynamic internal forces also increased from the muscle response with alternating increased and decreased activity of lower back muscles.

Low back muscles can either exert very high forces on the spine or cause spinal instability by relaxation. Their responses to WBV also depend on the posture and muscles fatigue. The factors of influence towards static inter-forces such as gravity, posture, postural muscle activity and body mass distribution. Due to discomfort caused by static and dynamic internal forces add up to the stress (internal load), it leads to strain (deformation) of spinal structures. The outcome of strain depends on the strength of the spinal structure and their ability to recover from the repetitive load. From that, the outcomes cause by static and dynamic of WBV can affect the deformation of human spinal structures (LBP).

LBP is the leading major cause of industrial disability among population under the age of 45 years old (Pope et al., 1998). However, despite the large volume of work done to understand the aetiology of LBP, a thorough understanding of the causes remains elusive (Okunribido et al., 2007). Despite these findings, there has
been limited work done to determine if the lumbar supports are actually capable of altering spine and pelvic posture at the level of the vertebrae (De Carvalho & Callaghan, 2012). The results of epidemiological studies show a higher prevalence rate of low-back pain, herniated disc and early degeneration of the spine in whole-body vibration exposed groups. Increased duration of vibration exposure and increased intensity are assumed to increase the risk, while periods of rest reduce the risk. Also, many drivers complain about disorders in the neck-shoulder although epidemiological researches are inconclusive on this effect (Gallais & Griffin, 2006).

2.3.1 Risk factor

According to the McPhee et al. (2001), a number of different work-related and individual factors are considered to be risk factors for back disorder but there is no clear understanding of the relative contribution of these factors. Also, there is no general explanation of how back disorders occur, specifically, what actually goes wrong in the back which gives rise to symptoms. However, studies indicate that some components of work increase the risk of back disorder and pain. Thus, other factors that can influence towards the probabilities on lower back pain area are heavy physical work, fixed (static) work posture, sedentary (sitting) work, frequent bending and twisting of the trunk, lifting and forceful movements, increased speed or movements, repetitive work and vibration.

There is also an area of loads and posture which is related to back pain and more to the musculoskeletal system (bones, joints, tendons and muscles) of exposure to WBV. By increasing the exposure of WBV, the risk of lower back pain problems will also increase. The following forms of vibration of most concern to the industries. WBV is associated with transportation (Giramkar & Kale, 2013). The effect on the body, for example women experiences more discomfort as compared to men although with the same level of discomfort. Male truck drivers are four times more likely than sedentary workers to develop a herniated lumbar disc, and 80% of motor coach operators have experienced back or neck pain as compared to 50% of non-drivers (Leevalavathy & Raj, 2013).

The combined effects of body posture, postural fatigue, dietary habits and whole-body vibration are possible causes for these disorders (Giramkar & Kale, 2013). The most commonly identified physical factors are prolonged sitting. WBV ergonomic mismatch among drivers (disparity between anthropometric sizes of the drivers and their physical environment), the type of vehicle seat, automatic or not automatic driv-
ing mechanisms (Alperovich-Najenson et al., 2010). According to Griffin (1990), back problems are the most frequent disorder, followed by digestive and reproductive system disorder and vestibular, visual and other nervous system problems. More precisely, there are several independent reports of displacement of intervertebral discs, degeneration of spinal vertebrae, osteoarthritis, etc. Abdominal pain, digestive problems, urinary frequency, prostitutes and haemorrhoids are reported. Problems with balance, vision, headaches and sleeplessness are also mentioned. Local circulatory disorders have been found where the feet have been in contact with severe vibration.

2.3.2 Causes of LBP

ISO 2631-5 (2004) explained on the effects of multiples shocks and of posture on the lumbar spine. Basically, the intervertebral disc, and paraspinal ligaments and muscles (soft tissues) can be at risk of injury in multiple mechanical shock environments for the following reasons:

1. The seated posture can be mechanically stressful on the disc.

2. Different postures can change the way the body responds to multiple loads, inconsistent with the model loads.

3. The intervertebral disc can change internal pressure, soften, tear and/or buckle with exposure to multiple loads.

4. The intervertebral motion segment depends on the proper functioning of the neuromuscular control system for active and passive stabilisation, and therefore to prevent buckling.

5. The impact can be uncomfortable and can be considered an unexpected, sudden load to an overcompensating response in the truck muscles.

6. Impact, especially following multiple load exposure, may trigger a buckling event in the motion segment due to the inability of the neuromuscular control system to respond fast enough in a coordinated fashion.
According to Gallais & Griffin (2006), back pain experienced by drivers might be associated with driving, sitting, or influence from the environment during driving. For example, back posture during sitting, forces at the feet when operating pedals, load from the arms, head posture, back movement, twisting to look rearward while reversing, forces during entry and exit from a vehicle can influence the risk of low back pain. Other than that, the risk of LBP increased due to WBV affecting the whole body, physical hard work, frequently twisting or bending, standing up and concentration demands. This environmental influence was associated with the development of herniated lumbar disc. This musculoskeletal complaint was highest cause for LBP and has a tendency to increase with age.

The specified condition of the spine is mostly related with herniated disc, degenerative disc disease, spondylolisthesis, spinal stenosis and osteoarthritis. The condition of lumbar spine while driving has been associated with the LBP. According to De Carvalho & Callaghan (2012), the use of lumbar supports could decrease the LBP during driving exposure. It has been reported that the trauma of spine can promote premature degeneration of spinal vertebrae (Battie et al., 2002; Hill et al., 2009; Seidel et al., 1998). Basically, the healthy inter-vertebral disc has two core components which are annulus fibrous and nucleus pulposus. Disc nutrition is at least partially dependent on diffusion from the cartilaginous vertebral end plate and the annulus (Figure 2.4).

![Figure 2.4: The vertebral column and lumbar vertebrae (Griffin, 1990)](image-url)
According to Griffin (1990), one of the proposed mechanisms of the action of vibration is the induction of microfracture at the end plates or subchondral trabeculae with a callus formed during healing (or some other change to the end plate) reducing nutrient diffusion with a consequent acceleration of the normal degeneration process in nucleus and annular fibres. This may lead to the damage of nucleus and the nucleus may lose all its water. Thus, the ability for the nucleus to act as a cushion becomes worse and the space between the vertebrae above and below the degenerating disc will narrow. Thus, the facet joints (located at the back of the spine) will shift, distorting the way these joints work together.

Health concerns over vibration exposure (frequency, amplitude, and duration) were first raised in the 1950s and many studies have been conducted which typically pointed to an association between occupational driving and back symptoms, admissions for disc disorders, and lumbar degeneration (Battie et al., 2002). According to Taher et al. (2012), the intervertebral disc (IVD) is composed of the nucleus pulposus (NP) centrally, the annulus fibrous (AF) peripherally, and the cartilaginous endplates cranially and caudally at the junction to the vertebral bodies.

![Figure 2.5: Degenerative change at lumbar spine (arrow) (Battie et al., 2002)](image_url)

NP, an abundance of proteoglycans allows for the absorption of water. NP is essential for the IVD’s handling axial loads. The researcher also stated that, the environmental factor also contribute toward the degeneration disc disease for manual material handling, frequent bending and twisting, and also whole-body vibration. The modest association between smoking and disc degeneration also has shown the possible influences of chemical exposures. The examples of this degeneration disc disease are shown in Figure 2.5.
2.4 Standard evaluation of WBV towards LBP

The assessment of health problem can be done using vibration method and statistical method. The values assessed must be representative of the actual working environment: in order to adapt the assessed values to real working conditions and it may be useful to adopt some statistical models. The real exposure can be obtained from vibration values and the statistically significant relationships were observed on the relative influence of predictor variables.

2.4.1 Assessment of WBV using ISO 2631-5 (2004)

According to ISO 2631-5 (2004), the detail about the assessment of adverse health effect is already provided to define a method of quantifying WBV containing multiple shocks in relation to human health at lumbar spine. Adverse effects on the lumbar spine are the dominating health risks of long-term exposure to vibration containing multiple shocks. The guidance on the assessment of multiple shocks, effects of multiple shocks, the background of calculation of spinal response in vertical direction and software calibration check and example of a computer program that can be used for calculation are provided in this standard.

In this standard, there is an explanation on daily equivalent static compression dose, $S_{ed}$ and also for the $R$ factor. Static compressive dose ($S_{ed}$) as Eq. (2.1) is measured in megapascals, which has been developed through biomechanical modelling to capture the linear relationship between peak acceleration and input shocks to responses in the spine (MPA) (Blood et al., 2010)

$$S_{ed} = \left[ \sum_{k=x,y,z} (m_k D_{kd})^6 \right]^{\frac{1}{6}} \tag{2.1}$$

Where,

$S_{ed}$ = Static compression dose.

Basically, to determination of the value of $D_{kd}$ includes the calculation of equation Eq. (2.2) and Eq. (2.3) below. The value of $m_k$ is constant for the dose coefficient at vertical and horizontal directions is shown in Table 2.2.
Table 2.2: The value of dose coefficient at y and z directions

<table>
<thead>
<tr>
<th>Direction</th>
<th>Value, MPa/(m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m_x)</td>
<td>0.015</td>
</tr>
<tr>
<td>(m_y)</td>
<td>0.035</td>
</tr>
<tr>
<td>(m_z)</td>
<td>0.032</td>
</tr>
</tbody>
</table>

\[
D_{kd} = D_k \left[ \frac{t_d}{t_m} \right]^{\frac{1}{6}}
\] (2.2)

Where,

- \(t_d\) = Duration of daily exposure
- \(t_m\) = Period over which \(D_k\) has been measured

\[
D_{kd} = D_k = \left[ A_{ik}^6 \right]^{\frac{1}{6}}
\] (2.3)

Where,

- \(A_{ik}\) = The \(i^{th}\) peak of the response acceleration \(a_{ik}(t)\)
- \(a_{ik}(t)\) = The acceleration time histories in the seat and in the spine
- \(k = x, y \text{ or } z\)

The equation of \(R\) factor which defined as the assessment of health-related effects related to the human response acceleration dose by taking into account the age increase and strength reduction as the exposure time increases is show in Eq. (2.4).

\[
R = \left[ \sum_{i=1}^{n} \left( \frac{S_{cd} \times 6^6}{S_{ui} - c} \right) \right]^{\frac{1}{6}}
\] (2.4)

Where,

- \(N\) = Number of exposure days per year
- \(i\) = The year counter
- \(n\) = Number of years of exposure
- \(c = 0.25\) Mpa (driving posture)
- \(S_{ui} = 6.75 + 0.066(b + i)\)
- \(b = \) The age at which the exposure starts

According to ISO 2631-5, \(R\) factor values below 0.8 indicate a low probability.
of adverse health effects to the lumbar spine while values greater than 1.2 suggest a high probability of adverse effects. Similarly, a daily equivalent static compression doses \((S_{ed})\) below 0.5 MPa reflects a low probability of an adverse health effect to the lumbar spine while values greater than 0.8 MPa suggest a high probability of adverse health effects (Eger et al., 2008). Mansfield (2004) stated that measurements of acceleration remote that are from the driving point are usually used in a combination with simultaneous measures at the driving point to calculate how vibration is transmitted through the body. The extent of the movement at any point on the body is related to the magnitude of the input vibration at the seat or floor and the transmissibility at the driving frequency. Thus, to identify the prediction of lower back problems, it is based from the acceleration dose based on ISO 2631-5 (2004) as shown in Table 2.3.

**Table 2.3: The assessment value based on ISO 2631-5 (2004)**

<table>
<thead>
<tr>
<th>Assessment of adverse health effects</th>
<th>Terminology</th>
<th>(S_{ed}) (MPa)</th>
<th>(R) factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low probability of an adverse health effect</td>
<td>Low</td>
<td>&lt;0.5</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td>Moderate probability of an adverse health effect</td>
<td>Moderate</td>
<td>0.5–0.8</td>
<td>0.8–1.2</td>
</tr>
<tr>
<td>High probability of an adverse health effect</td>
<td>High</td>
<td>&gt;0.8</td>
<td>&gt;1.2</td>
</tr>
</tbody>
</table>

The transmissibility can be defined as the ration of the vibration measured between two points (usually the driving point and the remote location). In order to measured of how well a seat is suitable to the spectrum of vibration entering seat, the calculations were expressed in Eq. (2.5) and Eq. (2.6) (Blood et al., 2010). The \(\text{SEAT. } r.m.s.\) is defined as vibration transmissibility using frequency-weighted acceleration absorb by body. Besides, \(\text{SEAT. } VDV\) can be found as vibration transmissibility using vibration dose value on effect of multiple shocks.

\[
\text{SEAT. } r.m.s. (\%) = \frac{r.m.s_{\text{seat}}}{r.m.s_{\text{floor}}} \times 100
\]  
(2.5)

\[
\text{SEAT. } VDV (\%) = \frac{VDV_{\text{seat}}}{VDV_{\text{floor}}} \times 100
\]  
(2.6)

A SEAT value of 100\% indicates that the dynamics properties of the seat have not improved or reduced the ride comfort on the seat; a SEAT value of greater than 100\% indicates that the ride is worse in the seat than on the floor, while a SEAT value of less than 100\% indicates that the dynamics properties of the seat have been effective in reducing the vibration (Mansfield. 2004). The response calculations as given in this standard are related to the prediction of the response or the soft bony vertebral endplate (hard tissue). Effects of multiple shocks and the posture on the intervertebral disc (soft
tissue) are discussed by this standard. A bending forward or twisting posture is likely to increase the adverse health effect.

2.4.2 Assessment effect of WBV using statistical analysis

The statistical analysis will use IBM Statistical Package for Social Science (SPSS v20). To test all effects from the types of road and the types of lorries, the data collected will be used. An analysis using mixed model will be conducted. This type of software can be used as a predictive analytics software and can make future predictions based on the data gained at the measurements process using questionnaire. The reliability of a measure from questionnaire must be established by testing for both consistency and stability. Consistency indicates how well the items measure a concept hang together as a set. Cronbach’s alpha is a reliability coefficient that indicates how well the items in a set are positively correlated to one another (Sekaran, 2006). According to Bond & Fox (2007), reliability value of Cronbach’s alpha (α) can refer to the Table 2.4.

Table 2.4: Reliability interpretation score for cronbach’s alpha (Bond & Fox, 2007)

<table>
<thead>
<tr>
<th>Cronbach’s alpha score</th>
<th>Realibility interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 - 1.0</td>
<td>Very good and high consistency</td>
</tr>
<tr>
<td>0.7 - 0.8</td>
<td>Good and acceptable</td>
</tr>
<tr>
<td>0.6 - 0.7</td>
<td>acceptable</td>
</tr>
<tr>
<td>&lt; 0.6</td>
<td>Item need to repair</td>
</tr>
<tr>
<td>&lt; 0.5</td>
<td>item need to remove</td>
</tr>
</tbody>
</table>

Field (2009), presented a four-stage process to represent model from statistical analysis to the real world. These stages are listed as follow;

1. Generate a hypothesis (or hypotheses) – this will usually be a prediction that some kind of effect exist in the population.

2. Collect some useful data.

3. Fits statistical model to the data.

4. Assess this model to see whether it supports initial predictions.

Usually, it is interesting to test the hypothesis: that is, testing the scientific questions that are generated. Within these questions, there is a prediction that has been made. This prediction is called an experimental hypothesis (it is the prediction that builds for
experimental manipulation which will have some effects or certain variables that relate to each other). The reverse possibility that the prediction is wrong and that the predicted effect does not exist is called null hypothesis. The variables can be categorised into independent variable and dependent variable. In this research, the alternative hypothesis is to find the relationship between the WBV and the LBP. The null hypothesis for the statistical analysis will be formed as there is no relationship between the WBV and LBP.

The experimental hypothesis can only be accepted if the analysis of outcome from any inferential statistics were able to reject the null hypothesis. Piaw (2006) stated that inferential statistical is used to explain the relation between each variable. Aim of this is to make the generalisation on the relation between each variable that is involved in this research. This means that, the use of inferential statistics is to make conclusions on the characteristics of the population depending on sample characteristics. The inferential statistics can be done using several analyses such as t-test, ANOVA test, Pearson correlation test and other related tests. Thus, to ensure that the null hypothesis is not significant, the significant test must be done. The procedure of significant test can be referred in Figure 2.6.

![Figure 2.6: Concept of significant test (Piaw, 2006)](image)

Correlation and regression analysis were conducted to investigate the relationship between different independent variables with the prevalence of LBP in the present study. Yamin (2013) stated that correlation can be expressed by the relationship between two variables or concepts numerically. Pearson correlation or Pearson product-moment correlation coefficient was conducted to measure the strength and direction of relation absence between independent and dependent variables. The strength of relation is determined according to the coefficient of Pearson, symbol of $r$. The acceptance of null hypothesis depends on the $p-value$ and $r-value$ obtaineds from correlation analysis. The detail about $p-value$ (Table 2.5) and $r-value$ (Table 2.6) can be explained in the table below.
Table 2.5: The $p$ – value (Piaw, 2006)

<table>
<thead>
<tr>
<th>$p$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$p &gt; 0.10$</td>
<td>No evidence against the null hypothesis.</td>
</tr>
<tr>
<td>$0.05 &lt; p &lt; 0.10$</td>
<td>Weak evidence against the null hypothesis</td>
</tr>
<tr>
<td>$0.01 &lt; p &lt; 0.05$</td>
<td>Moderate evidence against the null hypothesis</td>
</tr>
<tr>
<td>$0.01 &lt; p &lt; 0.01$</td>
<td>Strong evidence against the null hypothesis</td>
</tr>
<tr>
<td>$p &lt; 0.001$</td>
<td>Very strong evidence against the null hypothesis</td>
</tr>
</tbody>
</table>

Table 2.6: The correlation significant strength (Rowntree, 1981)

<table>
<thead>
<tr>
<th>Value of correlation coefficient ‘r’</th>
<th>Power relations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 to 1.0</td>
<td>Very high, very strong</td>
</tr>
<tr>
<td>0.7 to 0.89</td>
<td>High, strong</td>
</tr>
<tr>
<td>0.4 to 0.69</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.2 to 0.39</td>
<td>Weak, low</td>
</tr>
<tr>
<td>0.0 to 0.19</td>
<td>Very weak</td>
</tr>
</tbody>
</table>

Correlations can be a very useful research tool but there was limited information about the predictive power of variables. In regression analysis, a predictive model to our data and that model is then used to predict values of the dependent variable (DV) from one or more independent variables (IVs). Field (2009) stated that simple regression seeks to predict an outcome variable from a single variable whereas multiple regressions seek to predict an outcome from several predictors. This is an incredibly useful tool because it allows the research to go a step beyond the collected data. The idea that can be predicted any data will use the following general Eq. (2.7).

$$\text{Outcome}_i = (\text{Model}_i) + \text{error}_i$$ \hspace{1cm} (2.7)

Talib, (2015) highlighted three types of regression which are standard (forced entry), hierarchical (blockwise entry) and stepwise methods.

1. Standard (forced entry)

Forced entry is a method in which all predictors are forced into the model simultaneously in order to know how many independent variables are related to the dependent variables.
REFERENCES


