

To the Graduate Council:

I am submitting herewith a thesis written by Liangming Pan entitled "The human response study to Whole-body vibration in the cab of Heavy Duty Truck". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biomedical Engineering.

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THE HUMAN RESPONSE STUDY TO WHOLE-BODY VIBRATION IN THE CAB OF HEAVY DUTY TRUCK

A Thesis Presented
For the Master of Science Degree
The University of Tennessee, Knoxville

Liangming Pan
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Dedication

I would like to dedicate this thesis to my wife, for being a big support for me all through my ups and downs and for encouraging me to complete my masters. My dream to pursue higher education would not have been possible without her support.

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Abstract

Lower back pains are observed to be the most significant problem for most of the industrial workers who operate commercial trucks. Several factors such as road type, truck type, load, etc, have been found to affect the vibration exposure on the truck drivers.

The main purpose of the current research is to collect the responses of Whole-body vibration to the truck driver and analyze the current levels of excitation from a variety of trucks. Present thesis work also examines the effects of different trucks, road types and loads to Whole-body vibration.

Data collected in the United States on different types of trucks were processed with different processors and analysed as per the international standards: ISO 2361-1. First set of data were taken with HVM-100 on a scheduled on-road route from driver's seat cushion on different roads and load conditions. Second set of data were collected by DEWE data acquisition system from the trucks running on the same on-road route, with the application of additional transducers on driver's seat back, passenger's seat cushion as well as the cab floor.

The frequency-weighted r.m.s accelerations were compared by different trucks on two different road types: interstate and rural highway for HVM data. The results from the same trucks with loaded trailer or without loaded trailer were also discussed in this thesis. The data recorded by DEWE system were analyzed with Matlab program to compare the frequency-weighted accelerations for different trucks. Additional analysis with VDV and jerk were also done.

Road type was the primary factor affecting the driver's exposure. For both studies, the minimum 8-hr and the minimum 11-hr standard limits requiring a medical examination set by the standard for health were exceeded several times whereas the same for comfort was exceeded a lot of times.

Overall, the driver was found to be safe as per ISO 2631-1 but the comfort levels were often exceeded. It is suggested that necessary action be taken to increase the comfort.

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Nomenclature

WBV	Whole Body Vibration
Hz	Hertz (cycles/sec)
RMS	Root Mean Square
m/s^2	Meters per Second Square
$\text{m/s}^{1.75}$	Meters per Second 1.75 Square
eVDV	Estimated Vibration Dose Value
VDV	Vibration Dose Value
$a_w(t)$	Frequency weighted acceleration
CF	Crest Factor

Chapter-1 Introduction

Vibration is mechanical movement that oscillates about a fixed point. By definition, the motion is not constant but alternately greater and less than some average value. Today, human beings are highly exposed to vibrations increased rapidly due to the industrial revolution and new technology. As we know, people are primarily exposed to either localized vibration or vibration that affects the whole body. We can classify vibration by contact site to hand-transmitted vibration and whole-body vibration (WBV) [1]. Hand-transmitted vibration is localized vibration which only affects the hand-arm system, as it is caused by an individual holding a vibrating object such as tool, workpiece, or control device.

WBV is the vibration that affects the whole of the exposed person, i.e., the vibration affects all parts of the body. Most WBV exposures are associated with transportation where vehicle drivers or passengers are exposed to mechanical disturbances and impacts while traveling. It is usually transmitted through seat surfaces, backrests, and through the floor. WBV can affect comfort, performance, and health, depending on the magnitude, waveform, and exposure times and it has been found to be a significant factor of injury among the operators of vehicles and vibrating machineries. Lower back disorders are the most significant problems for many drivers operating commercial vehicles.

In addition to health, comfort for the drivers is also of great concern as it could result in a better performance. The discomfort produced by the whole-body vibration depends on various factors like magnitude, frequency, input position, direction and duration of vibration as well as physical characteristics, posture and orientation of the body, and the seat design. It is obvious that different trucks have different performance of vibration because of different design as well as the environment. Although the designs may result in meeting the standards and the driver comfort for a specific environment. It may not be equally good for another environment. Therefore, it is necessary to understand the various environments that will be a significant factor in the vehicle meeting the standard.

This thesis is primarily about measurement and evaluation of vibration exposure of heavy duty truck drivers on general road in the United States. This project is in fact a part of a larger project on improving heavy truck ergonomics. The main project also contains the measurement of air pollution concentrations and noise level inside heavy truck cabs and sleeping berths at different highway speeds. The aim of this project is to reduce fatigue and improve driver health and performance. All tests were conducted using standardized test procedures that can be reproduced in future years to determine how future truck designs may improve in-cab conditions for drivers and passenger.

Seventeen trucks manufactured by 3 different companies were tested in this study. The on-road test will involve driving the truck over a prescribed route which includes a mixture of interstate and rural highway travel over relatively level and sloped terrains. Each truck will haul an identical 53-ft utility trailer that has been loaded with approximately 30,000 lb. of palatalized garden topsoil. All trucks were from the model years 2006, 2007 and 2008, and have in-cab driver-sleeping berths, such that are used for long haul driving. To compare the performance of truck unloaded with the truck loaded, we chose three trucks from different makers to run a road test without trailer.

This project shared the resources of Commercial Vehicles Group, Research and development division, Columbus with financial assistance from Dr. Wasserman, The University of Tennessee at Knoxville. This project deals with the vibration analysis carried out performing various tests on different heavy trucks and is the basis for increased understanding of future truck design.

Chapter-2 Whole body vibration background

WBV occurs when a human is supported by a surface that is shaking and the vibration affects body parts remote from the site of exposure. For example, when a forklift truck drives over a bumpy surface, vibration is transmitted through the vehicle to the seat and footrest, which are the surfaces that support the driver. The vibration is then transmitted through the body of the driver to the head, which will move. It is common for people to experience WBV on most days of their lives. In most environments, people are primarily exposed to vibration while seated and are exposed to a wide range of vibration magnitudes, waveforms, and durations. WBV can be experienced either through an instantaneous shock with a high peak level or through repeated exposure to low peaks.

2.1 Effects of WBV

WBV affects the entire body. It has been found to be a significant factor of injury among the operators of vehicles and vibrating machineries. According to the U.S. Bureau of Labor Statistics, 2004, an estimated six million occupational workers are exposed to whole body vibration contributing to spinal problems, and more than one million workers are subjected to segmental vibrations [2]. The most commonly reported long-term health effect of WBV is spinal disorder and low back pain [3][4][5]. The highly effected regions reported are the lumbar part of the vertebral column and the thoracic region. There is also a high risk of abnormalities in the function of reproductive organs of women due to the long-term exposure to vibrations. This results in menstrual disturbances, miscarriages, etc.

It has many more widespread and varied short-term effects. Short-term effects include discomfort, headache, irritability, dizziness, blurred vision, chest pain, abdominal pain, nausea and loss of balance. Other short-term health effects of WBV associated with driving include haemorrhoids, high blood pressure, kidney disorders and even impotence and other adverse reproductive effects in both men and women [6]. The following Table 2.1 are the major long-term and short-term effects of WBV.

Table 2.1: Major long term and short term effects of WBV

Long term effects	Short term effects
Low back pain	Discomfort
Degenerative spinal changes	Head ache
Lumbar scoliosis	Chest pain
Disc disease	Abdomen pain
Disorders of gastro intestinal systems	Nausea
Herniated discs	Loss of balance
Abnormalities in reproductive organs	Blurred vision

Different parts of the human body have different natural frequencies. When a body is excited with a frequency that is equal to its own natural frequency, it will vibrate strongly due to resonance. Vibrations between 2.5 and 5 Hz generate strong resonance in the vertebra of the neck and the “lumbar” curve region. Vibrations between 20 to 30Hz can cause resonance between the head and shoulders, which can cause chronic musculoskeletal stress or even permanent damage to the effected region. At frequencies about 1 Hz and below, it might induce motion sickness, causing nausea, dizziness, vomiting and it can affect the safe handling of vehicles and performance of other tasks. This effect is worst between 0.125 and 0.25 Hz.

Muscle fatigue also occurs because of the exposure to WBV. The overuse of muscles while trying to change the natural frequency of the spine to reduce the amplitude of the spinal motions is the main reason of muscle fatigue. After time, the muscles will fatigue however a key factor is lumbar support by the seat to reduce the motion effects. Because the muscles try to react to the vibration energy to maintain balance and protect the spinal column, but these are often too slow as the muscular and nervous system cannot react fast enough to the external vibration inputs. For instance, when we are standing on a rail vehicle, the muscles will tighten up to help the body stay in position since the muscles cannot active quickly enough to fight the motion.

Vibration as a hazard to human health has received much more recognition or attention as more and more people are exposed to it. But due to various facts like WBV does not affect a specific target organ, it is a hazard with non specific health outcomes and usually a costly, technical and relatively difficult hazard to measure and evaluate and control.

The discomfort produced by WBV is also of great concern for the drivers. It depends on various factors like magnitude, frequency, direction, driver postures and duration of vibration. The design of the seat is also an important factor for comfort in vehicles. It is not surprising that a higher magnitude stimulus is more uncomfortable than a lower magnitude stimulus. For stimuli up to 2 min, longer-duration stimuli are more uncomfortable than shorter-duration stimuli. Discomfort tends to be proportional to vibration at low frequencies (below 1 or 2 Hz) because the body responds as a virtually rigid system. At slightly higher frequencies, overall discomfort is influenced by sensations in different parts of the body, as various body resonances tend to amplify the motion. At high frequencies, small postural changes can greatly reduce the vibration to the body whereas at low frequencies, posture has less effect. People have had more problems when they are twisted around to do their tasks. The durations are critical since the muscular fatigues allow greater motion which leads to fatigue failure of the components and then it is the remodeling time versus the damaging rate. A past document said that if you run for 170 miles per week, you will have a fracture in the ankle around 6 - 9 months.

2.2 Standards for WBV

The most well-know standards for measurement and evaluation of human exposure to WBV are BS 6841 (1987) and ISO 2631-1 (1997). Although BS 6841 (1987) was developed as a British standard, it has been used extensively outside Britain. Conversely, ISO 2631-1 (1997) has seen a gradual increase in use within Britain since its publication, despite the concurrently accepted British standard. The methods described in the two standards will not give identical results, except in contrived circumstances.

2.2.1 BS 6841(1987)

BS 6841: Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock (1987) was designed to consolidate methods that were already being used in the industry. The scope of the standard includes methods

for quantifying vibration and repeated shocks in relation to human health, interference with activities, discomfort, the probability of vibration perception, and the incidence of motion sickness. The standard states that vibration measurements on compliant seats should be made using an accelerometer mounted in a device such as an SAE pad placed on the seat surface. The standard also gives guidance on how to assess vibration measured at the seat back and at the feet.

To evaluate the effects of vibration on health, the frequency-weighted root mean square (RMS) acceleration should be calculated if the signals are of constant magnitude and have a crest factor of less than 6. The estimated vibration dose value (eVDV) should then be calculated. If the signals are not stationary, or if the crest factors are greater than 6, then the vibration dose value (VDV) should be calculated. The concept is that a few single peaks during a day will have a low average with time, but the high values will result in damage. Axes should be combined using a 4th power method. The standard defines a threshold of a VDV of 15 m/s^{1.75} where severe discomfort occurs and states that: “... there is currently no consensus of opinion on the precise relation between vibration dose values and the risk of injury ... it is reasonable to assume that increased exposure to vibration will be accompanied by increased risk of injury.” The standard is therefore careful to not present the 15-VDV threshold as a safe or unsafe border but a general indicator. Table 2.2 shows the semantic labels for the comfort according to this standard

Table 2.2: Comfort reactions to vibration environments, BS 6841

Semantic label	arms (m/s ²)	Semantic label
5, extremely uncomfortable	3.15	4, very uncomfortable
	2.5	
	2	
3, uncomfortable	1.6	2, fairly uncomfortable
	1.25	
	1.0	
	0.8	
1, a little uncomfortable	0.63	0, not uncomfortable
	0.5	
	0.4	
	0.315	
	0.25	

BS6841 (1987) provides guidance on vibration discomfort and perception. Although assessments can be made just using triaxial-translational acceleration measurements on the seat surface, guidance is also provided to include rotational vibration and vibration at the feet and backrest. The guidance is generally clear with little scope for confusion. Users need to take care to ensure that the correct frequency weightings are used, and that crest factors are monitored to ensure that the correct method of assessment is used.

2.2.2 ISO 2631-1 (1997)

ISO 2631-1: Mechanical Vibration and Shock - Evaluation of human exposure to whole-body vibration (1997) replaced an earlier version of the standard (ISO 2631, 1985). ISO 2631-1(1997) consists of two parts: Part 1 General requirements and Part 2 Continuous and shock-induced vibration in buildings. The Part 1 is the most widely used and the most relevant part of this standard.

The scope of the ISO 2631-1 includes methods for measuring periodic, random, and transient WBV, with annexes that provide guidance on the interpretation of the measurements. The first annex provides a definition of the frequency weightings and is normative. The other four annexes are informative and therefore do not form part of the standard itself.

The standard states that vibration should be measured at the interface between the human body and the vibration source. Measurements on a seat should be made beneath the ischial tuberosities (the bony points that can be felt if one sits on one's hands) using an accelerometer mount. The standard also gives guidance on how to approach vibration measurements made at the seat back and at the feet.

ISO 2631-1 gives the limits of vibration exposure in the range of 1-80Hz. These limits were chosen to insure comfort, working efficiency and safety or health. ISO limits are specified in terms of acceleration, frequency, time and direction of vibration. The frequency ranges of concern for vibration exposure are given as 0.5 to 80Hz for human comfort and 0.1 to 0.5Hz for motion sickness.

Evaluation of the effects of vibration on health is determined using the frequency-weighted RMS acceleration for each axis of translational vibration on the surface which supports the person if the crest factor is less than 9. Assessments are made independently along each axis, and horizontal vibration is multiplied by a scaling factor of 1.4. The overall assessment is usually carried out according to the worst axis of weighted RMS acceleration. If the crest factors exceed 9, then two alternative methods of assessment are suggested: the maximum transient vibration value and the VDV.

Two “health guidance caution zones” are included in ISO 2631-1 (1997) to assist with interpreting the worst axis of the frequency-weighted RMS acceleration (See Figure 2.1). Two zones are provided as they are derived from RMS and VDV approaches. The standard states that: *“For exposures below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely.”*

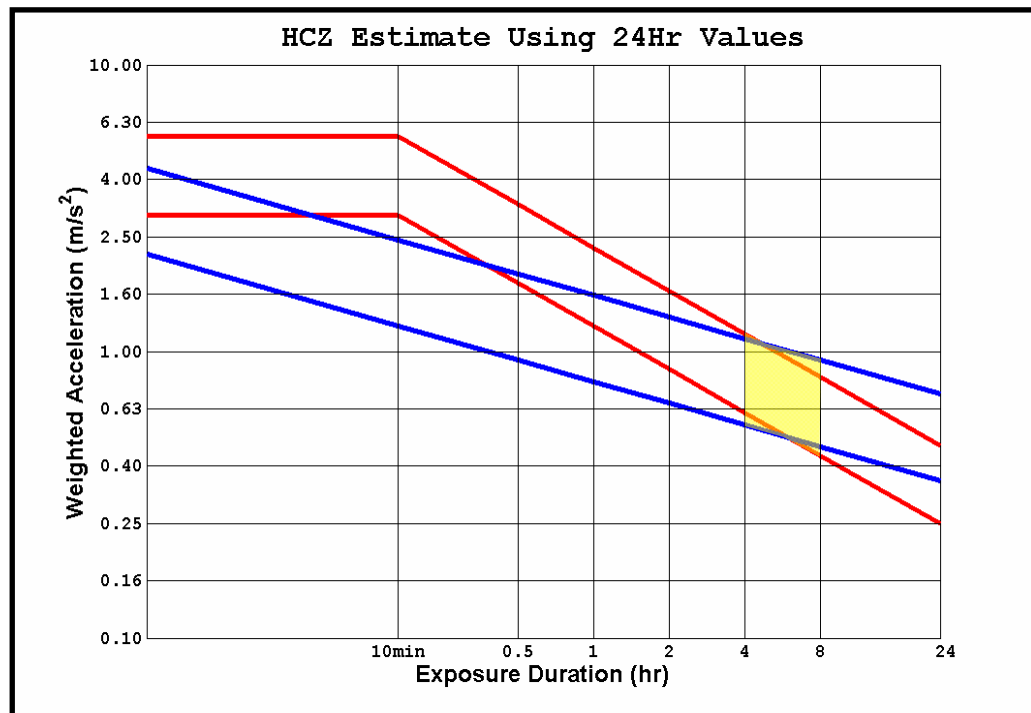


Figure 2.1: The two “health guidance caution zones”

The process of making a health assessment according to ISO 2631-1 (1997) is complex and can be confusing. If two individuals were asked to make measurements according to ISO 2631-1 (1997), a wide range of results could be attained. However, at the core of the standard is the method of using frequency-weighted RMS acceleration, and this is the primary method that most users apply.

For evaluation of the effects of vibration on comfort and perception according to ISO 2631-1 (1997), the frequency-weighted RMS acceleration is determined for the three translational axes on the seat. The methods to include rotational vibration and vibration at the feet and seat back are also described. For perception, multiplying factors of 1 are used on all translational vibration axes. If the crest factor exceeds 9, then VDV or the maximum transient vibration value should be used. Vibration from all axes should be combined. The following Table 2.3 shows the approximate indications of likely reactions to various magnitudes of overall vibration total values.

The limitation of this standard is that it explains only about human exposure to vibrations of frequencies up to 80Hz. This is an important aspect of ISO 2631, as many people are exposed to vibration frequencies less than 80Hz, while few of them are exposed to vibrations that are more than 80Hz. Most commonly the musculoskeletal disorders are caused by frequencies below 80Hz which implies that the standard is inadequate. These standards are applicable only to persons who are normally fit and not for people with disabilities. ISO recognized the exposure to spinal vibrations above 0.5 m/s^2 as injurious to the drivers. A company can be prosecuted if a driver is exposed to the spinal vibration level around 1.15 m/s^2 .

Table 2.3: Approximate indications of likely reactions to various vibration total values

Vibration Magnitude	Likely Reaction
Less than 0.315 m/s^2	Not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	A little uncomfortable
0.5 m/s^2 to 1 m/s^2	Fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	Uncomfortable
1.25 m/s^2 to 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortable

2.2.3 ANSI and ACGIH

These standards are used in the United States for assessing WBV. The ISO 2631 has not yet been accepted legally to be used in the USA. The ANSI standard 3.18 is taken from ISO 2631(1985) and ANSI 2000 is taken from ISO 2631(1997). Figure 2.2 below explains the established limits of acceptable exposure to WBV. The set of U-shaped curve shows the acceleration limits as a function of frequency and daily worker exposure time for the vertical (Z) axis. Figure 2.3 gives the limits of exposure of WBV in X and Y axes. If one or more of the axis Acceleration exceeds the standard, then the whole standard is supposed to be exceeded and the control measures should be applied.

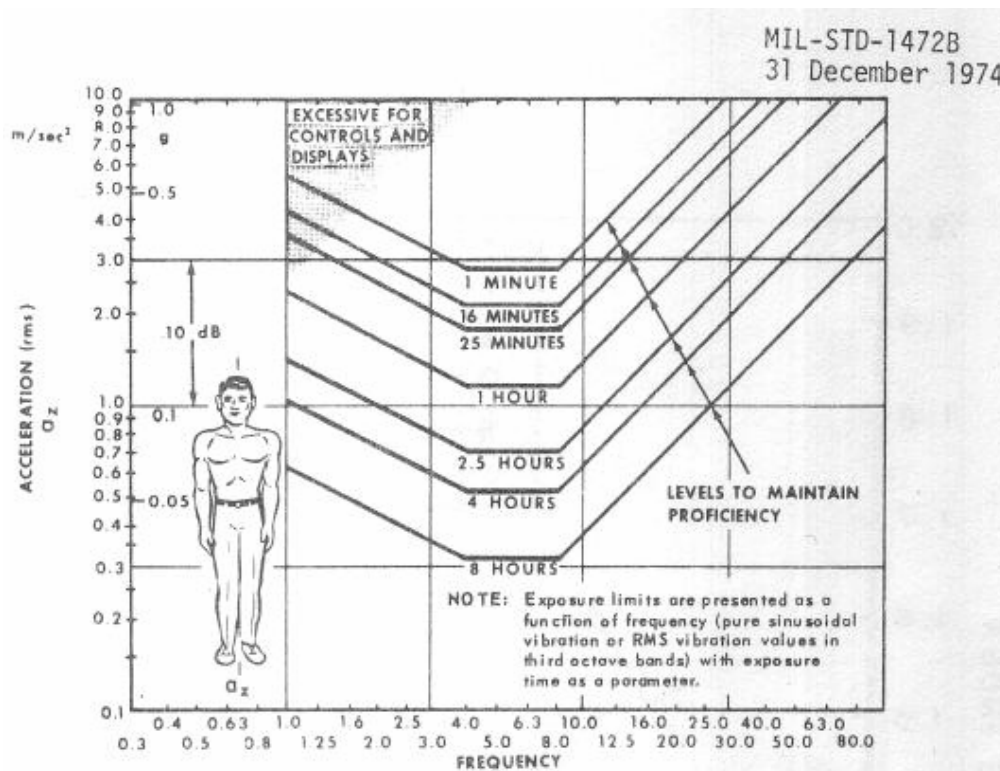


Figure 2.2: FDP boundary-Z axis

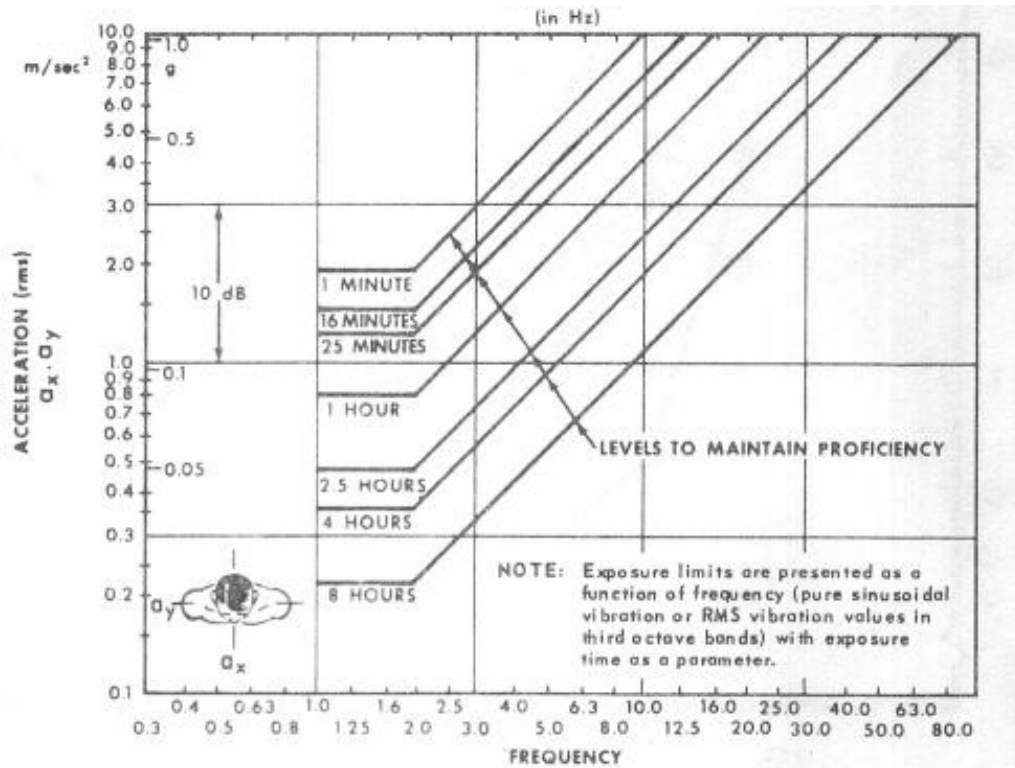


Figure 2.3: FDP boundary-X&Y axes

2.2.4 Directive 2002/44/EC

(On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents)

The European Community has passed a directive (Directive 2002/44/EC) to establish a legal limitation of human vibration exposure starting in July of 2005. It places specific limitations for the average amount of vibration exposure a truck driver can experience for an 8 hour day's driving. For the whole body exposure, the directive is based on the ISO 2631-1.

According to this directive, the daily exposure limit value standardized to an 8-hr reference period shall be 1.15 m/s^2 or, a VDV of $21 \text{ m/s}^{1.75}$. The daily exposure action value standardized to an 8-hr reference period shall be 0.5 m/s^2 or, a VDV of $9.1 \text{ m/s}^{1.75}$. Individuals that are exposed to an average level of vibration for an 8 hour/day in these

ranges must be medically examined on a schedule and no individual will be allowed to be exposed over a 1.15 m/s^2 average.

2.2.5 Comparison of BS 6841 (1987) and ISO 2631-1 (1997)

In many respects, British Standard BS 6841 (1987) and International Standard ISO 2631-1 (1997) are similar. For motion sickness assessments the standards are substantially identical; for perception and comfort evaluations they are broadly similar. The methods of acquiring data and the locations for measurement are alike. It is also possible to interpret ISO 2631-1 so that most vibration analyses can be carried out with a similar approach to BS 6841. However, notwithstanding the differences in clarity of the two standards, there are five core areas where BS 6841 and ISO 2631-1 differ as shown in the below table.

A comparison of measurements made with the two weightings for nine different vehicles has been done by Lewis and Griffin in 1998 [7]. See Table 2.4. It showed a maximum difference of 17% between the frequency-weighted RMS, with measurements made using W_k exceeding those made using W_b for all motorized vehicles. Rarely will the use of different frequency weightings alter the rank orders of analyzed data if each axis is considered separately.

Table 2.4: Key differences between BS 6841 (1987) and ISO 2631-1 (1997)

BS 6841	ISO 2631
Uses W_b frequency weighting for vertical vibration	Uses W_k frequency weighting for vertical vibration
No multiplication factors required for measurement of seat surface vibration	Horizontal vibration is scaled by a factor of 1.4 for measurements of seat surface vibration
Use of 15 VDV as criteria for health risk	Use of two “health guidance caution zones” as criteria for health risk
Use of combined axes for assessments	Use of “worst axis” for assessments, with option to use combined axes
Crest factor of 6 used as threshold for unreliability of RMS methods	Crest factor of 9 used as threshold for unreliability of RMS methods

The differences between the results obtained using alternative standards due to the multiplication factor for horizontal vibration depends on the relative contribution of the horizontal component to the total vibration exposure. If the vibration is solely in a horizontal axis, then ISO 2631-1's axes multiplier will increase the result by 40%. However, if using ISO 2631-1 and the worst axis is vertical, then the multipliers have no effect as the data from the horizontal axes are ignored in the final assessment. It is unfortunate that if either RMS or VDV data are used to estimate health risk based on either BS 6841 or ISO 2631-1, the results will be different for each of the orthogonal axes. For vertical vibration the frequency weightings are different; for horizontal vibration axes, multipliers apply for ISO 2631-1 but not for BS 6841.

Both ISO 2631-1 (1997) and BS 6841 (1987) use RMS as the basis for measurement of signals with crest factors below 9. In these cases the conversion from RMS to eVDV in BS 6841 alters the time dependency from one where a doubling of magnitude results in a 4-fold decrease in equivalent exposure to one with a 16-fold decrease in equivalent exposure. Retaining RMS throughout the analysis process is one of the reasons why one of the health guidance caution zones in ISO 2631-1 retain the four-fold relationship between doubling of vibration magnitude and equivalent exposure time. VDV is better suited to the analysis of signals with repeated or occasional shocks than RMS, as the influences of these events do not decay as subsequent time elapses.

In a similar study, Griffin has concluded that ISO 2631-1 causes unnecessary confusion because it is unclear in several important areas, such as which body postures and axes to be chosen, whether assessment of multi-axis vibration be based on the 'worst axis' or a combination of the weighted arms in all directions, why a 1.4 factor for health but not for comfort. The complexity, confusing approach, and content of ISO 2631-1 will not improve with an increased user population. Indeed, considering that the majority of this extended user group will be new to the field, scope for increasing the confusion is substantial.

The British Standard is better due to simpler, clearer evaluation method-same for health and comfort, reasonable actions associated with severe exposures to vibration or repeated shock. An improved version of International Standard for measuring, evaluating and assessing human exposure to vibration and shock is recommended [8].

2.3 WBV measurement and evaluation

Vibration measurement and evaluation is a complex topic and there are many paths that can be taken to turn a mechanical motion into a value or figure in a report. Measurement involves the assignment of numerical values according to some rules. Evaluation results in some indication of the relative or absolute worth, value or severity. A satisfactory vibration measurement or evaluation procedure is one which yields data containing the information necessary to make a correct decision.

A conceptual illustration of the measurement and evaluation of vibration is illustrated as below. First, a transducer must be attached to the vibrating surface. As we known, it is, at present, a cardinal principal that human vibration exposures are quantified by the vibration conditions at the interfaces between the environment and the human body. The transducer (almost always an accelerometer) converts the mechanical oscillation into an electrical property. The signal conditioning, which is attached to the transducer by a cable, converts the electrical property into a voltage that can be processed. Modern vibration-measuring equipment converts the voltage into a digital signal on which complex calculations can be carried out.

Vibration can occur in any direction. Complex stimuli simultaneously move vertically, laterally, and in the fore-and-aft directions. In addition, rotation is possible, producing a total of six axes of potential movement. WBV are measured in the X, Y and Z coordinate system given by ISO 2631-1 and illustrated in the following Figure 2.4. For WBV, the fore-and-aft direction is defined as the x-axis, lateral as the y-axis, and vertical as the z-axis. Roll is rotation around the x-axis, pitch is rotation around the y-axis, and yaw is rotation around the z-axis. The resultant of acceleration in longitudinal (X axis) and transverse directions (Y and Z axes) is the vector sum of accelerations in three axes.

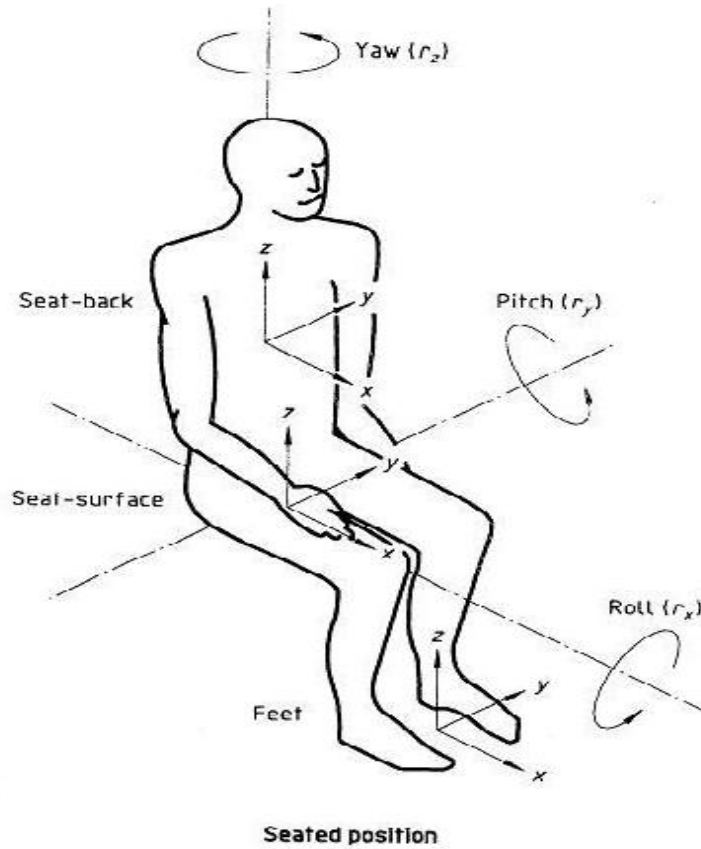


Figure 2.4: Coordinate system for seated position

Table 2.5: Summary of the most common frequency weightings

Summary of the Most Common Frequency Weightings Used for Analysis of Human Vibration Signals			
Frequency Weighting	Application Area	Frequency Range	Direction
W_b	Whole-Body	0.5-80 Hz	z-seat
W_c	Whole-Body	0.5-80 Hz	x-backrest
W_d	Whole-Body	0.5-80 Hz	x-seat
W_e	Whole-Body	0.5-80 Hz	Rotation-seat
W_f	Motion sickness	0.1-0.5 Hz	z-vertical
W_h	Hand-transmitted	8-1,000 Hz	x-hand y-hand z-hand
W_k	Whole-Body	0.5-80 Hz	z-seat

Once reliable and calibrated signals from the accelerometers have been acquired, they must be processed to generate numerical indicators suitable for the purpose of the assessment. A frequency weighting will almost always be required, as will basic statistical descriptors. A frequency weighting provides a model of the response of a person to the vibration. Another way of considering frequency weightings is that they are an inversion of an equal response curve. People are more sensitive to some frequencies of vibration than others, and this frequency dependence is simulated using the frequency weightings. For example, the body is more sensitive to WBV at about 5 Hz than at 50 Hz; therefore, the vibration at 50 Hz is weighted such that its relative contribution to the total signal is reduced accordingly. The concept can be extended such that there is a continuum of weighting factors across the frequency range of possible perception. Frequency weightings are thus applied to time-domain signals to modify them so that the weighted signal represents the human response to the vibration rather than the mechanical characteristics of the vibration surface. Frequency weightings are designed to not affect those frequencies where the body is most sensitive and to attenuate at those frequencies where the response of the body is less sensitive. In principle, weightings do not amplify at any frequency. Therefore, the magnitude of the frequency-weighted signal should not be more than the magnitude of the unweighted signal.

Frequency weightings can be implemented using analog electronics or, most commonly, using digital signal processing techniques. To be able to calculate all statistical functions, the weighting should be carried out in the time domain. Implementation of frequency weightings is difficult, and usually specialist software is required.

Although a wide variety of weightings can be found in the literature and standards, the most commonly used are W_b , W_k and W_d for WBV, and W_h for hand-transmitted vibration. See the Table 2.5. W_b and W_k are both used for vertical vibration only and are each characterized by a peak at 5 Hz. W_k is about 25% higher than W_b below 3 Hz and is lower than W_b at frequencies above 12 Hz. A potential user should ensure that at least these three weighting filters are provided. The Figure 2.5 shows the frequency weighting curves for principal weightings from ISO 2631-1 (1997).

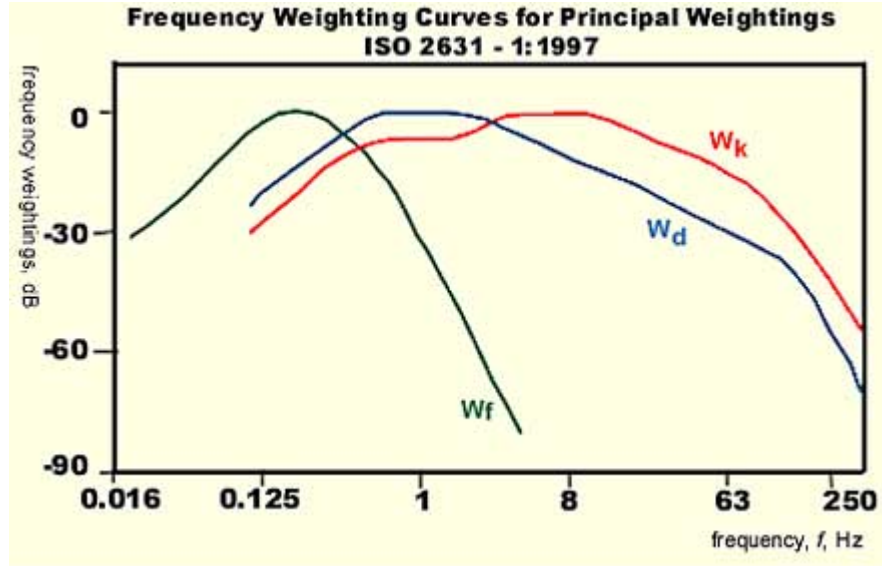


Figure 2.5: Frequency weighting curves from ISO 2631-1

The final stage of the measurement process is to carry out statistical measures of the frequency-weighted acceleration signal. By definition, vibration is a movement that oscillates about a fixed point. Therefore, assuming that there is no translation, the mean value of a vibration signal will, in theory, always be zero as all of the positive values will cancel out all of the negative values (if it is measured for an infinite duration or for a complete number of cycles at all frequencies). As such, the mean of the acceleration will not indicate the magnitude of the signal. The RMS solves this problem by squaring every value in the signal, taking the mean, and taking the square root of the final value. RMS is identical to standard deviation, if there is no offset in the acceleration signal. The unit of RMS acceleration is m/s^2 . Mathematically, RMS can be expressed as:

$$a_{w.r.m.s.} = \left[\frac{1}{T} \int_0^T a_w^2(t) dt \right]^{\frac{1}{2}}$$

Where, $a_w(t)$ is the frequency-weighted acceleration, in m/s^2 . T is the duration of the measurement, in s.

The peak acceleration is the maximum instantaneous acceleration at any time during the measurement period. Therefore, it only corresponds to the one sample of an acquired

time history with the maximum value. For vertical seat vibration, the sign of the peak can indicate whether an untethered occupant momentarily left the surface of the seat at any time. Some vibration meters report maximum RMS acceleration in addition to the peak acceleration. There is a fundamental difference between these quantities: the maximum RMS is the highest level averaged across a preset time averaging period; the peak acceleration is the highest instantaneous acceleration measured at any time during the entire measurement period. Peak acceleration will always be greater than the maximum RMS acceleration. It is essential that these measures are not confused.

The crest factor (CF) is a dimensionless quantity defined as the ratio of the peak acceleration to the RMS. If the signal contains a single instantaneous shock, then the CF would increase, but the RMS might not be substantially affected. Therefore CF is useful in assessing the applicability of RMS averaging. The Crest Factor determines if the data recorded for the time can be considered valid to predict safety. It states that the highest peak cannot exceed the average value by 9. For hand-transmitted vibration, CF might be of interest but of minor practical use, as RMS is used for all standardized analysis methods. For WBV, CF is sometimes used to indicate whether RMS or alternative assessment techniques are appropriate. Mathematically, CF can be expressed as:

$$CF = \frac{\max(a_w(t))}{RMS(a_w(t))}$$

Where, $a_w(t)$ is the frequency-weighted acceleration, in m/s^2 .

The VDV is a quantity that is only applied to WBV measurements. It was developed in response to experimental research that showed a 4th-power relationship between vibration magnitude and discomfort. Therefore, it emphasizes shocks more than the RMS. Another difference between RMS and VDV is that VDV will always accumulate and does not decay during periods of low, or zero, vibration magnitude. Furthermore, exposure to continuous vibration will cause VDV to continuously increase, whereas RMS will remain constant. For random vibration, VDV continuously increase to a final value of $1 m/s^{1.75}$. For the random vibration with additional shocks, VDV shows step increases at the time

of the shocks, and these do not decay like RMS. The final VDV for the vibration with shocks is $1.26 \text{ m/s}^{1.75}$. The relatively rapid convergence in values observed for RMS does not occur for VDV. The units of VDV are $\text{m/s}^{1.75}$, although occasionally, values are expressed with “VDV” used as the unit. Mathematically, VDV can be expressed as:

$$VDV = \sqrt[4]{\int_0^T a_w^4(t) dt}$$

Where T is the measurement duration and $a_w(t)$ is the frequency-weighted acceleration at time t.

The VDV is sensitive to individual high acceleration events and produces a cumulative dose over a (working) day. The graph in the following Figure 2.6 illustrates how the VDV responds more readily to shock than rms. We can see that RMS represents steady levels of vibration reasonably accurately but gives a poor representation of shocks and jolts whereas VDV gives a good representation of both steady levels of vibration and shocks and jolts.

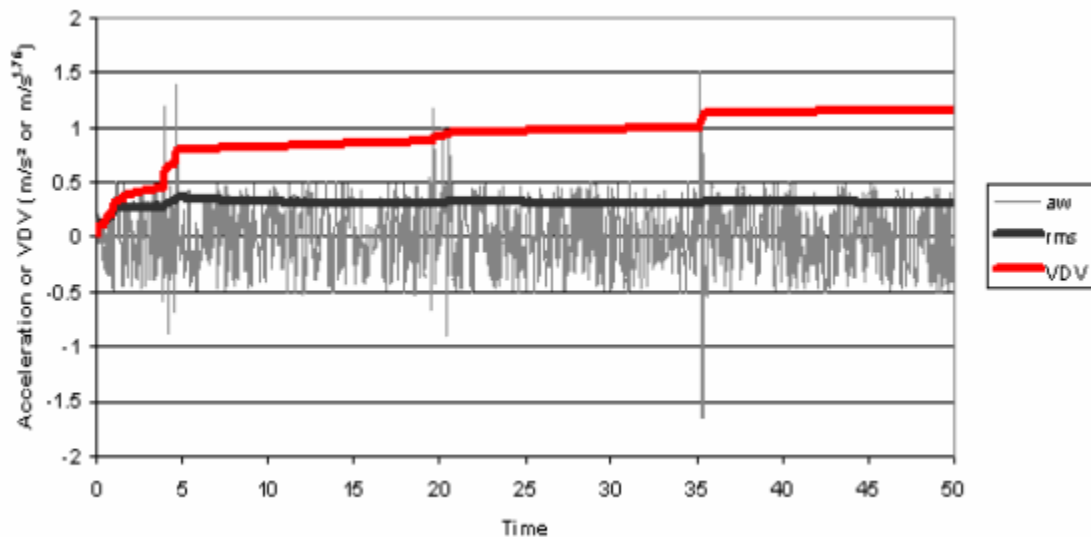


Figure 2.6: VDV vs. RMS acceleration

For many vibration assessments, individual measurements made in orthogonal axes should be combined. Although it can be argued that this is the “correct” approach, it is unfortunate that many standards advocate the use of the “worst axis” where by two of the three vibration measurements remain unused. To verify which axis is the worst, all axes require measurement anyway. The vibration total value of weighted RMS acceleration, determined from vibration in orthogonal coordinates is calculated as follows:

$$a_v = (k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2)^{\frac{1}{2}}$$

Where, a_{wx} , a_{wy} , a_{wz} are the frequency-weighted RMS accelerations with respect to the orthogonal axes X,Y and Z respectively. k_x , k_y , k_z are multiplying factors in the x-axis, y-axis, and z-axis, respectively. As stated in ISO 2631-1 (1997), for seated persons, these multiplying factors are equal to 1 when we use the vibration total value to evaluate the comfort of WBV.

2.3 Literature survey

In the U.S., an estimated six million workers are in occupations exposed to WBV and more than one million workers are in occupations exposed to hand-transmitted vibration [2]. Since Alice Hamilton’s seminal report in 1918 on vibration-induced hand disorders in quarry stonecutters, the potential health risks associated with prolonged and repeated vibration exposure have been well recognized and documented. Efforts to understand the exposure risk factors and adverse health effects of occupational vibration exposure have waxed and waned over the years. Despite numerous studies and technological advances in WBV measurement and control, the exposure risks and etiology of the adverse health effects are not well understood. There have been lots of studies but limited information concerning the exposures of WBV to the truck drivers.

CANN Adam P. et al. (2004) investigated the WBV exposure levels experienced by transport truck drivers to determine whether truck drivers’ exposure exceeded ISO 2631-1 (1997) guidelines and found road condition and truck type were the key predictors to

WBV experienced by the truck drivers. Other predictor variables included driver experience, truck mileage and seat type. Tests were conducted on four major highways with 5 min random samples taken every 30 min of travel at speeds greater than or equal to 80 km/h. Results indicated that the drivers were not on average at increased risk of adverse health effects from daily exposures when compared to ISO WBV guidelines [9].

In another study by the same group in 2003, WBV measurements were recorded for various types of heavy equipment used within the construction industry. Construction equipment was divided into mobile and stationary equipment categories, dependent upon the task performed. For example, the excavator was in a stationary position, whereas equipment such as bulldozers and graders were mobile while performing job tasks. The mobile equipments were found to be associated with greater levels (221%) of WBV than the stationary ones. Wheel loaders, off-road dump trucks, scrapers, skid steer vehicles, backhoes, bulldozers, crawler loaders, and concrete trowel vehicles exceeded the recommendations based on measured vibration dose values. No significant differences were found for rubber-tired versus tracked equipment [10].

Kjell Ahlin et al (2002) investigated the seriousness of the problem of whole body vibration when driving on roads and the relationship between road condition, vehicle properties, driver behavior and ride quality. It showed that road roughness has a far greater impact than vehicle properties and driver behavior including the choice of speed. The study also showed that low back pain among professional drivers is related to road roughness. It was concluded that rough roads may bring shock and rotational motion at levels high enough that they can exacerbate the risk of injury, comfort and motion sickness. Some of the vibrations transferred through the seat and back rest can be dampened by replacing old seats with new, fitted with improved vibration isolators. Further, it was recommended that the most efficient and single method to reduce such WBV is not highway speed reduction, nor vehicle design modification, but the renovation of the road [11].

Hoy, Mubarak et al. (2005) conducted a cross-sectional study to investigate the risks from WBV and posture demands for low back pain (LBP) among forklift truck (forklift) drivers. The forklift drivers were observed in respect of their sitting posture, including frequency with which different positions were adopted (bending, leaning and twisting) and postural analyses were conducted using the OWAS and RULA techniques. Forklift vibrations at the seat (exposure) were measured in the three orthogonal axes(x-fore and aft, y-lateral and z-vertical) under actual working conditions according to the recommendations of ISO 2631-1. The results showed that LBP was more prevalent amongst forklift drivers than among non-drivers and driving postures in which the trunk is considerably twisted or bent forward associated with greatest risk. Furthermore, forklift drivers showed to be exposed to acceptable levels of vibration in the x- and y-directions but not in the z-direction. The measured vibration exposures suggested the presence of severe shock loading, and the results indicated that WBV acts associatively with other factors (not independently) to precipitate LBP [12].

Okunribido, Magnusson et al. (2006) investigated the exposures of drivers to posture demands, manual materials handling (MMH) and vibration as risk factors for LBP among short-haul delivery drivers. They used a validated questionnaire to obtain information about driving experience, driving (sitting) posture, MMH, and health history among 64 drivers. Twelve persons were observed and videotaped during their work and vibration measurements were obtained for three types of delivery. The results indicated that systematic observation of the driving activity and MMH is necessary alongside any subjective questionnaire assessments, particularly driving duration and MMH. LBP is prevalent among short-haul delivery drivers (such as were considered in the present study) and likely to be transient (lasting less than a week) in nature rather than permanent. Short-haul delivery drivers clock up considerable hours of daily work time, but they are not likely to spend more than 30% of the time actually driving. Avoiding unduly rapid movement of loads during handling, reducing the need for twisting of the torso during driving, and preventing exposure to shock/jerking events are strategies that can help control precipitation of LBP [13].

Massaccesi, Pagnotta et al. (2003) used RULA, a method for the evaluation of the exposure to risk factors associated with work-related upper-limb disorders, to observe a high incidence of spinal in professional drivers; in particular, back and neck pain result in high rates of morbidity and low retirement age. Results showed a significant association between trunk and neck scores and all self-reported pains, aches or discomforts in the trunk or neck regions in all subjects. In particular, the neck score was significant in both postures, reflecting high loading of the neck. In this first RULA study of the working posture of professional truck drivers, the method proved to be a suitable tool for the rapid evaluation of the loading of neck and trunk. RULA evidenced that the posture adopted in street-washing trucks during cleaning operations was associated with a major risk for back pain, especially with non-adjustable seats. Ergonomic interventions aiming at modifying the truck's workstation are recommended with a view to helping prevent musculo-skeletal disorders [14].

Toren (2001) finished a study to quantify the muscle activity as a function of twisting angle, to quantify the range of motion (ROM) during active trunk rotation and to determine whether there were any differences between tractor drivers and office workers and between twisting direction for these variables. The subjects performed exertions in a seated position, twisting from the neutral position to the end of the ROM. The results showed that external oblique and erector spinae had significantly different activation patterns depending on twisting direction during active trunk rotation without external loads. For the contralateral external oblique and the ipsilateral erector spinae, the muscle effort required to twist the trunk was low up to about 20° twisting angle, then the muscle effort needed to twist the trunk increased progressively throughout the ROM. No significant differences due to occupation or twisting direction were found. The result implies that work in twisted trunk postures might be a risk factor for low-back pain. Differences that might exist between the workgroups are probably very difficult to reveal with this method [15].

Shrawan Kumar (2004) have done a study to determine if the vibration in sagittal (x), coronal (y) and vertical (z) axes of the seat pan of the heavy haul trucks used in

overburden mining, and the vibration experienced by the drivers at the third lumbar and seventh cervical vertebral levels in operating these trucks exceeded the ISO standards, thereby posing threat to safety. They found that the gender of the driver, truck make, and its carrying capacity did not have much effect but the body weight of the driver, the segment of the truck and the site of measurement had significant effect on the vibration exposure. The vibration at seat pan, C7 and L3 levels were recorded which frequently exceeded the ISO standards. Heavy haul trucks frequently generated vibrations in excess of ISO standards in overburden mining operation, which represented a health hazard [16].

Palmer, Griffin et al (2000) found that 7.2 million men and 1.8 million women in Great Britain are exposed to WBV at work in a 1 week period with 374 000 men and 9000 women exceeding the proposed British standard action level of $15 \text{ m/s}^{1.75}$. Occupations in which the estimated exposures mostly exceeded the standard were forklift truck and mechanical truck drivers, farm owners and managers, farm workers, and drivers of road goods vehicles. These also contributed the largest estimated numbers of workers in Great Britain with such levels of exposure [17].

Sarah Atkinson, Martin Robb and Neil J Mansfield (2000) found that peaks in the vibration can occur due to the driver sitting in the seat or leaving the seat. These measurements can dominate the total vibration exposure and measures should be taken to minimize their influence on the vibration measurement such that only ‘true’ vibration exposures are included [18].

Corbridge and Griffin (1986) conducted a study to determine the effect of frequency of WBV on comfort in the range 0.5-5Hz. It was found that there was little effect of vibration magnitude on the frequency dependency of vibration discomfort. Random vibration produced slightly greater discomfort than sinusoidal vibration but with the same frequency dependence. It was also found that, with vertical motion there was small difference between the responses of male and female subjects [19].

Griffin, Matsumoto (2002) investigated the effect of the magnitude of vertical vibration on the dynamic response of the seated human body. Eight male subjects were exposed to

random vibration in the 0.5 to 20 Hz frequency range at five magnitudes: 0.125, 0.25, 0.5, 1.0 and 2.0 ms^2 RMS. The dynamic responses of the body were measured at eight locations: T1, T5, T10 (thoracic vertebrae), L1, L3, L5 (lumbar vertebrae) and at the pelvis (the posterior-superior iliac spine). The force at the seat surface was also measured. Frequency response functions (transmissibilities and apparent mass) were used to represent the responses of the body. They found that the dynamic responses of seated subjects are non-linear with respect to vibration magnitude. Non-linear characteristics were observed in the apparent mass and in the transmissibilities to most measurement locations. Resonance frequencies in the frequency response functions decreased with increases in the vibration magnitude [20].

In a similar study by the same authors in 2000, the dynamic responses of the human body in a standing position and in a sitting position have been compared. The principal resonance in the apparent mass is in the range of 5-6Hz for both sitting and standing postures, exposed to vertical WBV, with slightly higher frequencies and lower apparent mass in the standing posture. There was greater transmission of vertical vibration to the pelvis and the lower spine and greater relative motion within the lower spine in the standing posture than in the sitting posture at the principal resonance and at higher frequencies [21].

Bovenzi and Zadini (1992) found that bus driving was associated with an increased risk of low back troubles, mainly due to WBV exposure and prolonged sitting in a constrained posture. The occurrence of low back symptoms increased with the increasing WBV exposure measured in terms of total (lifetime) vibration dose ($\text{years m/s}^{1.75}$), equivalent vibration magnitude (m/s^2) and duration of exposure (years of service). With more severe WBV exposure, highest prevalence of disc protrusion was found [22].

In a similar study, Jane Lyons (2001) found that professional drivers are at an increased risk for low back pain and injury due to various facts such as WBV, prolonged sitting, awkward postures, lifting and carrying, and psychological issues. Ergonomics could play an important role in reducing the risk of injury to the professional drivers by

implementing modifications to the work place (engineering controls), changes in administrative and management practice (administrative controls), and education of the worker (work practice controls) [23].

P Donati (1998) found that industrial trucks drivers may be exposed to high values of whole body vibration with frequencies below 10Hz due to surface irregularities and the lack of suspension systems on these vehicles. Machinery Directive 89/392/EEC and its amendments require that vibration measurements be made and values put into the instruction books if the whole body vibration values are greater than 0.5 m/s^2 [24].

Ronnie Lundstrom et al recommend that Absorbed power (P_{abs}) may be a better quantity for risk assessment than those specified in ISO 2631 since it also takes the dynamic force applied to the human body into account. In a study done on 15 male and 15 female subjects, it was found that P_{abs} was strongly related to the frequency of the vibration, peaking within the range of 4-6 Hz. The peak was predominantly located in the lower end of this range for females and for the relaxed sitting position. P_{abs} increased with Acceleration level and body weight. The results also indicate a need for differentiated guidelines for females and males [25].

S. Nishiyama and N Uesugi (2000) conducted a study that the magnitude of the vibrations transferred to a driver from the seat, steering wheel and pedals have been measured with both sinusoidal and random excitations in the vertical direction at frequencies up to 20 Hz. Measurement points being located on the surface of the head, chest, hip, thigh, shin, upper arm and lower arm. It was found that arm angle in driving posture has a substantial influence on the dynamic behavior of the human body while driving. An arm angle of about 120 degrees is preferred with respect to ride comfort and handling of the steering wheel and pedals. Random excitation showed the tendency that the peak value of Acceleration ratio was larger and the resonance frequency became higher when compared with the results of sinusoidal excitation [26].

S Maeda and M Morioka (1998) conducted a field study to characterize the health risks associated with garbage truck work in Japan. Three different types of truck were tested at

different loadings and on different road surfaces with the vibrations measured at the driver/seat interface(X, Y and Z-axes). The vibrations were compared with the health risk guidance according to Annex B of ISO 2631-1 to find that Japanese garbage truck drivers should not operate trucks for 2.5 hr/day under current working conditions [27].

Jang and Griffin (2000) investigated the interaction between the frequency of vibration and the relative phase between vibration at the seat and the feet on the discomfort of seated subjects exposed to vertical vibration in an experimental study. The results indicate that vibration discomfort is influenced by the phase between the seat and the feet, but that the effect depends on the frequency and magnitude of vibration and the posture of the body. The phase effect seems to be particularly important with low magnitudes of vibration at low frequencies. They also found that differential vibrations with greater phase difference caused greater discomfort at frequency up to 4Hz. The subjects were found to be sensitive to the phase angle mostly at lowest frequency and magnitude of vibration [28].

Huston, Zhao and Johnson (2000) talked about the shortcomings of power spectral density approach to measure WBV. The power spectral density is a statistic that decomposes a vibration signal into frequency components. The primary ISO 2631 whole-body vibration statistics are derived from the power spectral densities of tri-axial Acceleration measurements, usually taken at the seat cushion interface. A major shortcoming of the power spectral density approach is that it cannot distinguish between vibrations that contain mechanical shocks and those that do not. Two vibration signals, one that contains a few large isolated mechanical shocks and one that contains continual vibrations with minimal mechanical shocks, can have identical power spectral densities, though different levels of comfort, fatigue and injury e.g. driving on a rough road with many small bumps and driving on a smooth road with occasional large potholes. This shortcoming has been recognized by introducing Crest Factor [29].

Pope MH et al (1998) conducted epidemiological studies to determine whether there is support for a casual link between exposure to WBV and back disorders. It showed a great

evidence for a consistent and strong relationship that increases with increasing exposure. The risk was found to be elevated in broad range of driving occupation including truck drivers, earth moving machine operators, forklift drivers, bus drivers, agricultural workers and other vehicle drivers. Common control measures such as seat suspension were often found to be ineffective.

A review done by Wilder and Pope [1996] shows that:

- The magnitude of vibration transmitted to human spine is greatest at resonant frequencies from 4.5 to 5.5 Hz and from 9.4 Hz to 13.1 Hz.
- Bending and rotating postures as well as sitting postures(which rotate the pelvis backwards and flatten the lumbar spine) increases vibration transmission
- Muscles are fatigued by vibration exposure and oxygen consumption increases
- Vibration increases pressure within discs
- Movement of the intervertebral discs causes stress on the annular fibers

Age, working postures, repeated lifting and heavy labor, smoking, previous back pain, falls or other injury-causing events and stress-related factors including job satisfaction and control were factors other than vibration related to back disorders [30].

To sum up, road condition, vehicle and seat design, driver experience, body weight, measurement site etc has profound effect on the WBV exposure whereas gender, truck make, carrying capacity, vehicle properties and the driver behavior do not have much effect. Exposure to WBV is directly related to low back pain. Frequency response is affected by sitting posture, seatback inclination and the rocking of pelvis. Resonance at 5-6Hz is the worst for spine. Phase angle is important at low frequency. Even the arm angle in driving posture affects the comfort.

Age, heavy labor, previous pain or injury history, smoking and stress related factors like job satisfaction are the non-vibration factors related to back disorders. Reducing prolonged sitting and improving the seats, cabs and suspensions are the possible ways to reduce the WBV exposure.

Chapter-3 WBV testing methodology

3.1 Data collection

WBV was measured inside the cab of heavy duty trucks during an actual on-road driving test. Seventeen trucks, which are frequently called tractors, were tested in this study. There are two methods to acquire and analyze the vibration data: HVM-100 and the DEWE data acquisition system. HVM-100 collects the data from the driver's seat cushion and is used to find out the vibration exposure level of driver. DEWE system is used to collect the data of driver, passenger, and the cab floor.

Figure 3.1 is a picture of our tested truck. The on-road test will involve driving the truck over a prescribed route while a series of WBV measurements are made. The driving course will include a mixture of interstate and rural highway travel over relatively level and sloped terrains. Each truck will haul an identical 53-ft utility trailer that has been loaded with approximately 30,000 lb. of palatalized garden topsoil. We also recorded three different unloaded trucks' data to compare the results with the loaded trucks. Trucks from the model years 2006, 2007 and 2008 will be sampled and will include, to the best of the team's ability, trucks from different manufacturers (e.g., Freightliner, International, Volvo, Mack, Kenworth, Peterbuilt, etc.). All trucks will have in-cab driver-sleeping berths, such that are used for long haul driving.

Figure 3.2 is a two-dimensional map of the entire on-road route. The truck route for the on-road test will begin on interstate I-40 at the interstate mile marker number (MM) 376. The starting location is situated about 1-mile west from the city limits of Knoxville, Tennessee; note that the intersection of I-40 and I-140 is also the location of MM 376. Driving west from Knoxville on I-40, the route will proceed to the city limits of Crossville, Tennessee, i.e., the MM 322 exit. This segment of the route on I-40 west is approximately 55 miles in length. These segments of the on-road test just described represents interstate travel conditions over rolling hills and steep terrain.



Figure 3.1: The picture of test truck

During the interstate travel, the truck will pass the I-40 and I-75 junction, i.e., MM 368 and MM 84, respectively. For purpose of orientating the reader, this section of the truck route will pass several exits to towns, in particular three town and exits will be noted: Kingston (MM 350), Harriman (MM 247) and Crab Orchard (MM 329). At the exit to Crossville (MM 322), the truck will turnaround on the I-40 turnpike and proceed east on I-40 back towards the town of Harriman to enter a section of the rural highway system. At the MM 347 exit, the truck will exit I-40 and entered highway US-27. This return route along I-40 east is approximately 25 miles. These segments of the on-road test just described again represent interstate travel conditions over rolling hills and steep terrain.

The route will then continue to follow US-27 in a southwesterly direction through the towns of Rockwood and Spring City. This segment of the trip is approximately 25 miles. About 2-miles past Spring City, the truck will turn left on highway TN-68. Thus continuing in a westerly direction on TN-68, the route will pass Watts Bar Dam and eventually reach the entrance ramp to interstate I-75 (MM 60). This section of the journey is approximately 20 miles. These two segments of the on-road test just described represents rural highway travel conditions over mildly rolling hills and flat terrain.

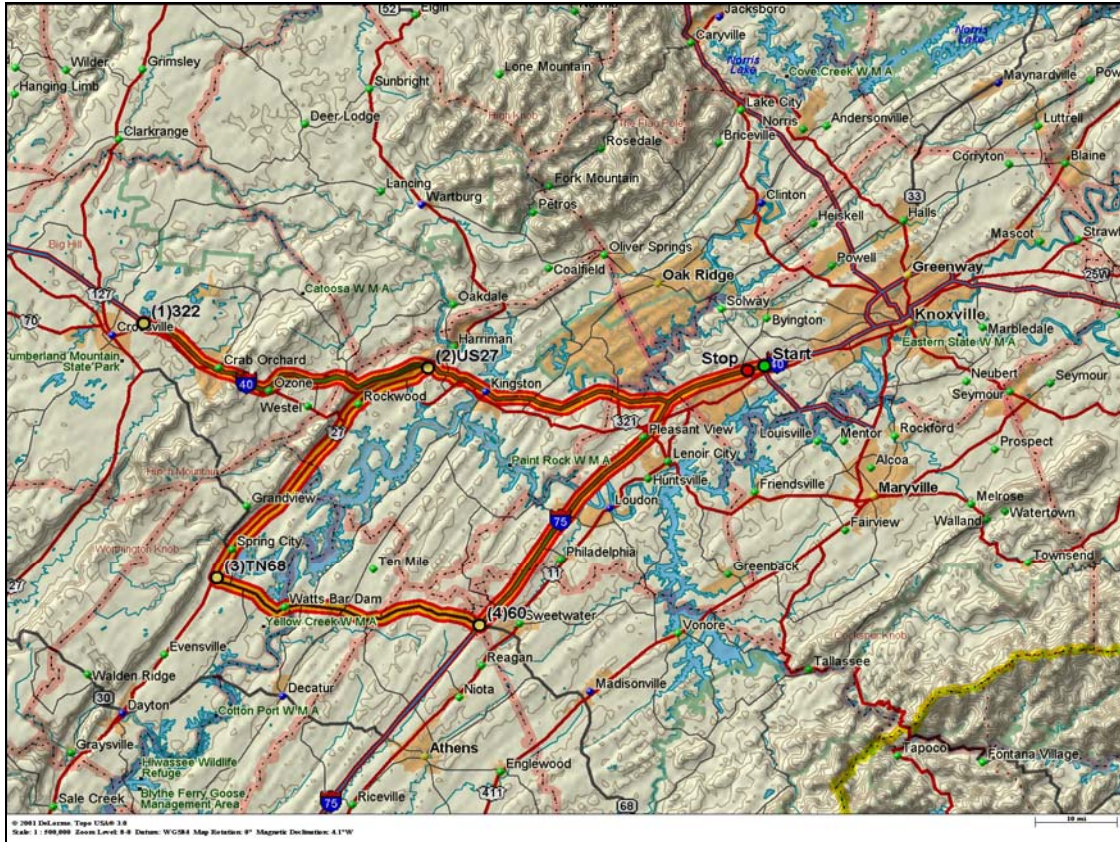


Figure 3.2: The on-road truck route (I-40, US-27, TN-68 and I-75)

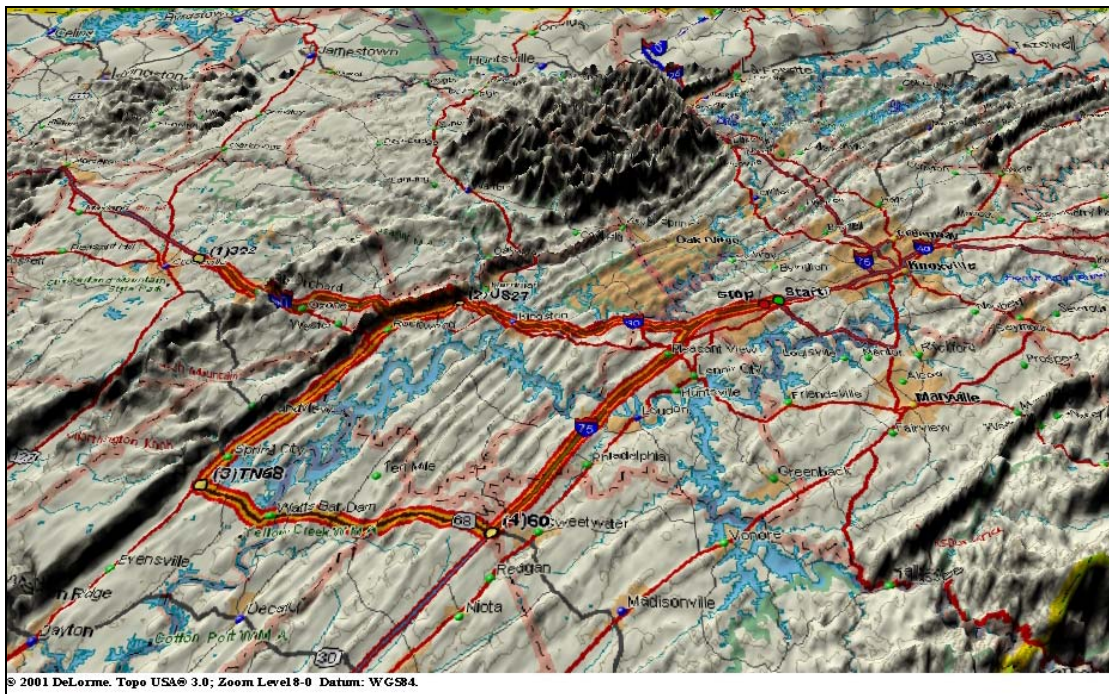


Figure 3.3: The relief of the terrain surrounding the truck route.

A three-dimensional relief map of the route is shown in the above Figure 3.3 to display the relative height of the hills and valleys that are adjoining the route.

The truck will then enter I-75 and proceed in a northeasterly direction back towards Knoxville. Along I-75, passing for a second time the junction of I-40 and I-75, i.e., MM 368 and MM 84, respectively; it should be noted that at this junction, I-75 becomes I-40 again. Finally the truck will proceed east on I-40 until reaching the Lovell Road exit (MM 374). The end point of the route for the on-road test is the Lovell Road exit. This segment of the route on I-75 and I-40 is approximately 35 miles in length; it represents interstate travel conditions over relatively flat terrain.

Every truck test was finished in two days. First day the initial equipment setup was done at the parking lot. Second day the road test was done along the scheduled route. Power was pulled from the truck's batteries and fed into portable power packs which powered the test equipments. Based on the ISO 2631-1 (1997) standard, three seat pads containing triaxial accelerometer were attached to both the seat pad cushions and the driver seat's back. A triaxial accelerometer was mounted to the floor under driver's seat and another one to the floor under passenger seat. The seat pads and triaxial accelerometers are listed in the Table 3.1 and their orientations are also shown.

Table 3.1: The transducer list and their orientations

Transducer List						
S. No	Transducer		Axis	Channel	Global Orientation	Local Orientation
1	Driver Back Seat Pad	☐ Check	X	34		
			Y	35		
			Z	36		
2	Driver Cushion Seat Pad	☐ Check	X	37		
			Y	38		
			Z	39		
3	Passenger Cushion Seat Pad	☐ Check	X	40		
			Y	41		
			Z	42		
4	Transducer under Driver	☐ Check	X	1		
			Y	2		
			Z	3		
5	Transducer under Passenger	☐ Check		4		
			X	5		
				6		

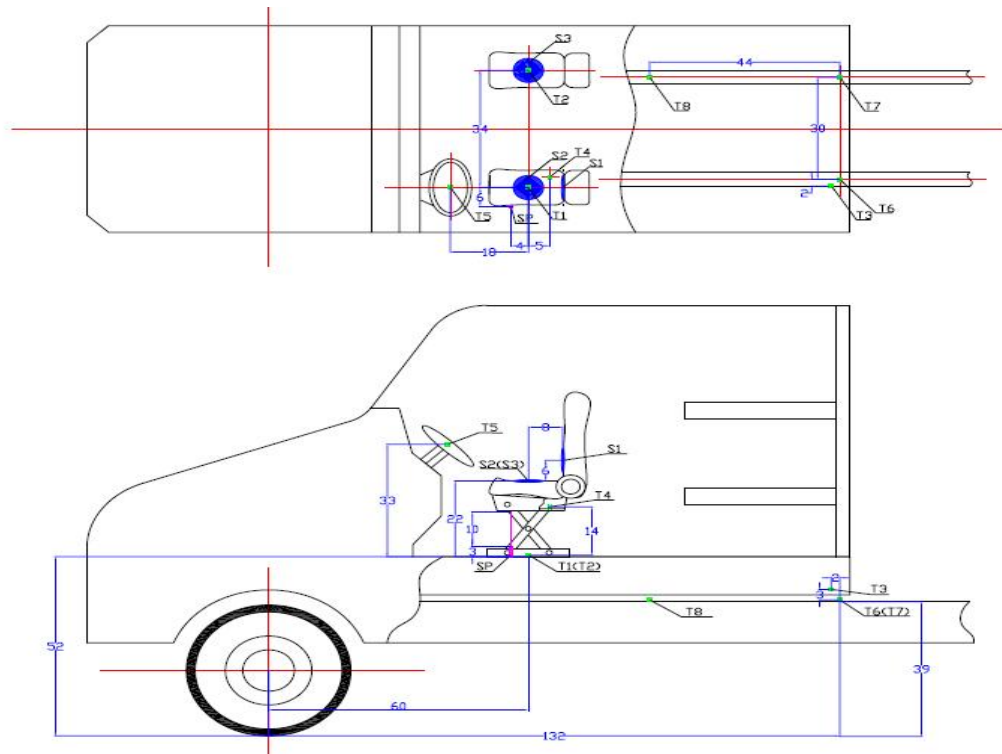


Figure 3.4: The locations of seat pads and triaxial accelerometers

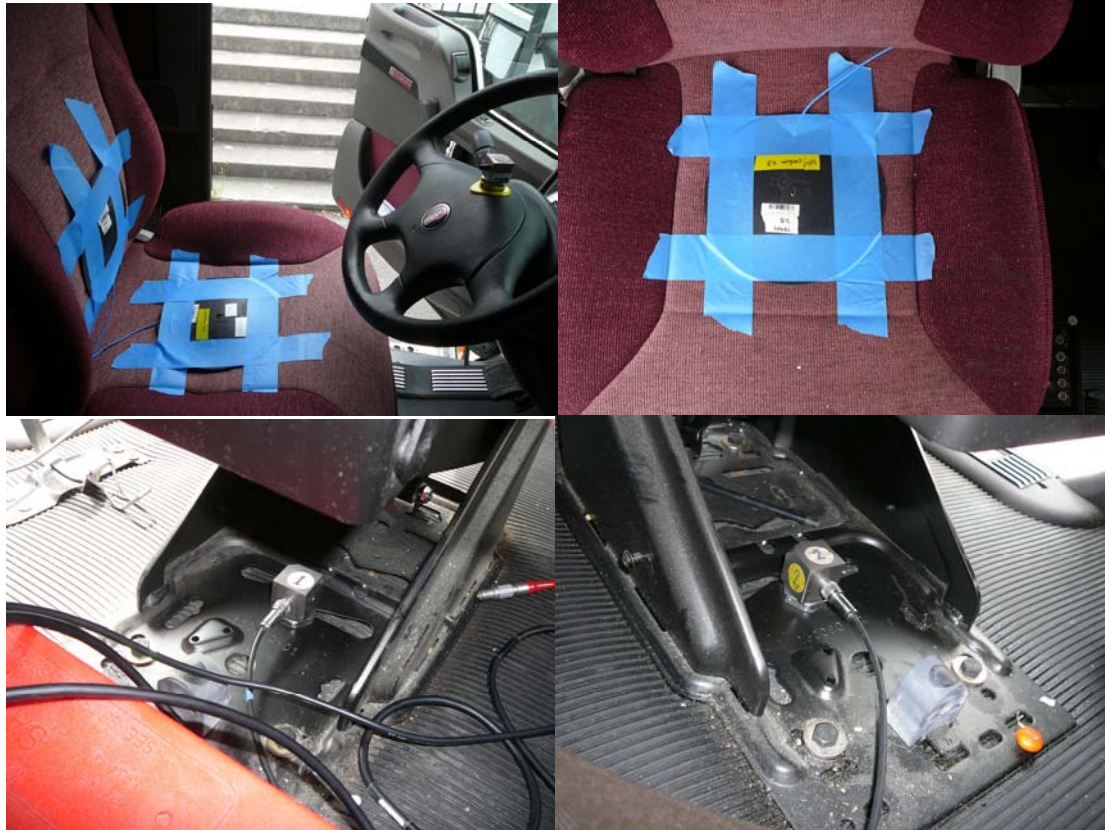


Figure 3.5: Seat pads and triaxial accelerometers at various locations

Also, the Figure 3.4 showed the locations of the seat pads and triaxial accelerometers used in the road tests. The Figure 3.5 showed the test transducers at various locations in the road tests. The complexity of the cab designs resulted in a little difference in mounting configurations of triaxial accelerometers.

The data was recorded and processed using a HVM-100 (hand-held vibration meter (Figure 3.6) as well as the DEWETRON data acquisition system (Figure 3.7 and Figure 3.8). For the first way, the HVM-100 recorded the driver seat pad's data in three channels along the 3 orthogonal directions [X-forward on truck, Y-side and Z-vertical] for the entire operating time every 5 min and gave directly the frequency-weighted RMS acceleration values after 1/3 octave filter. With these values, we compared with the ISO 2631-1 (1997) limits and had our conclusions.

For the second way, all the transducers' data were recorded, processed and analyzed around every 10 min by using the DEWETRON software DEWESoft. The data were

collected in fifteen channels for the entire operating time, with 3 channels along the 3 orthogonal directions for the driver, passenger and the floor. The recorded data were converted to Matlab files by DEWESoft. The files were then processed by using a Matlab program. After processing the data, frequency-weighted accelerations were calculated at each interval of time. The values were compared with the ISO 2631-1 (1997) standard. Besides acceleration, VDV and jerk rates were also calculated in this analysis.

3.2 Data acquiring and processing equipments

The data were acquired and processed with different equipments and programs. The following section gives a brief description to each of them.

3.2.1 HVM 100

The HVM 100 is a hand-held instrument for measuring human exposure to vibration, performing the relevant calculations and providing overall results on the LCD display. See the picture in Figure 3.6. Detailed vibration levels are easily stored in its built-in data logger, which can hold up to 100 separate time-history test files including all required metrics. It can perform simultaneous 3-channel measurements: X, Y and Z and can store up to 200 hours of time histories for each channel. Frequency weightings is automatically done fulfilling BS ISO 2631, 5349, 6841 and 8041 standards, both for hand-arm and whole-body vibration. Measuring all three axes of vibration simultaneously greatly simplifies the setup of a test and enhances the repeatability and correlation of the vibration data. From the three channels of measured data, the HVM 100 automatically calculates the important vector sum information and presents it as a fourth set of data values. Both Peak and RMS levels of the 3-axis may be stored together with the important vector sum. For compliance with the latest measurement standards, the HVM100 employs digital filters for each channel that can be enabled as needed, and will never be obsolete - should standards change, the filters can upgraded - electronically! The results, current and recalled from the memory can then be downloaded to a PC for analysis and archiving.



Figure 3.6: Larson Davis HVM 100

3.2.2 DEWETRON data acquisition system

3.2.2.1 DEWE-5001

The DEWE-5000 is one of the most popular multifunction data acquisition platforms provided by DEWETRON now. See the picture in Figure 3.7. It features the convenience of a notebook style design, where the display folds down and closes over the built-in keyboard when the system is not in use (you can also close it while the system is running if you like). Its rugged design and all-metal DEWETRON constructions set it apart from today's "plastic" instruments, and provide superior RFI/EMI/EMR/ESD characteristics. Everything is built this way, and tested in the lab for all of these parameters, as well as extreme temperature.

Like all DEWETRON systems, the DEWE-5001 is a rugged, all-metal PC instrument with high quality plug-in signal conditioning, one or more internal A/D cards, and great software. Because it's a regular computer running Windows XP, you can load whatever software you like. It has a DVD-CD-RW drive as standard, so you can burn gigabytes of data to inexpensive media in minutes. Or use the standard Ethernet or USB 2.0 interfaces to transfer data to another computer.



Figure 3.7: DEWE-5001

3.2.2.2 DEWESoft

Most data acquisition software packages allow us to display and record data from A/D boards, and to control signal conditioners. DEWESoft is the preeminent data acquisition software package in the world today because it can record all these different input types at the same time, and SYNCHRONOUSLY - regardless of their differing sample rates. DEWESoft not only does all this brilliantly, but also could add more information to the recorded data. We could plug one or more video cameras into the system and easily add synchronized VIDEO to your data. Or we could plug in a microphone for sound or a GPS antenna and suddenly record your exact position, heading, speed and distance for mobile applications, and we could draw a real-time map as we move around.

DEWESoft provides powerful user-configurable MATH channels, digital programmable filters, incredible customizable TRIGGERS, dynamic and static recording modes, and a combination dual speed recording mode. See the picture in Figure 3.8. It also can tap into the CAN BUS running through the vehicle and record the data from it. We don't have to add expensive wheel speed sensors or complicated steering wheel sensors (not easy with the airbags installed today - we have to remove the whole thing).

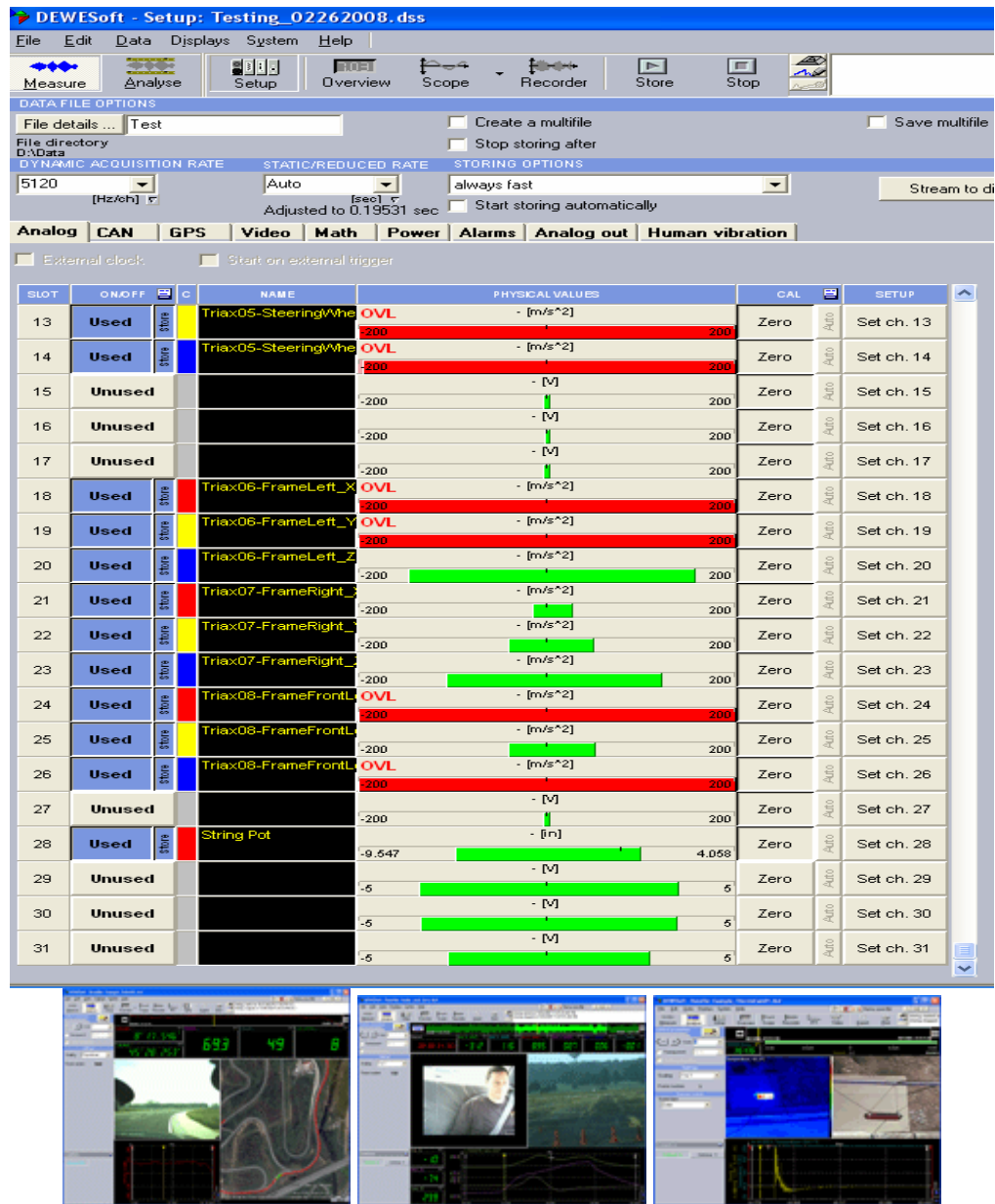


Figure 3.8: DEWESoft

3.2.3 Processing the converted files in Matlab

The Matlab program used for processing our files are compiled with Commercial Vehicles Group, Research and development division. Here are the steps to process the converted files in Matlab:

Create a new folder e.g. “Truck Test 1 01092008” (Truck name followed by the date).

Create subfolders “DataFiles”, “MatFiles”, “Analysis Results” and “Plots” under that folder.

Copy Matlab files AnalysisHeader.m, DeweSoftHeader.m under the directory where the recorded data are saved.

Open Matlab. Set the working directory to the “AnsiCodeUTK” subfolder where the all program files are saved.

Click Matlab menu File->set path, add the “AnsiCodeUTK” subfolder with the option “add with subfolders”.

Type `ISHVCode('WholeBody','DeweSoft',500,0,1,1,60);` select the converted data file to process.

The program will analyzed all the data file in the same subfolder. The results and the plots will be saved in ‘Plots’ and ‘AnalysisResults’ folders.

Chapter-4 HVM results and discussion

4.1 HVM 100 data study

HVM-100 was only used to measure the average RMS accelerations of the driver seat's cushion during our truck road test. As stated in the ISO 2631-1 (1997), for the evaluation of health performance, we applied the following frequency weighting by different axes for our tests with the multiplying factors as indicated:

- X-axis: W_d , $k=1.4$
- Y-axis: W_d , $k=1.4$
- Z-axis: W_k , $k=1.0$

For the evaluation of comfort performance, we applied the same frequency weighting but the multiplying factors are equal to one for all axes. These parameters were set up in the HVM-100 and every minute the HVM-100 gave us an average RMS acceleration value for each axis and a sum of three axes, the vibration total value, which calculated as stated in ISO 2631-1 (1997).

On an 8-hr driving day, regulations require that drivers exposed to over 0.5 m/s^2 frequency weighted RMS acceleration in any direction must be medically examined for spinal problems, and drivers should not be exposed to greater than 1.15 m/s^2 on driving days. For drivers exposed to 11-hr driving days, the exposure for medical examination drops to 0.426 m/s^2 and drivers should not be exposed to greater than 0.98 m/s^2 on driving days.

In brief, we had acquired the accelerations of the driver seat's cushion for 17 trucks with trailer loaded to analyze the health performance and the comfort performance of the truck on interstate and on the rural highway. Also we had tested three of these trucks from different makers without trailer loaded to make a comparison between different loading conditions.

4.2 HVM 100 data results for trucks with trailer

The following Table 4.1 and Figure 4.1 show the average RMS acceleration results on interstate and rural highway for one of trucks we tested. Every result is the average of 5 min segment results. The 8h STD and 11h STD in the figure are the minimum 8-hr and the minimum 11-hr standard limits requiring a medical examination. The vibration total values, Σ , of weighted RMS acceleration are also listed in the table. The X-axis and Y-axis are scaled by multiplying factor 1.4, and the Z-axis is scaled by multiplying factor 1. The vibration total value is calculated by using all multiplying factors 1.

On average, the weighted RMS acceleration values for all axes have not exceeded the standard limits. The scaled X, Y axes and Z axis have similar health performance. We could say this truck's health performance is good. All other test results obtained by processing the data are given in Appendix I. The average weighted RMS acceleration plots for trucks are given in Appendix II. The average RMS acceleration values greater than the minimum 8-hr or the 11-hr standard requiring a medical examination were highlighted with bold red or blue fonts, respectively.

Table 4.1: Average weighted RMS acceleration on Truck04

Truck 04	Segment	X	Y	Z	Σ	Road Type
	1	0.194	0.194	0.174	0.262	Interstate
	2	0.272	0.280	0.273	0.391	Interstate
	3	0.291	0.282	0.305	0.420	Interstate
	4	0.236	0.277	0.231	0.347	Interstate
	5	0.231	0.261	0.193	0.316	Interstate
	6	0.206	0.245	0.202	0.306	Interstate
	7	0.223	0.207	0.236	0.322	Interstate
	8	0.241	0.220	0.227	0.326	Highway
	9	0.220	0.196	0.221	0.306	Highway
	10	0.256	0.183	0.332	0.401	Highway
	11	0.256	0.244	0.326	0.412	Highway
	12	0.199	0.173	0.191	0.268	Highway
	13	0.214	0.197	0.230	0.309	Highway
	14	0.270	0.202	0.273	0.364	Highway
	15	0.304	0.350	0.311	0.454	Interstate
	16	0.272	0.246	0.275	0.380	Interstate
	17	0.265	0.249	0.272	0.377	Interstate

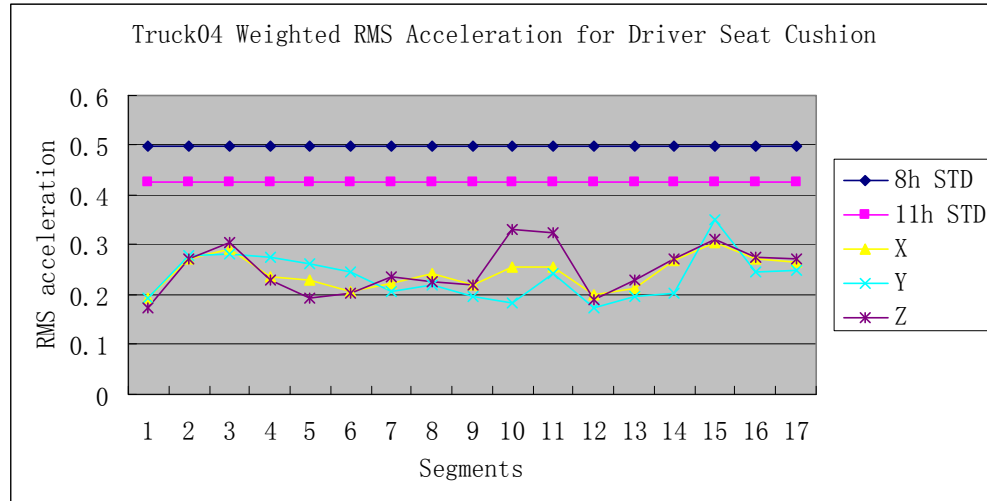


Figure 4.1: Average weighted RMS acceleration on Truck04

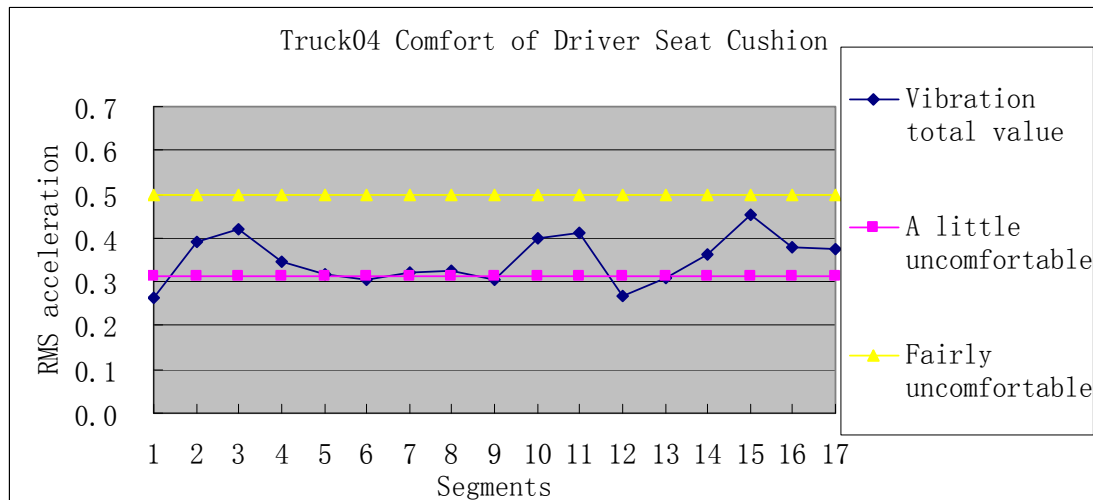


Figure 4.2: Vibration total value for comfort on Truck04

The vibration total values for the same truck are plotted in Figure 4.2. While looking at the chart, it can be seen that the driver may feel a little uncomfortable whereas it is not uncomfortable in two segments. Appendix-III contains the individual comfort charts for all trucks.

The following Table 4.2 shows the acceleration ranges of three axes measured by HVM 100 for the whole test of all tested trucks. The Table 4.3 and Figure 4.3 show the average RMS acceleration values of three axes measured by HVM 100 for the whole test of all tested trucks.

Table 4.2: Acceleration range of three axes

Truck	Range - a_x , m/s^2	Range - a_y , m/s^2	Range - a_z , m/s^2
Truck04	0.1582 – 0.3724	0.1456 – 0.3864	0.136 – 0.522
Truck05	0.1498 - 0.4802	0.1428 - 0.378	0.116 - 0.549
Truck06	0.1848 - 0.4158	0.1764 - 0.406	0.138 - 0.469
Truck07	0.1638 - 0.4018	0.154 - 0.343	0.123 - 0.457
Truck08	0.2002 - 0.6076	0.2072 - 0.5096	0.203 - 0.756
Truck09	0.189 - 1.456	0.2338 - 0.5278	0.181 - 0.676
Truck10	0.161 - 0.4746	0.2282 - 0.5656	0.182 - 0.752
Truck11	0.1242 - 0.511	0.1456 - 0.4774	0.196 - 0.726
Truck12	0.1582 - 0.5194	0.189 - 0.5488	0.221 - 0.759
Truck13	0.1582 - 0.4186	0.1932 - 0.5572	0.218 - 0.77
Truck14	0.1208 - 0.427	0.154 - 0.427	0.173 - 0.731
Truck15	0.1568 - 0.511	0.2198 - 0.7392	0.198 - 0.834
Truck16	0.1918 0.6356	0.1904 - 0.6146	0.163 - 0.819
Truck17	0.1778 - 0.599	0.151 - 0.512	0.2478 - 1.2054
Truck18	0.1387 - 0.4886	0.175 - 0.497	0.144 - 0.687
Truck19	0.1974 - 0.4956	0.2408 - 0.6734	0.2 - 0.641
Truck20	0.1191 - 0.322	0.1946 - 0.6664	0.144 - 0.598

Table 4.3: Average acceleration of three axes

Truck	a_x -avg., m/s^2	a_y -avg., m/s^2	a_z -avg., m/s^2	Σ -avg., m/s^2
Truck04	0.2432	0.235	0.2491	0.3485
Truck05	0.2687	0.2452	0.2932	0.3921
Truck06	0.3052	0.2542	0.2666	0.3903
Truck07	0.24	0.2214	0.25	0.3422
Truck08	0.3185	0.3127	0.3765	0.4921
Truck09	0.3222	0.3501	0.3731	0.5092
Truck10	0.2633	0.3335	0.3808	0.4872
Truck11	0.2292	0.2469	0.3443	0.4195
Truck12	0.2511	0.3232	0.4066	0.5008
Truck13	0.2326	0.3339	0.3836	0.4801
Truck14	0.2278	0.2583	0.3466	0.427
Truck15	0.2683	0.3793	0.3743	0.5005
Truck16	0.3167	0.3054	0.3446	0.4671
Truck17	0.2844	0.4798	0.2591	0.4752
Truck18	0.2492	0.2871	0.3160	0.4166
Truck19	0.2972	0.4103	0.3669	0.5140
Truck20	0.2017	0.3552	0.3065	0.4247

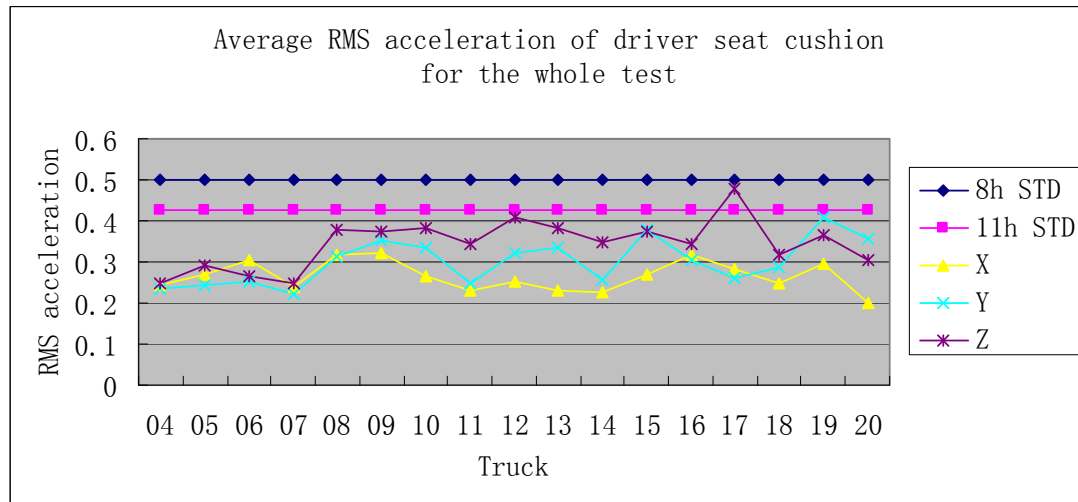


Figure 4.3: Average weighted RMS acceleration for trucks for the whole test

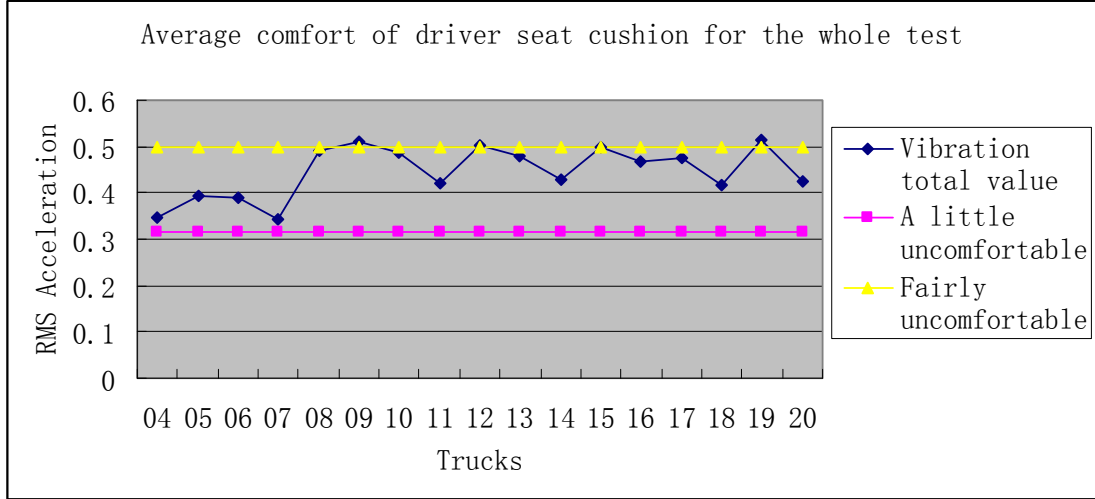


Figure 4.4: Vibration total value of comfort for trucks

Table 4.4: Acceleration range of three axes on interstate

Truck	Range - a_x , m/s^2	Range - a_y , m/s^2	Range - a_z , m/s^2
Truck04	0.1582 – 0.3542	0.638 – 0.3864	0.136 – 0.422
Truck05	0.1568 - 0.4116	0.161 - 0.3556	0.116 - 0.481
Truck06	0.1848 - 0.4158	0.1764 - 0.406	0.138 - 0.457
Truck07	0.1638 - 0.3556	0.154 - 0.3416	0.123 - 0.374
Truck08	0.2002 - 0.5894	0.2072 - 0.4914	0.203 - 0.629
Truck09	0.189 - 0.4438	0.2338 - 0.5278	0.181 - 0.6
Truck10	0.161 - 0.4746	0.2282 - 0.5656	0.182 - 0.613
Truck11	0.1242 - 0.3682	0.1456 - 0.378	0.196 - 0.525
Truck12	0.161 - 0.5194	0.189 - 0.5488	0.221 - 0.655
Truck13	0.1582 - 0.3882	0.2282 - 0.5572	0.218 - 0.602
Truck14	0.1208 - 0.427	0.154 - 0.427	0.173 - 0.577
Truck15	0.1568 - 0.4368	0.2534 - 0.6286	0.198 - 0.624
Truck16	0.1918 - 0.4816	0.1904 - 0.4802	0.163 - 0.599
Truck17	0.1778 - 0.4564	0.151 - 0.374	0.2478 - 0.8022
Truck18	0.1387 - 0.4004	0.175 - 0.4494	0.144 - 0.515
Truck19	0.1974 - 0.4956	0.2408 - 0.6734	0.2 - 0.597
Truck20	0.1498 - 0.2996	0.1946 - 0.6048	0.144 - 0.52

The average vibration total values of the whole test for all trucks are plotted in Figure 4.4. As we can see from the chart, most of our tested trucks had a little uncomfortable performance. There are four trucks which had a comfort performance in the beginning range of fairly uncomfortable.

The above Table 4.4 shows the acceleration ranges of three axes measured by HVM-100 for all tested trucks on interstate. The Table 4.5 and Figure 4.5 show the average RMS acceleration values of three axes measured by HVM-100 for all tested trucks on interstate. The average vibration total values on interstate for all trucks are plotted in Figure 4.6. As we can see from the chart, most of our tested trucks had a little uncomfortable performance. There is one truck which had a comfort performance in the beginning range of fairly uncomfortable.

Table 4.5: Average acceleration of three axes on interstate

Truck	a_x -avg., m/s^2	a_y -avg., m/s^2	a_z -avg., m/s^2	Σ -avg., m/s^2
Truck04	0.2478	0.2581	0.2437	0.3538
Truck05	0.2613	0.2344	0.2647	0.3638
Truck06	0.2904	0.2438	0.2365	0.3603
Truck07	0.2352	0.2177	0.2432	0.3342
Truck08	0.3031	0.3033	0.3573	0.4685
Truck09	0.2935	0.3493	0.3667	0.4914
Truck10	0.2584	0.3223	0.3784	0.4794
Truck11	0.2175	0.2391	0.3285	0.4009
Truck12	0.2523	0.3295	0.4075	0.5040
Truck13	0.2248	0.3442	0.3620	0.4636
Truck14	0.2175	0.2513	0.3292	0.4059
Truck15	0.2560	0.3698	0.3489	0.4741
Truck16	0.2933	0.2843	0.3232	0.4360
Truck17	0.2704	0.2489	0.4512	0.4507
Truck18	0.2418	0.2830	0.3063	0.4059
Truck19	0.2902	0.3860	0.3495	0.4905
Truck20	0.2059	0.3374	0.2957	0.4095

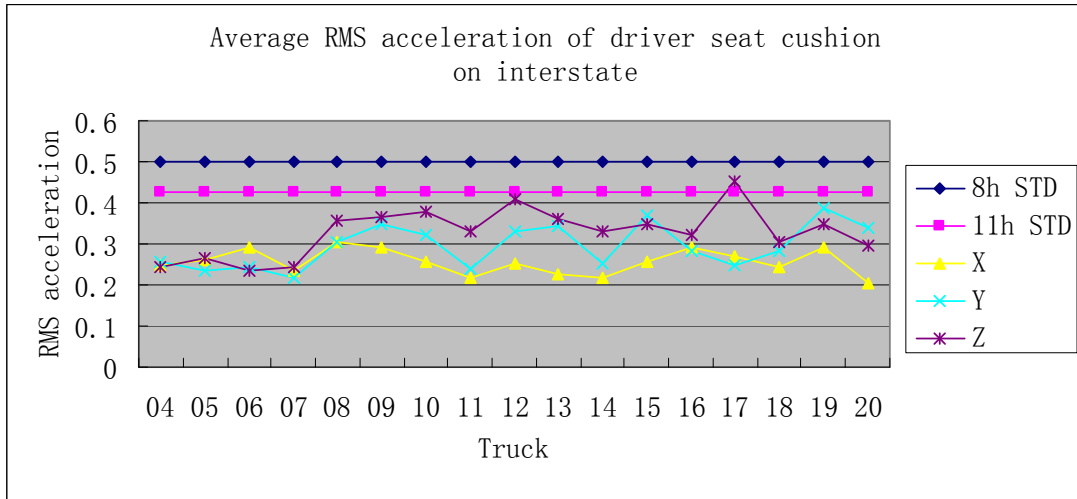


Figure 4.5: Average weighted RMS acceleration for trucks on interstate

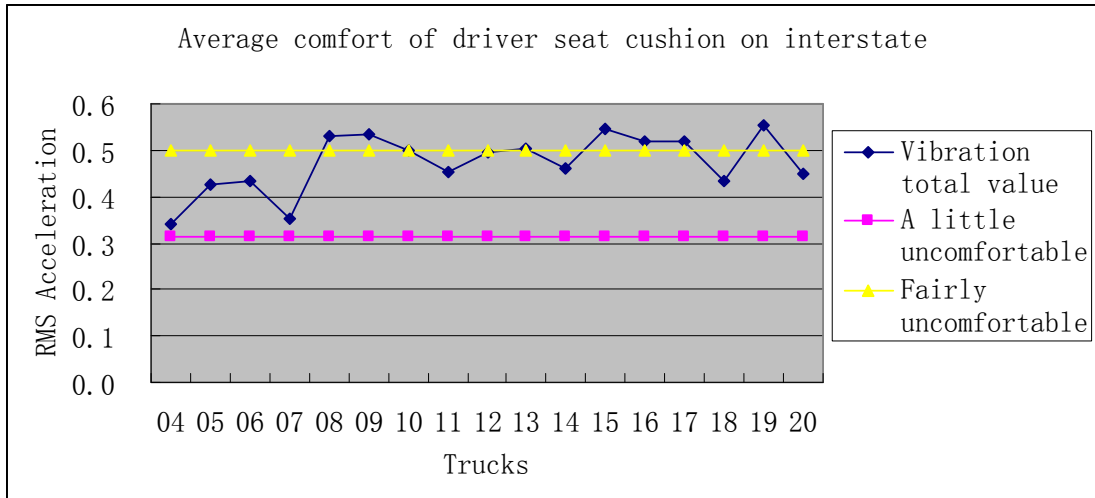


Figure 4.6: Vibration total value of comfort for trucks on interstate

The following Table 4.6 shows the acceleration ranges of three axes measured by HVM-100 for all tested trucks on rural highway. The Table 4.7 and Figure 4.7 show the average RMS acceleration values of three axes measured by HVM-100 for all tested trucks on rural highway.

Table 4.6: Acceleration range of three axes on rural highway

Truck	Range - a_x , m/s^2	Range - a_y , m/s^2	Range - a_z , m/s^2
Truck04	0.1596 – 0.3724	0.1456 – 0.2912	0.166 – 0.522
Truck05	0.1498 - 0.4802	0.1428 - 0.378	0.78 - 0.549
Truck06	0.2338 - 0.4074	0.1988 - 0.3976	0.182 - 0.469
Truck07	0.1834 - 0.4018	0.1652 - 0.343	0.152 - 0.457
Truck08	0.2114 - 0.6076	0.2226 - 0.5096	0.213 - 0.756
Truck09	0.2002 - 1.456	0.2422 - 0.5138	0.202 - 0.676
Truck10	0.1764 - 0.469	0.2296 - 0.5404	0.204 - 0.752
Truck11	0.1355 - 0.511	0.1624 - 0.4774	0.221 - 0.726
Truck12	0.1582 - 0.4592	0.2086 - 0.5236	0.23 - 0.759
Truck13	0.1694 - 0.4186	0.1932 - 0.497	0.254 - 0.77
Truck14	0.1568 - 0.4186	0.1736 - 0.42	0.215 - 0.731
Truck15	0.1834 - 0.511	0.2198 - 0.7392	0.227 - 0.834
Truck16	0.259 - 0.6356	0.21 - 0.6146	0.222 - 0.819
Truck17	0.217 - 0.595	0.155 - 0.512	0.2982 - 1.2054
Truck18	0.1722 - 0.4886	0.182 - 0.497	0.202 - 0.687
Truck19	0.2016 - 0.4662	0.2674 - 0.658	0.24 - 0.641
Truck20	0.1191 - 0.322	0.1946 - 0.6664	0.184 - 0.598

Table 4.7: Average acceleration of three axes on rural highway

Truck	a_x -avg., m/s^2	a_y -avg., m/s^2	a_z -avg., m/s^2	Σ -avg., m/s^2
Truck04	0.2366	0.2021	0.2569	0.3409
Truck05	0.2777	0.2585	0.3281	0.4266
Truck06	0.3264	0.2690	0.3096	0.4331
Truck07	0.2460	0.2262	0.2589	0.3525
Truck08	0.3425	0.3275	0.4066	0.5292
Truck09	0.3618	0.3511	0.3820	0.5336
Truck10	0.2709	0.3508	0.3845	0.4994
Truck11	0.2495	0.2605	0.3721	0.4522
Truck12	0.2489	0.3123	0.4051	0.4952
Truck13	0.2445	0.3184	0.4162	0.5051
Truck14	0.2451	0.2700	0.3758	0.4620
Truck15	0.2888	0.3952	0.4166	0.5445
Truck16	0.3557	0.3405	0.3803	0.5189
Truck17	0.3084	0.2763	0.5284	0.5171
Truck18	0.2615	0.2940	0.3321	0.4343
Truck19	0.3088	0.4509	0.3958	0.5532
Truck20	0.1947	0.3848	0.3245	0.4502

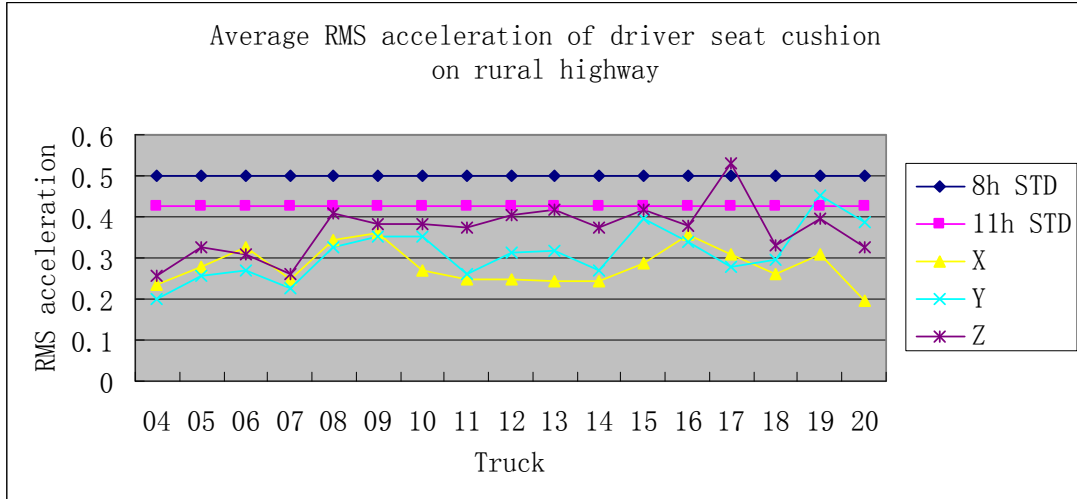


Figure 4.7: Average weighted RMS acceleration for trucks on rural highway

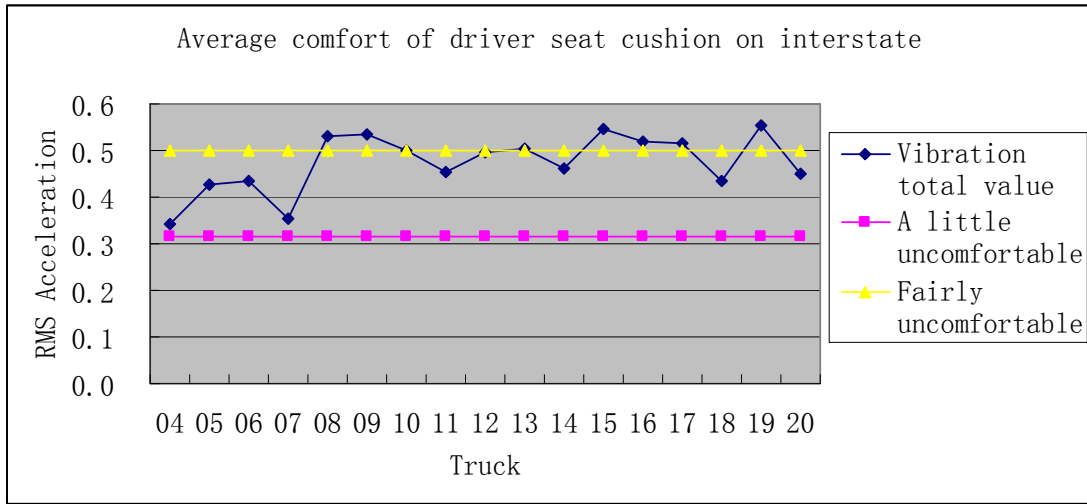


Figure 4.8: Vibration total value of comfort for trucks on rural highway

The average vibration total values on rural highway for all trucks are plotted in Figure 4.8. As we can see from the chart, all other tested trucks had a little uncomfortable performance except that those seven trucks which had a comfort performance in the range of fairly uncomfortable.

4.3 HVM 100 data discussions

4.3.1 Summary of truck observations with trailer

From the Table 4.2, Table 4.4 and Table 4.6, we can see the frequency-weighted RMS acceleration ranges in three axes for the whole test and on the separated road types: interstate and rural highway. Most of our trucks had a range between 0.1 m/s^2 and 0.6 m/s^2 in X-axis, a range between 0.15 m/s^2 and 0.7 m/s^2 in Y-axis, and a range between 0.15 m/s^2 and 0.8 m/s^2 in Z-axis. There were two instances that the acceleration exceeded 1 m/s^2 as the road conditions were too bad. We also can find that the trucks' minimum and maximum acceleration values are little lower on the interstate than on the rural highway for major of our trucks.

The Table 4.3, Table 4.5 and Table 4.7 show the average RMS accelerations in three axes for the whole test and on the separated road types: interstate and rural highway. In brief,

driver exposure is safe but he may feel a bit uncomfortable while driving on the way which can affect end of the day performance. For most trucks we tested, the driver seat in the trucks had sufficient actions to provide the required protection, but the values being measured are above the driver comfort levels as stated in the ISO 2631-1. The Truck17 had the worst health performance in Z-axis in all our tested trucks. Its average RMS acceleration in Z-axis exceeded the minimum 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination many times. And the worst segment's actions almost reached 0.8 m/s^2 .

As we can see from the results, at most of times, the Z-axis had the worst health performance and the X-axis had the best health performance for our trucks. But for the Truck06, the worst situation happened in the X-axis. For the Truck15, Truck19 and Truck20, the Y-axis had the worst performance except that the Truck15 had the worst health performance in the Z-axis when it was on the rural highway.

The following Figure 4.9, Figure 4.10 and Figure 11 show the comparison of RMS accelerations in three axes among the whole test and two different road types: interstate and rural highway. As shown in the figures for comparison of RMS acceleration in each axis for different road types, there were 14 trucks which had the worst health performance on rural highway in X-axis, 14 trucks which had the worst health performance on rural highway in Y-axis, and all trucks which had the worst health performance on rural highway in Z-axis except that the truck12 had a little worse performance on interstate than on the rural highway. Compared the average vibration actions between on the interstate and on the rural highway, we can find that the truck had a better health performance on the interstate than on the rural highway for all three axes except several instances.

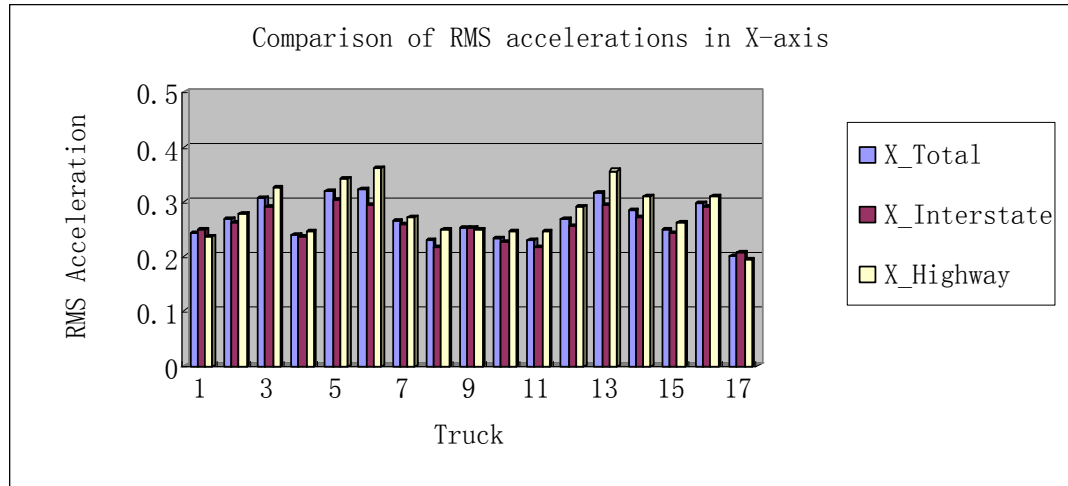


Figure 4.9: Comparison of RMS acceleration in X-axis

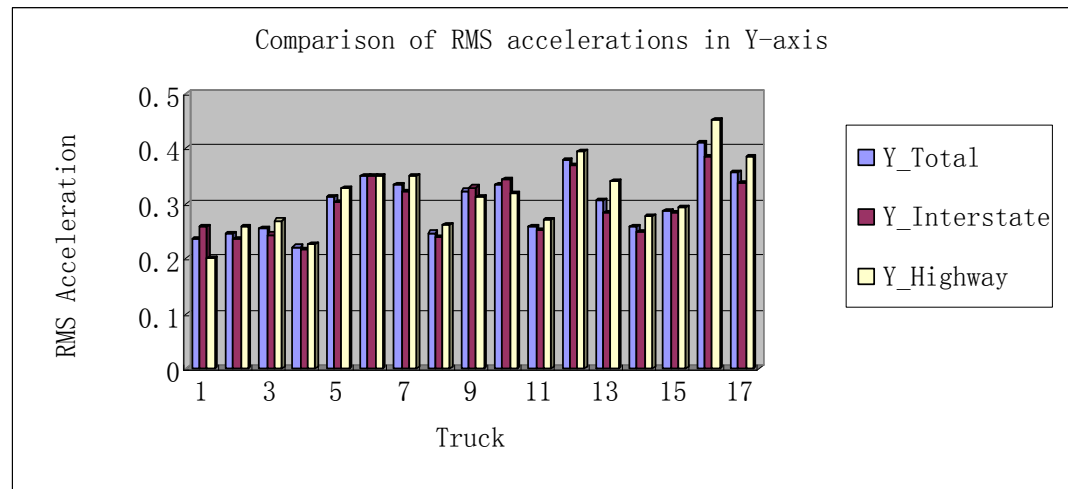


Figure 4.10: Comparison of RMS acceleration in Y-axis

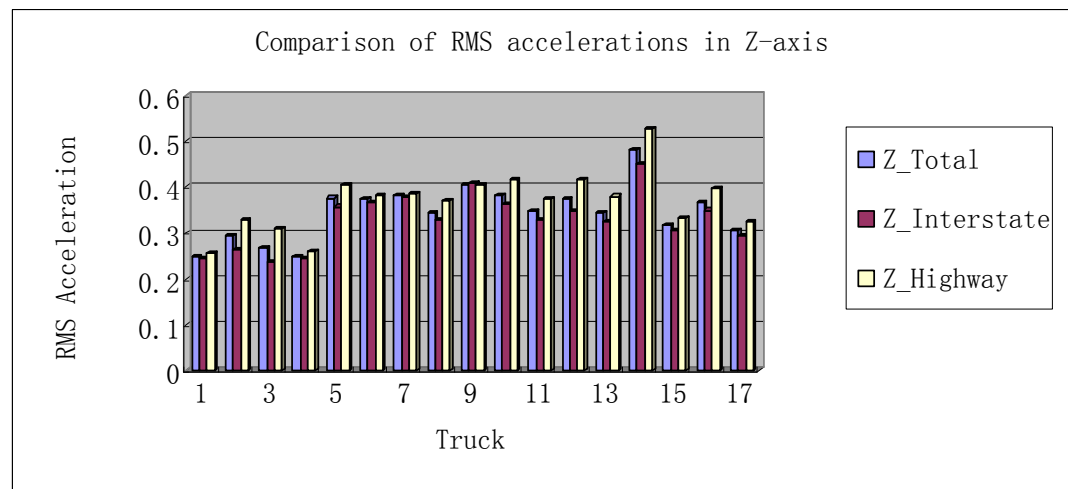


Figure 4.11: Comparison of RMS acceleration in Z-axis

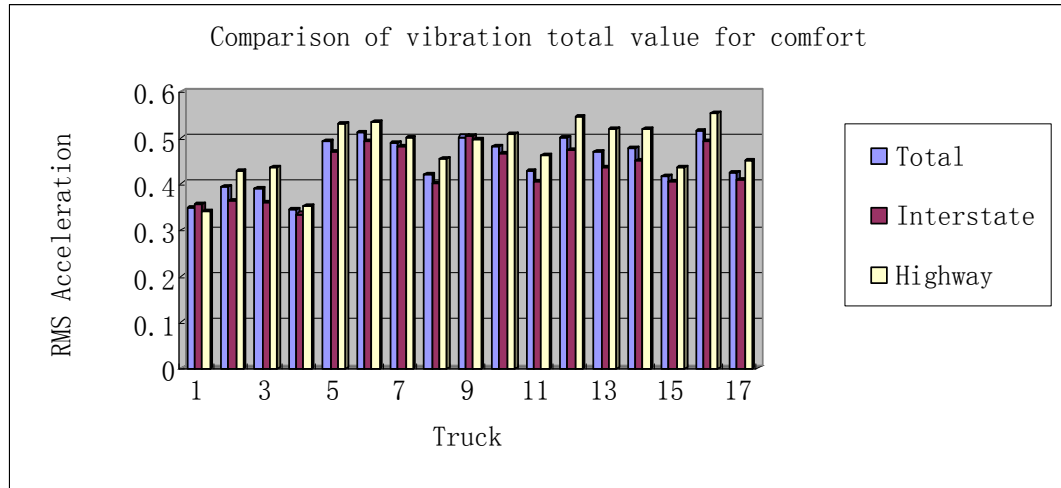


Figure 4.12: Comparison of vibration total value of comfort

Looking at the levels of comfort, from the Figure 4.4, we can say that we had 14 trucks that the comfort performance is in the range of a little uncomfortable as stated in ISO 2631-1. The other 4 trucks' comfort performance is in the beginning range of fairly uncomfortable. While we focused on the performance on interstate, we saw from the Figure 4.6 and Figure 4.8 that all trucks had a comfort performance in the range of a little uncomfortable except for Truck12, which is in the beginning range of fairly uncomfortable. But on rural highway, we had almost half of trucks' comfort performance in the range of fairly uncomfortable, which are all below 0.6 m/s^2 .

The Comparison of vibration total value among the whole test and two different road types is showed in Figure 4.12. Except for the Truck04 and Truck12, we found that all other trucks had a better comfort performance on interstate than on rural highway. The possible reason is that the road conditions on interstate are better.

This suggests again the driver seat was good enough to protect the driver whereas there is bit uncomfortable while driving on the way. For the whole test, we found the Truck19 had the worst comfort performance with an average vibration total value of 0.514 m/s^2 , which is above a little the fairly uncomfortable limit. While driving on the interstate, we found that the Truck12 had the worst comfort performance with an average vibration total value of 0.504 m/s^2 . While on the rural highway, we found that the Truck19 had the worst comfort performance with an average vibration total value of 0.5532 m/s^2 .

4.3.2 Individual Truck Observations

The following section is the main observations for individual truck with trailer we tested for the whole test and on two road types: interstate and rural highway.

Truck04: this truck had 17 segments for the road test, 10 on the interstate and 7 on the rural highway. As we can see from the results, this truck had a very good health performance during the driving. The worst instance happened in the Y-axis of the segment 15, 0.35 m/s^2 , which is well below the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As recorded, the truck was running on the interstate I-75N where was constructing in this segment. This could be the reason why the worst instance happened here. Except this segment, all other segments had a similar health performance in X and Y axes. And Compared to the scaled X and Y actions, the Z-axis still had the worst health performance for most of testing segments. And we can tell that this truck had a little better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 12 segments. In other 5 segments the comfort performance is in the range of not uncomfortable. And we can tell that this truck had a similar comfort performance on interstate and on highway.

Truck05: this truck had 20 segments for the road test, 10 on the interstate and 10 on the rural highway. As we can see from the results, this truck also had a very good health performance during the driving. The worst instance happened in the Z-axis of the segment 10, 0.401 m/s^2 , which is a little below the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, all segments had a similar health performance in X and Y axes. And Compared to the scaled X and Y actions, the Z-axis still had the worst health performance for most of testing segments. And we can tell that this truck had a little better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 17 segments. There was one segment in which the comfort performance is in the beginning range of fairly uncomfortable. The rest 2 segments had a comfort performance in the

range of not uncomfortable. And we can tell that this truck had a little better comfort performance on interstate than on highway.

Truck06: this truck had 17 segments for the road test, 10 on the interstate and 7 on the rural highway. As we can see from the results, this truck also had a very good health performance during the driving. The worst instance happened in the Z-axis of the segment 10, 0.353 m/s^2 , which is well below the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, all segments had a similar health performance in Y and Z axes except two segments. And Compared among the scaled X, the scaled Y and Z actions, the scaled X-axis had the worst health performance for all of testing segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 16 segments. There was one segment in which the comfort performance is in the range of not uncomfortable. And we can tell that this truck had a little better comfort performance on interstate than on highway.

Truck07: this truck had 16 segments for the road test, 9 on the interstate and 7 on the rural highway. As we can see from the results, this truck also had a very good health performance during the driving. The worst instance happened in the Z-axis of the segment 11, 0.318 m/s^2 , which is well below the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, all segments had a similar health performance in X, Y and Z axes. And Compared among the scaled X, the scaled Y and Z actions, the Z-axis had the worst health performance for all of testing segments except segment 8, in which the X-axis had the worst performance. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 10 segments. All other segments had the comfort performance in the range of not uncomfortable. And we can tell that this truck had a little better comfort performance on interstate than on highway.

Truck08: this truck had 18 segments for the road test, 11 on the interstate and 7 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving because it had several segments which exceeded the 8-hr and 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 10, 0.651 m/s^2 , which is well above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . There were other 3 segments, in which the vibration in Z-axis is over the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, all segments had a similar health performance in X and Y axes. And Compared among the scaled X, the scaled Y and Z actions, the Z-axis had the worst health performance for all of testing segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 12 segments. All other segments had the comfort performance in the range of fairly uncomfortable except the segment 10 had the comfort performance in the range of uncomfortable. And we can tell that this truck had a similar comfort performance on interstate and on highway.

Truck09: this truck had 19 segments for the road test, 11 on the interstate and 8 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving because it had two segments which exceeded the 8-hr standard requiring a medical examination and one segment which exceeded the 11-hr standard requiring a medical examination. The worst instance happened in the scaled X-axis of the segment 16, 0.543 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the first half part of segments had a similar health performance in Y and Z axes. The X-axis had a lower vibration than other two axes. The second half part of segments had a similar performance in X and Y axes except two segment 11 and 16. The Z-axis had the worst performance for this part. And Compared among the scaled X, the scaled Y and Z actions, the Z-axis had a little worse health performance than two other axes. And we can tell that this truck had a little better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 8 segments. All other

segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a better comfort performance on interstate than on highway.

Truck10: this truck had 23 segments for the road test, 14 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving because it had one segments which exceeded the 8-hr standard requiring a medical examination and four segments which exceeded the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 14, 0.606 m/s^2 , which is well above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had the best health performance for all segments. The scaled Y-axis had a worse health performance than the scaled X-axis and the Z-axis had the worst performance for all other segments except the segment 7, 11 and 16 had the worst performance in the scaled Y-axis. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 14 segments. All other segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a little better comfort performance on interstate than on highway.

Truck11: this truck had 22 segments for the road test, 14 on the interstate and 8 on the rural highway. As we can see from the results, this truck had a very good health performance during the driving and it only had one segment which exceeded the 8-hr standard requiring a medical examination and one segment which exceeded the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 13, 0.53 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis and the scaled Y-axis had a similar health performance for all segments. The scaled Y-axis had a little worse health performance than the scaled X-axis for most of segments. The Z-axis had the worst performance for all other segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 16 segments. There were 3 segments

which had the comfort performance in the range of fairly uncomfortable and 3 segments which had the comfort performance in the range of not uncomfortable. And we can tell that this truck had a better comfort performance on interstate than on highway.

Truck12: this truck had 22 segments for the road test, 14 on the interstate and 8 on the rural highway. As we can see from the results, this truck had a not good health performance during the driving because it had nine segment which exceeded the 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 10, 0.518 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had a better health performance than the scaled Y-axis for all segments except segment 20. The Z-axis had the worst or equal performance for all segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for half segments. The other half segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a little better comfort performance on interstate than on highway.

Truck13: this truck had 22 segments for the road test, 13 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving and it had seven segments which exceeded the 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 13, 0.543 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had the best health performance and it was well below the scaled Y-axis and the Z-axis for all segments. The Z-axis had a better performance than the scaled Y-axis for the first six segments. And the Z-axis had a worse performance than the scaled Y-axis for the rest segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 16 segments. The rest

segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a much better comfort performance on interstate than on highway.

Truck14: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving and it had four segments which exceeded the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 19, 0.475 m/s^2 , which is a little above the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, the scaled X-axis had the best health performance and it was a little below the scaled Y-axis for all segments. And the Z-axis had the worst health performance for most of segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 17 segments. There were 5 segments which had the comfort performance in the range of fairly uncomfortable and 2 segments which had the comfort performance in the range of not uncomfortable. And we can tell that this truck had a better comfort performance on interstate than on highway.

Truck15: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving and it had had seven segments which exceeded the 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 15, 0.616 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had the best health performance and it was well below the scaled Y-axis and the Z-axis for all segments. And the scaled Y-axis and the Z-axis had a similar health performance for most of segments. Half segments had the scaled Y-axis over the Z-axis and another half segments had the Z-axis over the scaled Y-axis (most happened on the rural highway). And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 11 segments. The other 13 segments

had the comfort performance in the range of fairly uncomfortable and the segment 15 reached the point 0.774 m/s^2 . And we can tell that this truck had a better comfort performance on interstate than on highway.

Truck16: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving and it had four segments which exceeded the 11-hr standard requiring a medical examination and one segment which exceeded the 8-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 15, 0.557 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis, the scaled Y-axis and the Z-axis had a similar health performance for most of segments. And the Z-axis had the worst or equal health performance for all segments. And we can tell that this truck had a much better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 16 segments. The other 8 segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a better comfort performance on interstate than on highway.

Truck17: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a very bad health performance during the driving and it had six segments which exceeded the 11-hr standard requiring a medical examination and seven segments which exceeded the 8-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 15, 0.791 m/s^2 , which is much above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis and the scaled Y-axis had a similar health performance which was well below the 11-hr standard requiring a medical examination for all segments. The scaled X-axis had a little worse performance than the scaled Y-axis for most of segments. And the Z-axis had the worst health performance for all segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as

stated in ISO-2631-1 for 17 segments. The other 7 segments had the comfort performance in the range of fairly uncomfortable and the segment 15 reached the point 0.791 m/s^2 . And we can tell that this truck had a well better comfort performance on interstate than on highway.

Truck18: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a good health performance during the driving and it had two segments which exceeded the 11-hr standard requiring a medical examination. The worst instance happened in the Z-axis of the segment 21, 0.458 m/s^2 , which is a little above the minimum 11-hr standard requiring a medical examination 0.426 m/s^2 . As we can see, the scaled X-axis and the scaled Y-axis had a similar health performance which was well below the 11-hr standard requiring a medical examination for all segments. The scaled X-axis had a little better performance than the scaled Y-axis for all segments. And the Z-axis had the worst or equal health performance for all segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 19 segments. The other 4 segments had the comfort performance in the range of fairly uncomfortable and the last segment had the comfort performance in the range of not uncomfortable. And we can tell that this truck had a well better comfort performance on interstate than on highway.

Truck19: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a not good health performance during the driving and it had ten segments which exceeded the 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination. The worst instance happened in the scaled Y-axis of the segment 16, 0.521 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had the best health performance which was well below the 11-hr standard requiring a medical examination for all segments. The scaled Y-axis had the worst health performance and the Z-axis was a little below the scaled Y-axis for most of segments. And we can tell that this truck had a better health performance on interstate

than on highway. For the comfort performance, this driver felt a little uncomfortable as stated in ISO-2631-1 for 11 segments. The other 13 segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a well better comfort performance on interstate than on highway.

Truck20: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway. As we can see from the results, this truck had a just good health performance during the driving and it had three segments which exceeded the 11-hr standard requiring a medical examination and one segment which exceeded the 8-hr standard requiring a medical examination. The worst instance happened in the scaled Y-axis of the segment 16, 0.526 m/s^2 , which is a little above the minimum 8-hr standard requiring a medical examination 0.5 m/s^2 . As we can see, the scaled X-axis had the best health performance which was well below the 11-hr standard requiring a medical examination for all segments. The scaled Y-axis had the worst health performance and the Z-axis was a little below the scaled Y-axis for most of segments. And we can tell that this truck had a better health performance on interstate than on highway. For the comfort performance, this driver felt a little uncomfortable for 20 segments. The other 4 segments had the comfort performance in the range of fairly uncomfortable. And we can tell that this truck had a well better comfort performance on interstate than on highway.

4.3.3 Comparison of truck vibration with trailer and no-trailer

We had tested three trucks without trailer: truck12, truck18 and truck20. All test results obtained by processing the recorded data are given in Appendix IV. The following Table 4.8 shows the acceleration ranges of three axes measured by HVM-100 for truck12, truck18 and truck20 when they were with trailer and without trailer. We can found the range of acceleration for trucks without trailer is a little higher than the trucks with trailer.

Table 4.8: Acceleration range of three axes

Truck	Range - a_x , m/s ²	Range - a_y , m/s ²	Range - a_z , m/s ²	Trailer/ No-Trailer
Truck12	0.1582 - 0.5194	0.189 - 0.5488	0.221 - 0.759	Yes
	0.161 - 0.5194	0.189 - 0.5488	0.288 - 0.807	
	0.1582 - 0.4592	0.2086 - 0.5236	0.23 - 0.759	
	0.1285 - 1.0206	0.217 - 0.5726	0.217 - 0.753	No
	0.1428 - 1.0206	0.217 - 0.5726	0.217 - 0.691	
	0.1285 - 0.455	0.2268 - 0.5306	0.221 - 0.753	
Truck18	0.1387 - 0.4886	0.175 - 0.497	0.144 - 0.687	Yes
	0.1387 - 0.4004	0.175 - 0.4494	0.144 - 0.687	
	0.1722 - 0.4886	0.182 - 0.497	0.202 - 0.687	
	0.1414 - 1.722	0.1834 - 0.476	0.17 - 0.539	No
	0.1582 - 1.722	0.224 - 0.476	0.17 - 0.517	
	0.1414 - 0.4704	0.1834 - 0.4592	0.183 - 0.539	
Truck20	0.1191 - 0.322	0.196 - 0.6664	0.144 - 0.598	Yes
	0.1498 - 0.2996	0.196 - 0.6048	0.144 - 0.52	
	0.1191 - 0.322	0.1946 - 0.6664	0.184 - 0.598	
	0.1274 - 0.3416	0.1708 - 0.5558	0.154 - 0.713	No
	0.1904 - 0.3416	0.2128 - 0.5278	0.189 - 0.6	
	0.1274 - 0.2996	0.1708 - 0.5558	0.154 - 0.713	

The following Table 4.9 shows the average RMS acceleration of three axes measured by HVM-100 for Truck12, Truck18 and Truck20 when they were with trailer and without trailer. The vibration total values for comfort evaluation are also listed in this table. We can found that the average RMS accelerations for trucks without trailer are a little higher than the trucks with trailer for most of the instances, whenever the trucks were droved on interstate or on the rural highway. We also can see that the vibration total values are higher for trucks without trailer than for trucks with trailer, which mean that the trucks had a better comfort performance when loaded with trailer.

Table 4.9: Average RMS acceleration of three axes

Truck	X	Y	Z	Σ	Road Type	Trailer/ No-Trailer
Truck12	0.2511	0.3232	0.4066	0.5008	Total	Yes
	0.2523	0.3295	0.4075	0.5040	Interstate	
	0.2489	0.3123	0.4051	0.4952	Highway	
	0.2332	0.3498	0.4201	0.5175	Total	No
	0.2320	0.3469	0.4112	0.5099	Interstate	
	0.2355	0.3550	0.4362	0.5312	Highway	
Truck18	0.2492	0.2871	0.3160	0.4166	Total	Yes
	0.2418	0.2830	0.3063	0.4059	Interstate	
	0.2615	0.2940	0.3321	0.4343	Highway	
	0.2631	0.3027	0.3128	0.4231	Total	No
	0.2705	0.3034	0.3133	0.4318	Interstate	
	0.2527	0.3018	0.3122	0.4109	Highway	
Truck20	0.2017	0.3552	0.3065	0.4247	Total	Yes
	0.2059	0.3374	0.2957	0.4095	Interstate	
	0.1947	0.3848	0.3245	0.4502	Highway	
	0.2247	0.3240	0.3384	0.4425	Total	No
	0.2366	0.3321	0.3331	0.4439	Interstate	
	0.2050	0.3107	0.3472	0.4402	Highway	

The following section is the comparing observations for individual truck with trailer and without trailer we tested.

Truck12: this truck had 22 segments for the road test, 14 on the interstate and 8 on the rural highway for both the test with trailer and the test without trailer. As we can see from the results, the truck test with trailer had a better health performance than without trailer. We had more segments which exceeded the 8-hr standard requiring a medical examination or the 11-hr standard requiring a medical examination. The worst instance for the test with trailer is happened in the Z-axis of the segment 10, 0.518 m/s^2 , as the worst instance for the test without trailer is happened in the Z-axis of the segment 14, 0.607 m/s^2 . As we can see, the scaled X-axis of the test with trailer had a little worse health performance for most of segments. But the scaled Y-axis and the Z-axis of the test with trailer had a better health performance for most of segments. And we also can find that the test with trailer had a little better comfort performance than the test without trailer for many segments.

Truck18: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway for the test with trailer and 14 on the interstate and 10 on the rural highway for the test without trailer. As we can see from the results, the truck test with trailer had a similar health performance with the test without trailer except some segment. The segment 8 had the worst action 0.529 in the scaled X-axis for the test without trailer, maybe because of a damaged road surface input. The worst instance for the test with trailer is happened in the Z-axis of the segment 21, 0.458 m/s^2 . As we can see, the scaled X-axis, the scaled Y-axis and the Z-axis had a similar health performance for most of segments. But there were several instances which had a much higher acceleration for the test with trailer in all three axes. And we also can see this phenomenon while looking at the comfort performance.

Truck20: this truck had 24 segments for the road test, 15 on the interstate and 9 on the rural highway for both the test with trailer and the test without trailer. As we can see from the results, the truck test with trailer had a better health performance than without trailer. The worst instance for the test with trailer is happened in the scaled Y-axis of the

segment 16, 0.526 m/s^2 , as the worst instance for the test without trailer is happened in the Z-axis of the segment 15, 0.4634 m/s^2 . As we can see, the scaled Y-axis of the test with trailer had a little worse health performance for most of segments. But the scaled X-axis and the Z-axis of the test with trailer had a better health performance for most of segments. And we also can find that the test with trailer had a better comfort performance than the test without trailer for many segments.

4.3.4 Comparison of truck vibration from different manufacturers

All the trucks we tested are from three different manufacturers. Here we state the three groups as TruckA, TruckB and TruckC. Truck04, Truck05, Truck06, Truck07 and Truck20 are from group TruckA. Truck08, Truck09, Truck10, Truck12, Truck15 and Truck19 are from group TruckB. Truck11, Truck13, Truck14, Truck16, Truck17 and Truck18 are from group TruckC. The following Table 4.10 and Table 4.11, and Figure 4.13, Figure 4.14 and Figure 4.15 showed the analyzed vibration results for these three different manufacturers on different road types (interstate and rural highway) and for the whole test.

Table 4.10: RMS acceleration range for different manufacturers

	X	Y	Z	Σ	
Truck A	0.1191 - 0.4802	0.1428 - 0.6664	0.1160 - 0.5980	0.1980 - 0.7750	Total
Truck B	0.1568 - 1.4560	0.1890 - 0.7392	0.1810 - 0.8340	0.2520 - 1.2300	
Truck C	0.1208 - 0.6356	0.1456 - 0.6146	0.1440 - 1.2054	0.2040 - 1.0800	
Truck A	0.1498 - 0.4158	0.1540 - 0.6048	0.1160 - 0.5200	0.1980 - 0.7010	Interstate
Truck B	0.1568 - 0.5894	0.1890 - 0.6734	0.1810 - 0.6550	0.2520 - 0.8370	
Truck C	0.1208 - 0.4816	0.1456 - 0.5572	0.1140 - 0.8022	0.2040 - 0.7690	
Truck A	0.1191 - 0.4802	0.1428 - 0.6664	0.1520 - 0.5980	0.2300 - 0.7750	Highway
Truck B	0.1582 - 1.4560	0.2086 - 0.7392	0.2020 - 0.8340	0.2950 - 1.2300	
Truck C	0.1355 - 0.6356	0.1550 - 0.6146	0.2020 - 1.2054	0.2720 - 1.0800	

Table 4.11: Average RMS acceleration for different manufacturers

	X	Y	Z	Σ	
TruckA	0.2517	0.2622	0.2731	0.3796	Total
TruckB	0.2868	0.3515	0.3797	0.5006	
TruckC	0.2567	0.2818	0.3691	0.4476	
TruckA	0.2481	0.2583	0.2567	0.3643	Interstate
TruckB	0.2756	0.3434	0.3680	0.4847	
TruckC	0.2442	0.2751	0.3501	0.4272	
TruckA	0.2563	0.2681	0.2956	0.4007	Highway
TruckB	0.3036	0.3646	0.3985	0.5258	
TruckC	0.2774	0.2933	0.4008	0.4816	

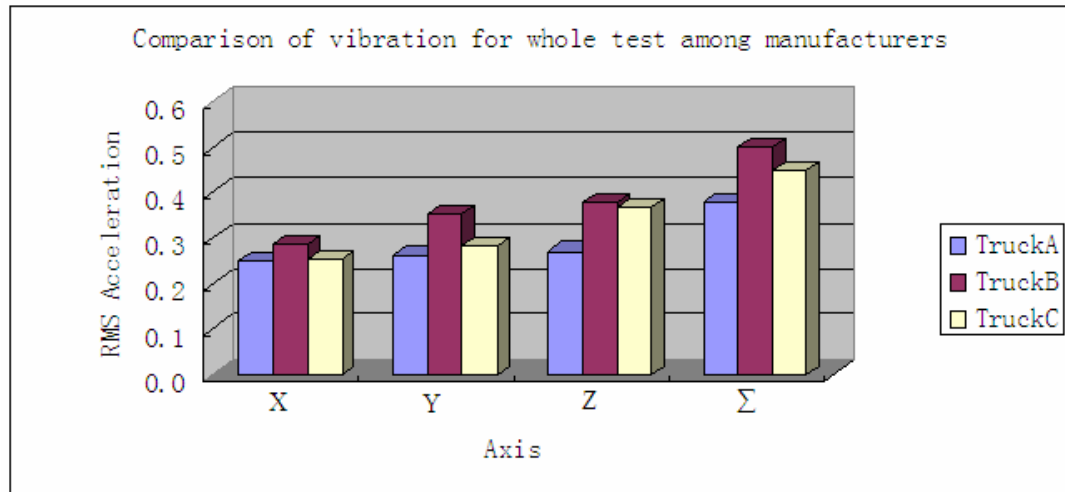


Figure 4.13: Comparison of vibration for whole test among manufacturers

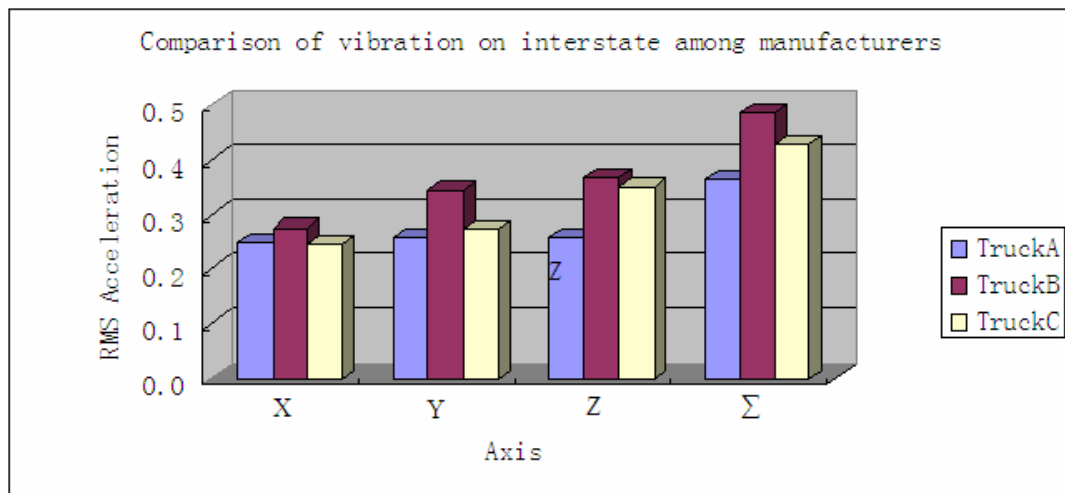


Figure 4.14: Comparison of vibration on interstate among manufacturers

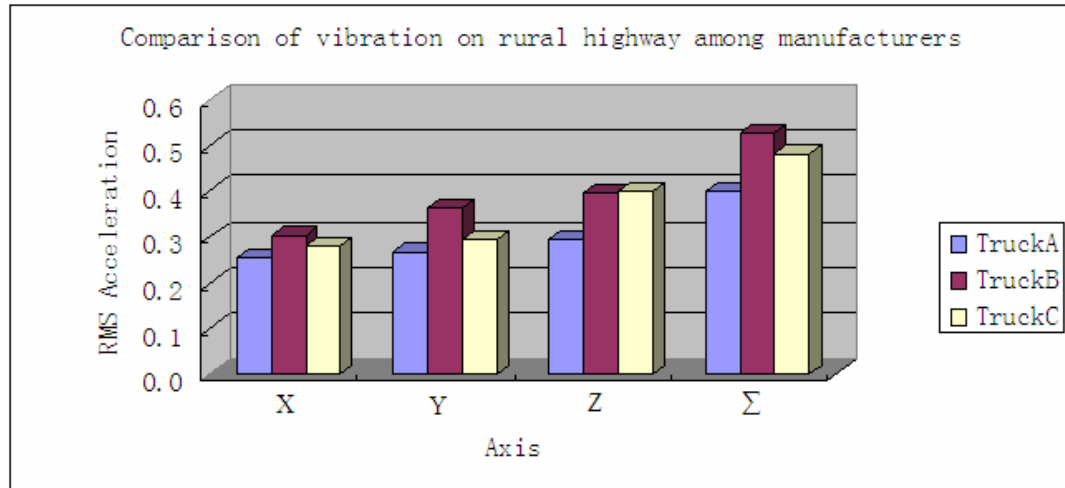


Figure 4.15: Comparison of vibration on rural highway among manufacturers

As we can see from Table 4.10, the group TruckB always had the highest acceleration ranges among three groups for all conditions. The group TruckA and the group TruckC had similar acceleration range but the group TruckC was a little worse than the group TruckA.

From the Table 4.11 and these above figures, we can see the comparing results more clearly. All trucks had an average vibration values well below the standard limits. The group TruckB had the worst health performance for all conditions except in the Z-axis on rural highway, in which the group TruckC was a little worse than the group TruckB. We also can see that in Z-axis, the group TruckB and the group TruckC had a similar health performance on both interstate and rural highway, and the group TruckA had the best health performance in this axis. The group TruckA and the group TruckB had a similar health performance in X-axis and Y-axis. In X-axis, the group TruckA had a little better health performance for the whole test and on rural highway whereas the group TruckA was a little worse on interstate. In Y-axis, the group TruckA always had a little better health performance for all conditions. For the comfort performance, we can see that the group TruckA had the best performance and the group TruckC had the worst. All groups' performance were in the range of a little uncomfortable as stated in ISO 2631-1 except that the group TruckB was in the beginning range of fairly uncomfortable for the whole test and on the rural highway.

In a word, for health performance, all trucks have a good performance. The group TruckB is the worst one and the group TruckA and TruckC have a similar performance in X-axis and Y-axis. The group TruckC is worse than the group TruckA in Z-axis. For comfort performance, all trucks may cause a little uncomfortable to the driver. The group TruckA is the best one and the group TruckC is the worst one.

Chapter-5 DEWE data discussion

5.1 DEWE data study

The DEWETRON data acquisition system was used to measure the vibration accelerations of the driver seat, the passenger seat and the cab floor during our truck road test. All the transducers' data were recorded, processed and analyzed for around every 10 min by using the DEWETRON software DEWESoft and Matlab program. We chose 6 trucks which had good analyzed results for our DEWE data study. Observations from the frequency-weighted accelerations are summarized in this section. Additional analysis with VDV and jerk as well as some comparison among different trucks are also included.

As we known, the minimum 8-hr standard limit requiring a medical examination is 0.5 m/s^2 frequency weighted RMS acceleration in any direction and the minimum 11-hr standard limit requiring a medical examination is 0.426 m/s^2 and 0.98 m/s^2 on 11-hr driving days. Drivers are not supposed to be exposed to greater than 1.15 m/s^2 on 8-hr driving days. For drivers exposed to 11-hr driving days, the exposure for medical examination drops to 0.426 m/s^2 and drivers should not be exposed to greater than.

The VDV is a quantity which can be measured with equipment which uses the forth-power integration. As stated in ISO 2631-1, the VDV exposure action value is $9.1 \text{ m/s}^{1.75}$ on 8-hr driving days. And the exposure limit value for 8-hr driving days is $21 \text{ m/s}^{1.75}$. Because our test didn't last to 8 hours, VDV values cannot be compared with these standard values numerically. We used the method from the European Union in the Physical Agents (Vibration) Directive to calculate the VDV for an entire day's work from a VDV measured during a shorter, but representative, period.

$$VDV = VDV_{part} \times \sqrt[4]{\frac{T}{t}}$$

Where VDV_{part} is VDV measured over a representative period t and T is the length of the full shift (8-hr shift for our study). The unit of VDV is $m/s^{1.75}$.

5.2 DEWE data results

The following Figure 5.1, Figure 5.2 and Figure 5.3 show the frequency-weighted acceleration results of the seat pad in three axes on driver back for one segment of our Truck02.

On average, the frequency-weighted acceleration values were in the range of $-0.2 m/s^2 - 0.2 m/s^2$ for X-axis and Y-axis at most of time, and $-0.5 m/s^2 - 0.5 m/s^2$ for Z-axis. There were not too many instances where the weighted acceleration over $0.5 m/s^2$.

As we know about CF, it is the ratio of the maximum frequency-weighted acceleration to the RMS acceleration. From the results we got, we found that the maximum frequency-weighted accelerations are about $1.5 - 2 m/s^2$. We could get that CF was not exceed 9 for our tests. As stated in ISO 2631-1, we could use the standard limits to evaluate the vibration performance of trucks. We found that this truck's health performance is very good in X-axis and Y-axis for this segment. The health performance is also good in Z-axis. The VDV was also shown in the figures, which is 1.12, 0.93 and 1.4 for this shorter segment and not for 8-hr driving day. Other selected test results from different transducers for different trucks are given in Appendix V.

The Table 5.1 shows the VDV values (after scaled to 8-hr driving shift) for the Truck02 on our 5 transducers. All other VDV results for different trucks are given in Appendix VI

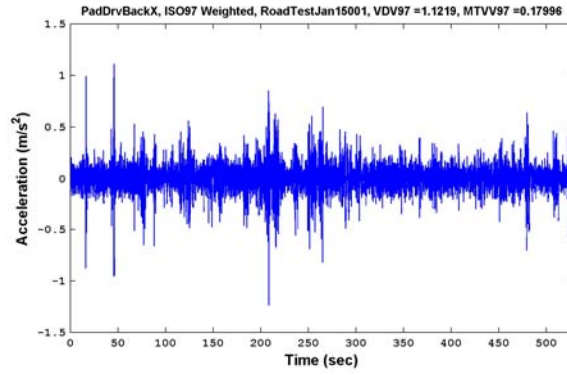


Figure 5.1: Weighted acceleration in X-axis on PadDrvBack for Truck02 Segment 01

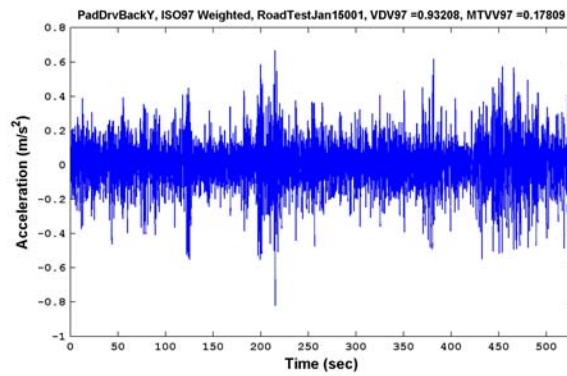


Figure 5.2: Weighted acceleration in Y-axis on PadDrvBack for Truck02 Segment 01

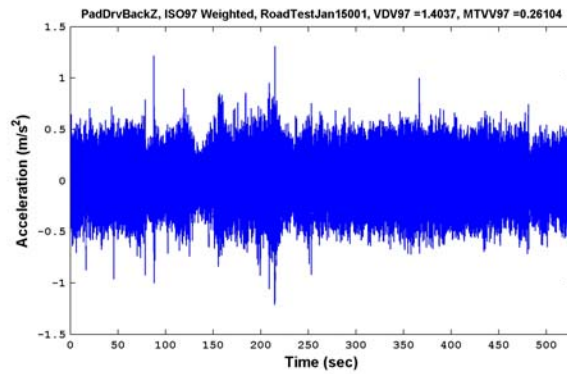


Figure 5.3: Weighted acceleration in Z-axis on PadDrvBack for Truck02 Segment 01

Table 5.1: VDV values for Truck02

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.05	2.53	3.81	2.23	3.68	3.26	2.32	3.67	3.26	1.25	5.36	7.34	1.18	2.04	6.95
2	3.34	3.00	3.83	2.01	2.52	3.19	4.13	2.69	3.28	1.12	5.41	7.16	1.15	2.80	7.62
3	4.68	3.60	4.56	3.03	3.35	4.54	4.12	3.07	4.47	1.65	4.94	7.79	1.61	2.81	8.14
4	4.74	3.79	4.35	3.10	3.21	4.04	3.75	3.16	4.07	1.62	3.84	6.90	1.46	2.43	7.85
5	3.83	3.05	3.73	2.61	3.14	3.17	2.60	2.77	3.07	1.17	3.97	6.08	1.23	2.74	8.04
6	3.33	3.62	3.89	2.81	3.56	3.26	2.89	3.38	3.13	2.14	5.27	7.16	2.50	3.73	10.10
7	5.20	2.39	4.72	3.91	2.32	4.38	3.76	2.63	4.24	1.50	4.06	5.82	1.80	3.09	8.10
8	3.64	2.53	3.97	2.69	2.68	3.25	2.86	2.45	3.22	1.38	3.93	6.08	1.70	2.86	8.48
9	3.21	3.23	4.08	2.79	3.94	3.28	3.82	3.30	3.47	1.68	4.20	6.27	2.39	2.98	8.17
10	4.96	2.93	4.83	3.68	3.62	4.50	3.66	3.11	4.39	2.74	3.55	6.59	2.75	2.53	8.28
11	5.56	2.90	6.25	3.78	3.14	6.42	4.44	3.44	6.09	2.08	4.23	8.12	1.91	3.36	9.60
12	4.70	3.40	5.29	3.27	3.73	5.19	3.83	3.38	4.95	1.85	3.46	7.57	1.98	2.81	9.23
13	4.15	3.87	4.48	2.92	3.91	3.96	3.67	3.67	3.90	1.92	3.36	6.46	2.22	2.68	8.47
14	4.59	2.87	4.50	3.07	2.78	4.10	4.26	3.12	3.94	1.94	3.29	6.05	1.43	2.65	8.11
15	5.19	4.62	5.18	3.40	4.22	4.37	3.99	3.86	4.61	2.25	4.88	8.46	2.39	4.19	10.33
16	4.40	3.11	4.45	3.01	2.80	3.94	4.28	2.76	3.93	1.82	4.81	7.23	1.87	4.07	9.27
17	3.99	2.88	4.38	2.98	3.10	3.73	3.00	2.72	3.84	1.47	3.12	6.41	1.67	2.49	8.53
Average	4.27	3.20	4.49	3.02	3.28	4.03	3.61	3.13	3.99	1.74	4.22	6.91	1.84	2.96	8.54

The following Figure 5.4, Figure 5.5 and Figure 5.6 show the RMS jerk results of the seat pad in three axes on driver back for one segment of our Truck02. We could see that the RMS jerk values for this segment 24.6 in X-axis, 83.4 in Y-axis and 101.3 in Z-axis. The Table 5.2 lists the RMS jerk values for the truck02 on our 5 transducers. All other RMS jerk results for different trucks are given in Appendix VIII.

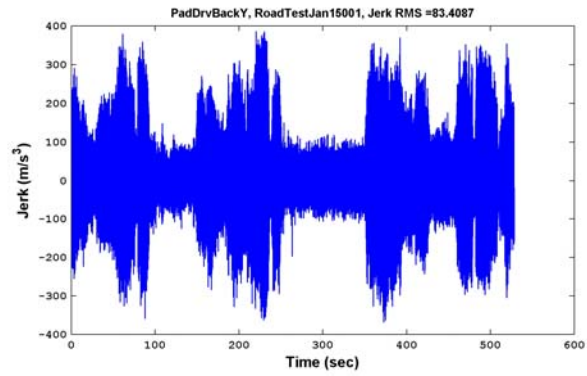


Figure 5.4: RMS jerk in X-axis on PadDrvBack for Truck02 Segment 01

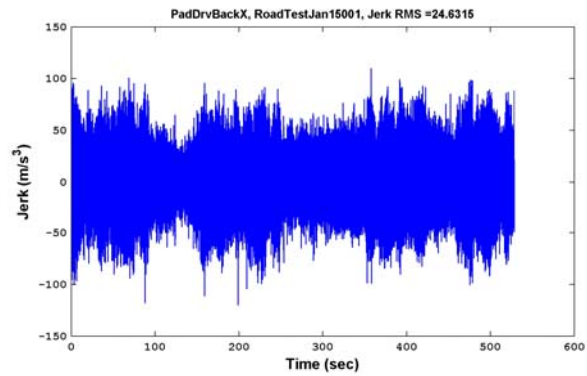


Figure 5.5: RMS jerk in Y-axis on PadDrvBack for Truck02 Segment 01

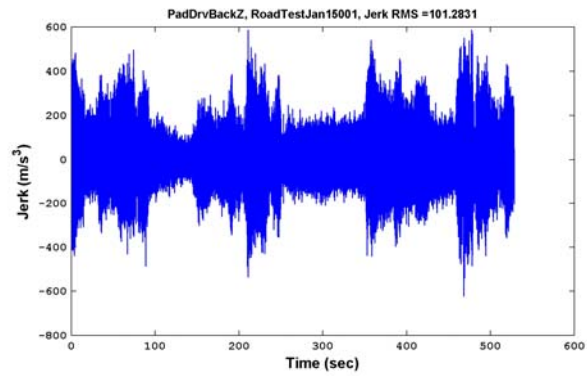


Figure 5.6: RMS jerk in Z-axis on PadDrvBack for Truck02 Segment 01

Table 5.2: RMS jerk values for Truck02

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	24.6	83.4	101.3	102.4	121.3	33.2	99.1	139.0	39.8	111.6	151.7	294.5	106.9	149.7	340.4
2	26.0	100.1	115.5	78.1	124.9	41.5	107.4	134.9	70.5	117.8	168.8	344.1	106.9	166.6	389.7
3	26.1	102.5	111.4	95.4	130.6	35.1	140.0	142.7	74.2	116.5	208.8	350.8	134.2	208.4	364.8
4	22.8	101.6	110.4	128.3	143.9	43.4	173.4	179.0	103.5	142.6	236.6	361.6	174.8	239.1	473.9
5	30.6	94.5	101.6	89.5	124.0	32.6	154.8	168.0	63.8	131.7	212.2	268.6	155.2	217.6	347.7
6	20.1	65.5	75.7	64.0	103.8	23.0	126.0	137.6	48.9	105.9	161.0	168.4	124.4	163.7	260.0
7	27.8	94.9	115.7	85.1	121.2	27.2	97.6	147.3	24.3	110.4	180.6	244.0	140.1	183.3	271.3
8	24.3	65.0	28.1	59.4	99.5	23.4	84.7	115.3	30.6	84.9	120.4	163.7	91.6	123.9	157.0
9	29.0	85.0	126.3	74.7	106.5	33.0	106.7	128.8	65.1	102.9	141.0	256.0	98.8	144.1	253.4
10	26.6	73.4	105.6	69.4	103.3	27.6	106.8	134.2	49.1	91.3	126.0	209.4	96.1	128.9	211.8
11	30.0	82.5	116.7	61.2	104.2	31.8	100.7	135.7	34.5	106.4	129.1	254.2	97.3	131.9	235.4
12	22.2	76.7	91.5	72.9	100.5	25.9	117.5	132.9	48.8	98.0	148.2	199.9	109.7	149.0	202.5
13	29.7	91.9	120.7	86.6	115.1	33.6	131.9	130.0	81.7	104.3	160.0	273.8	120.9	160.1	261.7
14	31.7	91.5	119.9	79.2	116.3	34.1	123.0	132.0	73.6	106.0	147.3	277.5	113.8	148.9	250.0
15	26.2	93.7	100.2	79.9	100.2	28.4	128.2	153.7	53.5	124.9	193.0	244.8	141.2	196.6	239.6
16	31.0	103.4	123.6	79.0	125.0	33.7	116.3	143.1	44.4	105.4	182.5	280.4	122.6	184.3	243.3
17	35.2	86.9	114.1	78.7	110.8	32.4	115.3	133.0	58.8	108.6	152.3	251.6	125.3	154.7	241.6

5.3 DEWE data discussion

5.3.1 Observations from the frequency-weighted acceleration plots

From these frequency-weighted acceleration plots, we can roughly tell that both the driver and passenger seats in the truck have given sufficient protection, but it may be a little uncomfortable while driving because we always found some instances which over the standard limits.

As we seen, the frequency-weighted acceleration values were in the range of $-0.25 \text{ m/s}^2 - 0.25 \text{ m/s}^2$ for X-axis, $-0.3 \text{ m/s}^2 - 0.3 \text{ m/s}^2$ for Y-axis, and $-0.5 \text{ m/s}^2 - 0.5 \text{ m/s}^2$ for Z-axis at most of time for our seat pads on trucks. These vibration from the two transducers on the cab floor were in the range of $-0.2 \text{ m/s}^2 - 0.2 \text{ m/s}^2$ for X-axis, $-0.25 \text{ m/s}^2 - 0.25 \text{ m/s}^2$ for Y-axis, and $-0.8 \text{ m/s}^2 - 0.8 \text{ m/s}^2$ for Z-axis at most of time. From the vibration in Z-axis for seat pads and transducers on cab floor, we could find that the seats reduced the vertical vibration a lot. Because I haven't got the calculated results for the frequency-weighted accelerations yet, there aren't some numerical results that could show clearly the health and comfort performance. We could say these trucks have a not bad health and comfort performance because the RMS acceleration didn't over the standard limit too much as we could tell from these plots.

5.3.2 VDV analysis

As listed in Appendix VI, we could find that VDV_s on seat pads for all the trucks average between $3-5 \text{ m/s}^{1.75}$ (after scaling up the values to 8-hr) for most of times. The worst instance happened in the Z-axis of the driver back seat pad on truck06, $6.06 \text{ m/s}^{1.75}$. This axis is also the worst direction for most of our trucks for all seat pads. For the transducers on the cab floor, the average VDV_s were in the range of $2-9.8 \text{ m/s}^{1.75}$ for most of times. The worst instance happened in the Z-axis of the transducer on the cab floor under passenger seat for truck05, $9.89 \text{ m/s}^{1.75}$. This axis is also the worst direction for most of our trucks for these two transducers on cab floor. Individual VDV plots for all the trucks

are given in Appendix VII. Looking at these plots, the driver seat is never above the exposure action value of $9.1 \text{ m/s}^{1.75}$ in all our trucks and always well below the exposure action value. The passenger seat is only above the exposure action value of $9.1 \text{ m/s}^{1.75}$ one time in all our trucks and it was in the Z-axis of seat pad on the passenger cushion of truck06. The cab floor under driver is above this limit several time and they are all in the Z-axis. The worst condition is the cab floor under passenger and it is above this limit quite a lot of time in the Z-axis for every truck. None have however reached the exposure limit value of $21 \text{ m/s}^{1.75}$. Figure 30 and 31 shows the variation of the driver and the passenger seat VDV along the time segments for all the trucks.

5.2.5 Jerk analysis

Jerk, the rate of change of Acceleration, is the measurement of how fast the magnitude of Acceleration changes over a period of time. An intensive jerk may reduce the chance of the body to suddenly increase its bearing capacity through the muscular brace.

Table 5.3 shows the average RMS jerk values for all the trucks. Figure 5.7 to Figure 5.11 show the average RMS jerk values for all the trucks from separate seat pad or transducers. Individual jerk plots are given in Appendix-IX.

Table 5.3: Average RMS jerk values for trucks

Truck	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Truck02	27.3	87.8	104.6	81.4	114.8	31.8	119.4	140.4	56.8	109.9	165.9	261.4	121.2	167.7	279.1
Truck03	30.5	70.7	132.7	83.3	125.3	53.1	99.8	165.1	37.6	86.1	187.0	225.6	107.5	181.9	173.0
Truck04	37.0	88.8	170.0	87.5	136.0	41.9	125.2	151.5	52.8	89.9	199.0	247.9	121.6	198.2	207.4
Truck05	28.6	71.7	151.9	84.7	105.0	24.6	101.4	143.1	50.0	107.7	181.2	234.5	125.7	181.4	189.7
Truck06	40.2	66.4	238.2	335.2	151.8	36.5	361.8	155.7	79.1	104.1	242.1	425.7	128.4	212.3	338.6
Truck07	55.7	99.0	245.1	244.6	120.7	32.6	417.8	154.5	81.2	127.3	280.1	405.6	148.3	266.1	327.1

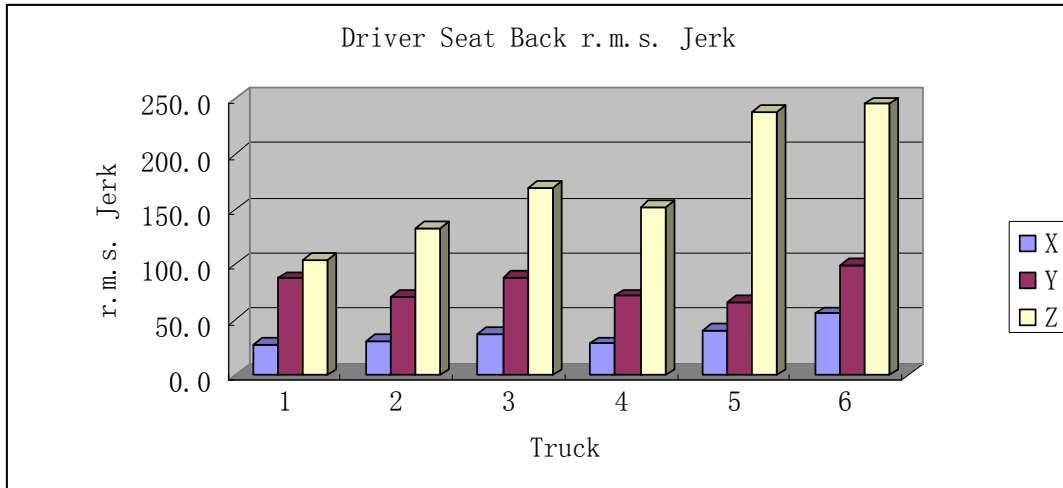


Figure 5.7: Driver seat back RMS jerk for trucks

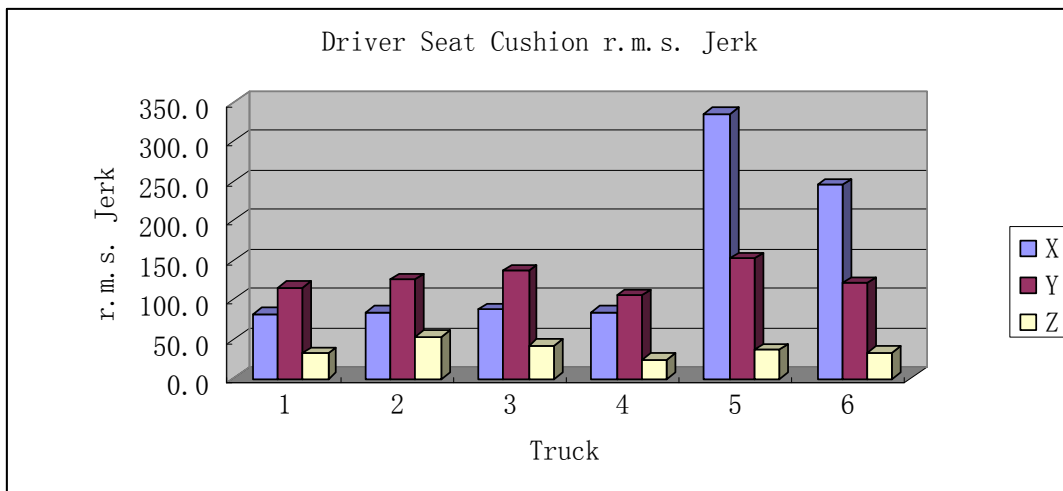


Figure 5.8: Driver seat cushion RMS jerk for trucks

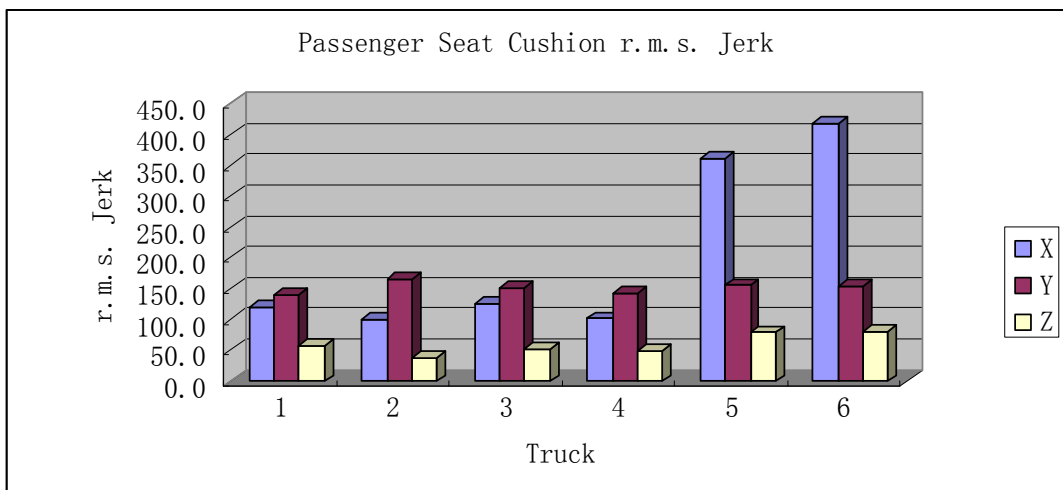


Figure 5.9: Passenger seat cushion RMS jerk for trucks

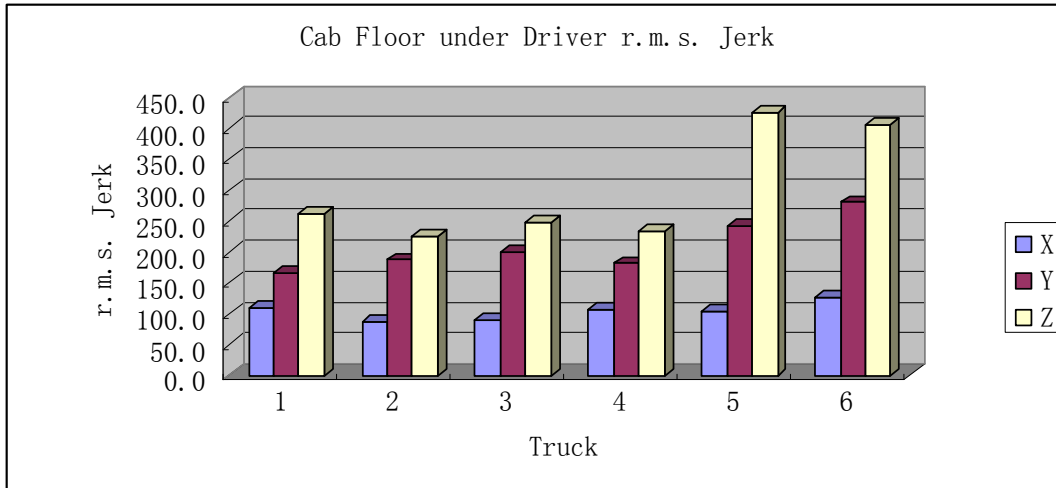


Figure 5.10: Cab floor under driver RMS jerk for trucks

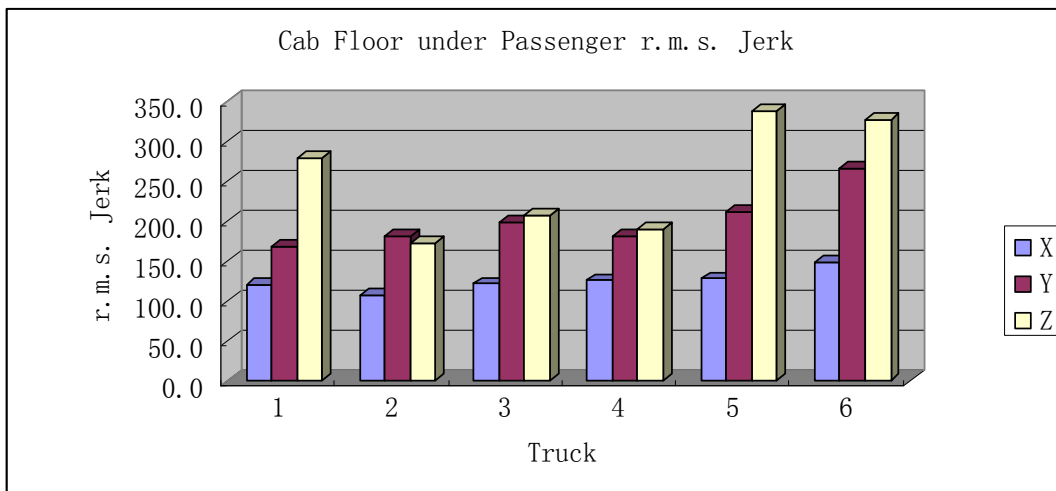


Figure 5.11: Cab floor under passenger RMS jerk for trucks

Looking at jerks for the driver seat back (Figure 5.7), X-axis is the least and Z-axis is the highest for all trucks. This means that there is less fore-aft followed by side to side jerk than up and down. Both the driver seat cushion (Figure 5.8) and the passenger seat cushion (Figure 5.9) give higher jerk along Y-axis for first four trucks and higher jerk along X-axis for last two trucks. Z-axis is the least for all trucks. Both the cab floor under driver (Figure 5.10) and under passenger (Figure 5.11) give the highest jerk along Y-axis for all trucks and the least jerk along X-axis. Truck06 and truck07 show comparatively higher jerk in all directions. And the cab floor has higher jerks than the seats. Individual jerk plots in Appendix-IX show too much variation in the rate suggesting that the driver might have decreased muscular ability to bear the continuous vibration exposure.

Chapter-6 Conclusion and recommendations

Seventeen trucks were tested by HVM-100 and six trucks were tested by DEWE data acquisition system. The test results were analyzed to find the human responses to WBV. The following are the conclusions that can be drawn from the present research.

First, the type of road was found to be a primary factor, which influences the driver's and passenger's vibration exposure. As expected, smoother roads gave a lower level of Acceleration exposure. Ride on the interstate transmitted lower exposures than on the rural highway in most of testing trucks. Load was another factor but didn't have same effects as the road type. Most of the time, the truck running with loaded trailer have a better performance than the truck without trailer.

Second, Driver and passenger were found to be safe as per ISO 2631-1 but the comfort levels were often exceeded. As we can seen from the study of HVM-100 data, most of tests have the level of comfort in 'a little uncomfortable' range. Though safe with respect to health, the feeling of uncomfortable may decrease the driver's performance and ability to control the vehicle. So the necessary action should be taken to increase the comfort.

Third, The VDV for the trucks tested by DEWE were calculated. And we found that the driver seat and the passenger seat had a very good performance in VDV for most of tests. Only the passenger seat was above the exposure action value of $9.1 \text{ m/s}^{1.75}$ one time. The cab floor had many times which over this limit in the Z-axis, especially under the passenger. But none have however reached the exposure limit value of $21 \text{ m/s}^{1.75}$.

Similarly, lots of jerk have been found in all trucks mainly in fore-aft followed by side to side direction for the truck seats. The cab floor had the highest jerk in vertical directions. Severe jerks might have reduced the ability of the muscles to bear the high vibration exposures. Jerk, mostly being proportional to a_{rms} value, could be another way of measuring the exposure but no reference is available as per acceptable limit of the jerk values. Further study in this matter is recommended.

Though the study was done with different kinds of trucks and variety of roads, seat suspensions and type of seats didn't vary much. We found that many of the truck seats are from one company. These could also be some of the major factors of vibration exposure. This is a place for further research.

There is another vibration input to the driver: the steering wheel. It is hard to measure the correct data from the steering wheel because the setup of transducer will be a big challenge. But it has an important effect on the performance of driver vibration exposure. So it is recommend giving focus on here and trying to find out the correct effects of the steering wheel.

Different standards are being followed in Europe and America. There have been lots of debates on which standard is better to follow. Same set of data could be good as per one standard and bad as per the other. Each has its own limits. Even within ISO 1997, we got lots of discrepancies in assessing the exposure by different methods. Therefore, a better version of the International Standard to be followed everywhere is necessary.

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<http://www.hse.gov.uk/vibration/vdv.htm>

Appendix I: RMS acceleration results for trucks with trailer

Table A1.1: Average weighted RMS acceleration on Truck04

Truck 04	Segment	X	Y	Z	Σ	Road Type
	1	0.194	0.194	0.174	0.262	Interstate
	2	0.272	0.280	0.273	0.391	Interstate
	3	0.291	0.282	0.305	0.420	Interstate
	4	0.236	0.277	0.231	0.347	Interstate
	5	0.231	0.261	0.193	0.316	Interstate
	6	0.206	0.245	0.202	0.306	Interstate
	7	0.223	0.207	0.236	0.322	Interstate
	8	0.241	0.220	0.227	0.326	Highway
	9	0.220	0.196	0.221	0.306	Highway
	10	0.256	0.183	0.332	0.401	Highway
	11	0.256	0.244	0.326	0.412	Highway
	12	0.199	0.173	0.191	0.268	Highway
	13	0.214	0.197	0.230	0.309	Highway
	14	0.270	0.202	0.273	0.364	Highway
	15	0.304	0.350	0.311	0.454	Interstate
	16	0.272	0.246	0.275	0.380	Interstate
	17	0.265	0.249	0.272	0.377	Interstate

Table A1.2: Average weighted RMS acceleration on Truck05

Truck 05	Segment	X	Y	Z	Σ	Road Type
	1	0.222	0.202	0.255	0.334	Interstate
	2	0.192	0.199	0.184	0.270	Interstate
	3	0.305	0.251	0.333	0.436	Interstate
	4	0.253	0.233	0.256	0.337	Interstate
	5	0.274	0.289	0.226	0.363	Interstate
	6	0.240	0.216	0.240	0.333	Interstate
	7	0.254	0.234	0.252	0.353	Interstate
	8	0.224	0.192	0.252	0.328	Highway
	9	0.297	0.192	0.341	0.425	Highway
	10	0.342	0.292	0.401	0.513	Highway
	11	0.213	0.184	0.237	0.310	Highway
	12	0.249	0.196	0.271	0.353	Highway
	13	0.242	0.207	0.310	0.384	Highway
	14	0.368	0.357	0.337	0.497	Interstate
	15	0.307	0.284	0.302	0.425	Interstate
	16	0.255	0.221	0.238	0.339	Interstate
	17	0.322	0.252	0.354	0.460	Interstate
	18	0.264	0.331	0.365	0.473	Highway
	19	0.281	0.286	0.346	0.448	Highway
	20	0.268	0.284	0.364	0.461	Highway

Table A1.3: Average weighted RMS acceleration on Truck06

Truck 06	Segment	X	Y	Z	Σ	Road Type
	1	0.267	0.218	0.228	0.336	Interstate
	2	0.302	0.256	0.250	0.377	Interstate
	3	0.349	0.276	0.275	0.419	Interstate
	4	0.295	0.247	0.222	0.353	Interstate
	5	0.274	0.254	0.181	0.324	Interstate
	6	0.311	0.239	0.234	0.366	Interstate
	7	0.267	0.214	0.216	0.326	Interstate
	8	0.227	0.196	0.184	0.283	Highway
	9	0.271	0.214	0.244	0.348	Highway
	10	0.353	0.253	0.351	0.468	Highway
	11	0.333	0.314	0.319	0.456	Highway
	12	0.281	0.244	0.257	0.371	Highway
	13	0.339	0.258	0.323	0.443	Highway
	14	0.346	0.333	0.333	0.477	Interstate
	15	0.331	0.314	0.326	0.461	Interstate
	16	0.292	0.226	0.218	0.343	Interstate
	17	0.318	0.275	0.292	0.419	Highway

Table A1.4: Average weighted RMS acceleration on Truck07

Truck 07	Segment	X	Y	Z	Σ	Road Type
	1	0.223	0.210	0.226	0.315	Interstate
	2	0.251	0.237	0.264	0.361	Interstate
	3	0.280	0.244	0.299	0.399	Interstate
	4	0.226	0.214	0.251	0.335	Interstate
	5	0.215	0.220	0.215	0.307	Interstate
	6	0.229	0.188	0.223	0.308	Interstate
	7	0.228	0.191	0.229	0.312	Interstate
	8	0.204	0.197	0.173	0.266	Highway
	9	0.215	0.212	0.218	0.308	Highway
	10	0.249	0.197	0.293	0.370	Highway
	11	0.302	0.282	0.318	0.433	Highway
	12	0.211	0.210	0.216	0.304	Highway
	13	0.265	0.237	0.289	0.384	Highway
	14	0.261	0.240	0.271	0.371	Highway
	15	0.227	0.218	0.251	0.336	Interstate
	16	0.255	0.244	0.266	0.366	Interstate

Table A1.5: Average weighted RMS acceleration on Truck08

Truck 08	Segment	X	Y	Z	Σ	Road Type
	1	0.240	0.275	0.278	0.361	Interstate
	2	0.346	0.358	0.415	0.546	Interstate
	3	0.365	0.372	0.436	0.573	Interstate
	4	0.318	0.304	0.366	0.482	Interstate
	5	0.253	0.288	0.294	0.401	Interstate
	6	0.321	0.288	0.354	0.471	Interstate
	7	0.272	0.286	0.318	0.424	Interstate
	8	0.250	0.260	0.267	0.370	Highway
	9	0.298	0.308	0.355	0.468	Highway
	10	0.527	0.440	0.651	0.813	Highway
	11	0.270	0.280	0.291	0.402	Highway
	12	0.335	0.301	0.386	0.501	Highway
	13	0.338	0.291	0.439	0.541	Highway
	14	0.331	0.319	0.388	0.509	Highway
	15	0.385	0.394	0.456	0.601	Interstate
	16	0.295	0.285	0.359	0.461	Interstate
	17	0.314	0.318	0.379	0.495	Interstate
	18	0.276	0.261	0.346	0.439	Interstate

Table A1.6: Average weighted RMS acceleration on Truck09

Truck 09	Segment	X	Y	Z	Σ	Road Type
	1	0.217	0.294	0.266	0.372	Interstate
	2	0.320	0.421	0.420	0.563	Interstate
	3	0.340	0.422	0.401	0.569	Interstate
	4	0.328	0.407	0.407	0.551	Interstate
	5	0.260	0.339	0.319	0.441	Interstate
	6	0.279	0.318	0.325	0.445	Interstate
	7	0.293	0.351	0.395	0.511	Interstate
	8	0.277	0.328	0.346	0.462	Interstate
	9	0.231	0.253	0.259	0.349	Highway
	10	0.272	0.333	0.335	0.454	Highway
	11	0.416	0.425	0.529	0.702	Highway
	12	0.393	0.415	0.447	0.606	Highway
	13	0.343	0.298	0.263	0.429	Highway
	14	0.349	0.327	0.383	0.516	Highway
	15	0.347	0.371	0.427	0.560	Highway
	16	0.543	0.387	0.412	0.653	Highway
	17	0.314	0.351	0.398	0.521	Interstate
	18	0.324	0.323	0.393	0.511	Interstate
	19	0.274	0.288	0.361	0.459	Interstate

Table A1.7: Average weighted RMS acceleration on Truck10

Truck 10	Segment	X	Y	Z	Σ	Road Type
	1	0.189	0.256	0.266	0.349	Interstate
	2	0.238	0.295	0.329	0.426	Interstate
	3	0.311	0.361	0.475	0.583	Interstate
	4	0.285	0.329	0.405	0.510	Interstate
	5	0.254	0.323	0.392	0.488	Interstate
	6	0.216	0.274	0.312	0.399	Interstate
	7	0.225	0.326	0.292	0.406	Interstate
	8	0.263	0.309	0.366	0.468	Interstate
	9	0.217	0.295	0.369	0.451	Interstate
	10	0.232	0.319	0.361	0.457	Interstate
	11	0.217	0.292	0.274	0.378	Highway
	12	0.279	0.328	0.399	0.503	Highway
	13	0.309	0.374	0.465	0.579	Highway
	14	0.397	0.495	0.606	0.757	Highway
	15	0.293	0.388	0.389	0.530	Highway
	16	0.213	0.299	0.278	0.382	Highway
	17	0.268	0.363	0.367	0.490	Highway
	18	0.269	0.336	0.399	0.503	Highway
	19	0.301	0.381	0.434	0.554	Highway
	20	0.291	0.367	0.440	0.552	Interstate
	21	0.269	0.337	0.388	0.495	Interstate
	22	0.252	0.308	0.371	0.466	Interstate
	23	0.266	0.314	0.380	0.480	Interstate

Table A1.8: Average weighted RMS acceleration on Truck11

Truck 11	Segment	X	Y	Z	Σ	Road Type
	1	0.186	0.205	0.314	0.371	Interstate
	2	0.178	0.206	0.274	0.336	Interstate
	3	0.246	0.299	0.344	0.441	Interstate
	4	0.272	0.277	0.387	0.475	Interstate
	5	0.243	0.255	0.354	0.434	Interstate
	6	0.165	0.195	0.236	0.291	Interstate
	7	0.153	0.171	0.261	0.310	Interstate
	8	0.186	0.192	0.305	0.359	Interstate
	9	0.197	0.217	0.291	0.357	Interstate
	10	0.157	0.172	0.253	0.302	Highway
	11	0.191	0.182	0.268	0.327	Highway
	12	0.266	0.235	0.377	0.454	Highway
	13	0.346	0.349	0.530	0.635	Highway
	14	0.276	0.333	0.427	0.526	Highway
	15	0.219	0.277	0.351	0.431	Highway
	16	0.259	0.255	0.367	0.449	Highway
	17	0.283	0.280	0.404	0.493	Highway
	18	0.289	0.334	0.420	0.524	Interstate
	19	0.253	0.257	0.340	0.426	Interstate
	20	0.254	0.263	0.355	0.441	Interstate
	21	0.201	0.229	0.329	0.394	Interstate
	22	0.223	0.246	0.387	0.453	Interstate

Table A1.9: Average weighted RMS acceleration on Truck12

Truck 12	Segment	X	Y	Z	Σ	Road Type
	1	0.199	0.322	0.321	0.419	Interstate
	2	0.272	0.391	0.432	0.549	Interstate
	3	0.305	0.444	0.498	0.627	Interstate
	4	0.285	0.436	0.469	0.597	Interstate
	5	0.224	0.344	0.368	0.470	Interstate
	6	0.224	0.323	0.343	0.442	Interstate
	7	0.263	0.283	0.378	0.469	Interstate
	8	0.206	0.270	0.370	0.441	Interstate
	9	0.234	0.303	0.403	0.487	Interstate
	10	0.313	0.375	0.518	0.624	Interstate
	11	0.205	0.271	0.283	0.372	Highway
	12	0.216	0.310	0.349	0.441	Highway
	13	0.304	0.341	0.475	0.574	Highway
	14	0.295	0.360	0.480	0.582	Highway
	15	0.184	0.263	0.284	0.364	Highway
	16	0.258	0.287	0.416	0.498	Highway
	17	0.263	0.312	0.458	0.541	Highway
	18	0.257	0.321	0.453	0.538	Highway
	19	0.292	0.361	0.471	0.575	Interstate
	20	0.262	0.249	0.397	0.472	Interstate
	21	0.245	0.269	0.408	0.483	Interstate
	22	0.219	0.276	0.373	0.451	Interstate

Table A1.10: Average weighted RMS acceleration on Truck13

Truck 13	Segment	X	Y	Z	Σ	Road Type
	1	0.191	0.345	0.309	0.417	Interstate
	2	0.192	0.366	0.320	0.435	Interstate
	3	0.220	0.395	0.364	0.486	Interstate
	4	0.262	0.470	0.433	0.579	Interstate
	5	0.194	0.347	0.301	0.415	Interstate
	6	0.208	0.461	0.323	0.484	Interstate
	7	0.231	0.290	0.341	0.432	Interstate
	8	0.200	0.278	0.309	0.394	Interstate
	9	0.218	0.329	0.383	0.475	Interstate
	10	0.151	0.204	0.298	0.376	Highway
	11	0.172	0.275	0.331	0.442	Highway
	12	0.268	0.318	0.412	0.503	Highway
	13	0.281	0.319	0.543	0.621	Highway
	14	0.293	0.407	0.519	0.630	Highway
	15	0.189	0.250	0.288	0.360	Highway
	16	0.241	0.288	0.403	0.484	Highway
	17	0.271	0.382	0.483	0.587	Highway
	18	0.236	0.295	0.428	0.505	Highway
	19	0.283	0.363	0.456	0.561	Interstate
	20	0.244	0.265	0.384	0.404	Interstate
	21	0.266	0.289	0.401	0.489	Interstate
	22	0.214	0.277	0.382	0.456	Interstate

Table A1.11: Average weighted RMS acceleration on Truck14

Truck 14	Segment	X	Y	Z	Σ	Road Type
	1	0.168	0.186	0.255	0.311	Interstate
	2	0.172	0.200	0.270	0.328	Interstate
	3	0.264	0.277	0.417	0.498	Interstate
	4	0.250	0.287	0.370	0.458	Interstate
	5	0.300	0.330	0.420	0.526	Interstate
	6	0.260	0.353	0.388	0.498	Interstate
	7	0.162	0.254	0.248	0.328	Interstate
	8	0.153	0.253	0.238	0.319	Interstate
	9	0.216	0.196	0.298	0.364	Interstate
	10	0.136	0.174	0.231	0.279	Interstate
	11	0.213	0.232	0.324	0.393	Interstate
	12	0.168	0.208	0.251	0.315	Highway
	13	0.204	0.235	0.270	0.350	Highway
	14	0.261	0.239	0.390	0.464	Highway
	15	0.277	0.329	0.444	0.584	Highway
	16	0.294	0.295	0.467	0.552	Highway
	17	0.191	0.238	0.290	0.362	Highway
	18	0.216	0.241	0.330	0.402	Highway
	19	0.283	0.322	0.475	0.563	Highway
	20	0.312	0.324	0.466	0.565	Highway
	21	0.259	0.269	0.387	0.469	Interstate
	22	0.248	0.260	0.359	0.441	Interstate
	23	0.257	0.255	0.375	0.455	Interstate
	24	0.205	0.243	0.357	0.422	Interstate

Table A1.12: Average weighted RMS acceleration on Truck15

Truck 15	Segment	X	Y	Z	Σ	Road Type
	1	0.201	0.353	0.275	0.400	Interstate
	2	0.237	0.400	0.341	0.476	Interstate
	3	0.269	0.405	0.382	0.516	Interstate
	4	0.294	0.472	0.438	0.591	Interstate
	5	0.304	0.428	0.417	0.559	Interstate
	6	0.201	0.299	0.252	0.360	Interstate
	7	0.237	0.349	0.309	0.431	Interstate
	8	0.225	0.346	0.277	0.404	Interstate
	9	0.256	0.331	0.345	0.456	Interstate
	10	0.205	0.269	0.273	0.364	Interstate
	11	0.230	0.327	0.319	0.428	Interstate
	12	0.207	0.307	0.257	0.369	Highway
	13	0.255	0.336	0.357	0.466	Highway
	14	0.289	0.348	0.416	0.530	Highway
	15	0.378	0.539	0.616	0.774	Highway
	16	0.380	0.511	0.503	0.678	Highway
	17	0.236	0.300	0.319	0.419	Highway
	18	0.289	0.410	0.415	0.548	Highway
	19	0.304	0.404	0.431	0.563	Highway
	20	0.262	0.402	0.435	0.553	Highway
	21	0.333	0.416	0.436	0.577	Interstate
	22	0.301	0.386	0.394	0.526	Interstate
	23	0.279	0.373	0.390	0.511	Interstate
	24	0.267	0.394	0.385	0.513	Interstate

Table A1.13: Average weighted RMS acceleration on Truck16

Truck 16	Segment	X	Y	Z	Σ	Road Type
	1	0.300	0.292	0.344	0.455	Interstate
	2	0.259	0.243	0.260	0.363	Interstate
	3	0.307	0.308	0.358	0.473	Interstate
	4	0.353	0.352	0.413	0.543	Interstate
	5	0.308	0.292	0.345	0.458	Interstate
	6	0.237	0.225	0.245	0.338	Interstate
	7	0.245	0.246	0.267	0.364	Interstate
	8	0.243	0.231	0.222	0.327	Interstate
	9	0.297	0.274	0.291	0.426	Interstate
	10	0.230	0.214	0.236	0.325	Interstate
	11	0.281	0.282	0.321	0.428	Interstate
	12	0.322	0.279	0.257	0.398	Highway
	13	0.328	0.321	0.325	0.463	Highway
	14	0.334	0.300	0.407	0.517	Highway
	15	0.416	0.412	0.557	0.695	Highway
	16	0.477	0.452	0.469	0.669	Highway
	17	0.274	0.272	0.273	0.387	Highway
	18	0.351	0.335	0.371	0.502	Highway
	19	0.403	0.396	0.432	0.590	Highway
	20	0.297	0.298	0.331	0.448	Highway
	21	0.374	0.399	0.437	0.584	Interstate
	22	0.291	0.258	0.328	0.428	Interstate
	23	0.356	0.349	0.428	0.555	Interstate
	24	0.320	0.299	0.354	0.472	Interstate

Table A1.14: Average weighted RMS acceleration on Truck17

Truck 17	Segment	X	Y	Z	Σ	Road Type
	1	0.283	0.249	0.476	0.469	Interstate
	2	0.255	0.241	0.378	0.405	Interstate
	3	0.295	0.273	0.461	0.476	Interstate
	4	0.373	0.312	0.577	0.578	Interstate
	5	0.299	0.245	0.498	0.482	Interstate
	6	0.228	0.23	0.359	0.38	Interstate
	7	0.231	0.233	0.372	0.389	Interstate
	8	0.234	0.22	0.362	0.38	Interstate
	9	0.209	0.195	0.367	0.359	Interstate
	10	0.208	0.214	0.357	0.364	Interstate
	11	0.272	0.256	0.459	0.458	Interstate
	12	0.232	0.177	0.348	0.346	Highway
	13	0.287	0.24	0.415	0.432	Highway
	14	0.343	0.289	0.595	0.568	Highway
	15	0.395	0.349	0.791	0.719	Highway
	16	0.356	0.341	0.673	0.641	Highway
	17	0.256	0.234	0.369	0.397	Highway
	18	0.24	0.228	0.416	0.412	Highway
	19	0.308	0.284	0.559	0.537	Highway
	20	0.297	0.289	0.486	0.498	Highway
	21	0.34	0.311	0.655	0.611	Interstate
	22	0.266	0.25	0.459	0.453	Interstate
	23	0.322	0.271	0.58	0.545	Interstate
	24	0.239	0.234	0.41	0.412	Interstate

Table A1.15: Average weighted RMS acceleration on Truck18

Truck 18	Segment	X	Y	Z	Σ	Road Type
	1	0.192	0.238	0.234	0.319	Interstate
	2	0.251	0.277	0.299	0.4	Interstate
	3	0.313	0.371	0.424	0.547	Interstate
	4	0.315	0.325	0.343	0.47	Interstate
	5	0.182	0.26	0.23	0.322	Interstate
	6	0.222	0.275	0.255	0.358	Interstate
	7	0.155	0.246	0.2	0.294	Interstate
	8	0.225	0.239	0.268	0.358	Interstate
	9	0.171	0.233	0.235	0.312	Interstate
	10	0.223	0.239	0.287	0.368	Interstate
	11	0.232	0.281	0.302	0.398	Interstate
	12	0.211	0.242	0.24	0.332	Highway
	13	0.19	0.235	0.245	0.326	Highway
	14	0.282	0.309	0.339	0.451	Highway
	15	0.306	0.333	0.439	0.544	Highway
	16	0.324	0.336	0.421	0.537	Highway
	17	0.215	0.262	0.261	0.355	Highway
	18	0.25	0.294	0.328	0.428	Highway
	19	0.298	0.319	0.35	0.469	Highway
	20	0.277	0.316	0.366	0.468	Highway
	21	0.358	0.392	0.458	0.593	Interstate
	22	0.244	0.279	0.323	0.417	Interstate
	23	0.283	0.298	0.388	0.486	Interstate
	24	0.261	0.292	0.349	0.446	Interstate

Table A1.16: Average weighted RMS acceleration on Truck19

Truck 19	Segment	X	Y	Z	Σ	Road Type
	1	0.256	0.337	0.29	0.419	Interstate
	2	0.267	0.338	0.306	0.433	Interstate
	3	0.325	0.406	0.394	0.541	Interstate
	4	0.347	0.464	0.479	0.631	Interstate
	5	0.352	0.433	0.421	0.578	Interstate
	6	0.28	0.348	0.286	0.428	Interstate
	7	0.272	0.351	0.295	0.433	Interstate
	8	0.238	0.309	0.246	0.372	Interstate
	9	0.286	0.377	0.324	0.47	Interstate
	10	0.233	0.299	0.284	0.391	Interstate
	11	0.279	0.359	0.342	0.471	Interstate
	12	0.239	0.34	0.28	0.387	Highway
	13	0.255	0.423	0.316	0.473	Highway
	14	0.329	0.428	0.411	0.562	Highway
	15	0.35	0.493	0.469	0.636	Highway
	16	0.369	0.521	0.509	0.682	Highway
	17	0.318	0.499	0.409	0.587	Highway
	18	0.242	0.379	0.288	0.431	Highway
	19	0.321	0.459	0.407	0.57	Highway
	20	0.355	0.515	0.474	0.65	Highway
	21	0.273	0.45	0.395	0.544	Interstate
	22	0.311	0.425	0.372	0.524	Interstate
	23	0.347	0.497	0.432	0.611	Interstate
	24	0.289	0.396	0.375	0.512	Interstate

Table A1.17: Average weighted RMS acceleration on Truck20

Truck 20	Segment	X	Y	Z	Σ	Road Type
	1	0.215	0.371	0.337	0.455	Interstate
	2	0.176	0.239	0.24	0.32	Interstate
	3	0.206	0.341	0.292	0.405	Interstate
	4	0.265	0.418	0.417	0.546	Interstate
	5	0.226	0.371	0.34	0.46	Interstate
	6	0.213	0.341	0.301	0.416	Interstate
	7	0.18	0.309	0.222	0.339	Interstate
	8	0.196	0.368	0.268	0.402	Interstate
	9	0.204	0.34	0.27	0.397	Interstate
	10	0.176	0.257	0.208	0.306	Interstate
	11	0.192	0.305	0.268	0.371	Interstate
	12	0.161	0.349	0.223	0.357	Highway
	13	0.169	0.427	0.24	0.406	Highway
	14	0.173	0.285	0.296	0.38	Highway
	15	0.257	0.461	0.464	0.597	Highway
	16	0.215	0.526	0.365	0.548	Highway
	17	0.155	0.299	0.278	0.368	Highway
	18	0.214	0.379	0.345	0.463	Highway
	19	0.224	0.453	0.391	0.533	Highway
	20	0.185	0.284	0.318	0.399	Highway
	21	0.198	0.342	0.292	0.406	Interstate
	22	0.204	0.307	0.292	0.393	Interstate
	23	0.229	0.378	0.359	0.477	Interstate
	24	0.209	0.372	0.329	0.448	Interstate

Appendix II: RMS acceleration plots for trucks with trailer

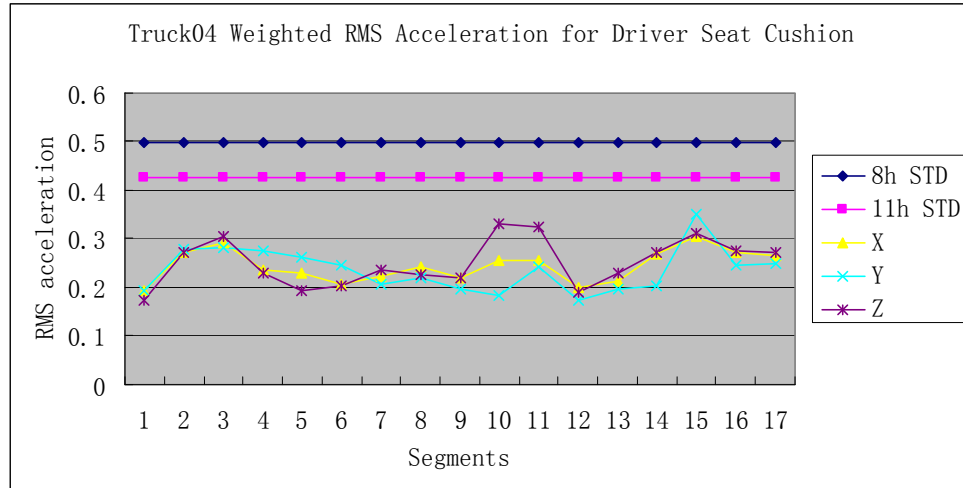


Figure A2.1: Average weighted RMS acceleration on Truck04

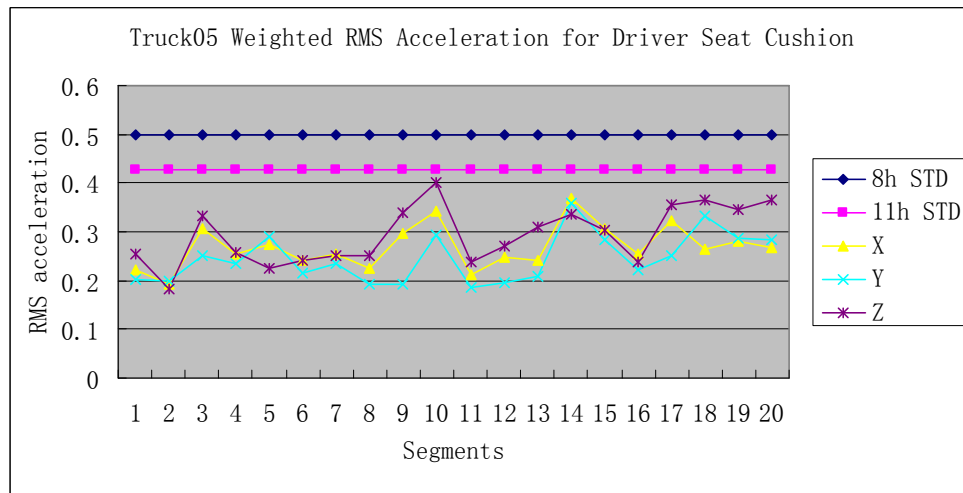


Figure A2.2: Average weighted RMS acceleration on Truck05

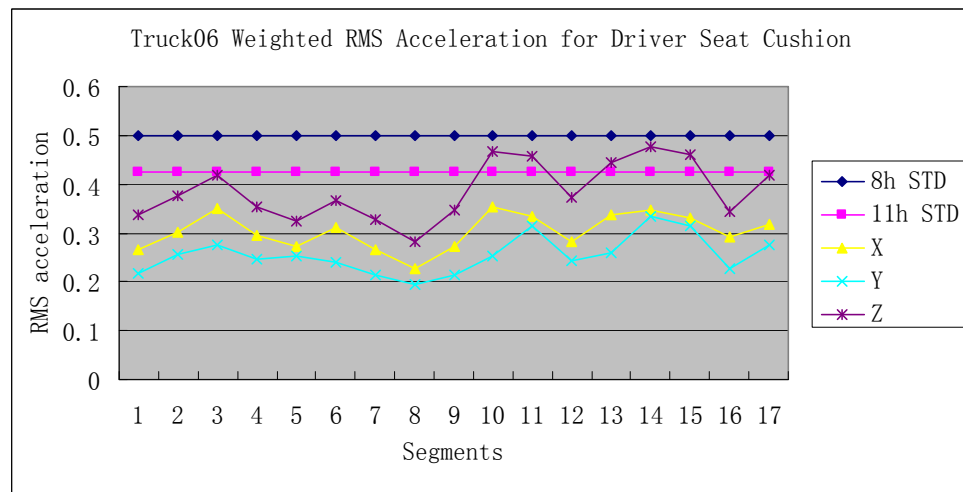


Figure A2.3: Average weighted RMS acceleration on Truck06

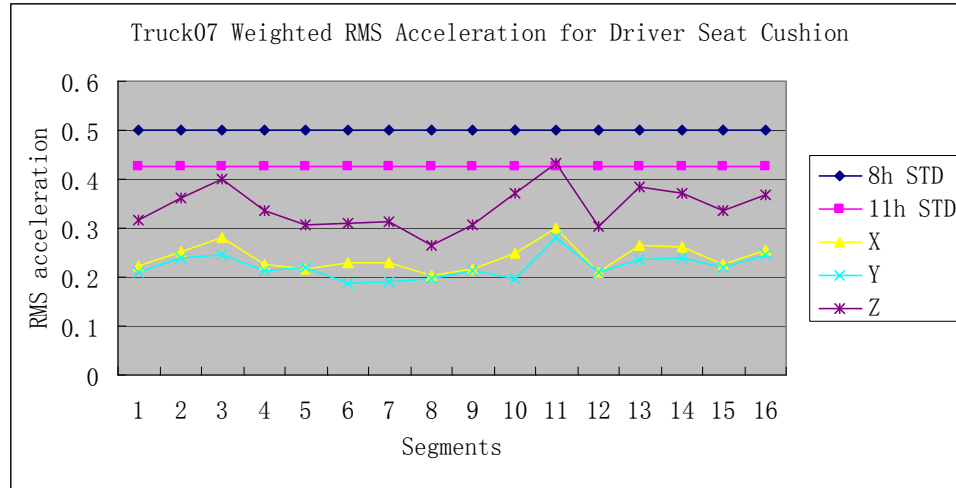


Figure A2.4: Average weighted RMS acceleration on Truck07

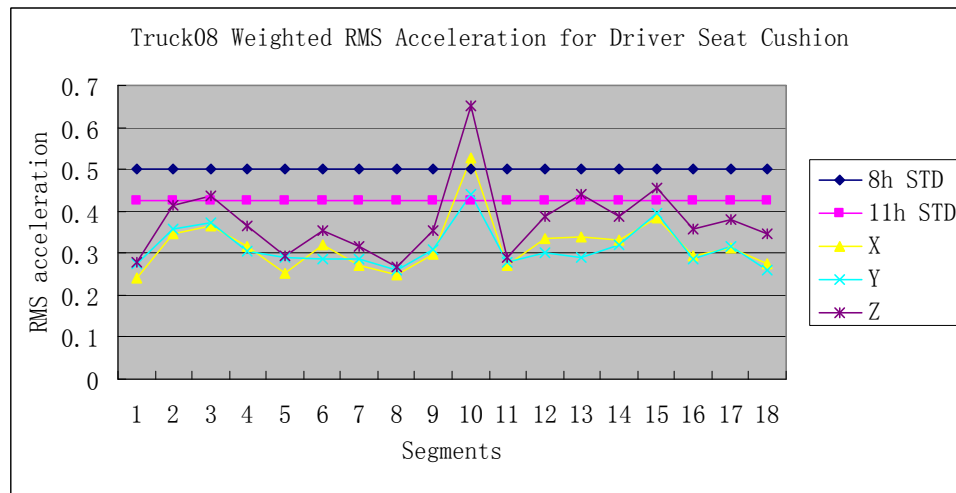


Figure A2.5: Average weighted RMS acceleration on Truck08

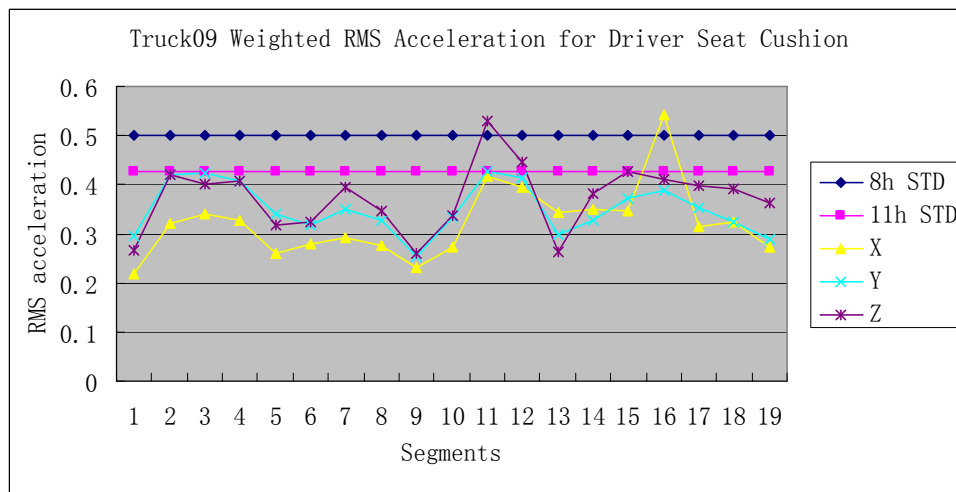


Figure A2.6: Average weighted RMS acceleration on Truck09

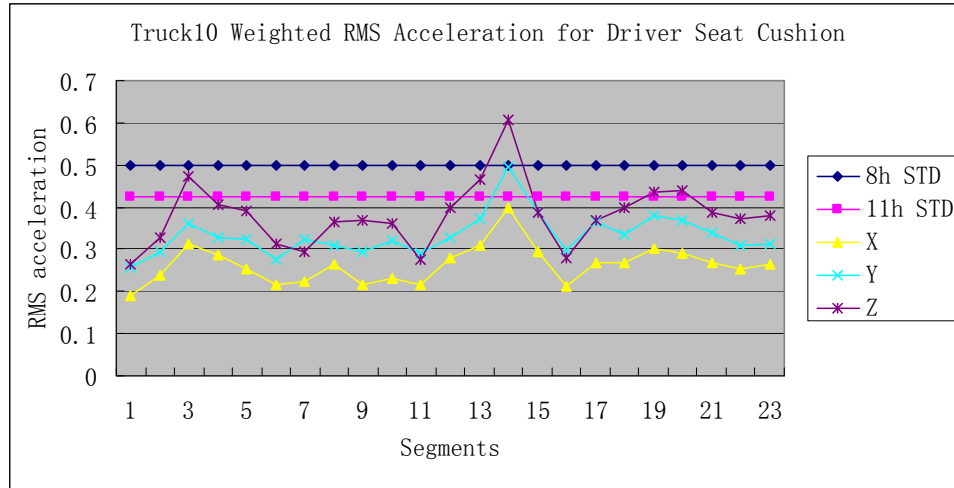


Figure A2.7: Average weighted RMS acceleration on Truck10

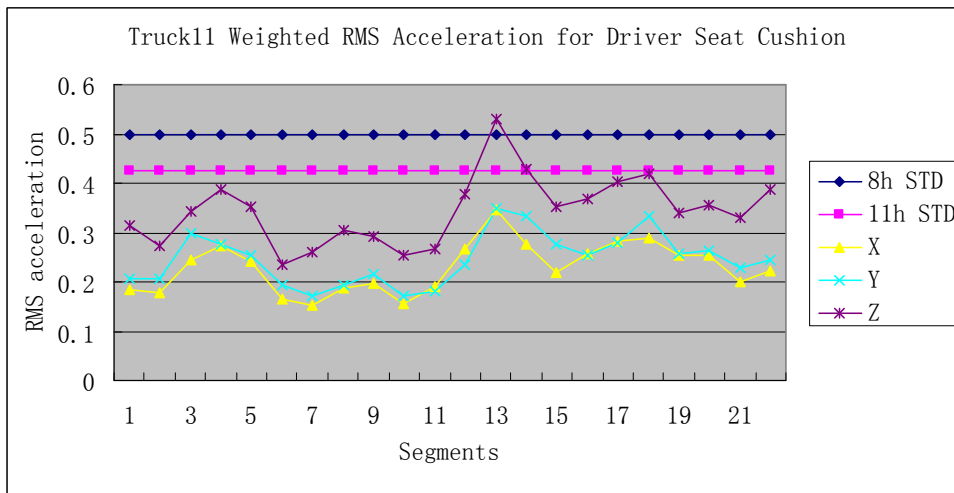


Figure A2.8: Average weighted RMS acceleration on Truck11

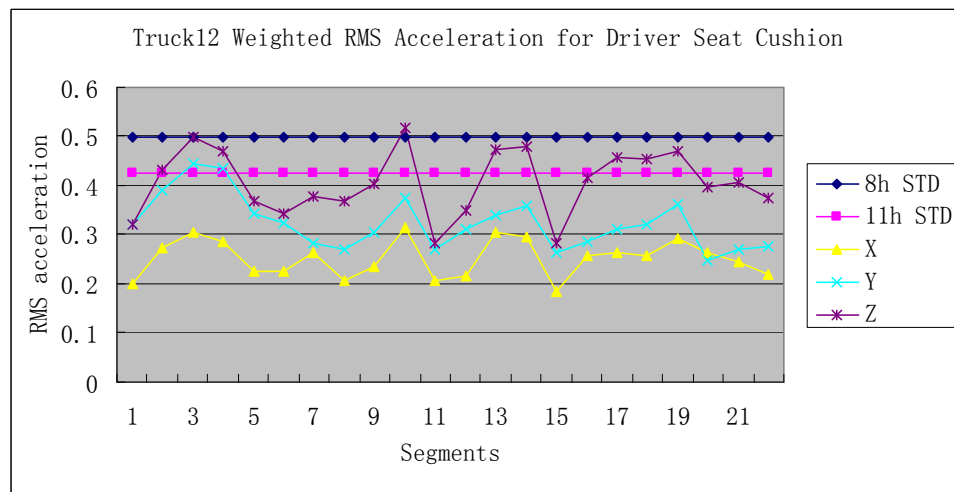


Figure A2.9: Average weighted RMS acceleration on Truck12

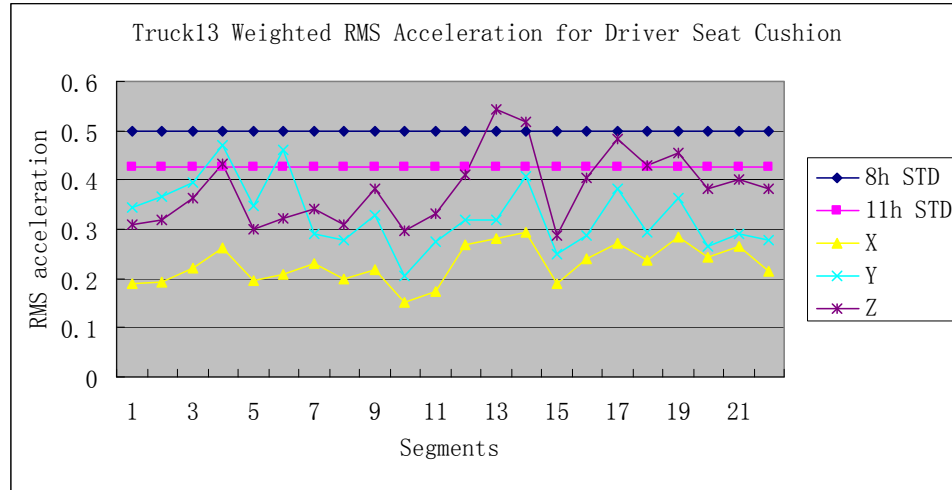


Figure A2.10: Average weighted RMS acceleration on Truck13

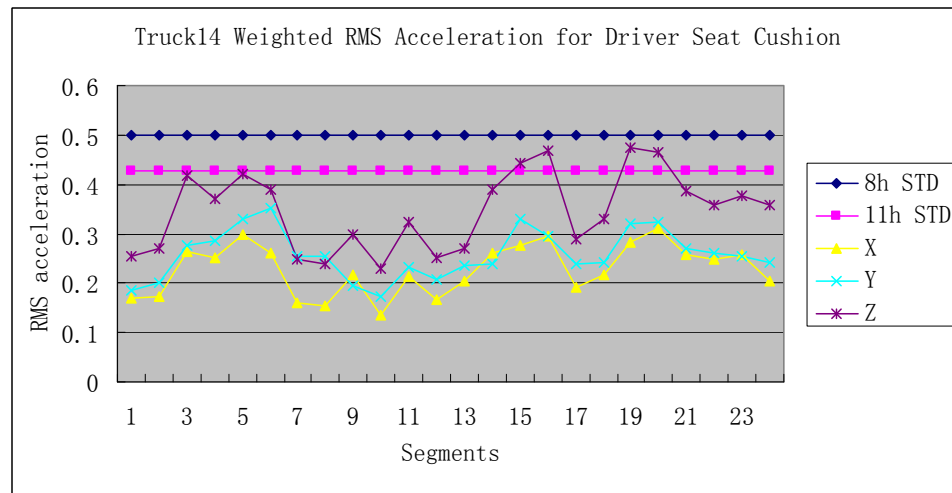


Figure A2.11: Average weighted RMS acceleration on Truck14

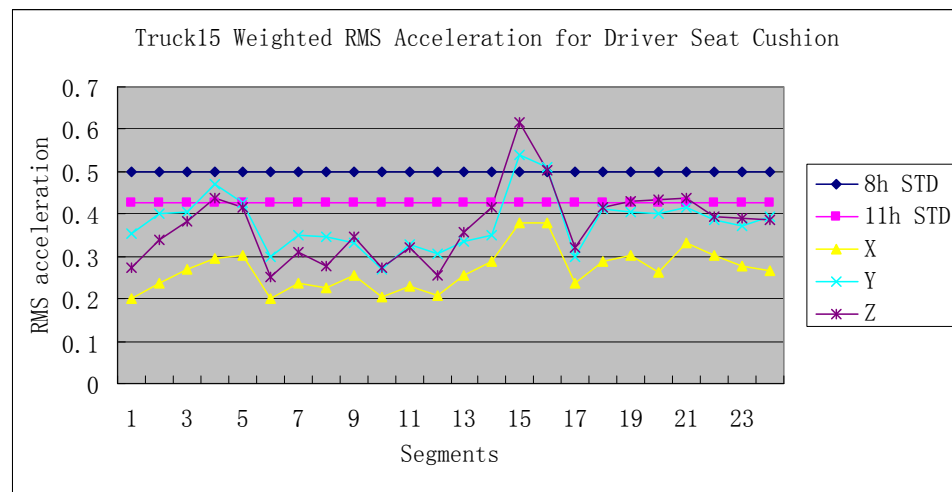


Figure A2.12: Average weighted RMS acceleration on Truck15

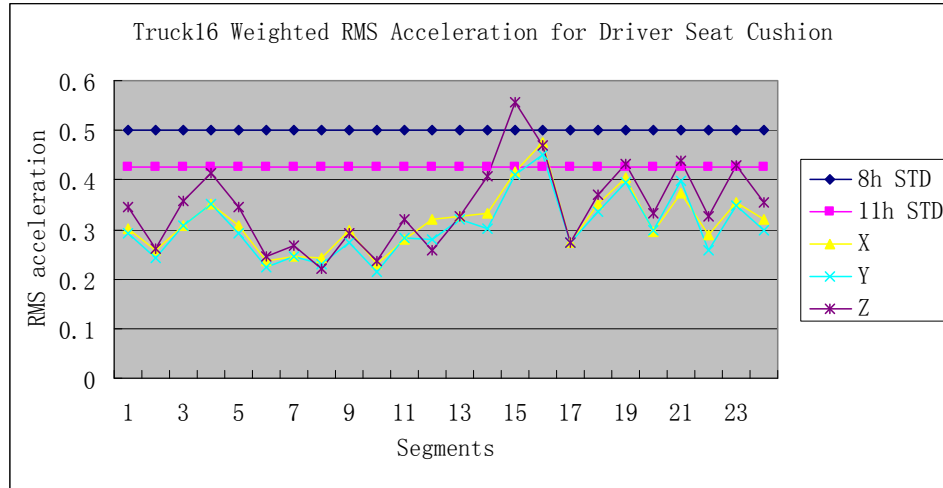


Figure A2.13: Average weighted RMS acceleration on Truck16

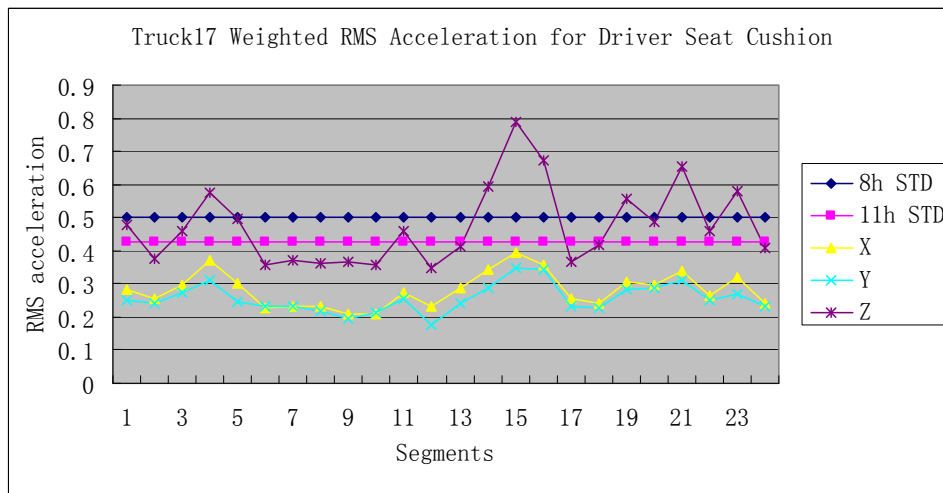


Figure A2.14: Average weighted RMS acceleration on Truck17

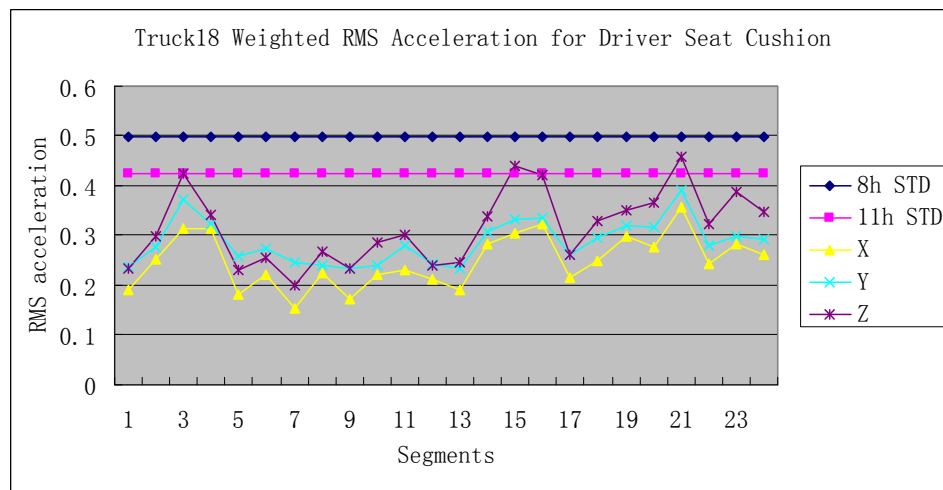


Figure A2.15: Average weighted RMS acceleration on Truck18

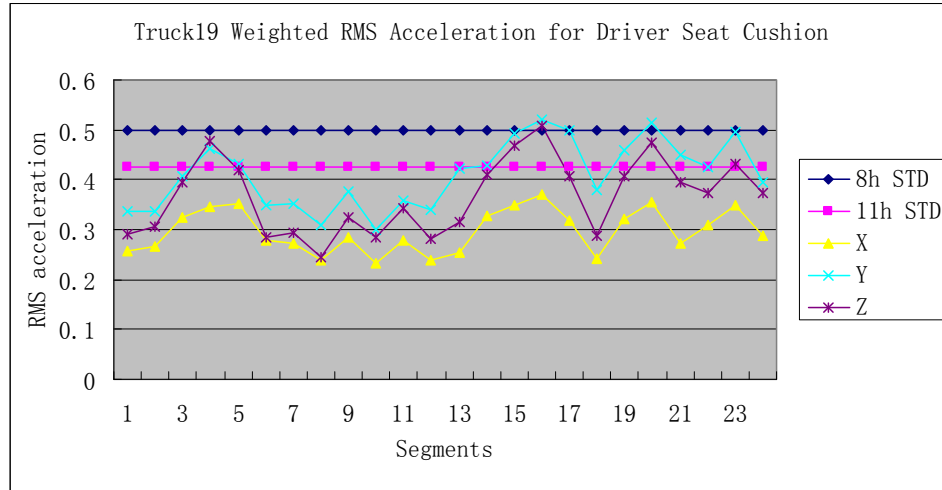


Figure A2.16: Average weighted RMS acceleration on Truck19

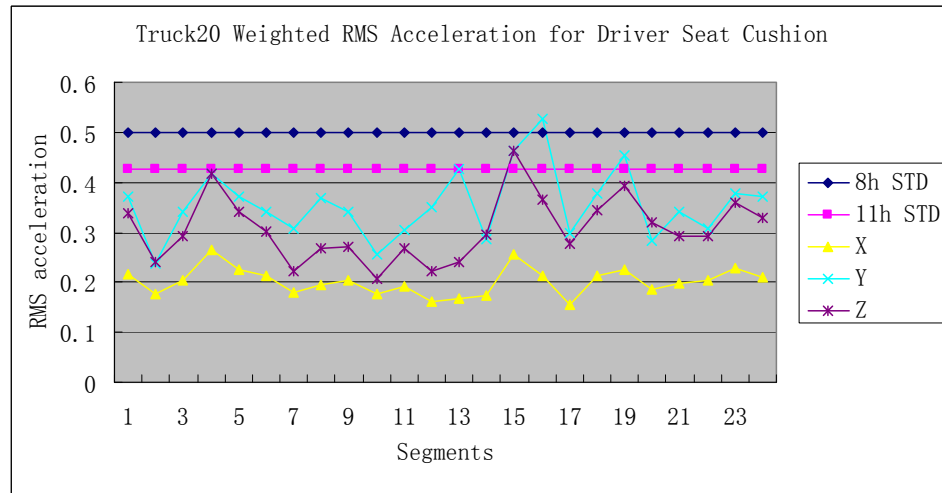


Figure A2.17: Average weighted RMS acceleration on Truck20

Appendix III: Vibration total value plots for trucks with trailer

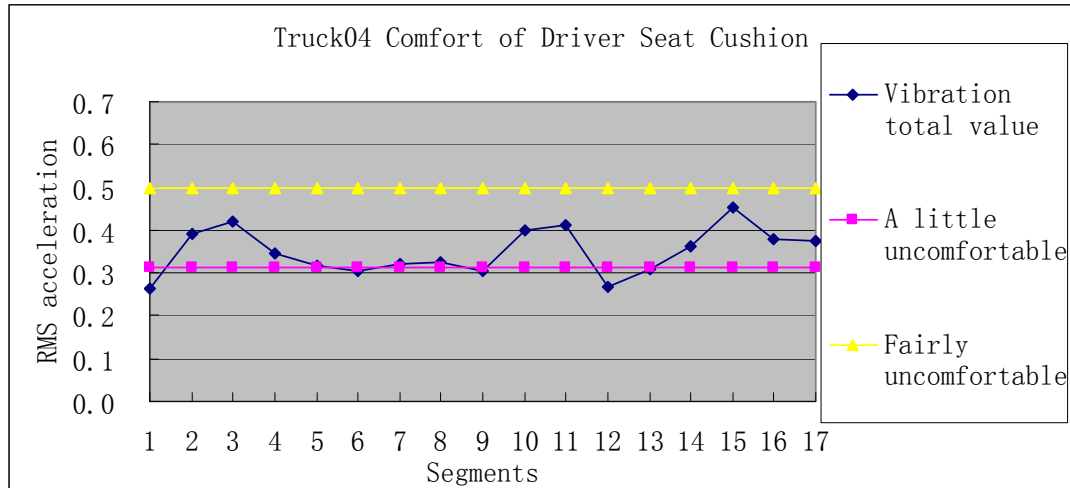


Figure A3.1: Vibration total value for comfort on Truck04

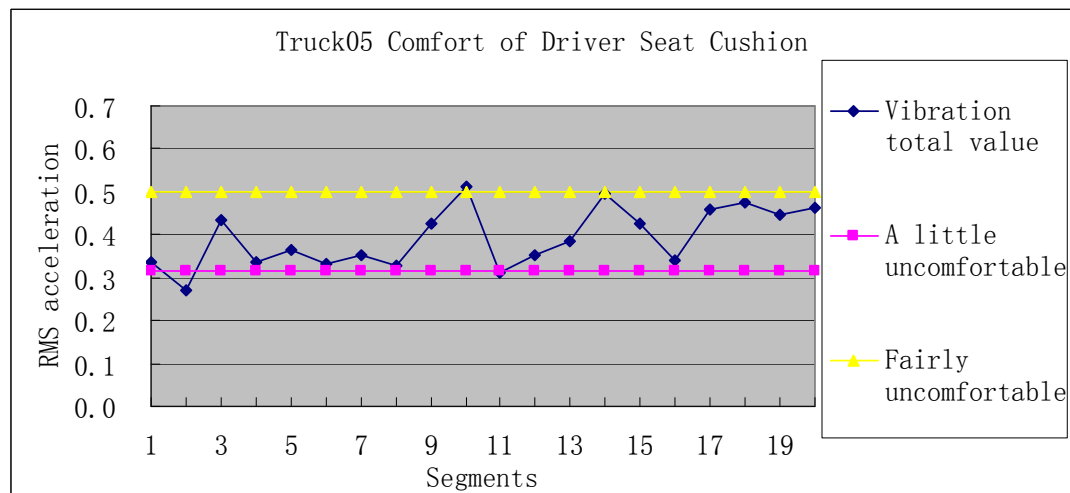


Figure A3.2: Vibration total value for comfort on Truck05

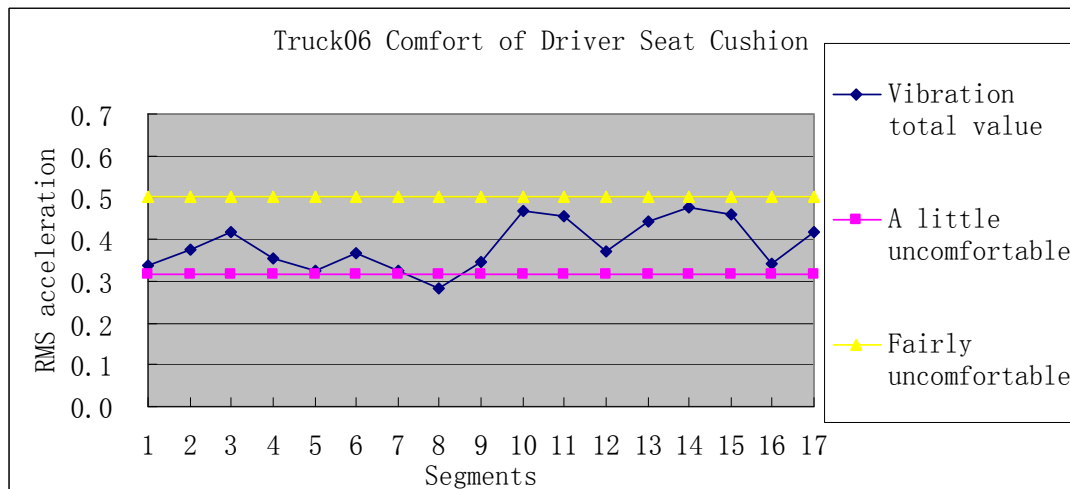


Figure A3.3: Vibration total value for comfort on Truck06

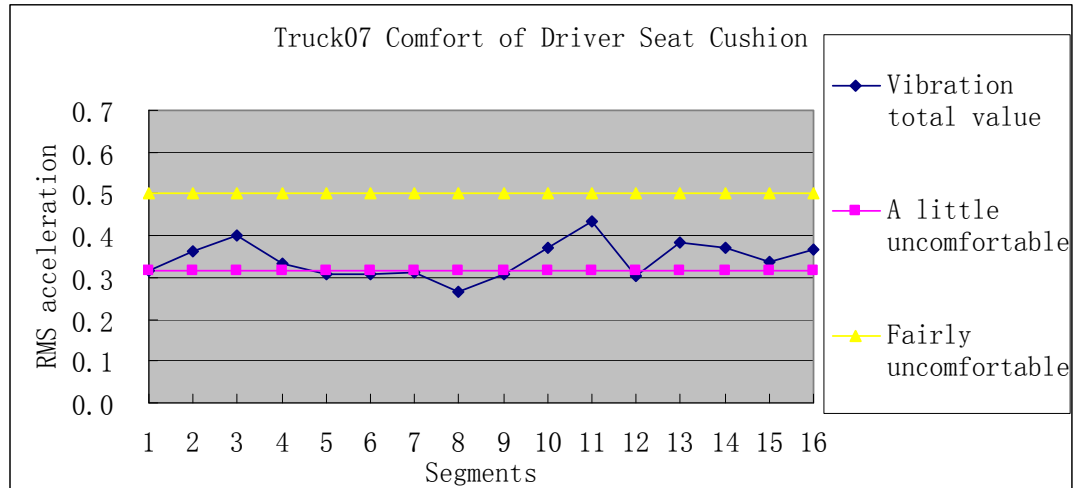


Figure A3.4: Vibration total value for comfort on Truck07

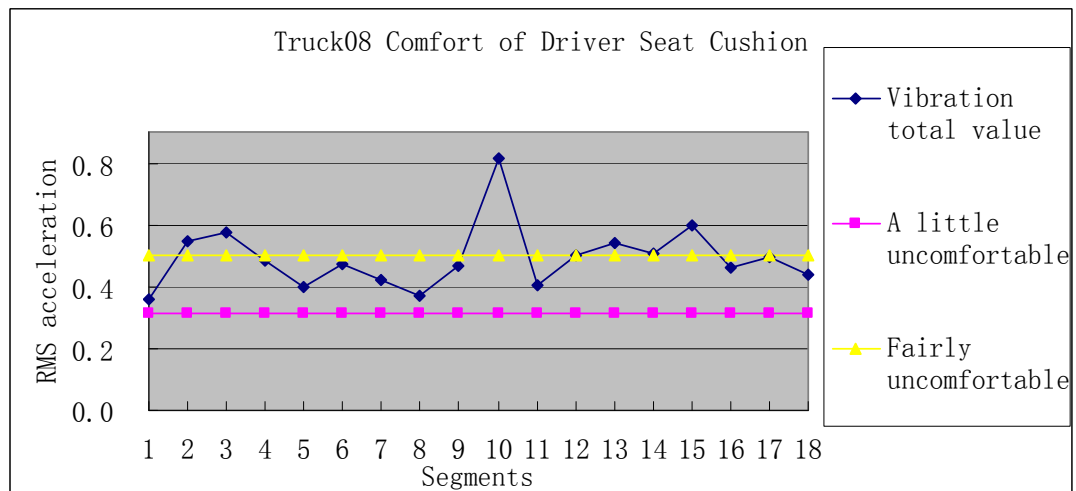


Figure A3.5: Vibration total value for comfort on Truck08

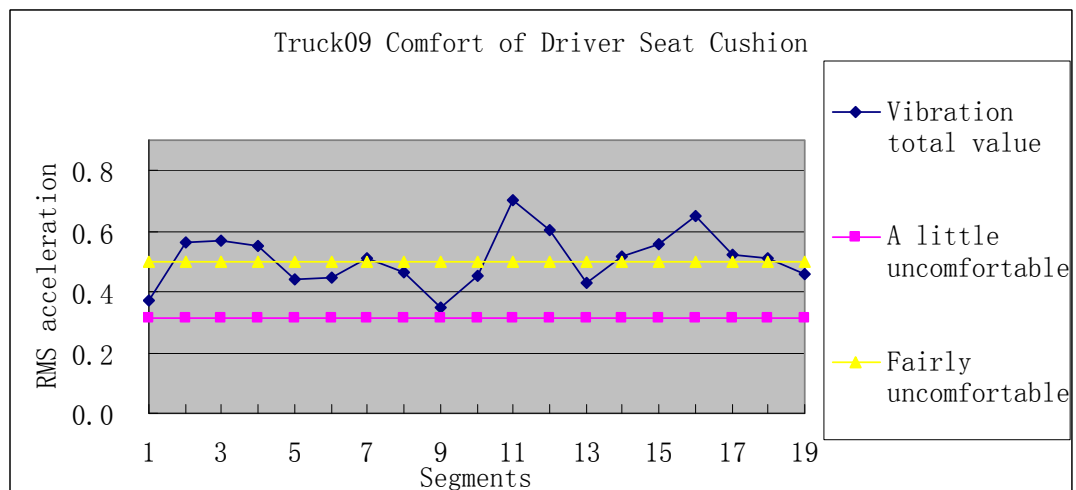


Figure A3.6: Vibration total value for comfort on Truck09

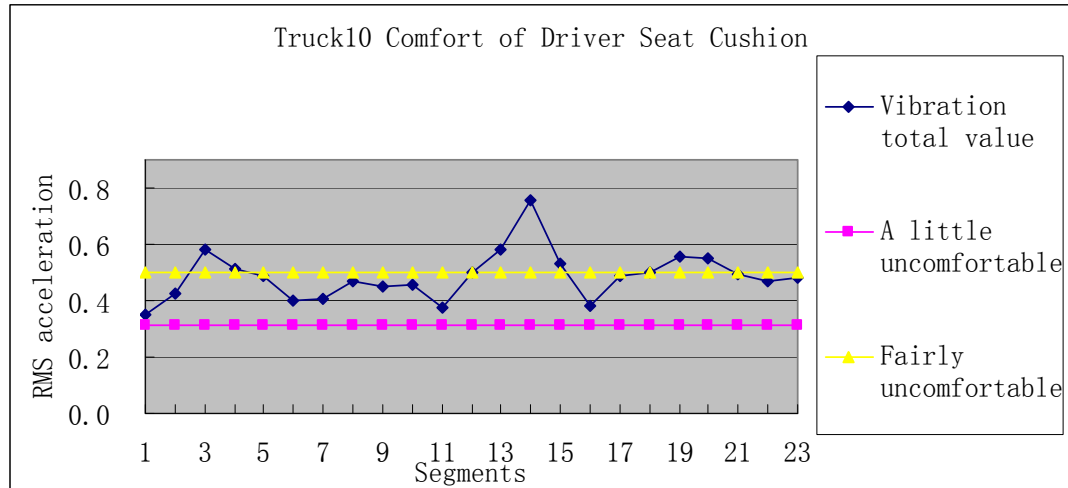


Figure A3.7: Vibration total value for comfort on Truck10

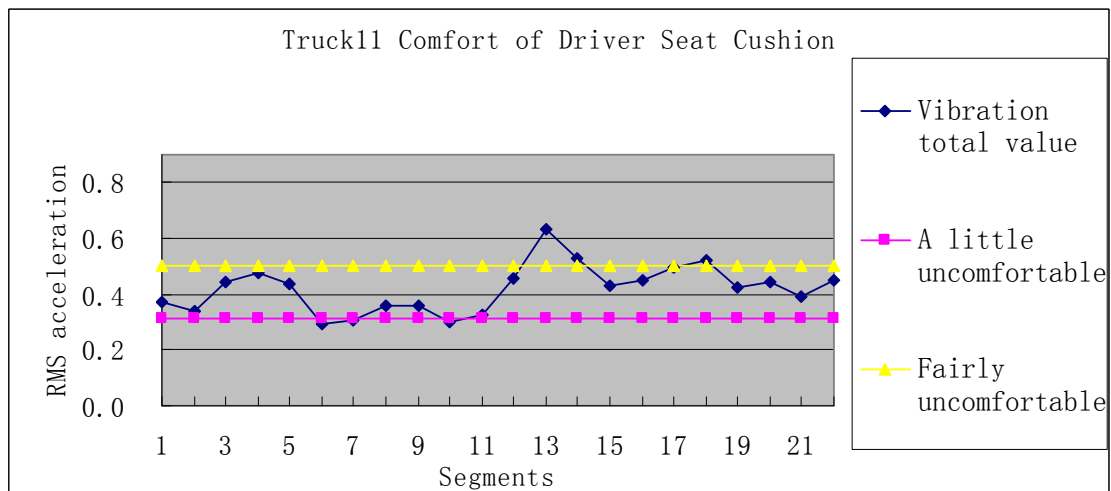


Figure A3.8: Vibration total value for comfort on Truck11

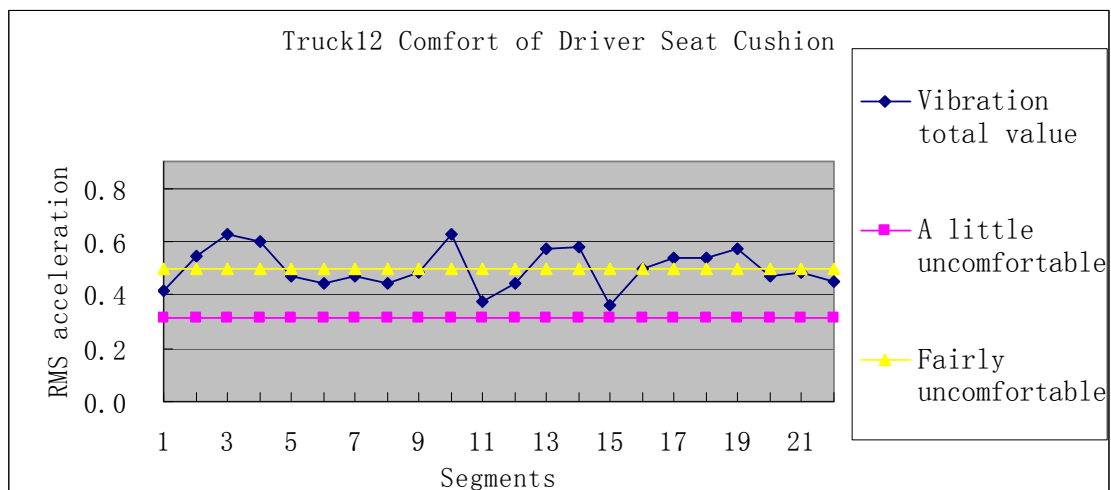


Figure A3.9: Vibration total value for comfort on Truck12

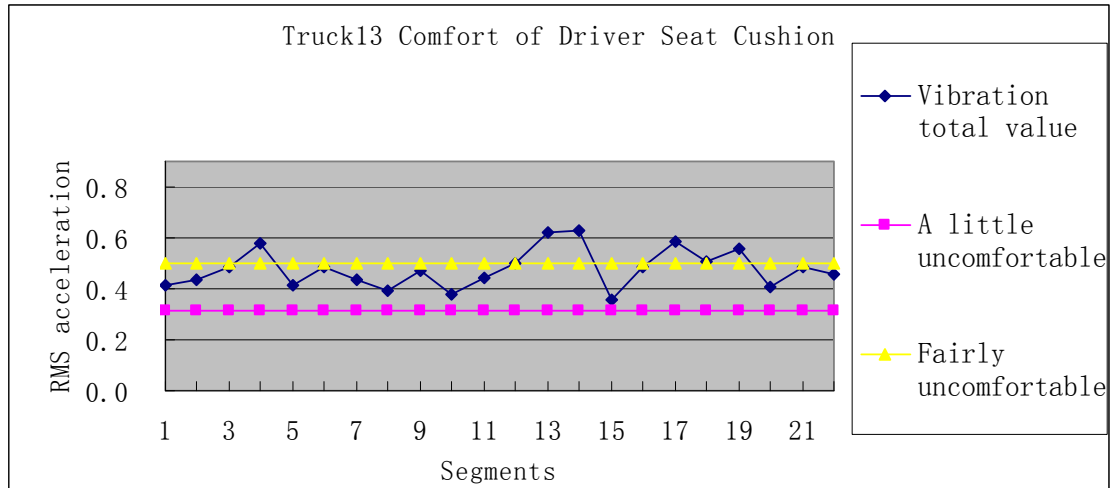


Figure A3.10: Vibration total value for comfort on Truck13

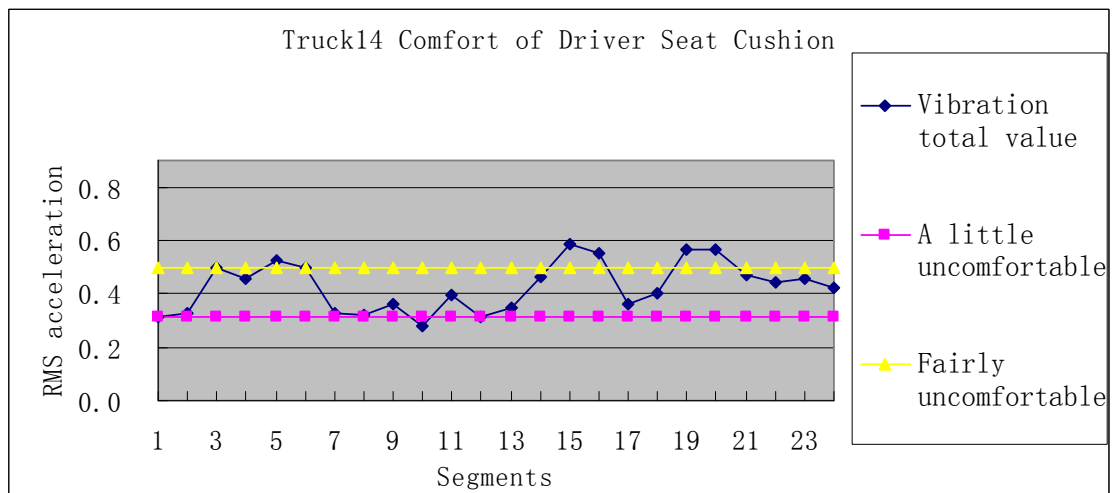


Figure A3.11: Vibration total value for comfort on Truck14

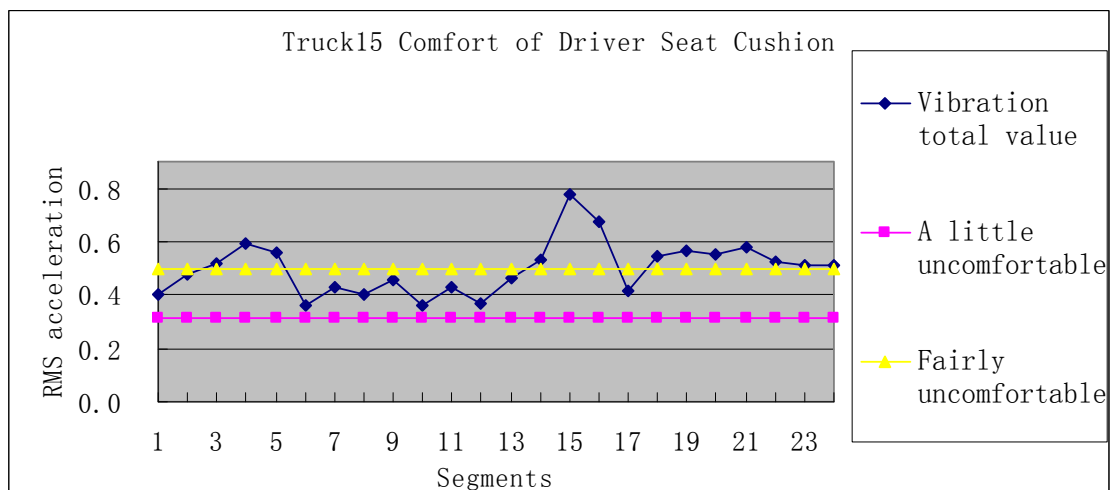


Figure A3.12: Vibration total value for comfort on Truck15

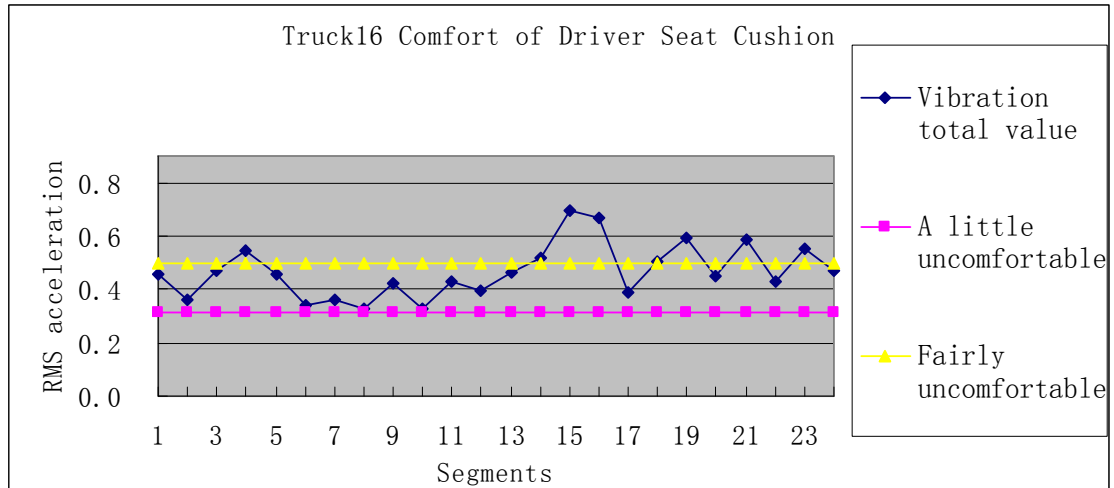


Figure A3.13: Vibration total value for comfort on Truck16

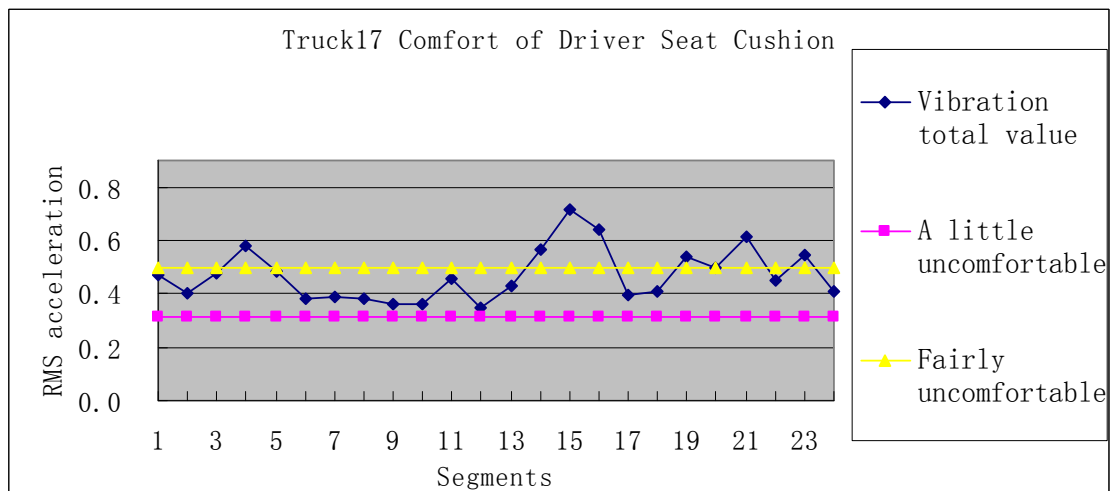


Figure A3.14: Vibration total value for comfort on Truck17

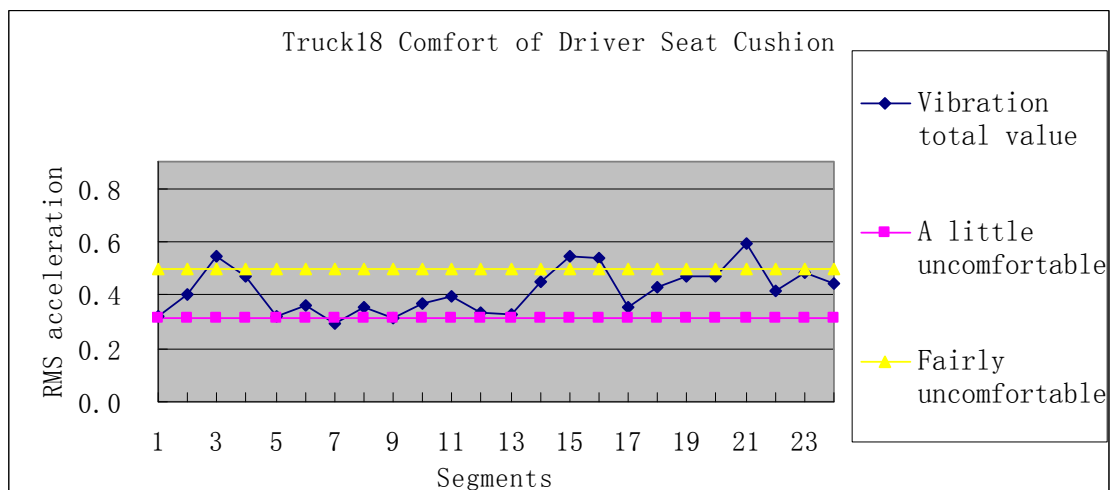


Figure A3.15: Vibration total value for comfort on Truck18

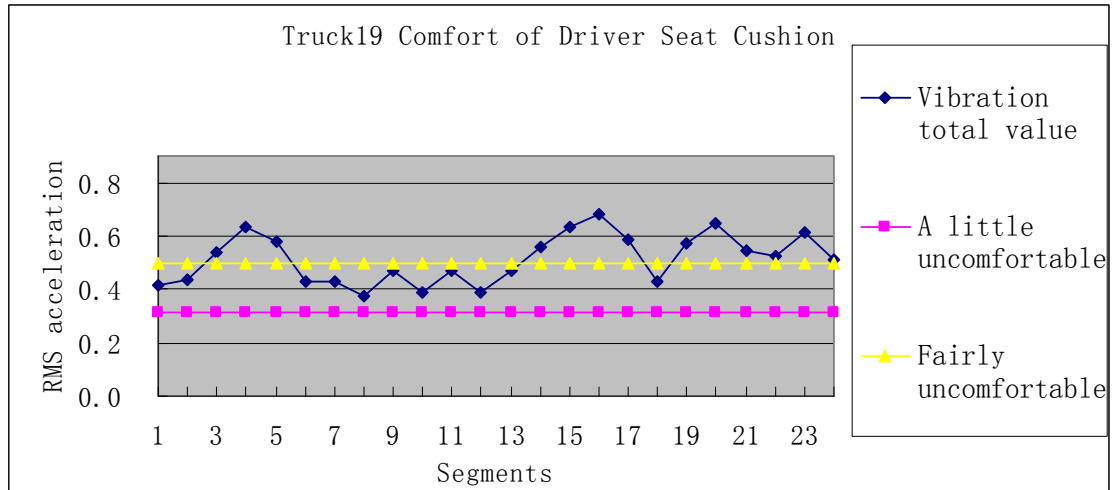


Figure A3.16: Vibration total value for comfort on Truck19

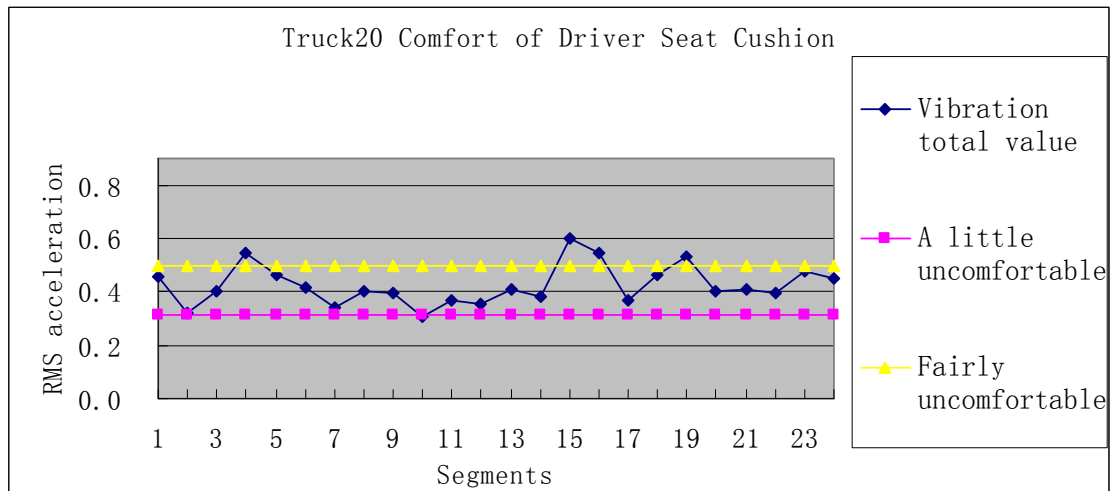


Figure A3.17: Vibration total value for comfort on Truck20

Appendix IV: Comparison of trucks with or without trailer

Table A4.1: Average weighted RMS acceleration on Truck12 without trailer

Truck 12	Segment	X	Y	Z	Σ	Road Type
	1	0.176	0.299	0.337	0.418	Interstate
	2	0.199	0.356	0.344	0.45	Interstate
	3	0.231	0.412	0.466	0.574	Interstate
	4	0.281	0.487	0.546	0.677	Interstate
	5	0.39	0.361	0.429	0.592	Interstate
	6	0.235	0.342	0.371	0.475	Interstate
	7	0.184	0.267	0.293	0.374	Interstate
	8	0.221	0.351	0.373	0.477	Interstate
	9	0.197	0.353	0.393	0.486	Interstate
	10	0.199	0.353	0.408	0.499	Interstate
	11	0.159	0.293	0.239	0.323	Highway
	12	0.234	0.374	0.29	0.417	Highway
	13	0.247	0.356	0.483	0.573	Highway
	14	0.297	0.394	0.607	0.701	Highway
	15	0.281	0.443	0.55	0.668	Highway
	16	0.143	0.237	0.283	0.344	Highway
	17	0.246	0.345	0.45	0.543	Highway
	18	0.23	0.326	0.5	0.574	Highway
	19	0.266	0.36	0.512	0.602	Interstate
	20	0.241	0.286	0.43	0.505	Interstate
	21	0.226	0.326	0.435	0.519	Interstate
	22	0.2	0.303	0.419	0.492	Interstate

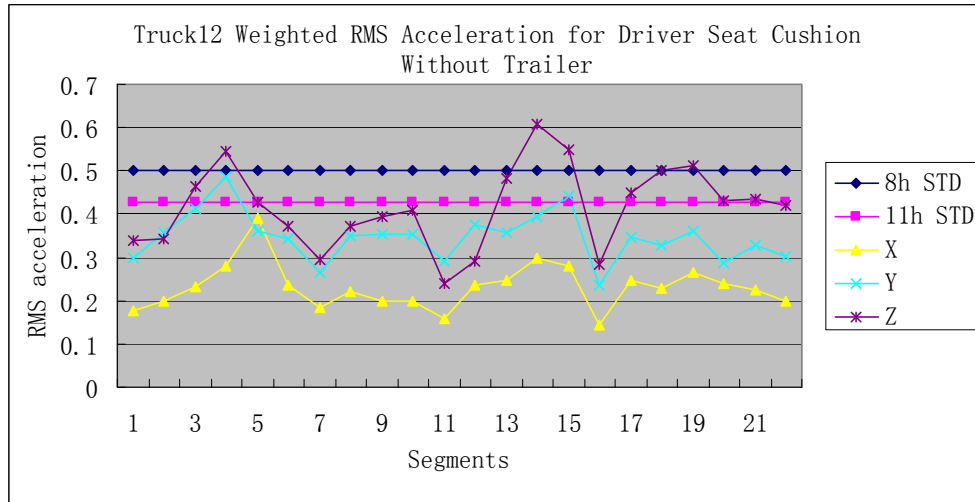


Figure A4.1: Average weighted RMS acceleration on Truck12 without trailer

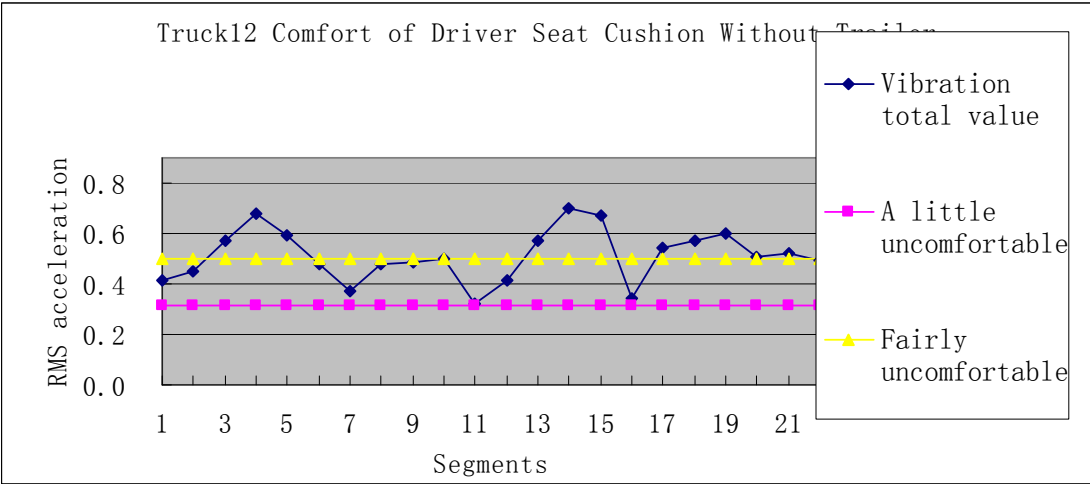


Figure A4.2: Vibration total value for comfort on Truck12 without trailer

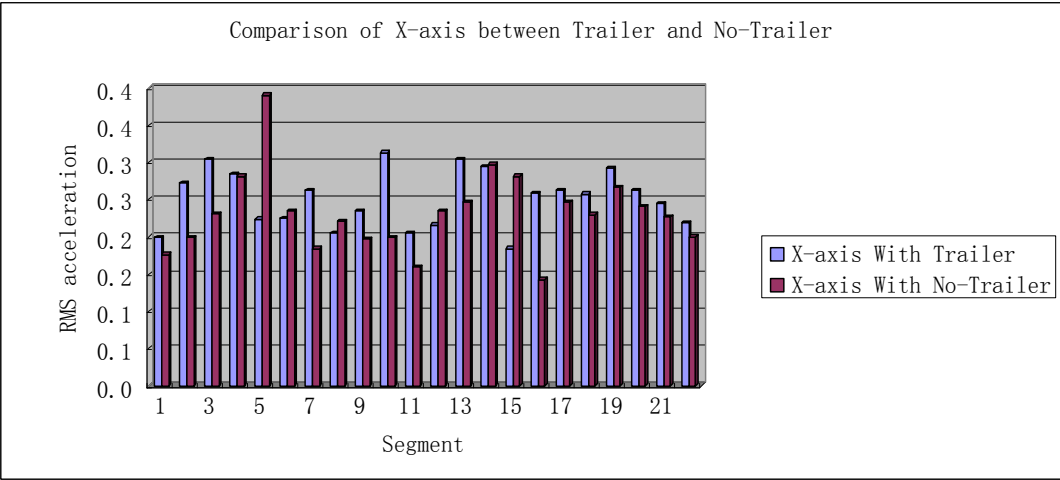


Figure A4.3: Comparison of X-axis on Truck12 between with and without trailer

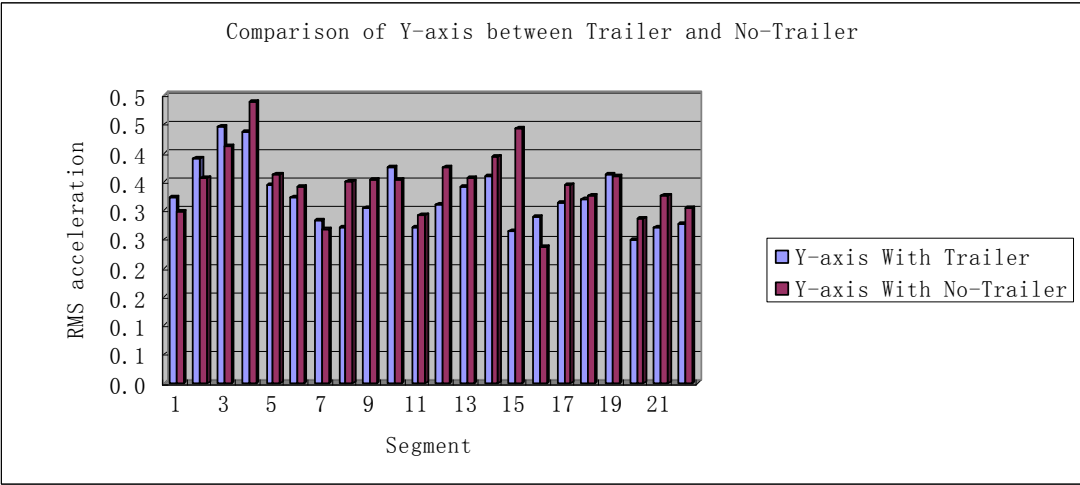


Figure A4.4: Comparison of Y-axis on Truck12 between with and without trailer

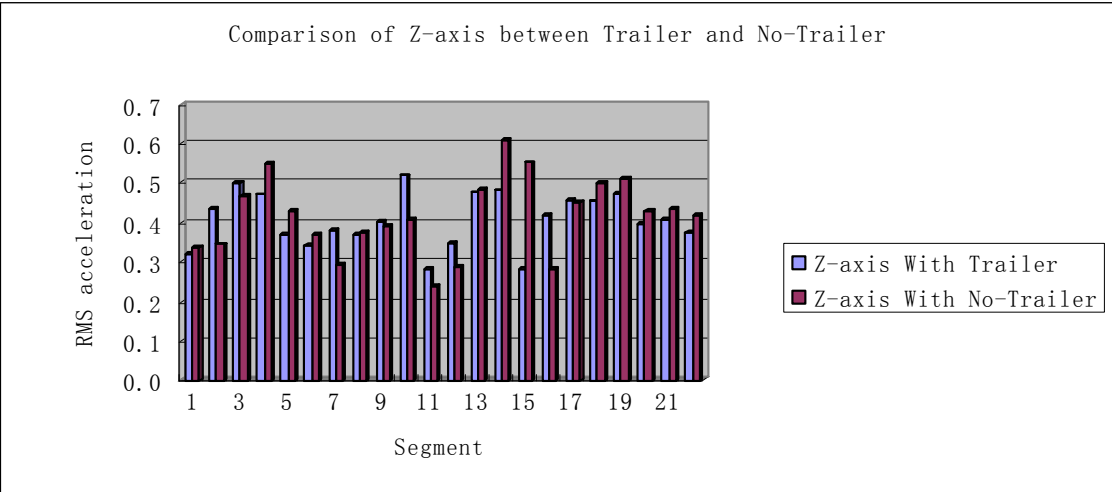


Figure A4.5: Comparison of Z-axis on Truck12 between with and without trailer

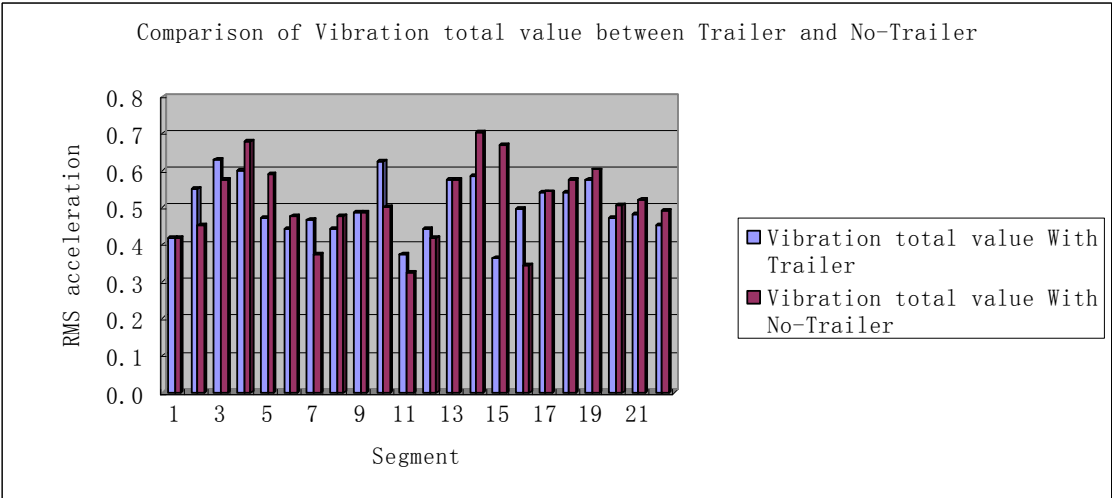


Figure A4.6: Comparison of vibration total value on Truck12 between with and without trailer

Table A4.2: Average weighted RMS acceleration on Truck18 without trailer

Truck 18	Segment	X	Y	Z	Σ	Road Type
	1	0.239	0.274	0.293	0.392	Interstate
	2	0.224	0.302	0.302	0.405	Interstate
	3	0.26	0.332	0.352	0.462	Interstate
	4	0.277	0.323	0.363	0.472	Interstate
	5	0.243	0.324	0.319	0.425	Interstate
	6	0.188	0.27	0.247	0.344	Interstate
	7	0.212	0.267	0.239	0.342	Interstate
	8	0.529	0.307	0.294	0.565	Interstate
	9	0.188	0.236	0.212	0.301	Interstate
	10	0.242	0.272	0.29	0.389	Interstate
	11	0.191	0.23	0.217	0.305	Highway
	12	0.22	0.225	0.209	0.307	Highway
	13	0.223	0.293	0.294	0.401	Highway
	14	0.274	0.323	0.382	0.488	Highway
	15	0.306	0.341	0.396	0.413	Highway
	16	0.247	0.347	0.32	0.441	Highway
	17	0.21	0.29	0.266	0.369	Highway
	18	0.314	0.326	0.347	0.474	Highway
	19	0.309	0.356	0.398	0.519	Highway
	20	0.233	0.288	0.294	0.394	Highway
	21	0.405	0.43	0.465	0.626	Interstate
	22	0.238	0.265	0.311	0.401	Interstate
	23	0.312	0.364	0.394	0.521	Interstate
	24	0.23	0.282	0.305	0.4	Interstate

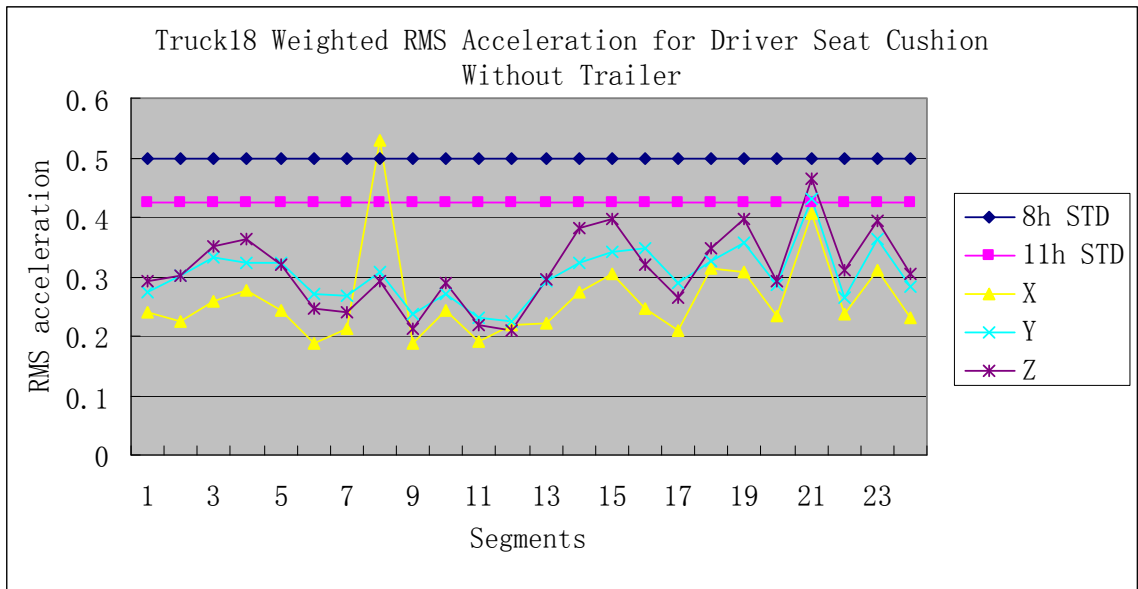


Figure A4.7: Average weighted RMS acceleration on Truck18 without trailer

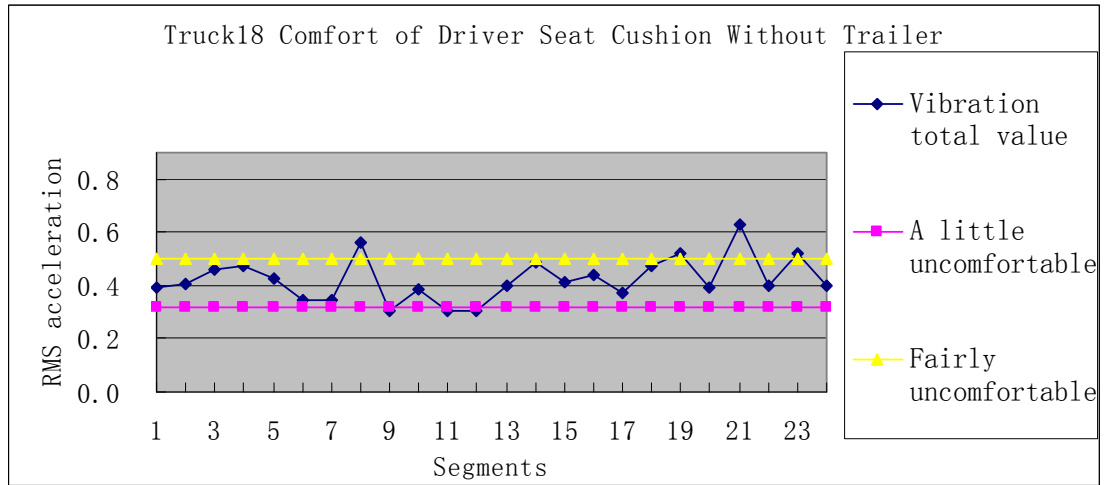


Figure A4.8: Vibration total value for comfort on Truck18 without trailer

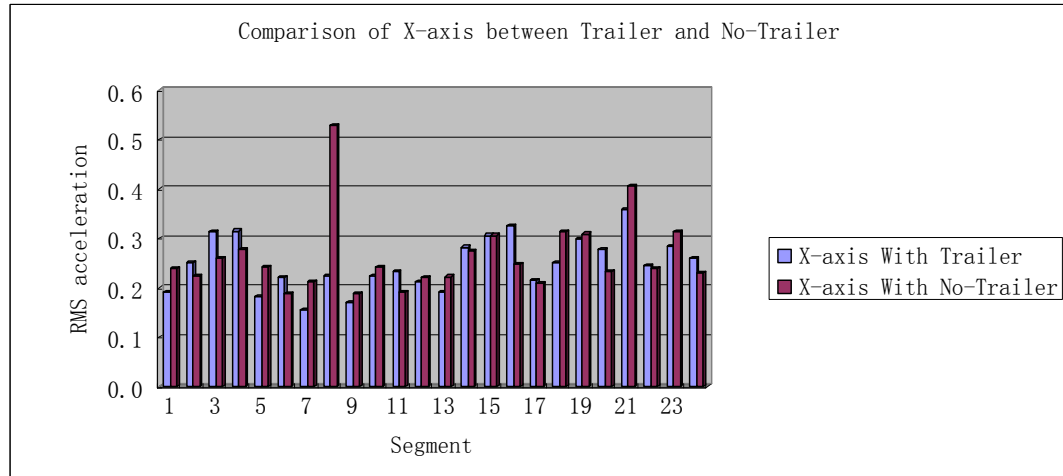


Figure A4.9: Comparison of X-axis on Truck18 between with and without trailer

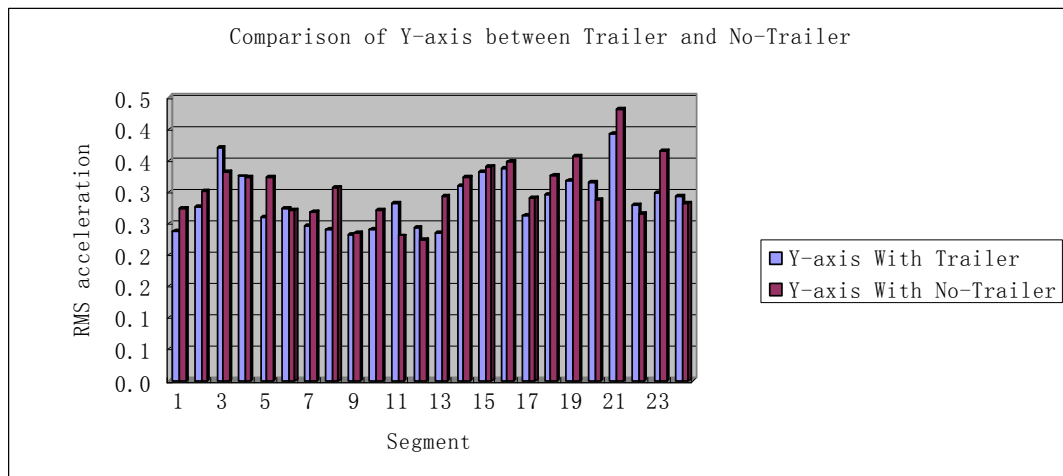


Figure A4.10: Comparison of Y-axis on Truck18 between with and without trailer

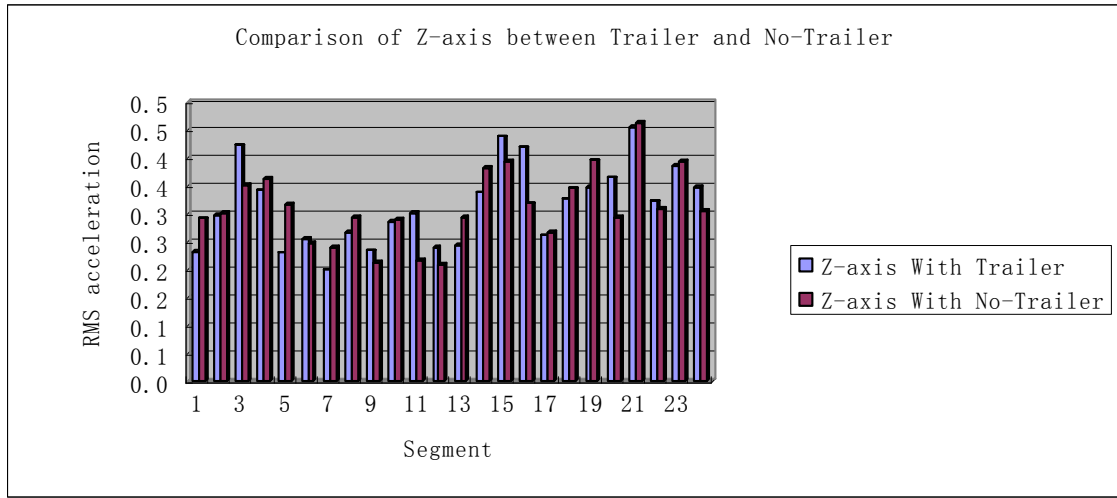


Figure A4.11: Comparison of Z-axis on Truck18 between with and without trailer

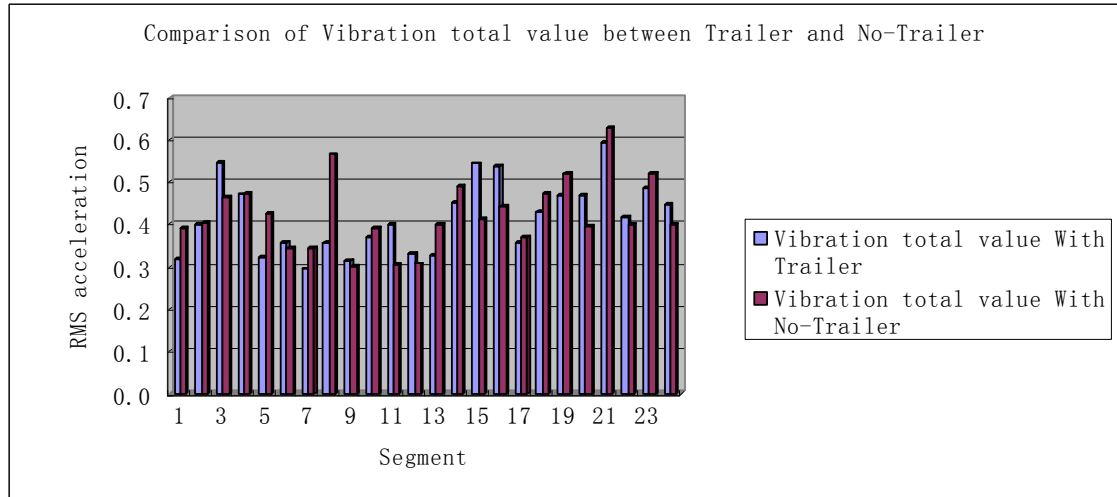


Figure A4.12: Comparison of vibration total value on Truck18 between with and without trailer

Table A4.3: Average weighted RMS acceleration on Truck20 without trailer

Truck 20	Segment	X	Y	Z	Σ	Road Type
	1	0.2408	0.3002	0.3718	0.4614	Interstate
	2	0.2355	0.2803	0.2898	0.3904	Interstate
	3	0.2372	0.3279	0.3436	0.4488	Interstate
	4	0.278	0.4024	0.511	0.6158	Interstate
	5	0.2419	0.39	0.4468	0.5538	Interstate
	6	0.2111	0.31	0.2676	0.3786	Interstate
	7	0.2181	0.355	0.291	0.4156	Interstate
	8	0.2162	0.352	0.2568	0.3956	Interstate
	9	0.2134	0.3755	0.3546	0.4716	Interstate
	10	0.2162	0.3097	0.2428	0.3622	Interstate
	11	0.2377	0.3091	0.3282	0.4308	Interstate
	12	0.154	0.2542	0.232	0.3174	Highway
	13	0.1707	0.2663	0.1992	0.3053	Highway
	14	0.1842	0.2733	0.3346	0.409	Highway
	15	0.2226	0.327	0.4634	0.5422	Highway
	16	0.2145	0.3797	0.434	0.5382	Highway
	17	0.2139	0.3707	0.4022	0.5054	Highway
	18	0.2495	0.3279	0.3558	0.4616	Highway
	19	0.2178	0.3576	0.3992	0.5002	Highway
	20	0.2181	0.2394	0.3046	0.3822	Highway
	21	0.2318	0.3077	0.2946	0.4028	Interstate
	22	0.2556	0.2926	0.3082	0.4146	Interstate
	23	0.2848	0.3856	0.4346	0.5522	Interstate
	24	0.2302	0.2831	0.2558	0.365	Interstate

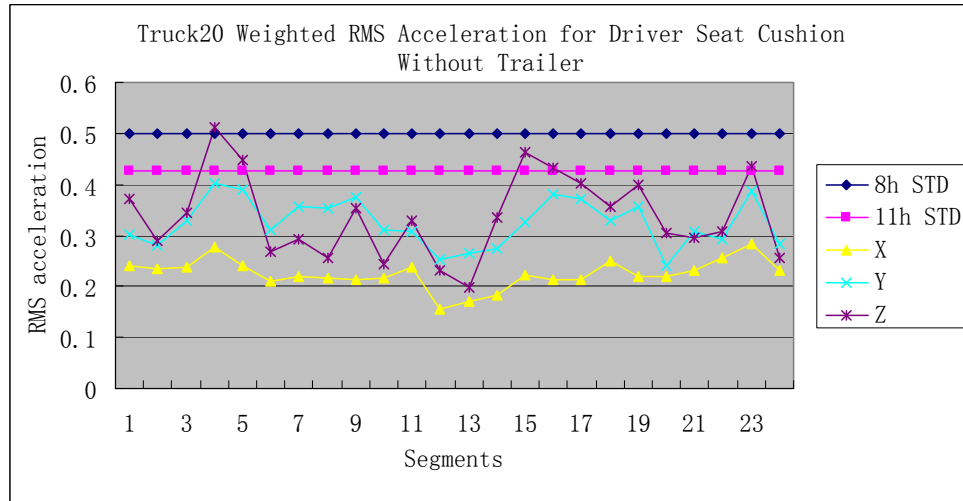


Figure A4.13: Average weighted RMS acceleration on Truck20 without trailer

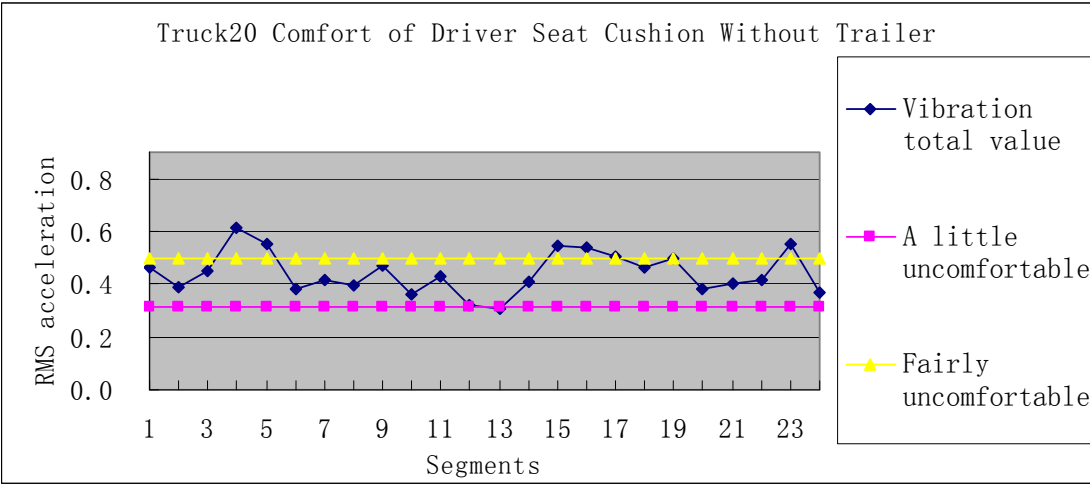


Figure A4.14: Vibration total value for comfort on Truck20 without trailer

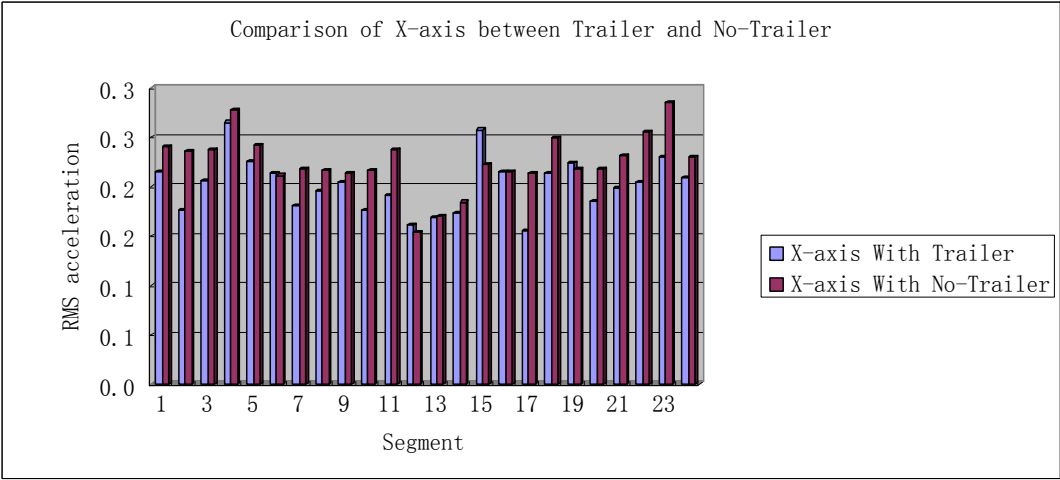


Figure A4.15: Comparison of X-axis on Truck20 between with and without trailer

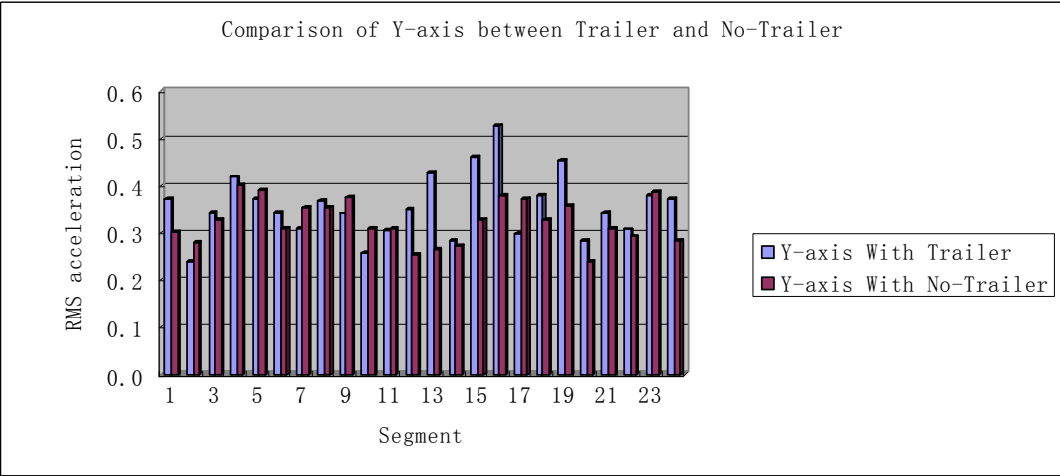


Figure A4.16: Comparison of Y-axis on Truck20 between with and without trailer

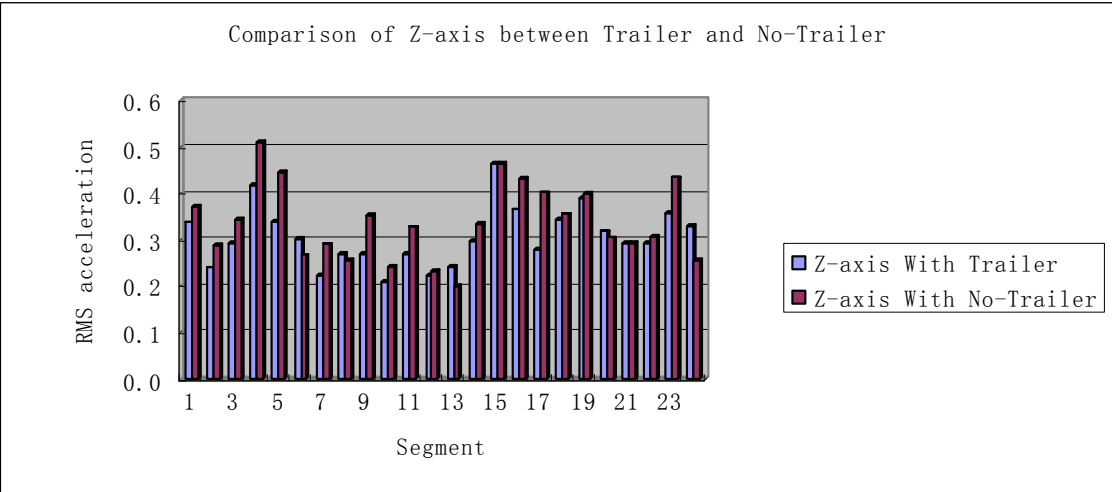


Figure A4.17: Comparison of Z-axis on Truck20 between with and without trailer

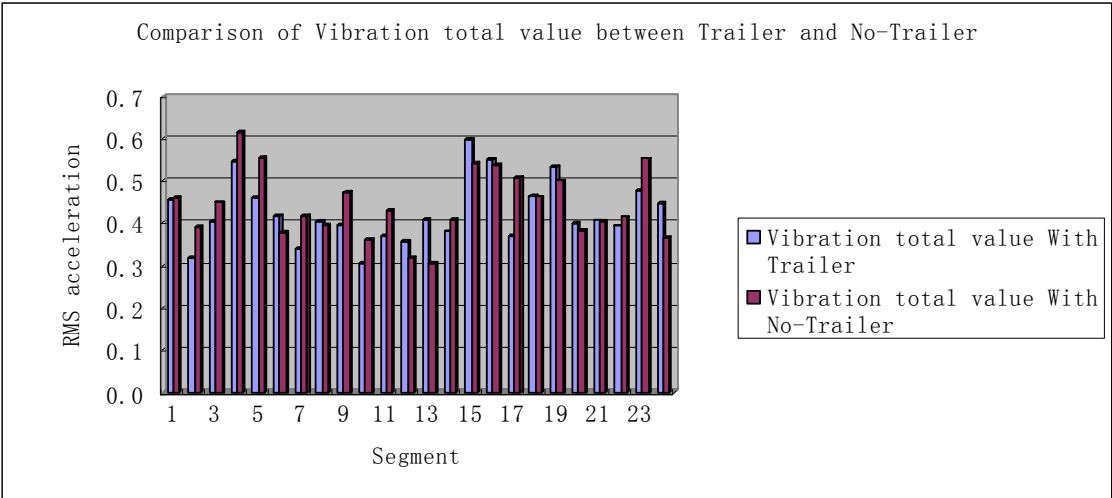


Figure A4.18: Comparison of vibration total value on Truck20 between with and without trailer

Appendix V: Selected weighted acceleration and VDV results

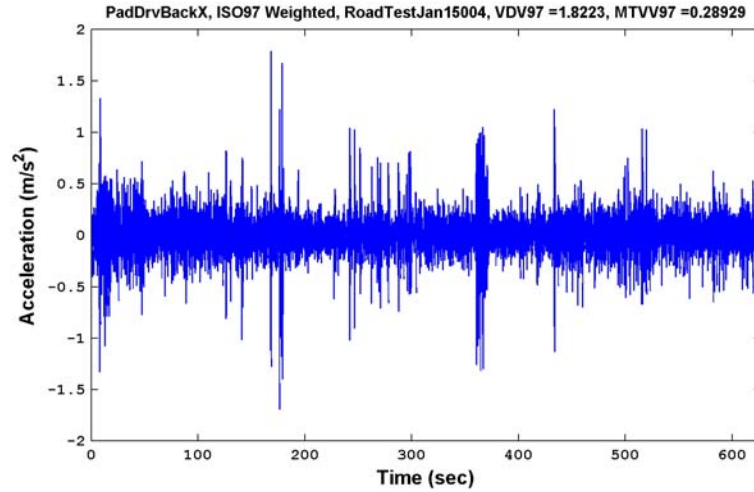


Figure A5.1: Weighted acceleration in X-axis on PadDrvBack for Truck02 Segment 04

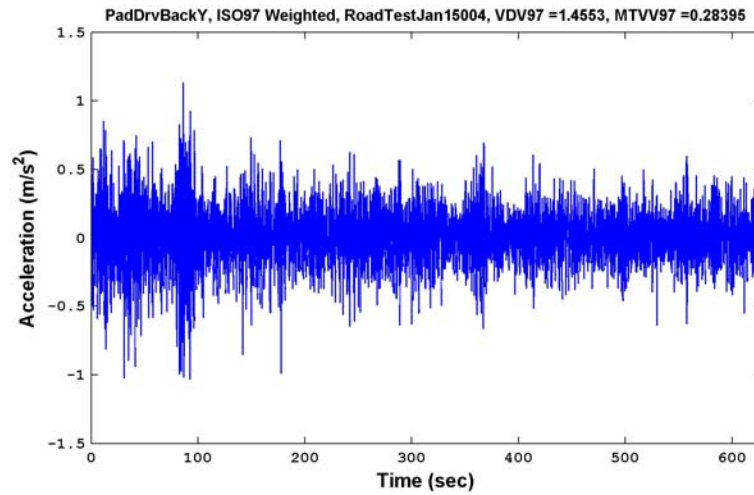


Figure A5.2: Weighted acceleration in Y-axis on PadDrvBack for Truck02 Segment 04

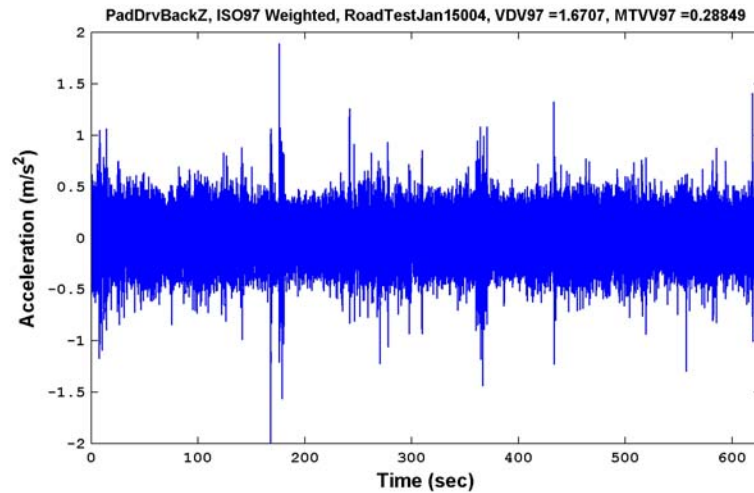


Figure A5.3: Weighted acceleration in Z-axis on PadDrvBack for Truck02 Segment 04

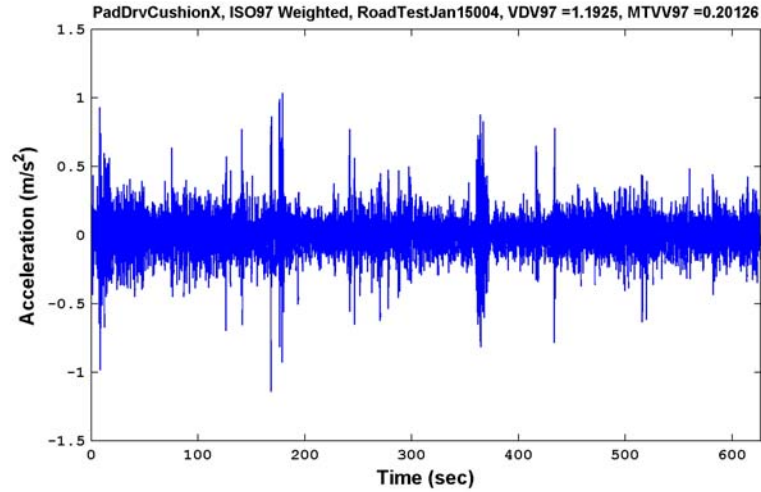


Figure A5.4: Weighted acceleration in X-axis on PadDrvCushion for Truck02 Segment 04

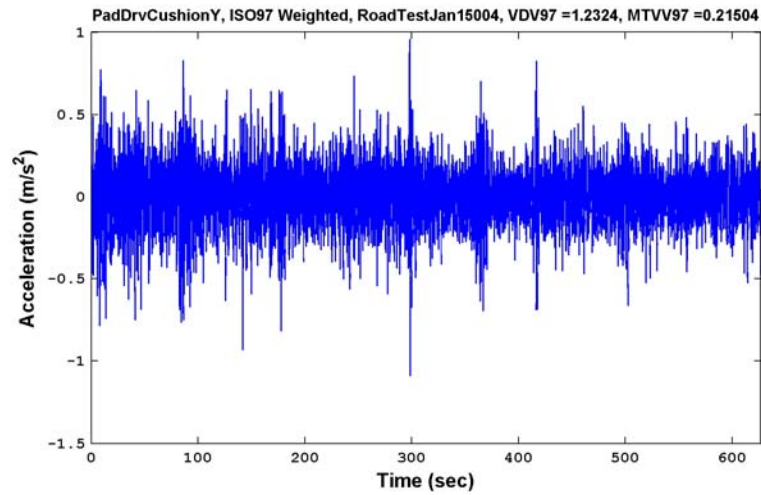


Figure A5.5: Weighted acceleration in Y-axis on PadDrvCushion for Truck02 Segment 04

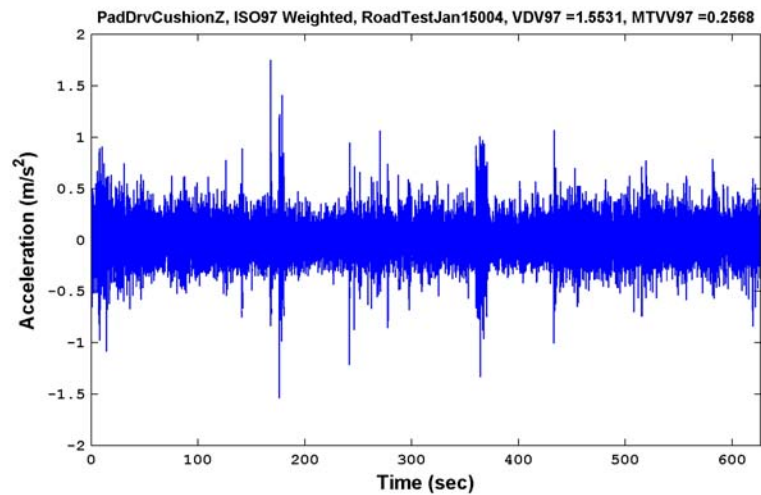


Figure A5.6: Weighted acceleration in Z-axis on PadDrvCushion for Truck02 Segment 04

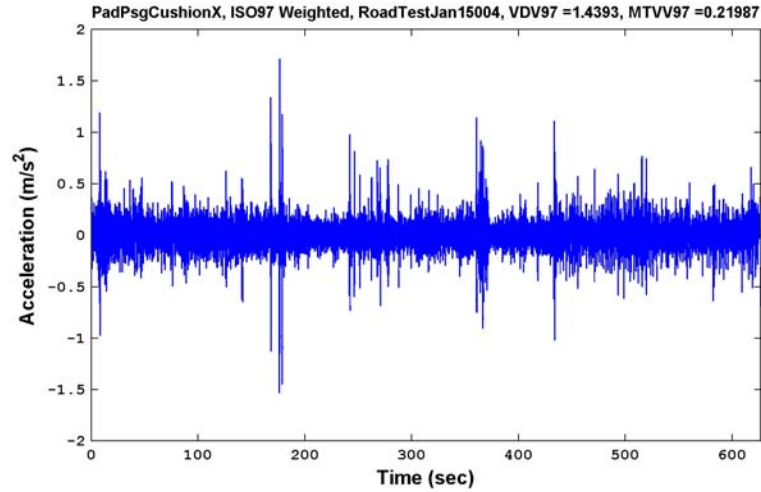


Figure A5.7: Weighted acceleration in X-axis on PadPsgCushion for Truck02 Segment 04

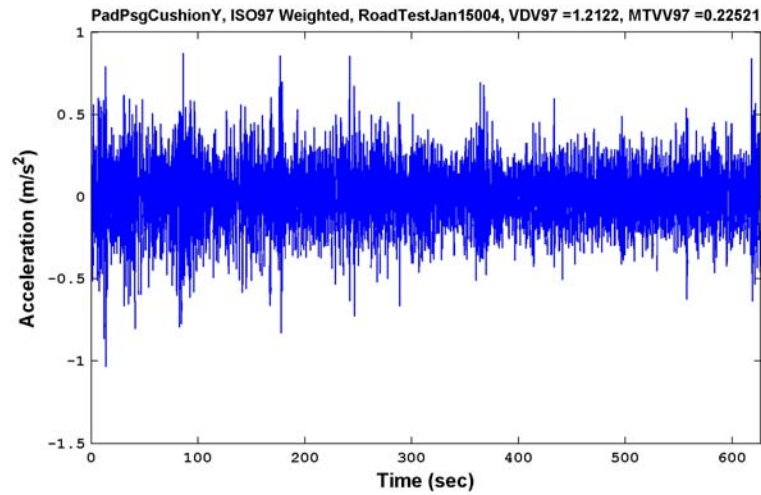


Figure A5.8: Weighted acceleration in Y-axis on PadPsgCushion for Truck02 Segment 04

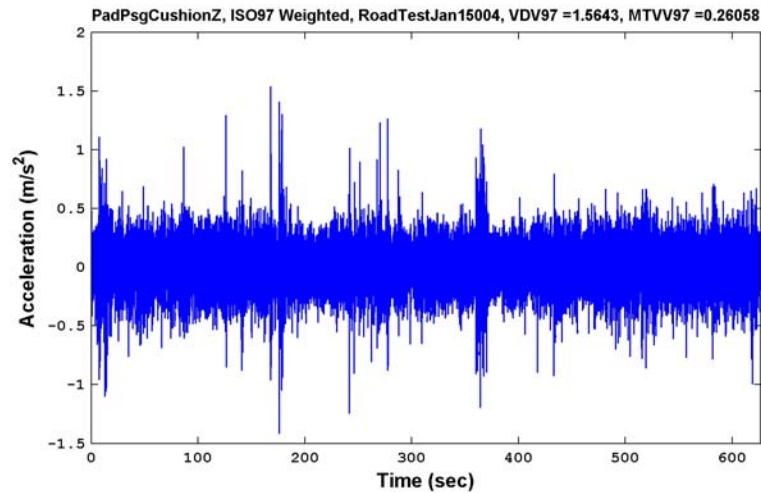


Figure A5.9: Weighted acceleration in Z-axis on PadPsgCushion for Truck02 Segment 04

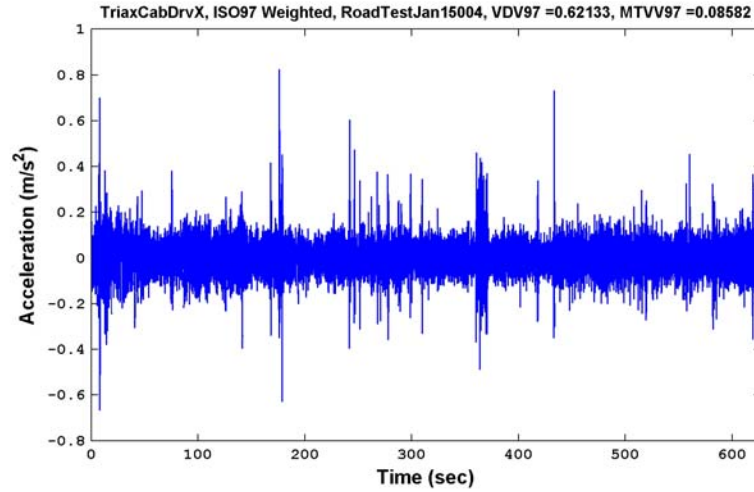


Figure A5.10: Weighted acceleration in X-axis on TriaxCabDrv for Truck02 Segment 04

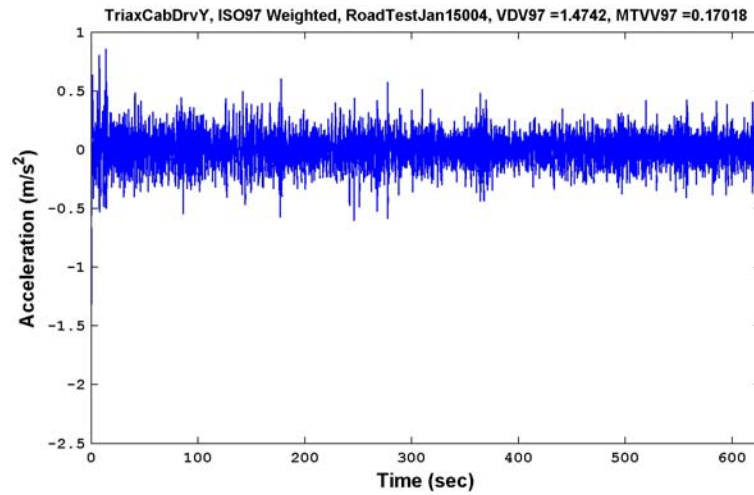


Figure A5.11: Weighted acceleration in Y-axis on TriaxCabDrv for Truck02 Segment 04

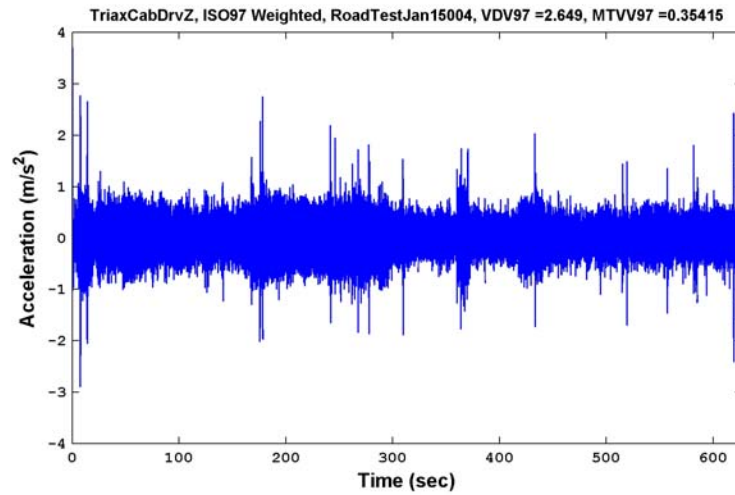


Figure A5.12: Weighted acceleration in Z-axis on TriaxCabDrv for Truck02 Segment 04

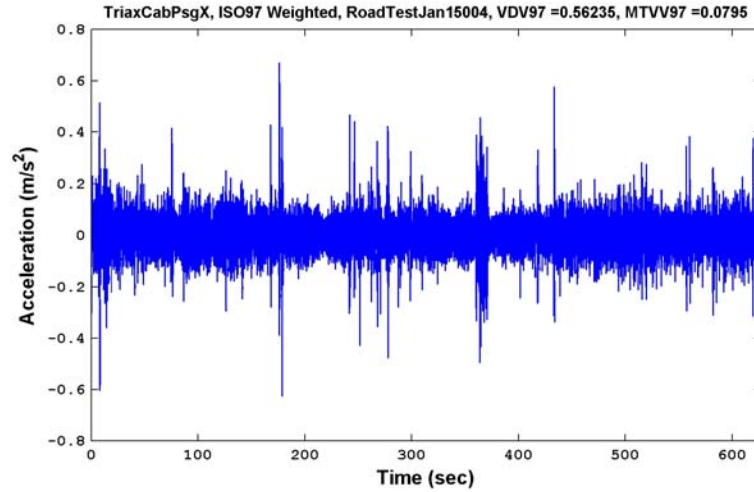


Figure A5.13: Weighted acceleration in X-axis on TriaxCabPsg for Truck02 Segment 04

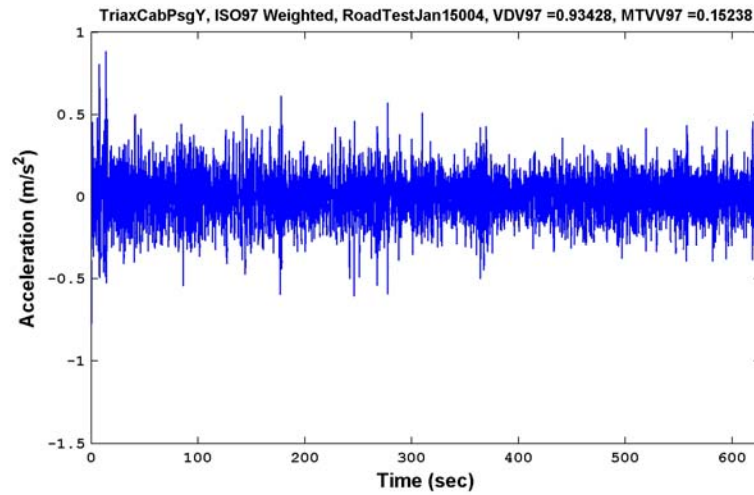


Figure A5.14: Weighted acceleration in Y-axis on TriaxCabPsg for Truck02 Segment 04

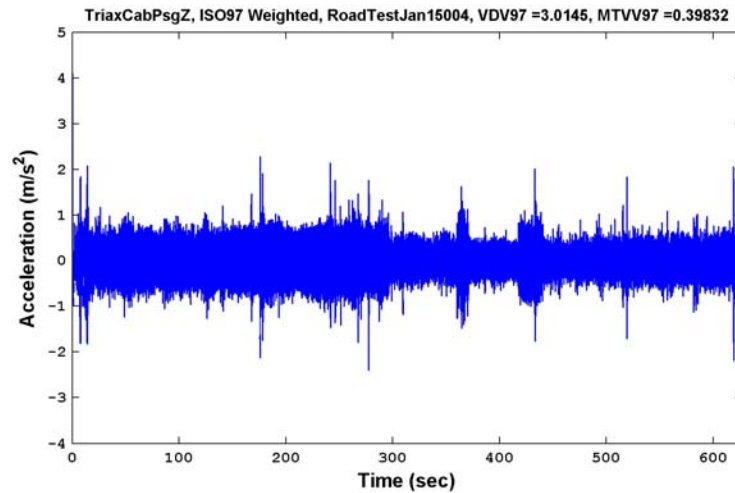


Figure A5.15: Weighted acceleration in Z-axis on TriaxCabPsg for Truck02 Segment 04

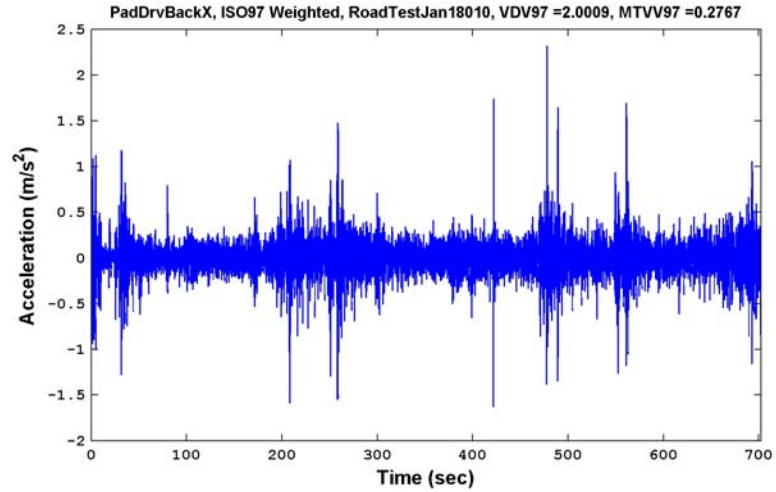


Figure A5.16: Weighted acceleration in X-axis on PadDrvBack for Truck03 Segment 10

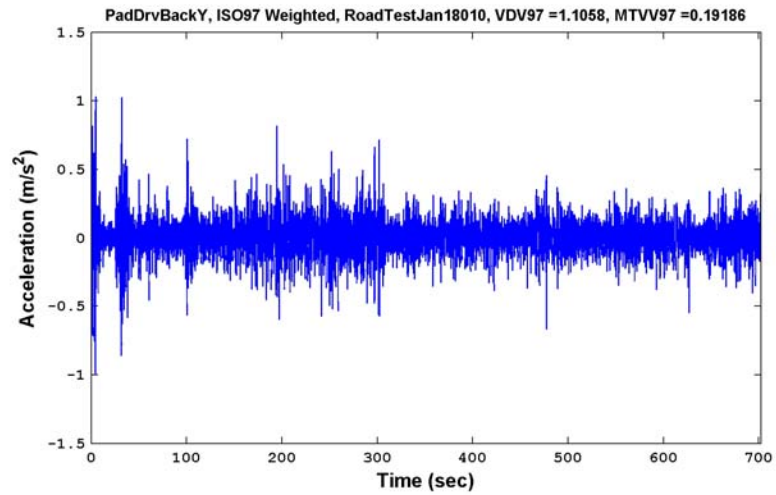


Figure A5.17: Weighted acceleration in Y-axis on PadDrvBack for Truck03 Segment 10

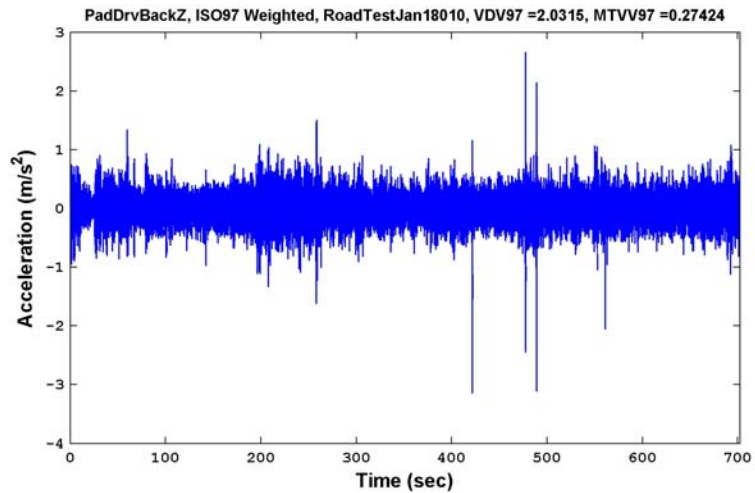


Figure A5.18: Weighted acceleration in Z-axis on PadDrvBack for Truck03 Segment 10

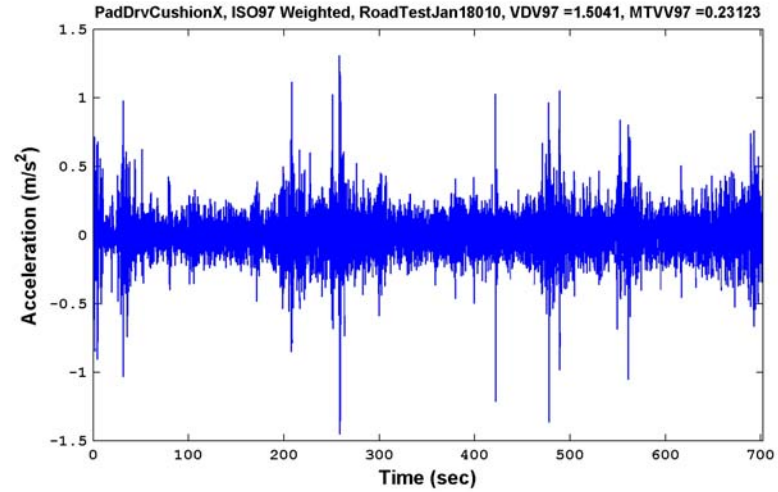


Figure A5.19: Weighted acceleration in X-axis on PadDrvCushion for Truck03 Segment 10

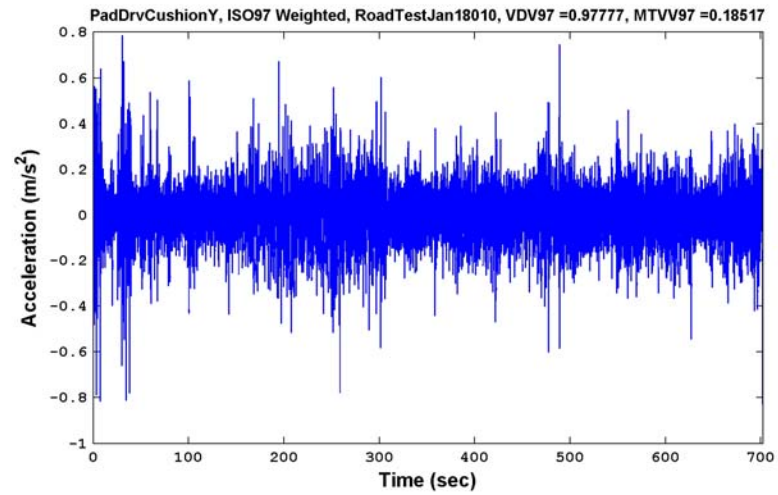


Figure A5.20: Weighted acceleration in Y-axis on PadDrvCushion for Truck03 Segment 10

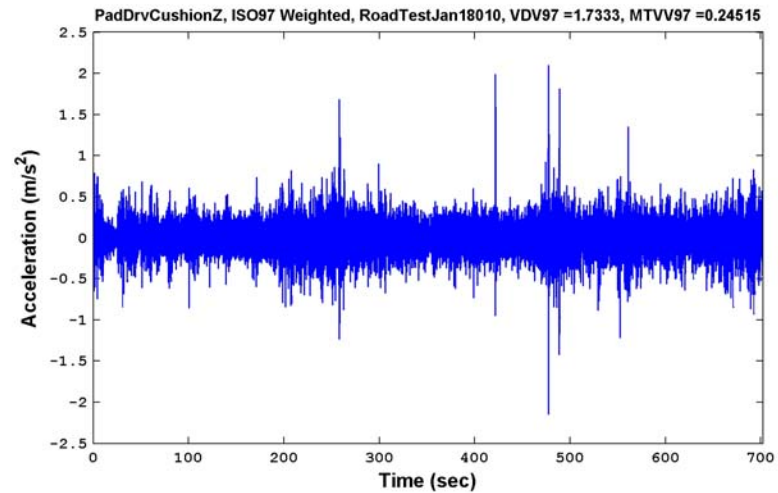


Figure A5.21: Weighted acceleration in Z-axis on PadDrvCushion for Truck03 Segment 10

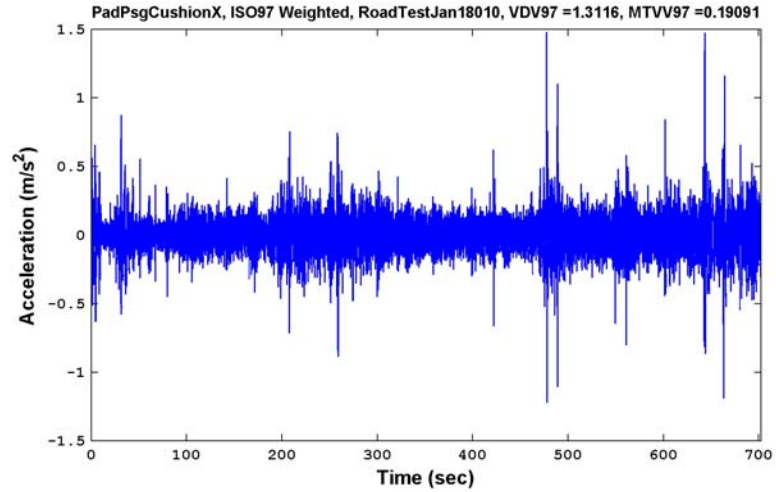


Figure A5.22: Weighted acceleration in X-axis on PadPsgCushion for Truck03 Segment 10

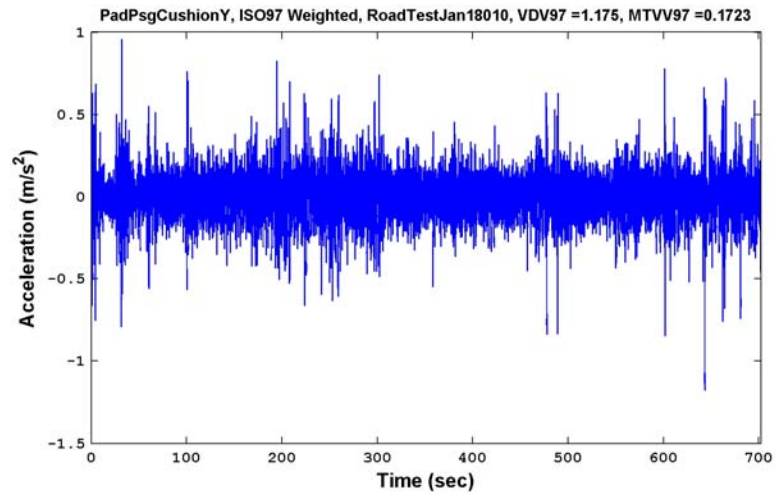


Figure A5.23: Weighted acceleration in Y-axis on PadPsgCushion for Truck03 Segment 10

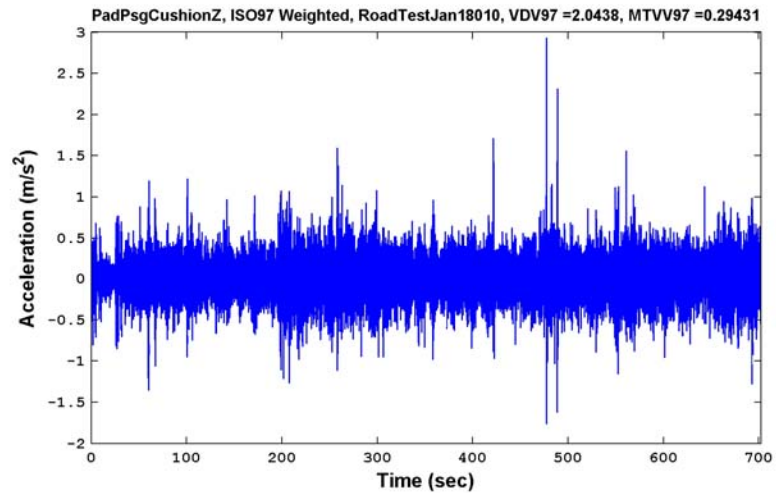


Figure A5.24: Weighted acceleration in Z-axis on PadPsgCushion for Truck03 Segment 10

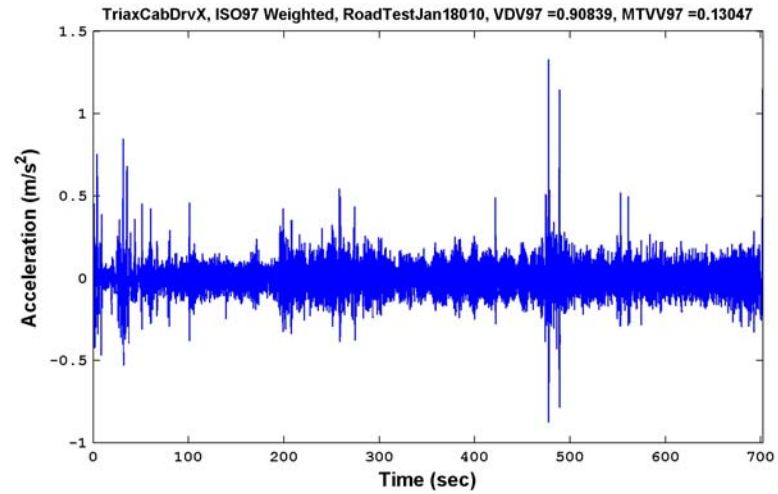


Figure A5.25: Weighted acceleration in X-axis on TriaxCabDrv for Truck03 Segment 10

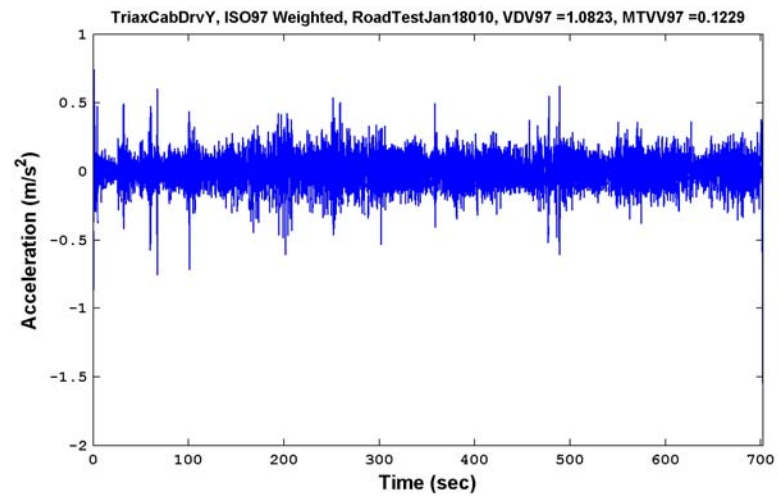


Figure A5.26: Weighted acceleration in Y-axis on TriaxCabDrv for Truck03 Segment 10

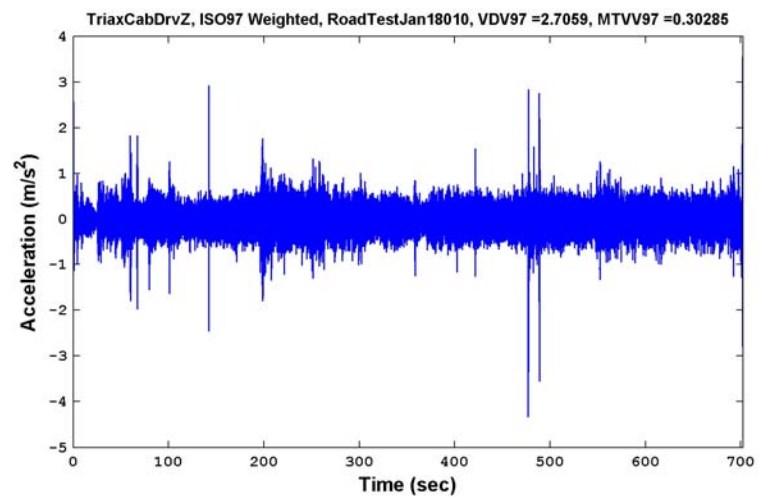


Figure A5.27: Weighted acceleration in Z-axis on TriaxCabDrv for Truck03 Segment 10

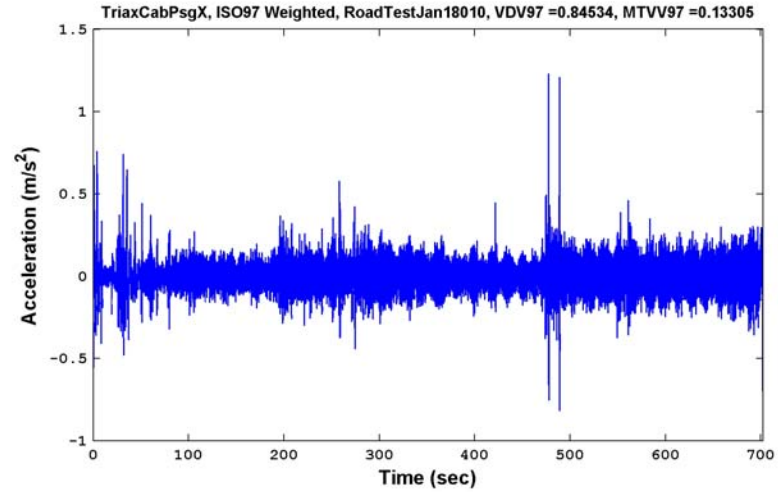


Figure A5.28: Weighted acceleration in X-axis on TriaxCabPsg for Truck03 Segment 10

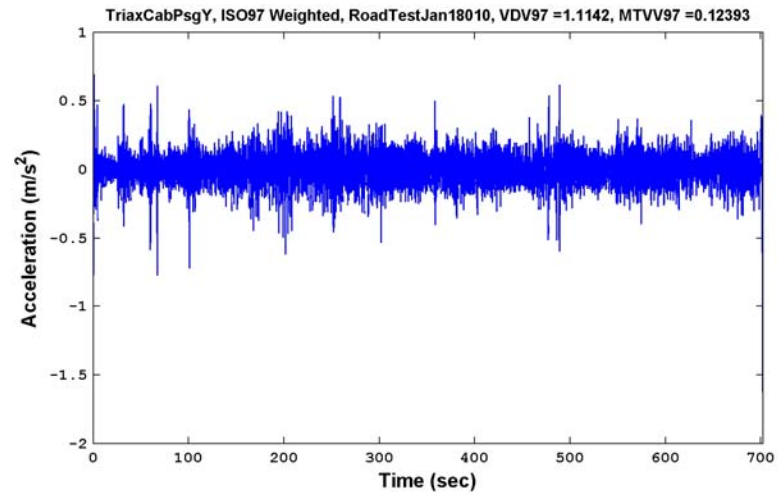


Figure A5.29: Weighted acceleration in Y-axis on TriaxCabPsg for Truck03 Segment 10

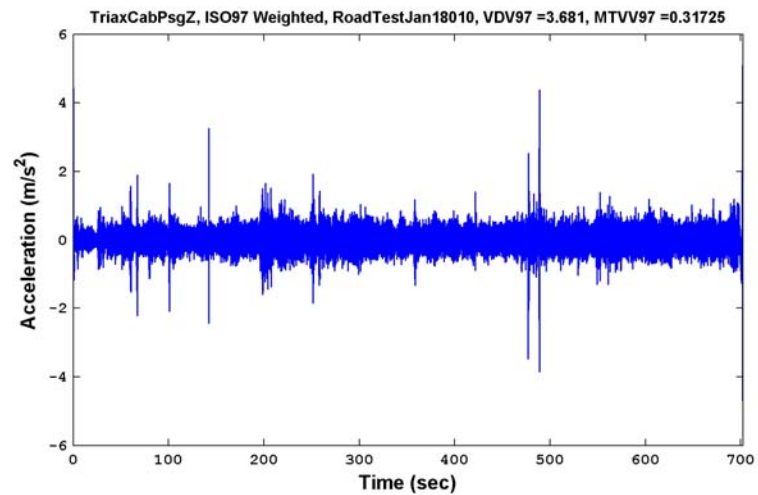


Figure A5.30: Weighted acceleration in Z-axis on TriaxCabPsg for Truck03 Segment 10

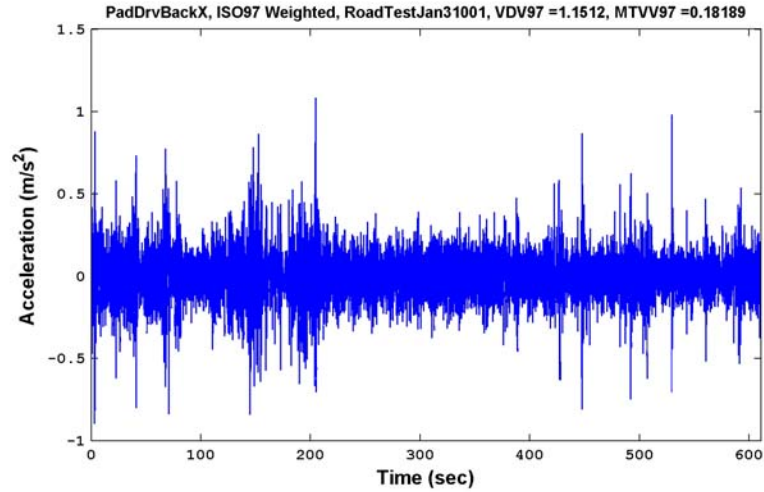


Figure A5.31: Weighted acceleration in X-axis on PadDrvBack for Truck04 Segment 01

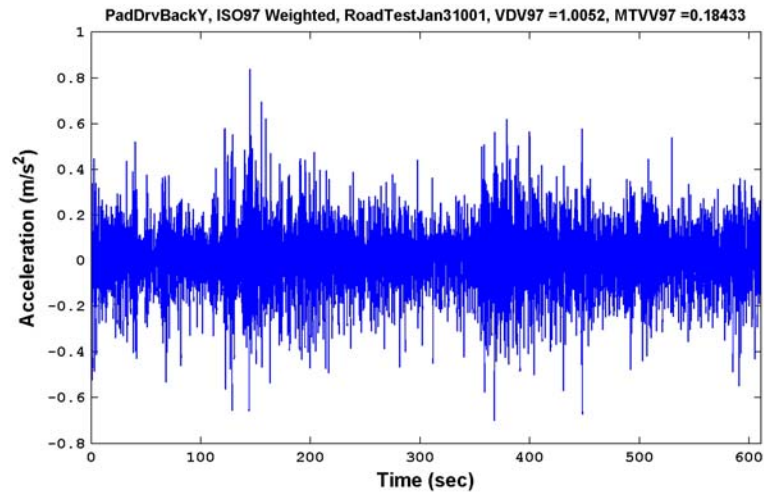


Figure A5.32: Weighted acceleration in Y-axis on PadDrvBack for Truck04 Segment 01

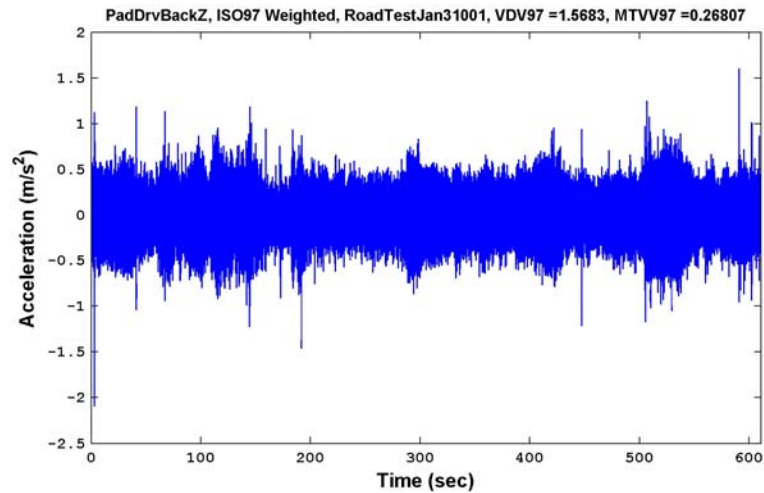


Figure A5.33: Weighted acceleration in Z-axis on PadDrvBack for Truck04 Segment 01

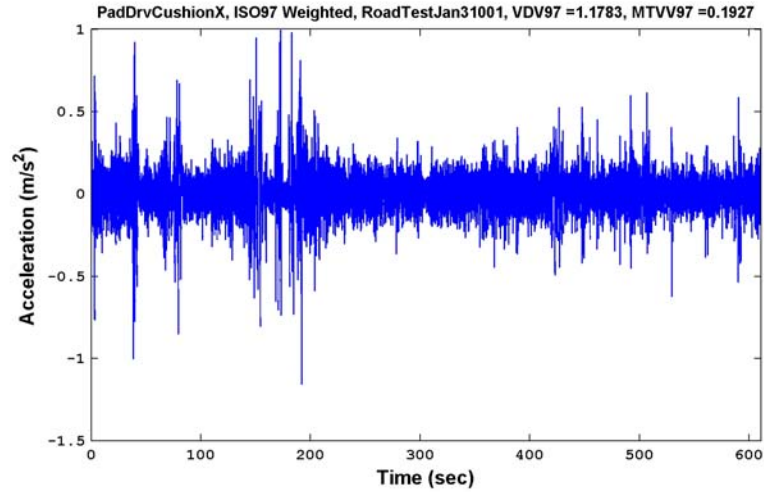


Figure A5.34: Weighted acceleration in X-axis on PadDrvCushion for Truck04 Segment 01

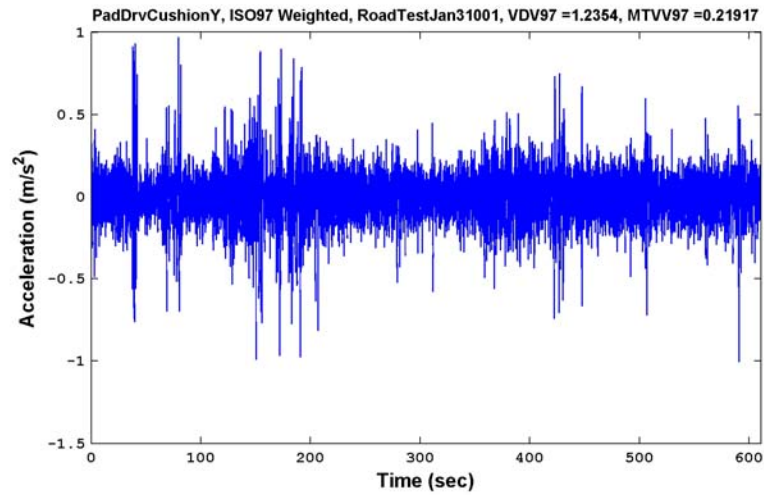


Figure A5.35: Weighted acceleration in Y-axis on PadDrvCushion for Truck04 Segment 01

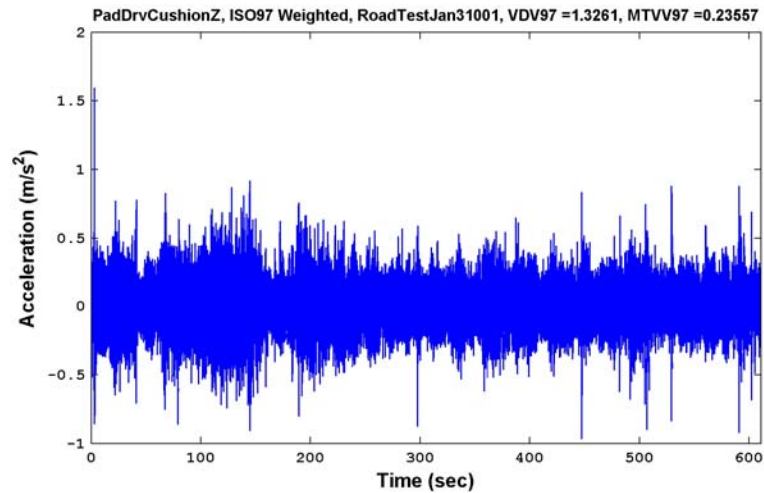


Figure A5.36: Weighted acceleration in Z-axis on PadDrvCushion for Truck04 Segment 01

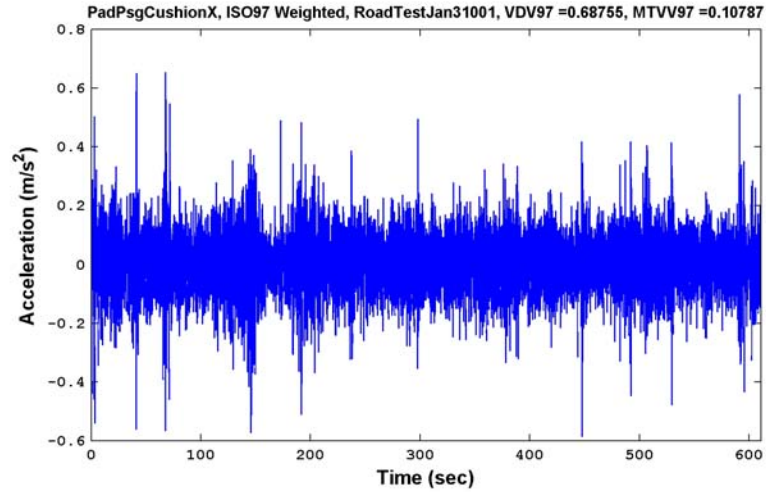


Figure A5.37: Weighted acceleration in X-axis on PadPsgCushion for Truck04 Segment 01

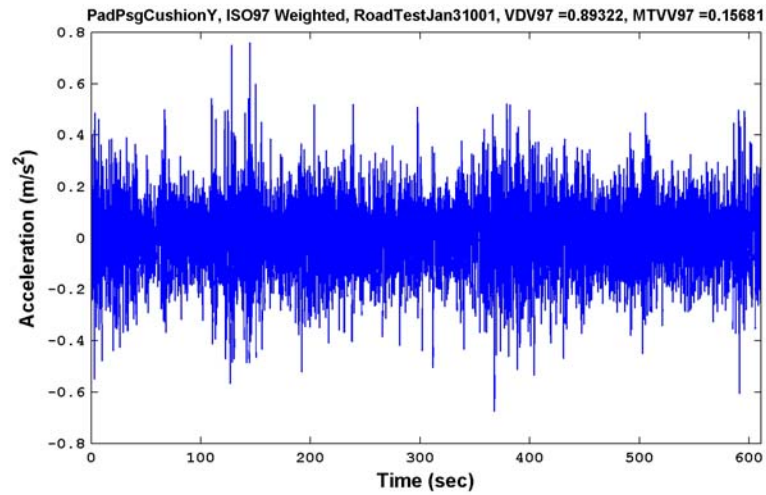


Figure A5.38: Weighted acceleration in Y-axis on PadPsgCushion for Truck04 Segment 01

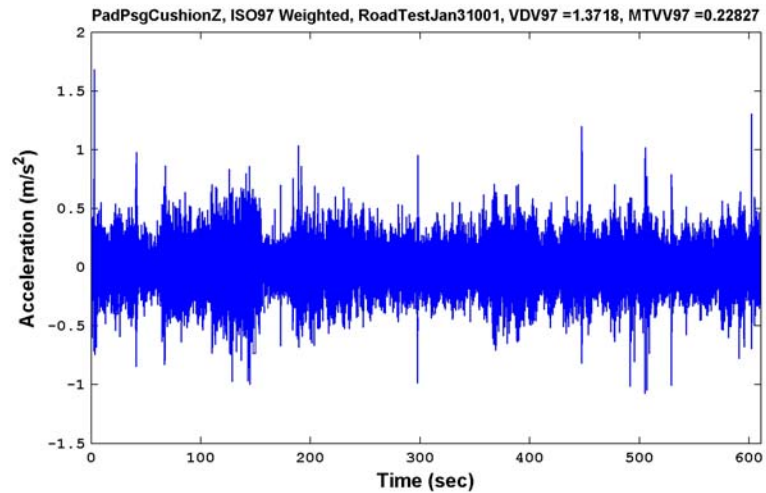


Figure A5.39: Weighted acceleration in Z-axis on PadPsgCushion for Truck04 Segment 01

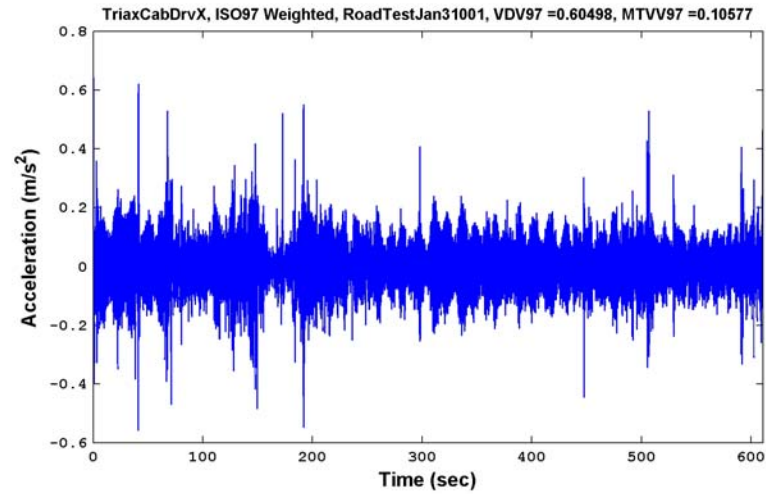


Figure A5.40: Weighted acceleration in X-axis on TriaxCabDrv for Truck04 Segment 01

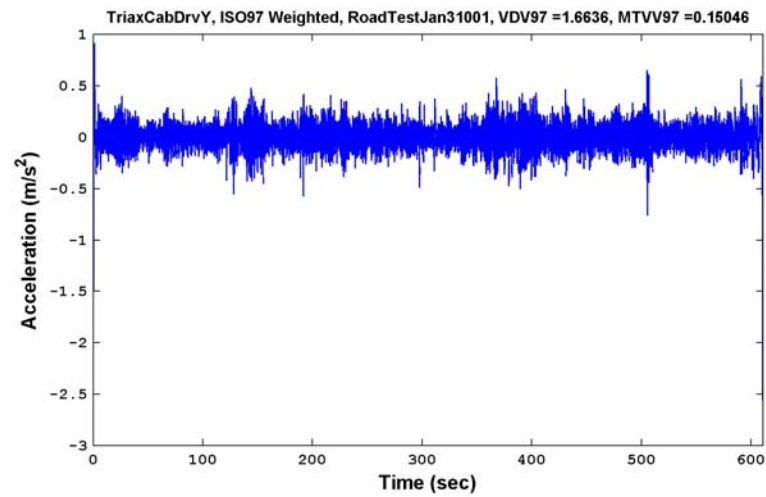


Figure A5.41: Weighted acceleration in Y-axis on TriaxCabDrv for Truck04 Segment 01

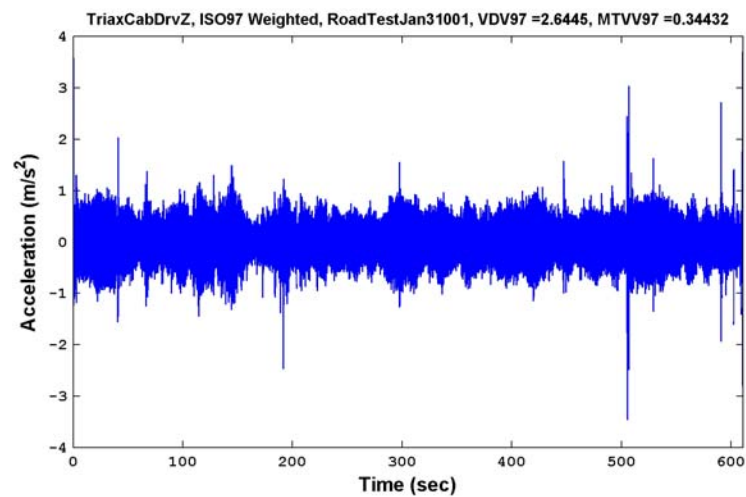


Figure A5.42: Weighted acceleration in Z-axis on TriaxCabDrv for Truck04 Segment 01

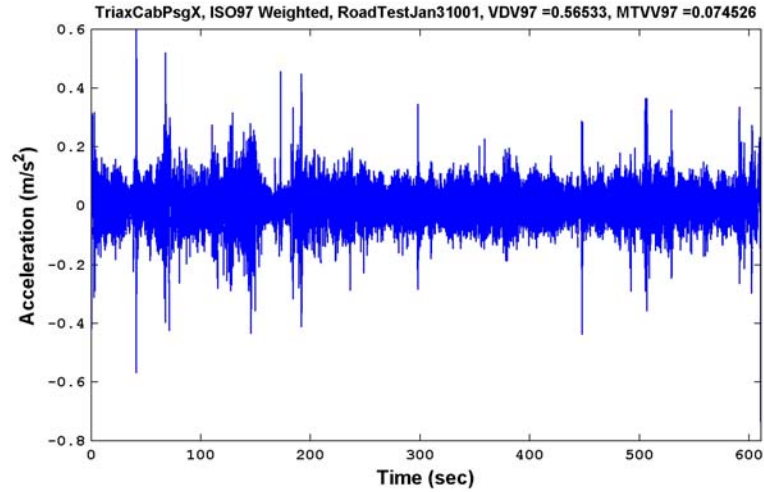


Figure A5.43: Weighted acceleration in X-axis on TriaxCabPsg for Truck04 Segment 01

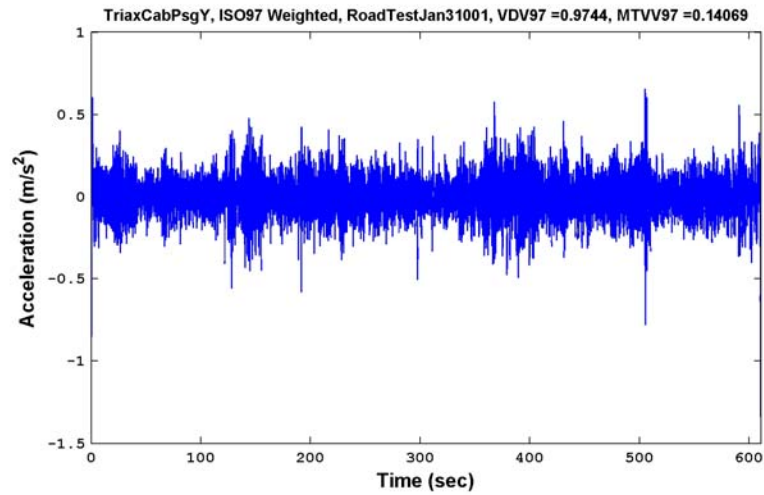


Figure A5.44: Weighted acceleration in Y-axis on TriaxCabPsg for Truck04 Segment 01

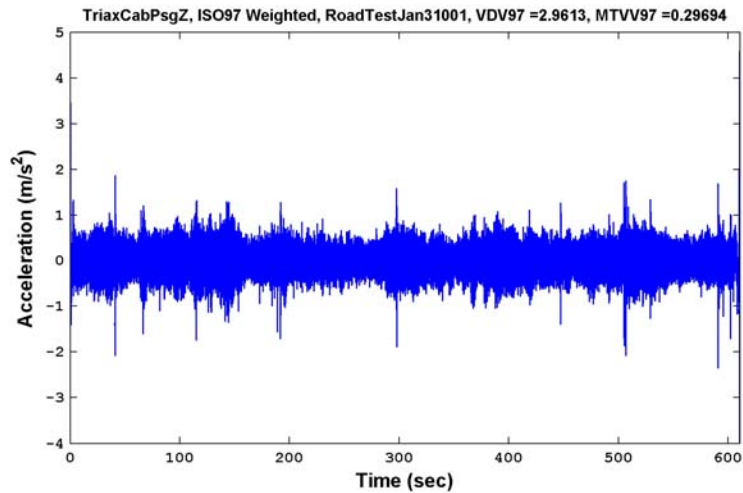


Figure A5.45: Weighted acceleration in Z-axis on TriaxCabPsg for Truck04 Segment 01

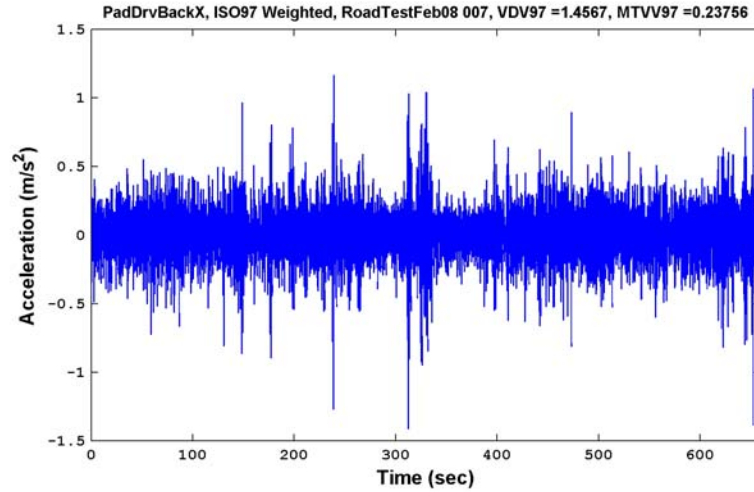


Figure A5.46: Weighted acceleration in X-axis on PadDrvBack for Truck05 Segment 07

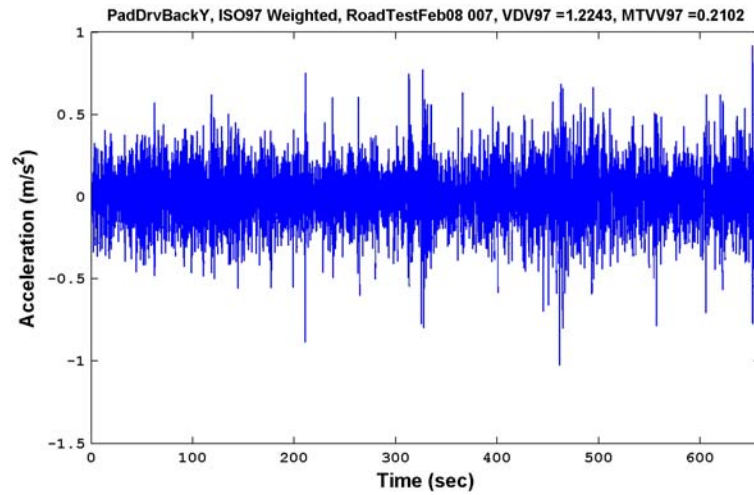


Figure A5.47: Weighted acceleration in Y-axis on PadDrvBack for Truck05 Segment 07

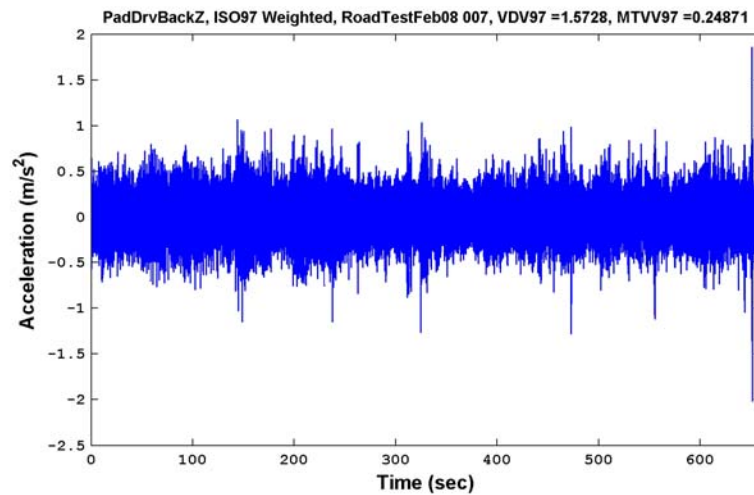


Figure A5.48: Weighted acceleration in Z-axis on PadDrvBack for Truck05 Segment 07

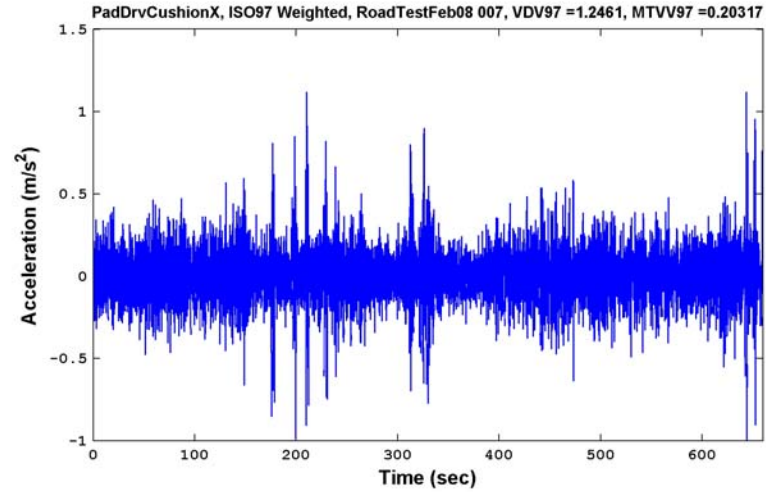


Figure A5.49: Weighted acceleration in X-axis on PadDrvCushion for Truck05 Segment 07

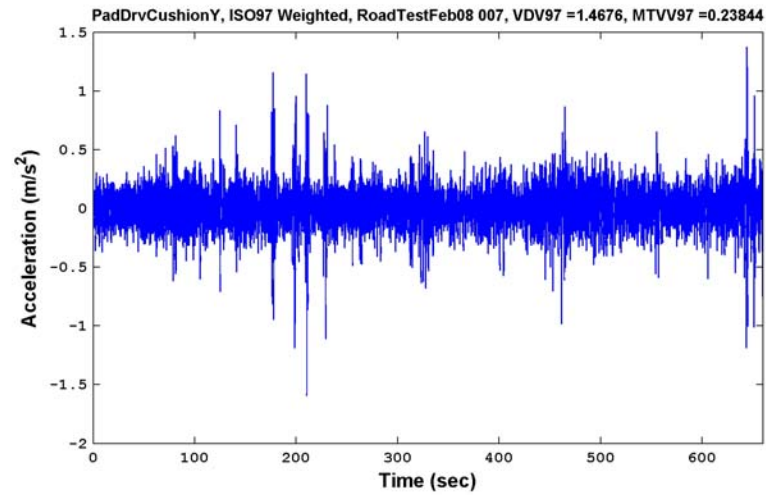


Figure A5.50: Weighted acceleration in Y-axis on PadDrvCushion for Truck05 Segment 07

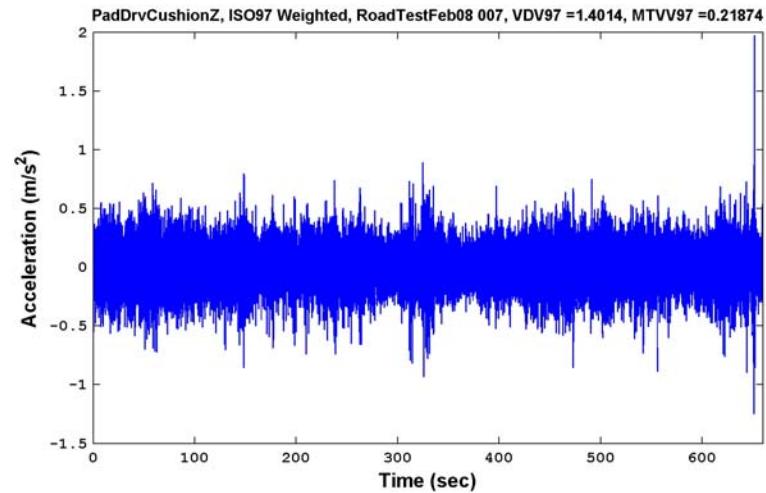


Figure A5.51: Weighted acceleration in Z-axis on PadDrvCushion for Truck05 Segment 07

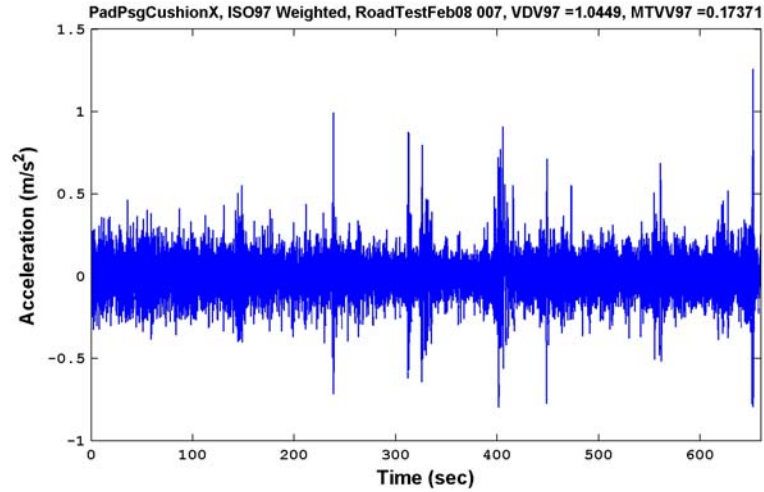


Figure A5.52: Weighted acceleration in X-axis on PadPsgCushion for Truck05 Segment 07

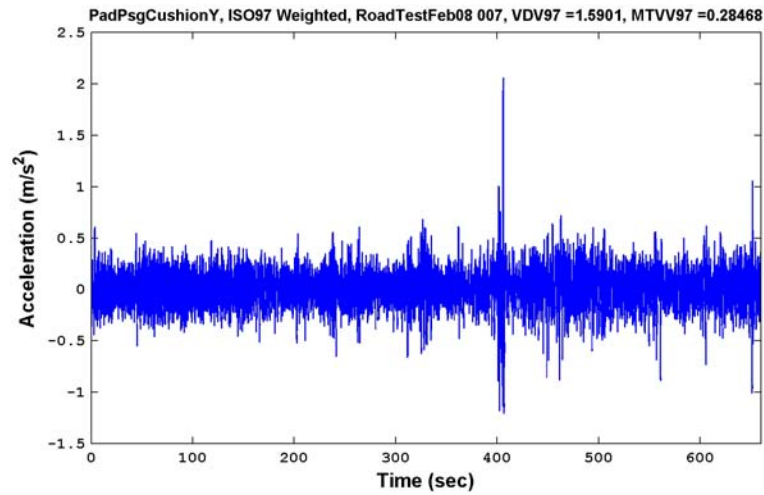


Figure A5.53: Weighted acceleration in Y-axis on PadPsgCushion for Truck05 Segment 07

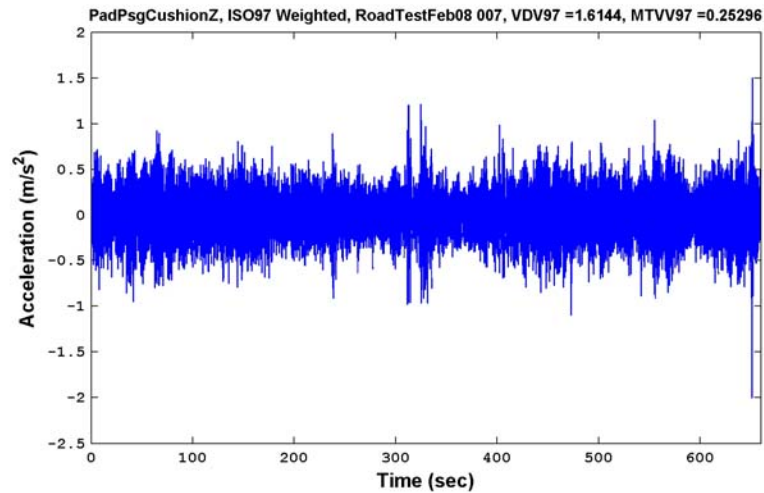


Figure A5.54: Weighted acceleration in Z-axis on PadPsgCushion for Truck05 Segment 07

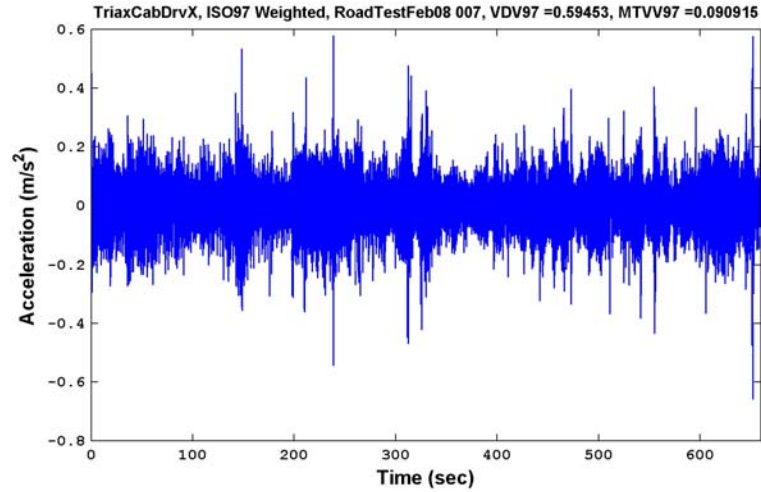


Figure A5.55: Weighted acceleration in X-axis on TriaxCabDrv for Truck05 Segment 07

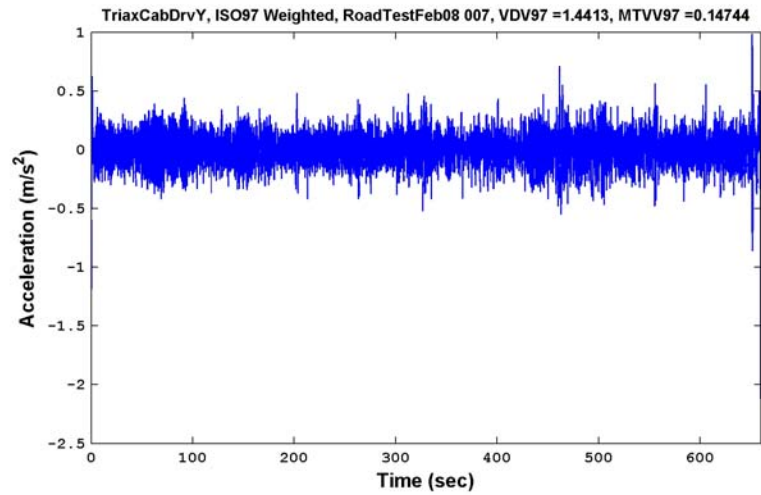


Figure A5.56: Weighted acceleration in Y-axis on TriaxCabDrv for Truck05 Segment 07

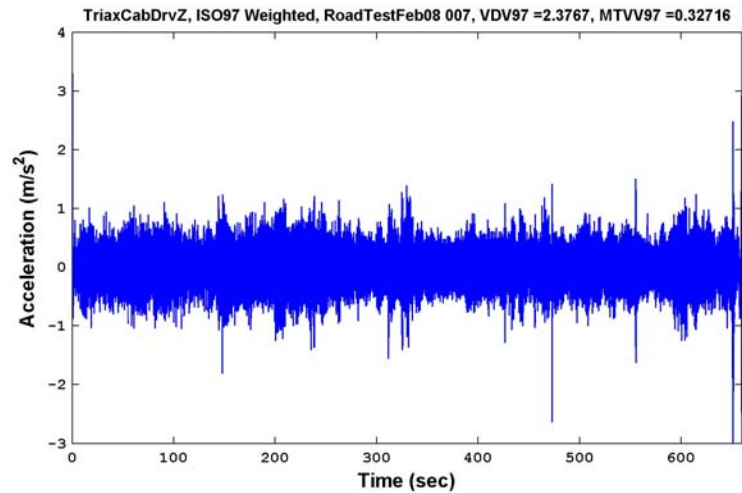


Figure A5.57: Weighted acceleration in Z-axis on TriaxCabDrv for Truck05 Segment 07

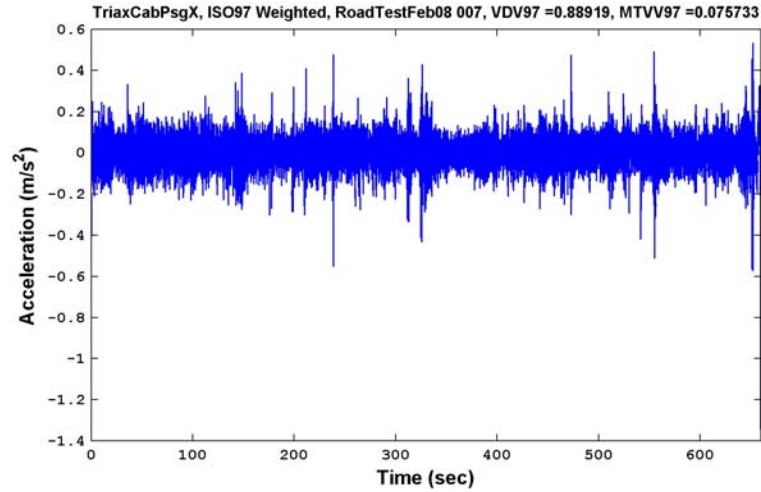


Figure A5.58: Weighted acceleration in X-axis on TriaxCabPsg for Truck05 Segment 07

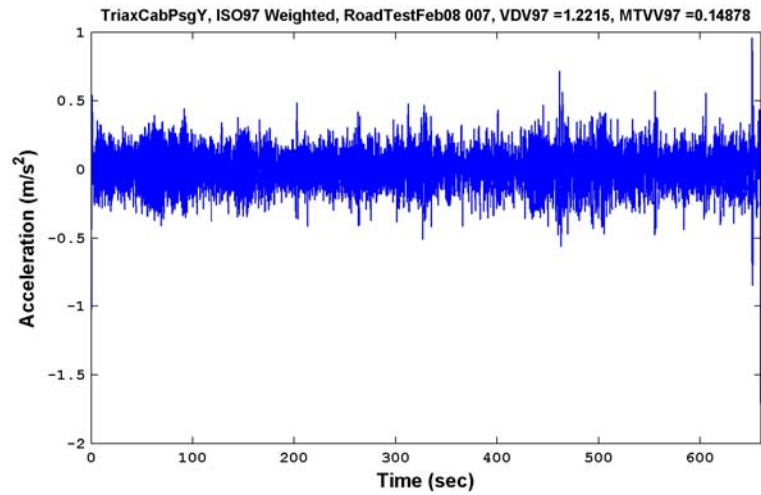


Figure A5.59 Weighted acceleration in Y-axis on TriaxCabPsg for Truck05 Segment 07

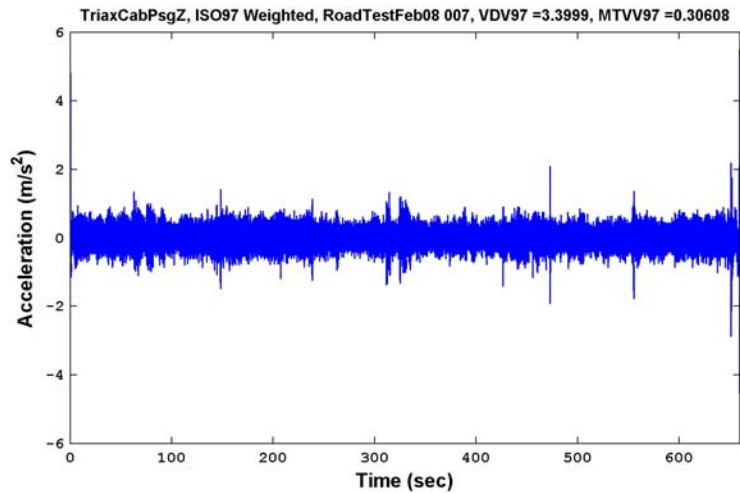


Figure A5.60: Weighted acceleration in Z-axis on TriaxCabPsg for Truck05 Segment 07

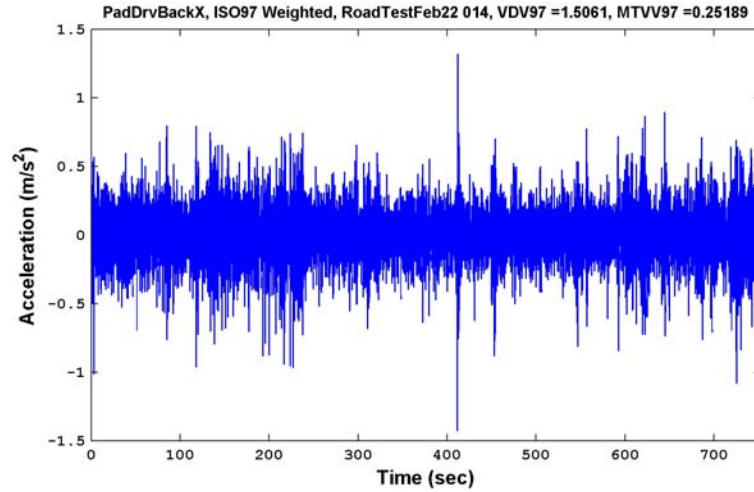


Figure A5.61: Weighted acceleration in X-axis on PadDrvBack for Truck06 Segment 01

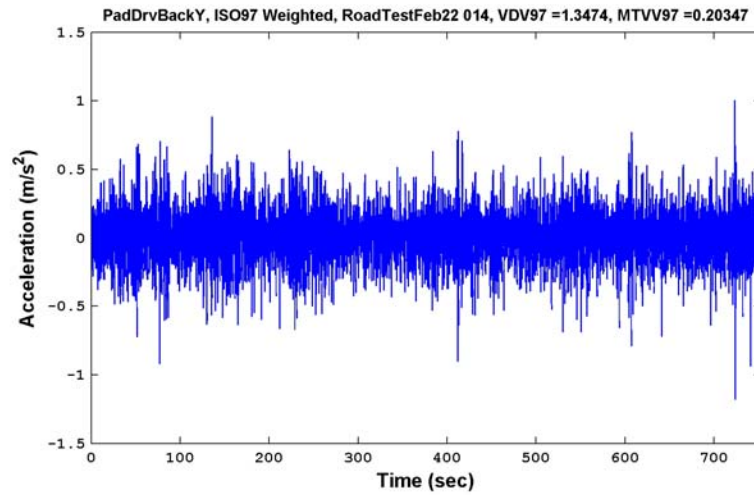


Figure A5.62: Weighted acceleration in Y-axis on PadDrvBack for Truck06 Segment 01

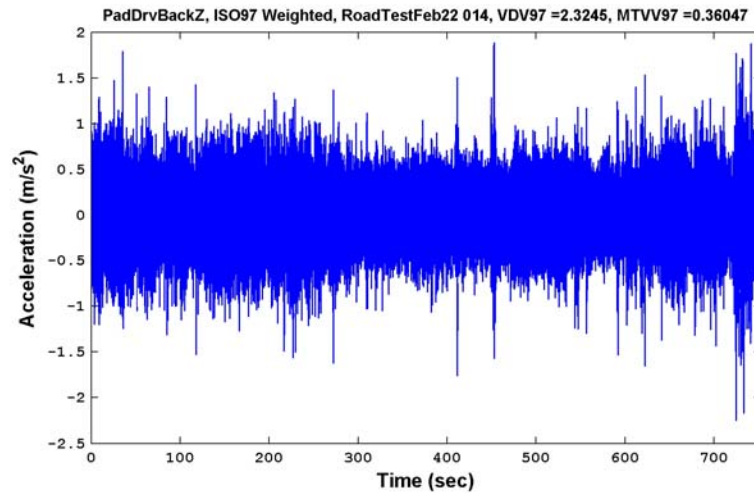


Figure A5.63: Weighted acceleration in Z-axis on PadDrvBack for Truck06 Segment 01

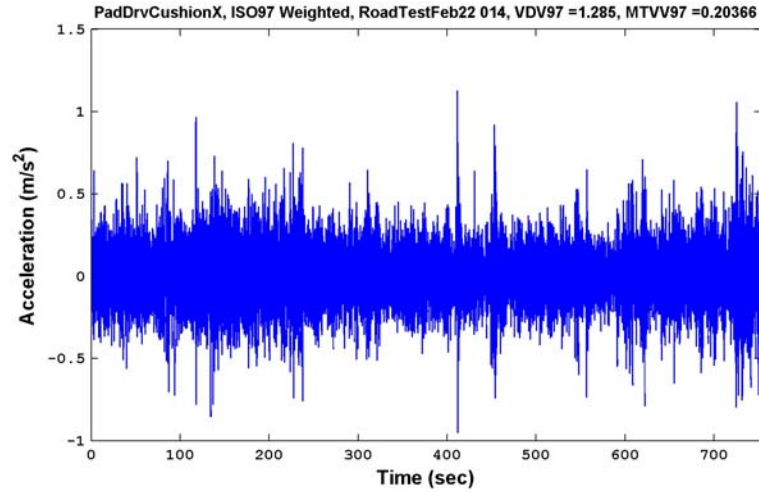


Figure A5.64: Weighted acceleration in X-axis on PadDrvCushion for Truck06 Segment 01

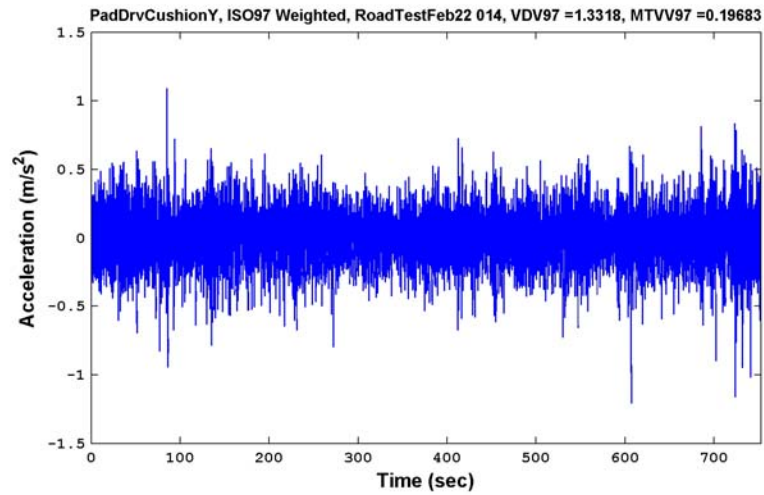


Figure A5.65: Weighted acceleration in Y-axis on PadDrvCushion for Truck06 Segment 01

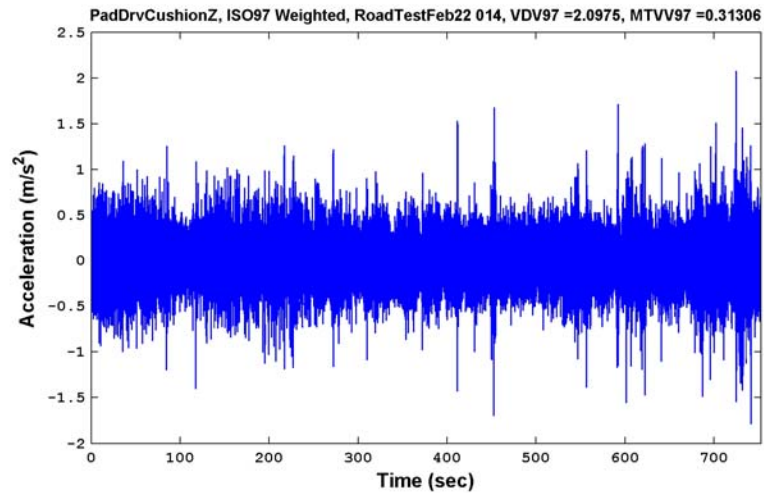


Figure A5.66: Weighted acceleration in Z-axis on PadDrvCushion for Truck06 Segment 01

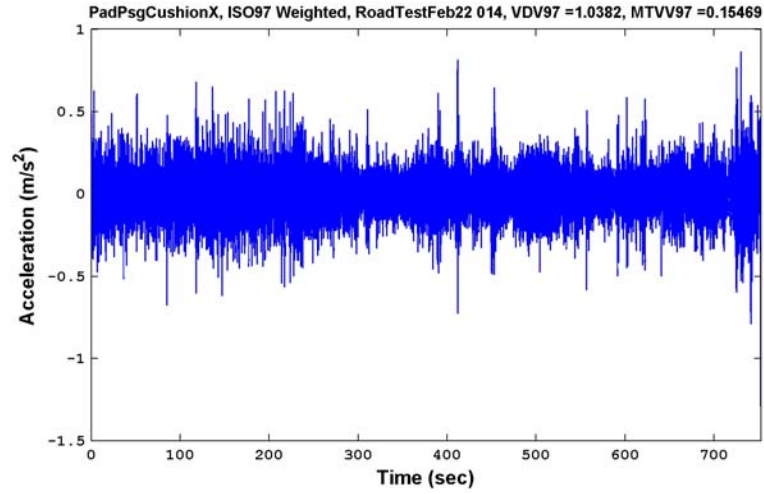


Figure A5.67: Weighted acceleration in X-axis on PadPsgCushion for Truck06 Segment 01

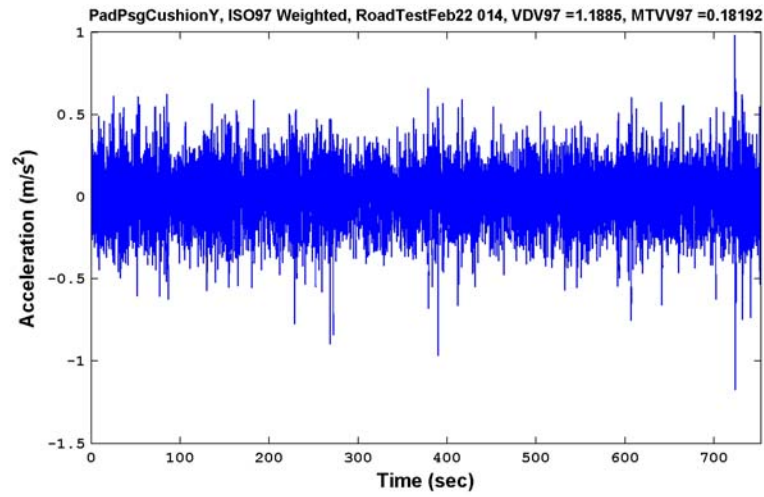


Figure A5.68: Weighted acceleration in Y-axis on PadPsgCushion for Truck06 Segment 01

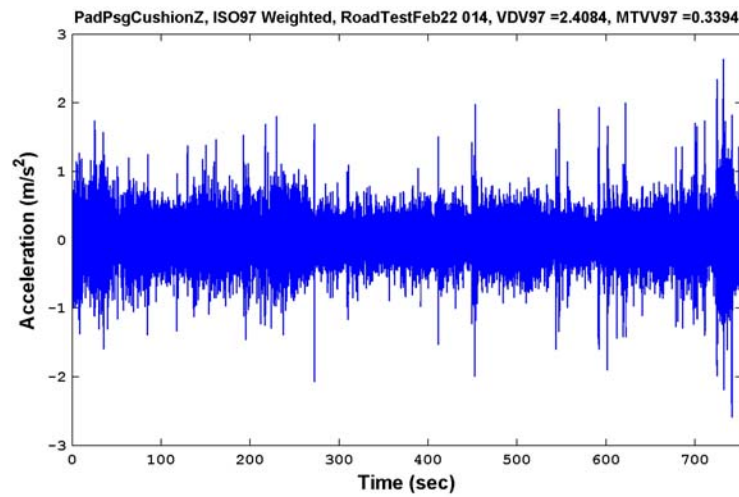


Figure A5.69: Weighted acceleration in Z-axis on PadPsgCushion for Truck06 Segment 01

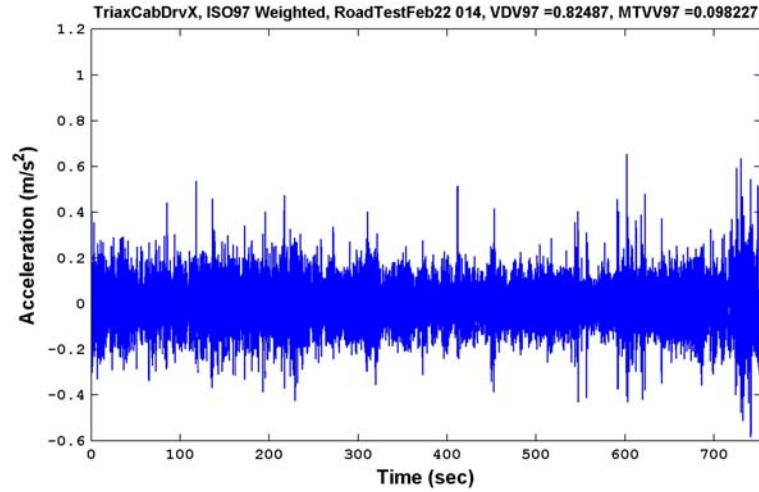


Figure A5.70: Weighted acceleration in X-axis on TriaxCabDrv for Truck06 Segment 01

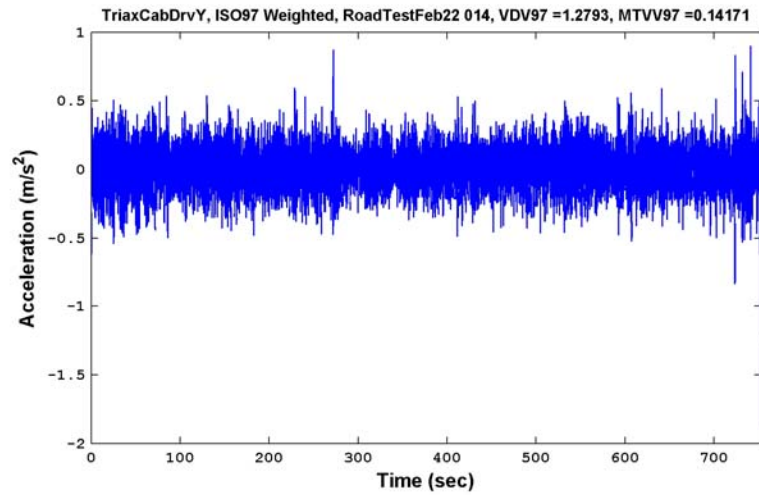


Figure A5.71: Weighted acceleration in Y-axis on TriaxCabDrv for Truck06 Segment 01

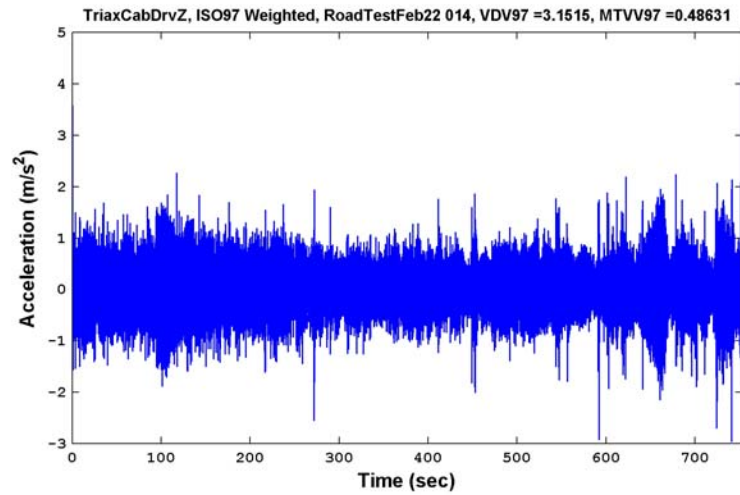


Figure A5.72: Weighted acceleration in Z-axis on TriaxCabDrv for Truck06 Segment 01

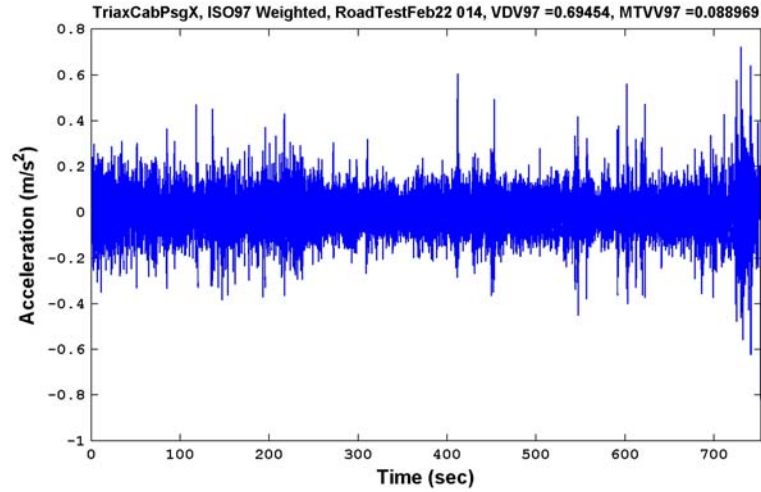


Figure A5.73: Weighted acceleration in X-axis on TriaxCabPsg for Truck06 Segment 01

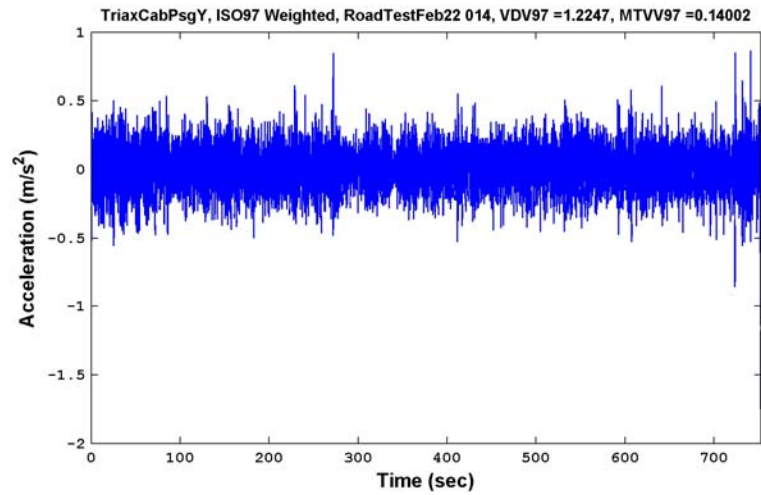


Figure A5.74 Weighted acceleration in Y-axis on TriaxCabPsg for Truck06 Segment 01

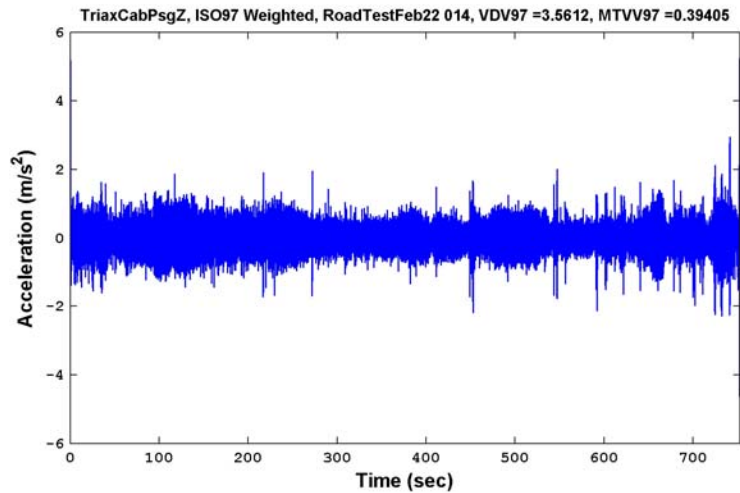


Figure A5.75: Weighted acceleration in Z-axis on TriaxCabPsg for Truck06 Segment 01

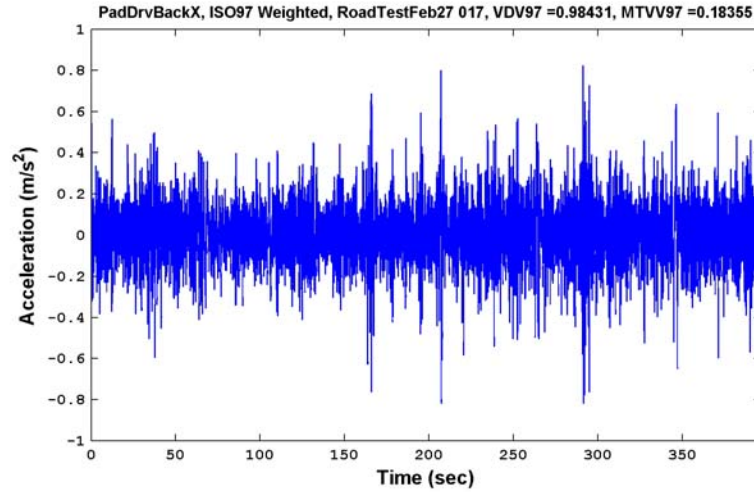


Figure A5.76: Weighted acceleration in X-axis on PadDrvBack for Truck07 Segment 01

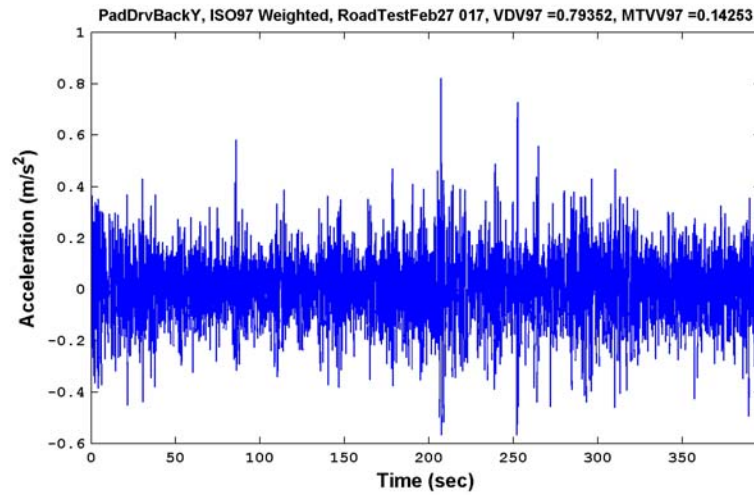


Figure A5.77: Weighted acceleration in Y-axis on PadDrvBack for Truck07 Segment 01

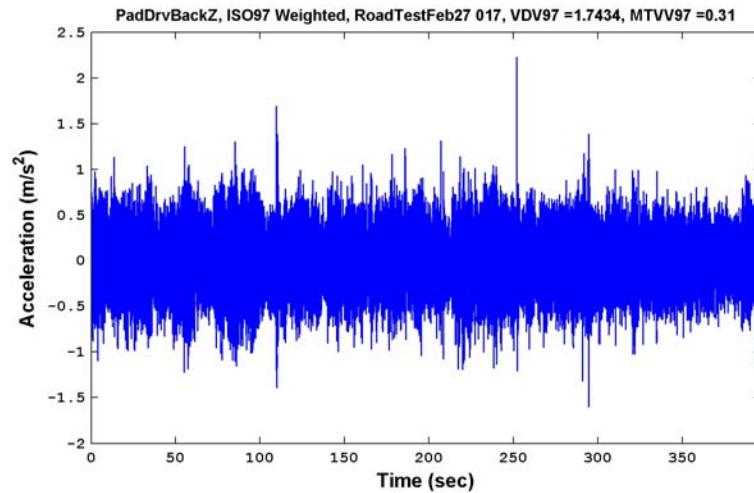


Figure A5.78: Weighted acceleration in Z-axis on PadDrvBack for Truck07 Segment 01

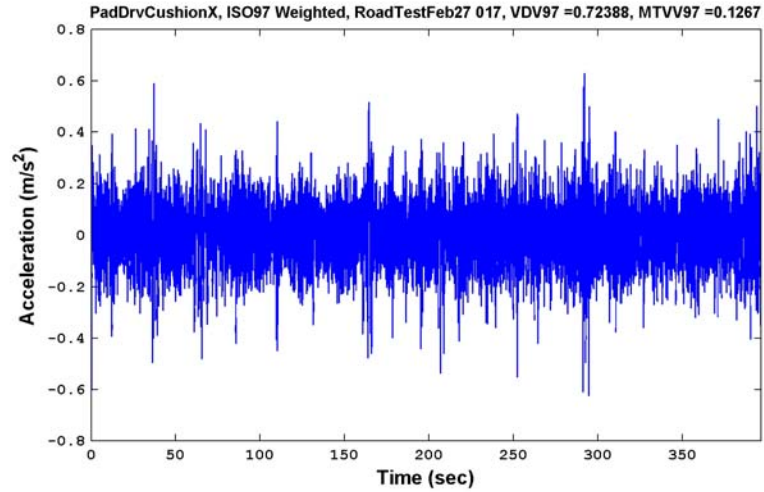


Figure A5.79: Weighted acceleration in X-axis on PadDrvCushion for Truck07 Segment 01

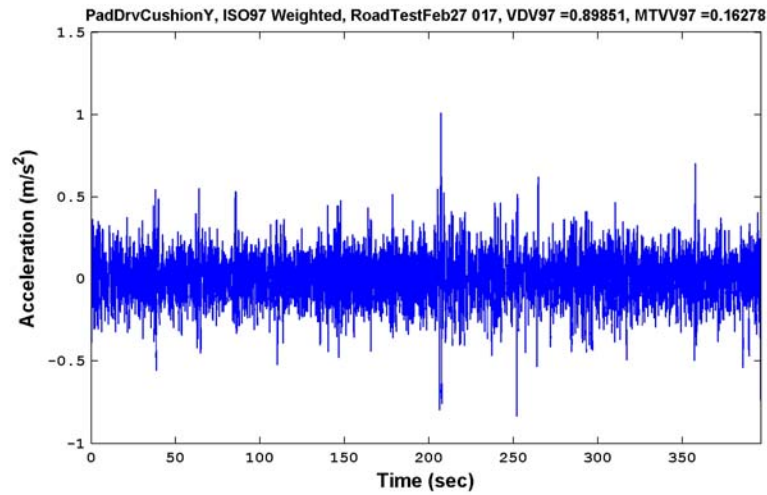


Figure A5.80: Weighted acceleration in Y-axis on PadDrvCushion for Truck07 Segment 01

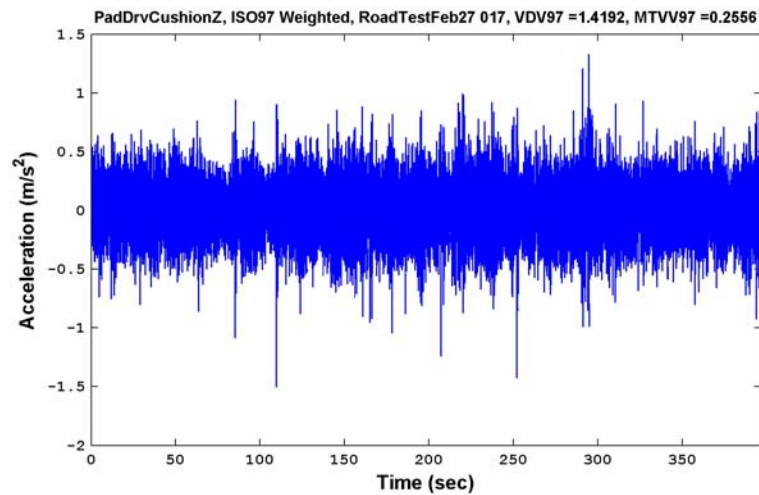


Figure A5.81: Weighted acceleration in Z-axis on PadDrvCushion for Truck07 Segment 01

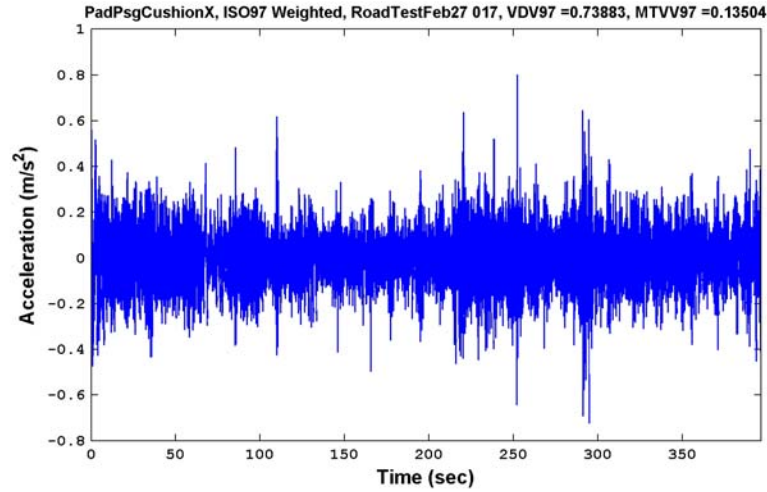


Figure A5.82: Weighted acceleration in X-axis on PadPsgCushion for Truck07 Segment 01

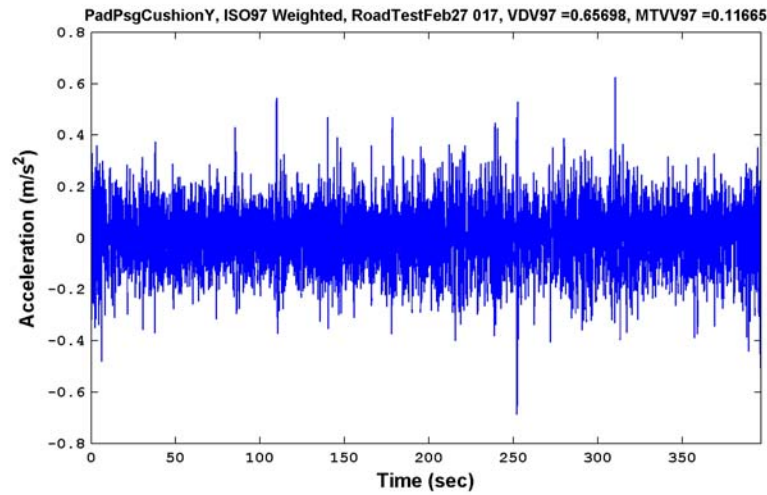


Figure A5.83: Weighted acceleration in Y-axis on PadPsgCushion for Truck07 Segment 01

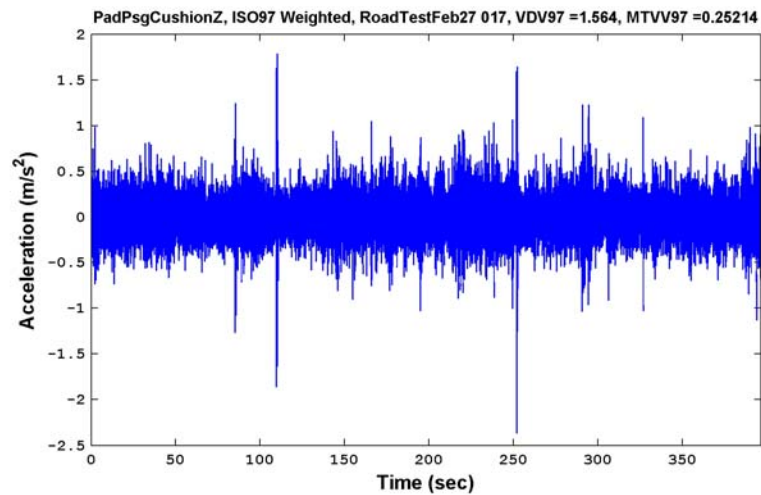


Figure A5.84: Weighted acceleration in Z-axis on PadPsgCushion for Truck07 Segment 01

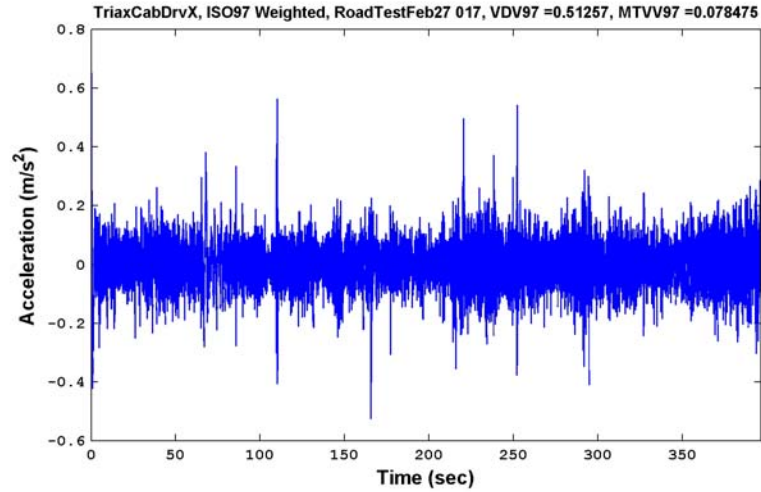


Figure A5.85: Weighted acceleration in X-axis on TriaxCabDrv for Truck07 Segment 01

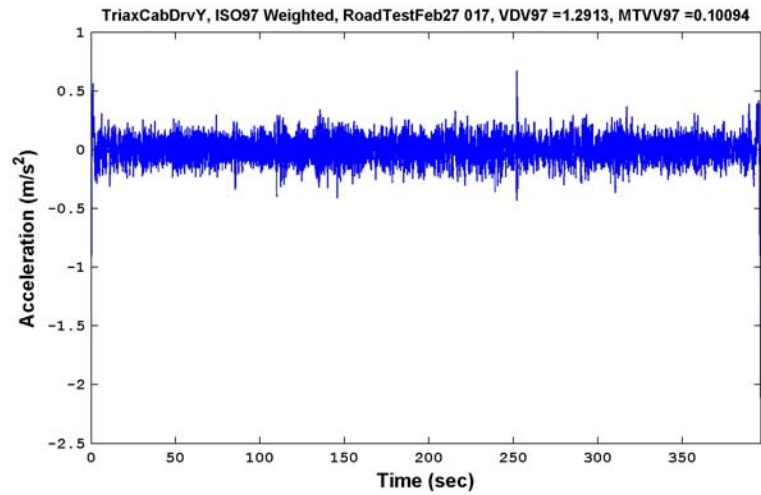


Figure A5.86: Weighted acceleration in Y-axis on TriaxCabDrv for Truck07 Segment 01

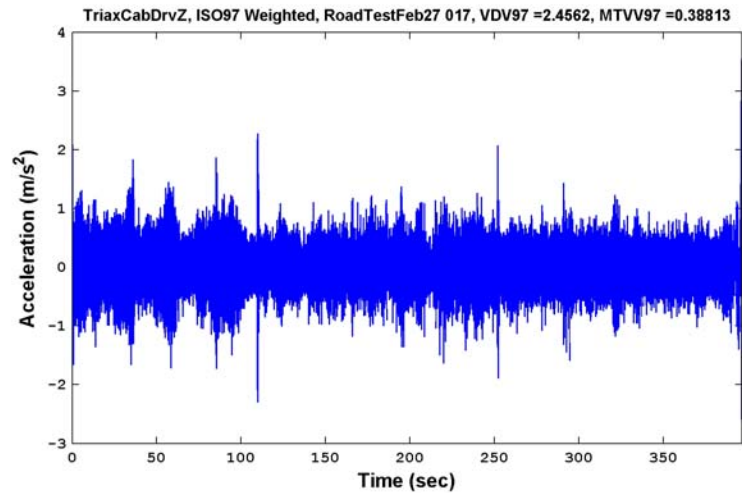


Figure A5.87: Weighted acceleration in Z-axis on TriaxCabDrv for Truck07 Segment 01

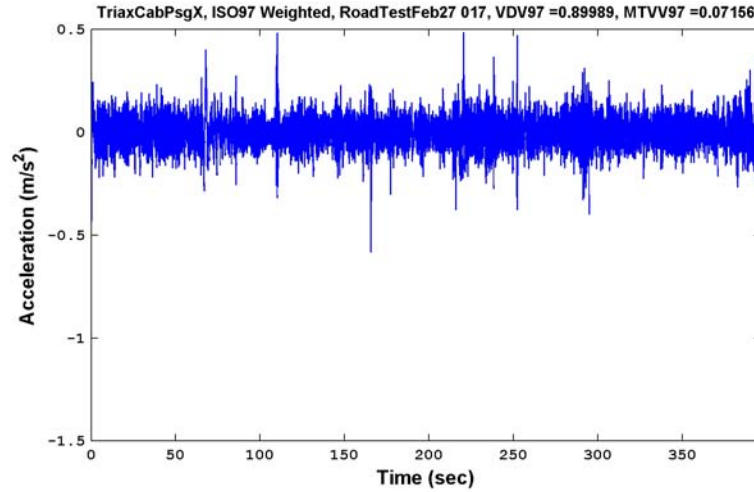


Figure A5.88: Weighted acceleration in X-axis on TriaxCabPsg for Truck07 Segment 01

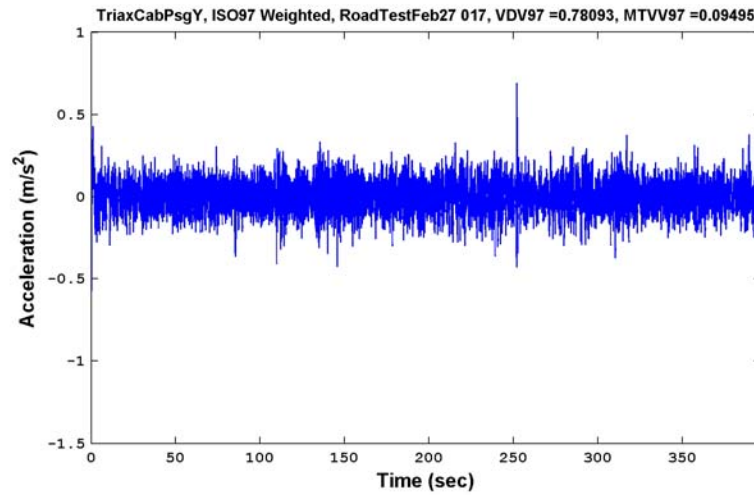


Figure A5.89 Weighted acceleration in Y-axis on TriaxCabPsg for Truck07 Segment 01

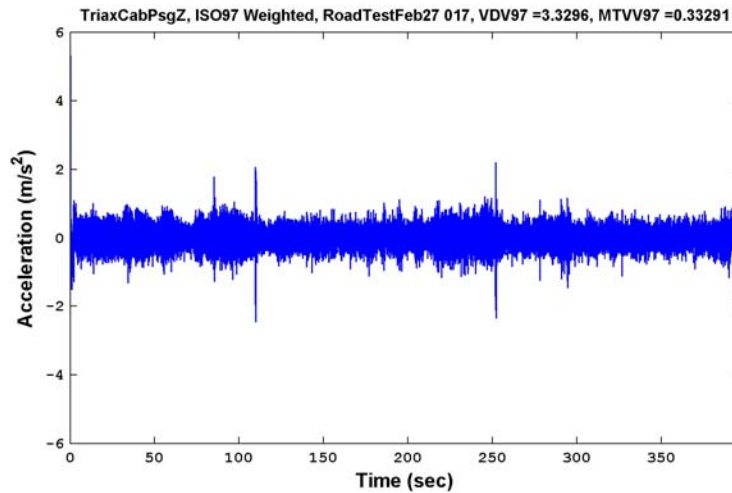


Figure A5.90: Weighted acceleration in Z-axis on TriaxCabPsg for Truck07 Segment 01

Appendix VI: VDV results for trucks

Table A6.1: VDV values for Truck02

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.05	2.53	3.81	2.23	3.68	3.26	2.32	3.67	3.26	1.25	5.36	7.34	1.18	2.04	6.95
2	3.34	3.00	3.83	2.01	2.52	3.19	4.13	2.69	3.28	1.12	5.41	7.16	1.15	2.80	7.62
3	4.68	3.60	4.56	3.03	3.35	4.54	4.12	3.07	4.47	1.65	4.94	7.79	1.61	2.81	8.14
4	4.74	3.79	4.35	3.10	3.21	4.04	3.75	3.16	4.07	1.62	3.84	6.90	1.46	2.43	7.85
5	3.83	3.05	3.73	2.61	3.14	3.17	2.60	2.77	3.07	1.17	3.97	6.08	1.23	2.74	8.04
6	3.33	3.62	3.89	2.81	3.56	3.26	2.89	3.38	3.13	2.14	5.27	7.16	2.50	3.73	10.10
7	5.20	2.39	4.72	3.91	2.32	4.38	3.76	2.63	4.24	1.50	4.06	5.82	1.80	3.09	8.10
8	3.64	2.53	3.97	2.69	2.68	3.25	2.86	2.45	3.22	1.38	3.93	6.08	1.70	2.86	8.48
9	3.21	3.23	4.08	2.79	3.94	3.28	3.82	3.30	3.47	1.68	4.20	6.27	2.39	2.98	8.17
10	4.96	2.93	4.83	3.68	3.62	4.50	3.66	3.11	4.39	2.74	3.55	6.59	2.75	2.53	8.28
11	5.56	2.90	6.25	3.78	3.14	6.42	4.44	3.44	6.09	2.08	4.23	8.12	1.91	3.36	9.60
12	4.70	3.40	5.29	3.27	3.73	5.19	3.83	3.38	4.95	1.85	3.46	7.57	1.98	2.81	9.23
13	4.15	3.87	4.48	2.92	3.91	3.96	3.67	3.67	3.90	1.92	3.36	6.46	2.22	2.68	8.47
14	4.59	2.87	4.50	3.07	2.78	4.10	4.26	3.12	3.94	1.94	3.29	6.05	1.43	2.65	8.11
15	5.19	4.62	5.18	3.40	4.22	4.37	3.99	3.86	4.61	2.25	4.88	8.46	2.39	4.19	10.33
16	4.40	3.11	4.45	3.01	2.80	3.94	4.28	2.76	3.93	1.82	4.81	7.23	1.87	4.07	9.27
17	3.99	2.88	4.38	2.98	3.10	3.73	3.00	2.72	3.84	1.47	3.12	6.41	1.67	2.49	8.53
Average	4.27	3.20	4.49	3.02	3.28	4.03	3.61	3.13	3.99	1.74	4.22	6.91	1.84	2.96	8.54

Table A6.2: VDV values for Truck03

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.89	2.93	4.37	2.93	3.13	3.77	2.18	2.91	4.35	1.45	5.16	7.42	1.61	2.89	7.68
2	5.43	3.32	5.14	4.22	3.51	4.41	2.89	3.17	5.82	1.72	4.26	7.38	1.74	2.81	9.04
3	5.59	3.24	5.40	4.64	3.34	4.63	3.06	3.13	5.80	1.81	3.67	7.99	1.69	2.96	8.87
4	3.69	3.88	3.74	3.28	3.76	3.23	3.73	4.64	4.92	2.75	3.56	6.22	2.96	3.12	9.52
5	6.05	3.10	5.10	4.16	2.87	4.49	2.86	2.98	5.13	1.63	4.62	6.71	1.77	4.30	9.50
6	3.94	3.39	4.07	2.99	3.16	3.64	2.26	3.35	4.71	2.13	3.64	6.32	4.32	3.44	9.22
7	5.06	2.80	5.10	3.81	2.47	4.39	3.32	2.97	5.17	2.30	2.74	6.85	2.14	2.82	9.32
8	5.44	4.67	6.12	1.62	2.93	5.31	2.62	3.17	6.43	2.12	3.42	7.62	2.18	3.31	10.60
9	4.75	3.48	5.02	3.66	3.32	4.20	2.41	3.78	5.51	1.95	3.18	7.65	2.15	3.01	9.75
10	4.31	3.84	3.76	3.54	3.58	3.99	2.27	3.71	5.10	1.96	2.74	6.44	1.98	2.69	9.54
11	4.31	2.80	4.50	3.21	2.61	4.00	2.36	3.20	4.91	1.98	3.03	6.42	2.04	3.23	9.66
12	5.12	4.32	5.01	3.72	3.77	4.16	2.71	4.04	5.66	2.05	3.61	8.40	1.97	3.78	10.47
13	4.69	3.06	4.78	3.40	2.73	3.91	2.53	2.99	5.17	1.87	3.22	7.24	2.35	3.17	9.52
14	3.75	2.56	4.28	2.84	3.00	3.83	2.26	2.73	4.73	1.52	3.79	6.58	2.20	3.68	10.16
15	5.48	5.70	5.76	4.49	4.79	5.68	4.39	5.43	7.96	2.95	4.11	6.85	3.18	4.07	11.53
Average	4.77	3.54	4.81	3.50	3.27	4.24	2.79	3.48	5.42	2.01	3.65	7.07	2.29	3.29	9.62

Table A6.3: VDV values for Truck04

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.02	2.63	4.11	3.09	3.24	3.47	1.80	2.34	3.59	1.59	4.36	6.93	1.48	2.55	7.76
2	3.68	3.56	4.58	3.08	3.21	3.82	5.08	4.07	4.70	1.66	4.90	7.41	1.56	3.70	9.38
3	5.28	3.63	6.20	4.79	3.72	5.10	3.27	3.47	5.53	2.07	4.73	8.43	1.97	3.83	10.04
5	3.23	2.54	4.99	2.54	2.85	3.71	3.55	3.40	6.31	1.88	3.70	8.22	1.76	3.16	10.16
6	3.65	2.70	5.05	3.15	2.99	3.76	2.42	2.85	5.02	1.57	3.49	7.26	2.02	3.00	9.45
7	2.88	2.72	4.38	3.80	3.78	3.23	2.28	2.83	4.55	2.15	5.75	7.80	2.33	5.21	13.47
8	4.87	2.79	5.34	3.30	2.88	4.63	2.48	2.97	4.97	1.71	2.72	6.94	1.47	2.54	9.75
9	3.39	2.93	4.18	2.51	2.63	3.65	1.94	2.53	3.99	1.78	5.42	6.57	1.94	4.60	8.98
10	3.85	3.45	4.09	3.64	3.66	3.34	2.79	3.25	3.68	2.57	4.21	5.79	2.52	3.28	8.00
11	4.42	2.68	5.18	3.47	3.20	4.54	2.57	2.49	5.28	2.12	4.14	6.92	1.98	3.39	9.09
12	5.36	3.24	6.28	3.82	3.19	5.70	3.51	3.78	5.99	2.19	3.80	8.64	2.12	3.15	10.17
13	4.49	3.64	5.92	3.22	3.26	5.34	2.99	4.06	5.37	2.17	4.61	8.76	2.29	3.78	11.40
14	3.02	3.09	3.80	2.90	3.28	2.93	2.53	4.01	3.15	2.32	3.52	5.65	2.28	2.84	9.02
15	3.81	3.46	4.60	3.11	3.23	3.92	5.17	3.79	4.40	2.02	3.68	6.44	1.91	3.13	9.21
16	4.26	3.40	5.14	5.14	3.13	4.37	2.64	3.62	4.65	2.56	3.96	7.56	1.71	3.42	10.28
17	4.33	5.00	5.14	3.25	3.94	4.33	4.63	4.28	5.29	1.97	4.14	8.45	1.91	3.84	10.33
18	4.11	3.32	5.12	2.72	2.81	4.10	2.50	2.88	4.46	2.01	3.58	7.83	2.08	3.24	10.82
19	3.76	2.86	4.57	2.89	2.86	3.87	2.21	2.60	4.37	1.73	3.73	6.64	2.00	3.28	9.35
Average	3.97	3.20	4.93	3.36	3.21	4.10	3.02	3.29	4.74	2.00	4.14	7.35	1.96	3.44	9.81

Table A6.4: VDV values for Truck05

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.71	2.95	4.11	2.99	3.51	3.49	2.15	2.94	3.71	1.80	4.27	6.44	1.32	2.36	7.82
2	4.39	3.22	4.25	3.04	2.89	3.48	2.24	3.07	4.46	2.06	4.13	6.66	1.46	2.87	8.41
3	4.98	3.52	5.19	3.83	3.66	4.42	2.72	3.46	5.03	1.87	2.88	7.56	1.78	2.57	9.05
4	4.15	2.58	4.14	3.17	3.10	3.68	2.49	2.75	5.32	1.82	2.78	7.17	1.45	2.55	10.09
5	3.93	2.71	4.30	3.05	3.02	3.56	1.90	2.77	5.04	1.48	5.15	6.43	2.25	4.67	9.93
6	5.28	2.66	5.21	3.96	2.80	4.16	2.38	2.77	7.70	1.82	5.12	6.21	1.86	4.52	9.47
7	3.74	3.15	4.04	3.20	3.77	3.60	2.69	4.09	4.15	1.53	3.70	6.12	2.29	3.14	8.74
9	4.85	2.53	5.96	3.69	2.91	5.04	3.99	4.34	5.98	2.34	4.10	7.55	1.97	3.40	10.11
10	5.33	4.03	6.96	4.81	4.58	6.20	4.70	5.13	8.32	3.36	4.99	9.86	2.41	4.35	11.74
11	3.49	3.39	3.44	3.13	3.59	3.02	2.81	4.09	3.33	2.08	4.11	5.50	2.24	3.46	9.09
12	4.11	3.40	4.19	3.59	3.65	3.70	3.02	3.26	5.11	2.42	3.94	6.45	2.50	3.43	10.23
13	3.99	3.17	4.86	3.47	3.44	4.09	2.43	3.12	5.30	1.98	3.62	6.79	1.68	3.30	9.66
14	4.83	4.72	5.35	3.77	4.10	4.34	2.82	3.83	6.24	2.39	4.78	8.58	2.12	4.37	11.07
15	4.72	3.53	4.56	3.11	2.96	4.05	2.70	3.09	4.95	1.84	3.81	7.81	2.15	3.63	11.05
16	3.58	2.69	4.11	3.16	3.13	3.61	2.21	2.42	4.43	1.87	3.42	6.35	1.74	3.08	9.88
17	5.64	3.02	6.15	4.21	3.51	5.26	3.59	2.72	5.45	2.67	2.86	9.25	2.05	2.62	11.86
Average	4.42	3.20	4.80	3.51	3.41	4.11	2.80	3.37	5.28	2.08	3.98	7.17	1.95	3.39	9.89

Table A6.5: VDV values for Truck06

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	2.97	2.51	5.59	2.49	2.62	4.37	1.83	2.13	5.00	1.78	3.78	8.05	1.37	3.00	8.33
3	3.86	3.16	6.16	3.05	2.95	4.67	2.37	2.56	6.52	2.11	3.99	8.35	1.51	3.39	9.53
4	4.70	3.38	6.79	3.85	3.33	5.25	2.96	2.91	7.34	1.96	2.81	8.41	1.67	2.71	9.55
5	3.70	3.00	6.34	2.64	2.91	4.70	2.19	2.64	6.45	1.89	4.72	8.64	1.84	4.59	9.50
6	3.90	3.90	5.81	3.26	3.34	4.69	2.52	3.36	6.24	2.34	3.21	6.62	2.27	3.23	9.19
7	5.67	2.84	5.80	4.44	2.92	4.91	3.18	2.44	6.33	1.79	3.83	7.41	1.71	3.34	8.72
8	3.06	2.93	5.26	2.46	2.81	4.38	1.93	2.76	5.29	1.93	3.91	6.91	1.43	3.18	8.87
9	2.80	2.38	4.99	2.62	2.70	3.90	2.40	2.56	4.08	1.98	3.55	7.37	1.60	2.56	8.94
10	4.15	2.67	5.71	3.25	2.93	5.50	2.77	2.27	6.98	2.03	4.07	7.98	1.74	3.17	9.72
11	4.55	3.25	6.86	4.06	3.74	6.44	2.83	2.72	7.75	2.46	3.66	9.13	1.96	3.04	9.50
12	3.65	3.44	6.47	3.21	3.57	5.33	2.43	0.28	7.48	1.92	3.73	8.88	1.79	3.18	9.78
13	3.55	3.41	5.29	3.30	3.41	4.61	2.37	2.84	5.51	1.94	3.85	7.15	2.24	3.33	9.44
14	3.76	3.36	5.77	3.21	3.31	5.22	2.59	2.96	6.00	2.04	3.18	7.84	1.72	3.06	8.86
15	4.18	4.55	6.95	3.53	3.74	6.01	3.27	3.61	9.14	2.06	3.55	9.61	1.91	3.40	10.45
16	4.03	3.81	6.69	3.28	3.73	6.18	2.60	3.33	10.61	2.07	3.95	9.26	2.15	3.73	11.20
17	3.71	3.16	5.78	3.32	3.08	4.99	2.38	2.48	6.06	1.91	3.27	7.34	2.09	3.08	9.85
18	5.20	3.17	6.84	4.06	3.30	6.73	3.33	2.65	8.76	2.16	3.17	9.31	2.00	3.04	10.06
Average	3.97	3.23	6.06	3.30	3.20	5.17	2.59	2.62	6.80	2.02	3.66	8.13	1.82	3.24	9.50

Table A6.6: VDV values for Truck07

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	3.03	2.83	6.01	2.39	2.62	4.03	4.24	4.34	8.99	1.39	3.44	7.42	1.54	2.05	8.65
2	3.38	3.51	6.30	2.66	2.98	4.52	2.31	2.85	5.64	1.49	3.75	7.93	1.41	2.77	9.58
3	4.76	3.83	6.25	3.46	3.46	5.07	2.86	3.33	7.57	1.90	3.72	9.45	1.85	2.86	9.11
4	3.05	3.02	6.05	2.06	2.68	4.20	1.93	2.45	5.29	2.11	4.12	8.16	1.28	3.39	8.97
5	3.60	3.80	5.27	2.81	3.40	4.00	2.19	3.13	4.89	1.96	4.05	6.43	2.66	3.13	8.37
6	4.76	2.88	5.39	4.21	2.64	4.24	2.59	2.46	6.09	1.80	4.86	7.11	1.60	3.50	8.68
7	2.99	2.45	5.03	2.38	2.45	4.04	2.02	2.61	4.83	1.30	3.45	6.85	1.87	2.22	8.35
8	3.32	2.85	5.59	3.01	3.19	4.03	2.80	2.40	4.52	2.85	3.50	6.67	2.64	2.35	8.34
9	4.15	2.38	5.47	3.30	2.72	4.52	2.75	2.17	6.26	1.96	3.73	7.61	1.88	2.33	8.90
10	4.27	2.90	6.01	3.37	2.95	5.22	3.06	2.53	6.88	1.92	4.03	9.18	2.03	2.72	9.44
11	3.75	3.35	6.38	2.90	3.27	5.05	2.68	2.84	6.80	2.02	3.85	8.29	1.97	2.76	9.54
12	2.94	2.68	5.02	2.39	3.02	3.87	2.39	2.31	4.73	2.08	3.48	6.66	2.18	2.34	8.71
13	3.64	3.42	5.13	2.99	3.15	4.33	2.86	2.86	4.97	2.54	3.13	6.92	2.41	2.41	8.90
14	4.26	4.08	6.47	3.35	3.64	5.15	2.89	3.35	6.99	2.26	3.66	8.32	2.03	3.02	9.85
15	3.90	3.05	5.94	2.95	2.95	4.86	2.89	2.82	7.03	2.02	4.03	8.04	1.81	3.15	10.28
16	3.32	3.77	5.62	2.78	3.42	4.49	2.75	3.13	6.85	1.66	3.98	8.00	1.79	2.97	10.32
17	2.86	2.31	5.08	2.10	2.63	4.15	2.16	1.93	4.56	1.49	3.77	7.18	2.63	2.28	9.72
Average	3.65	3.12	5.71	2.89	3.01	4.46	2.67	2.79	6.05	1.93	3.80	7.66	1.97	2.72	9.16

Appendix VII: VDV plots for trucks

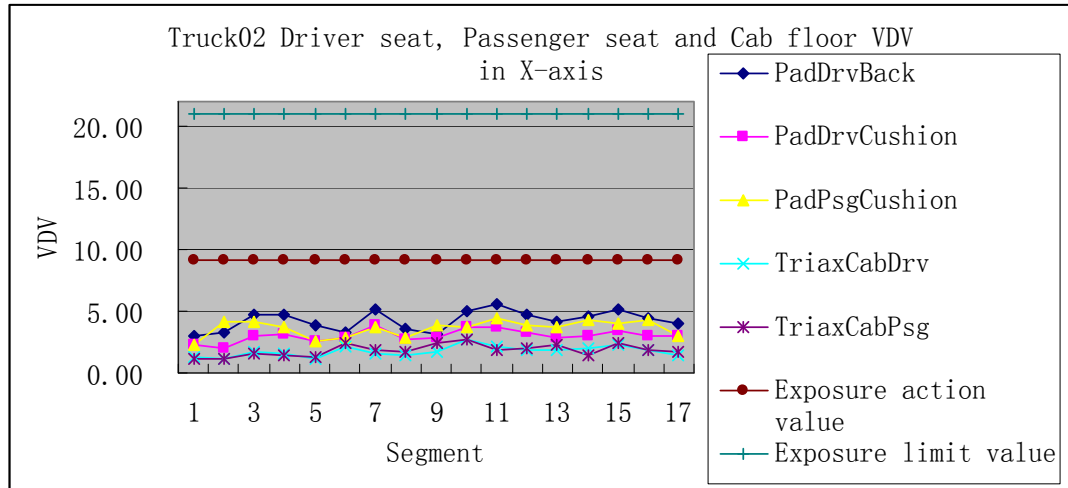


Figure A7.1: Truck02 driver seat, passenger seat and cab floor VDV in X-axis

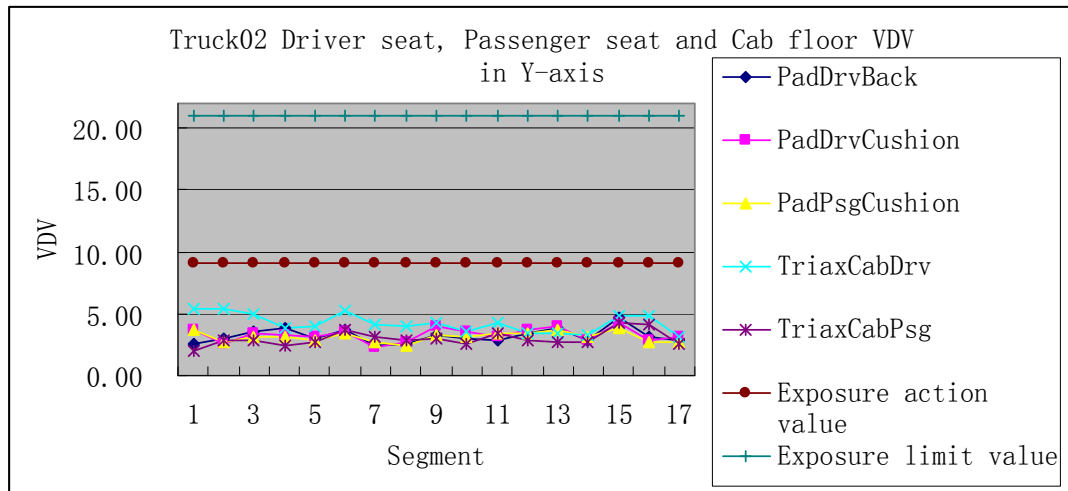


Figure A7.2: Truck02 driver seat, passenger seat and cab floor VDV in Y-axis

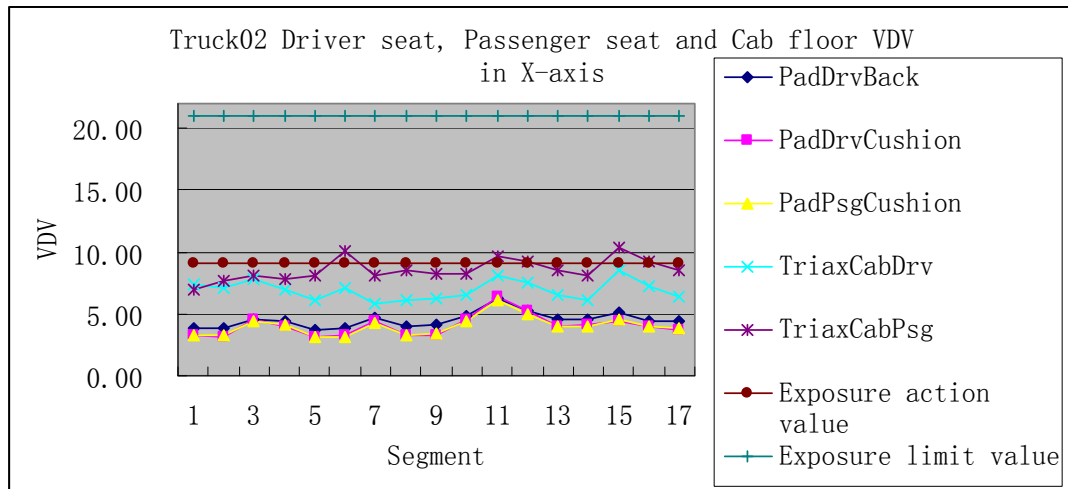


Figure A7.3: Truck02 driver seat, passenger seat and cab floor VDV in Z-axis

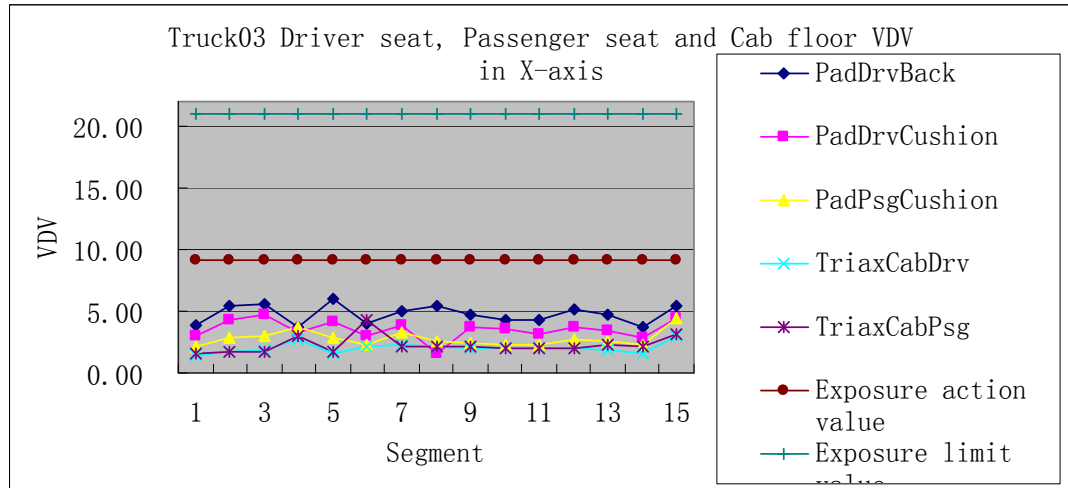


Figure A7.4: Truck03 driver seat, passenger seat and cab floor VDV in X-axis

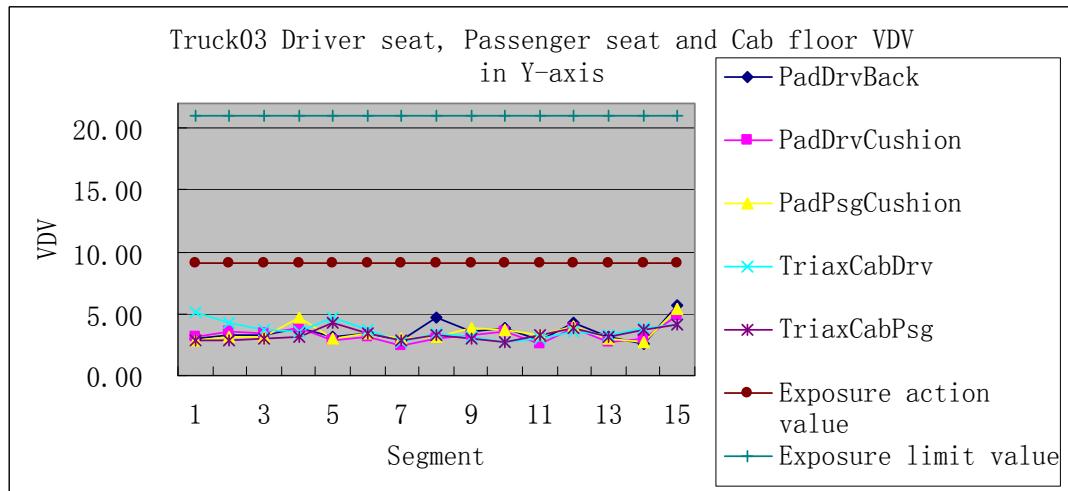


Figure A7.5: Truck03 driver seat, passenger seat and cab floor VDV in Y-axis

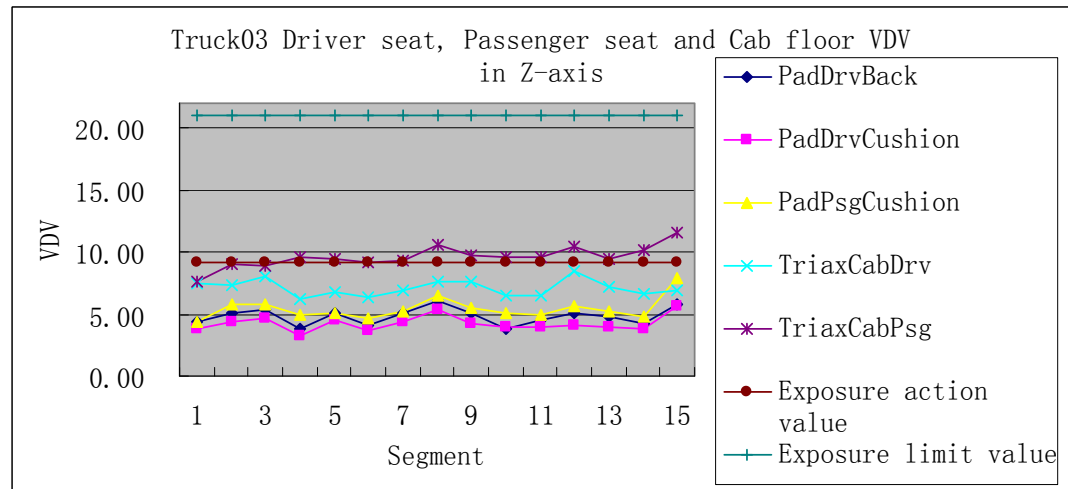


Figure A7.6: Truck03 driver seat, passenger seat and cab floor VDV in Z-axis

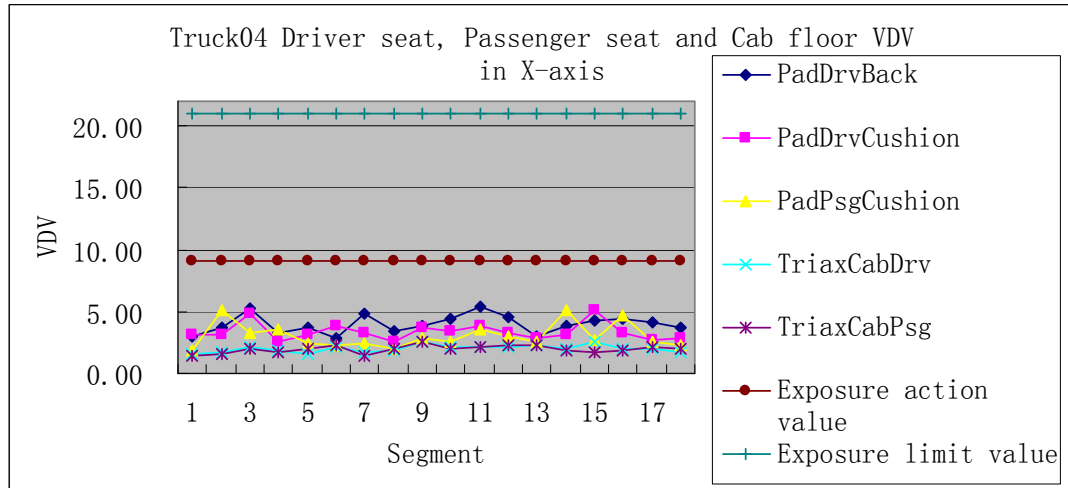


Figure A7.7: Truck04 driver seat, passenger seat and cab floor VDV in X-axis

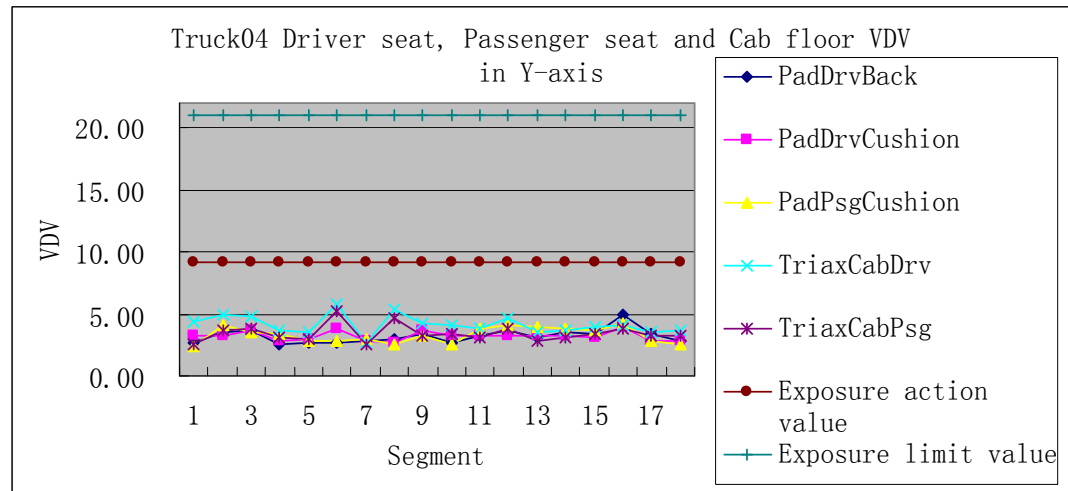


Figure A7.8: Truck04 driver seat, passenger seat and cab floor VDV in Y-axis

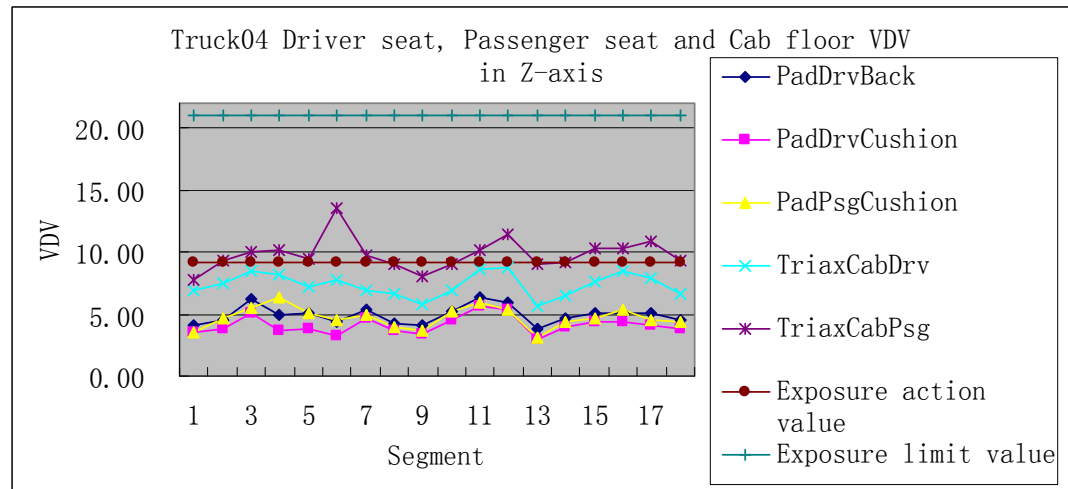


Figure A7.9: Truck04 driver seat, passenger seat and cab floor VDV in Z-axis

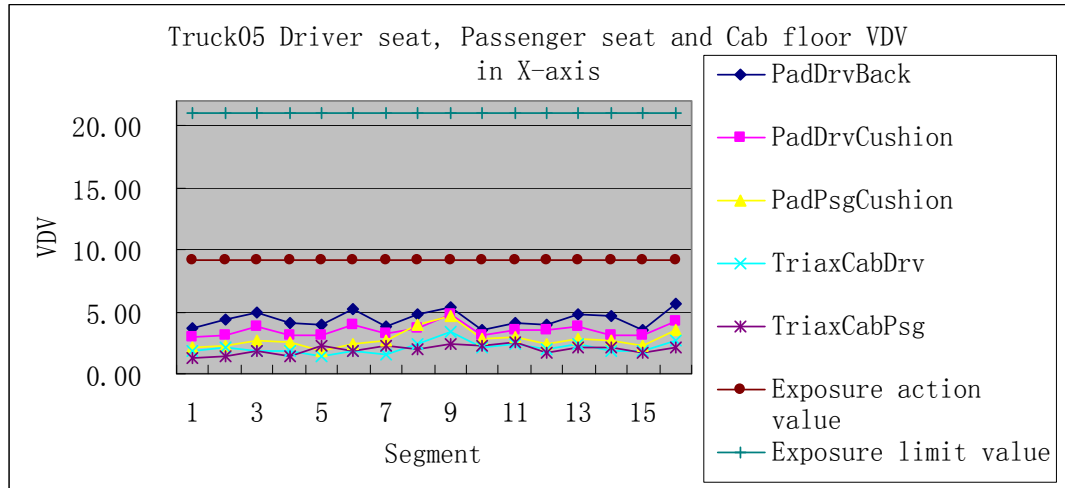


Figure A7.10: Truck05 driver seat, passenger seat and cab floor VDV in X-axis

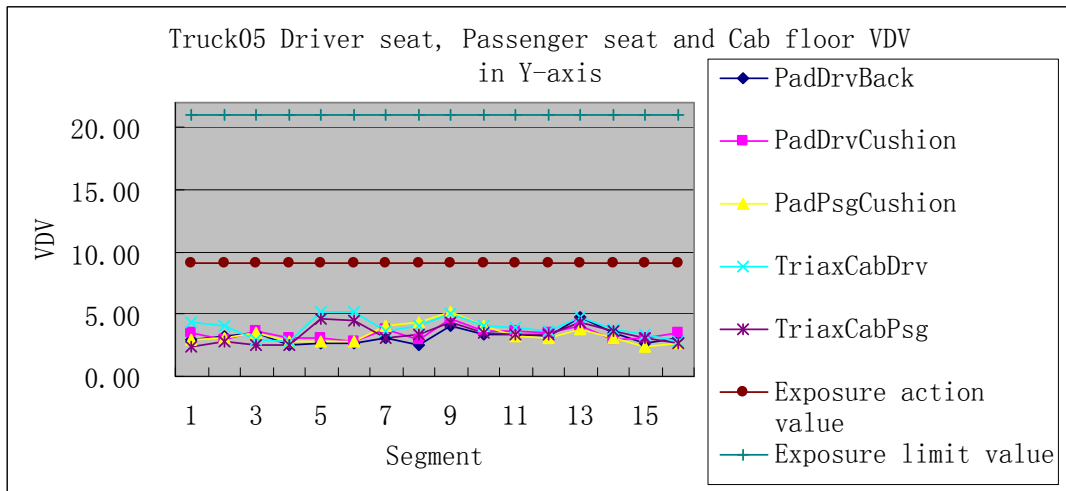


Figure A7.11: Truck05 driver seat, passenger seat and cab floor VDV in Y-axis

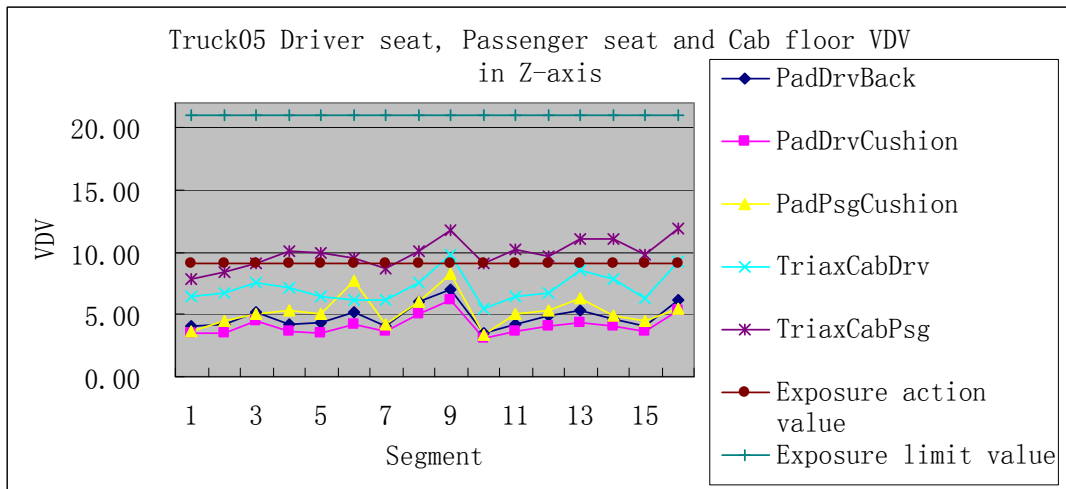


Figure A7.12: Truck05 driver seat, passenger seat and cab floor VDV in Z-axis

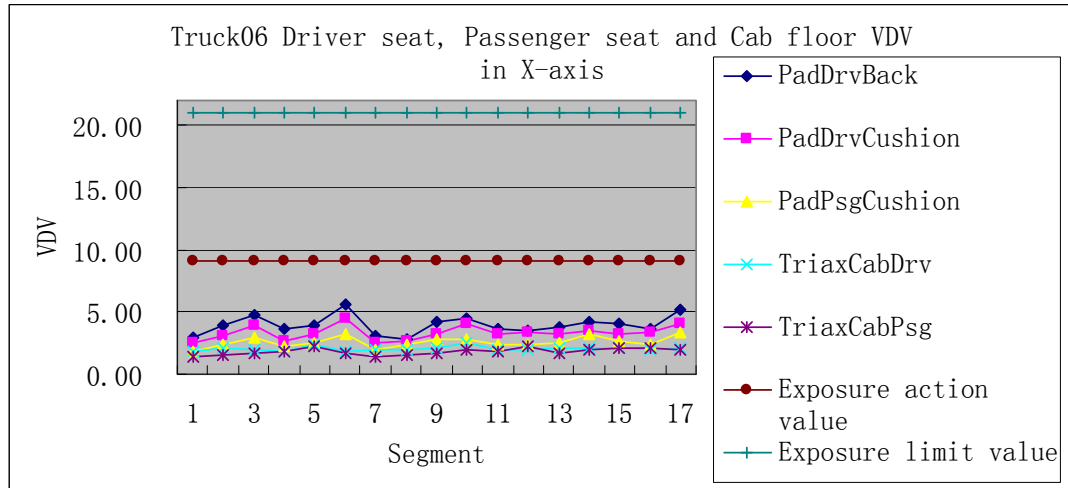


Figure A7.13: Truck06 driver seat, passenger seat and cab floor VDV in X-axis

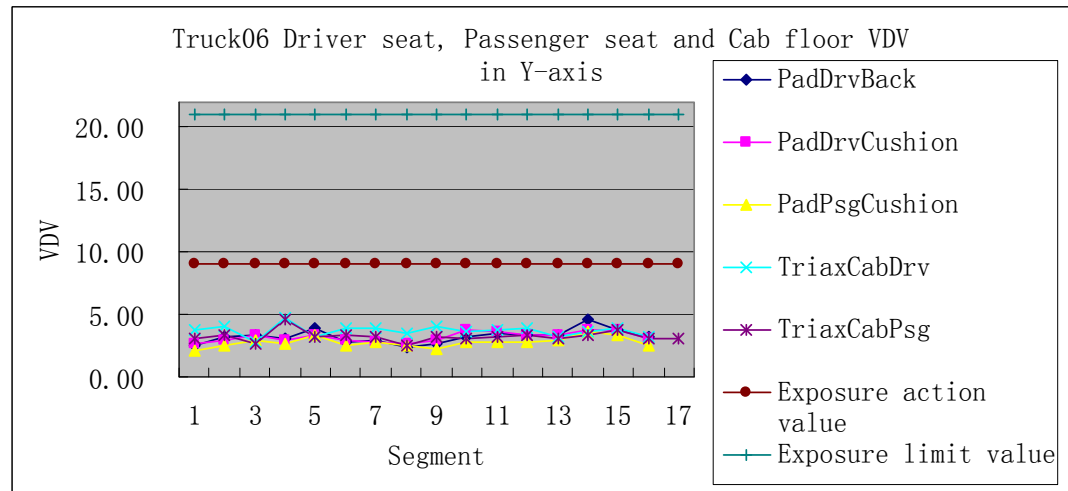


Figure A7.14: Truck06 driver seat, passenger seat and cab floor VDV in Y-axis

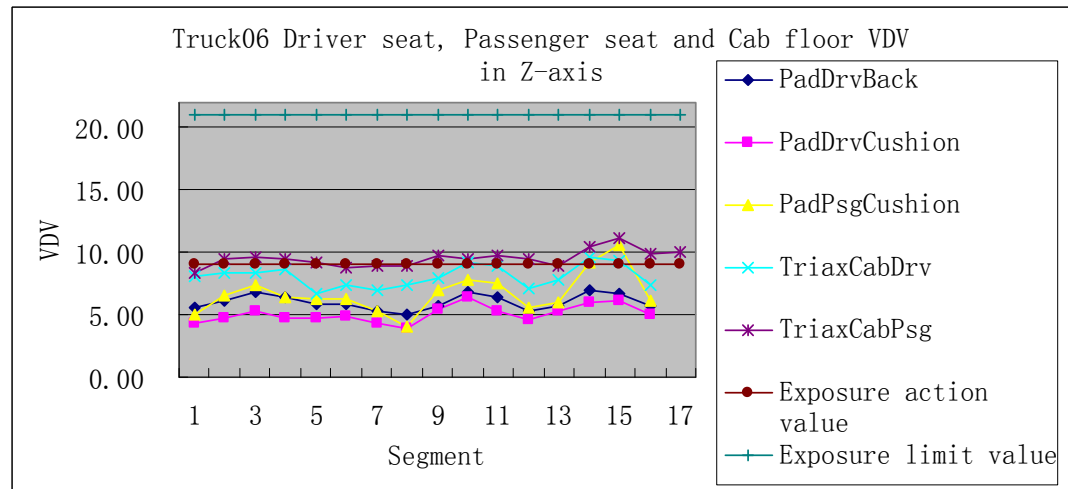


Figure A7.15: Truck06 driver seat, passenger seat and cab floor VDV in Z-axis

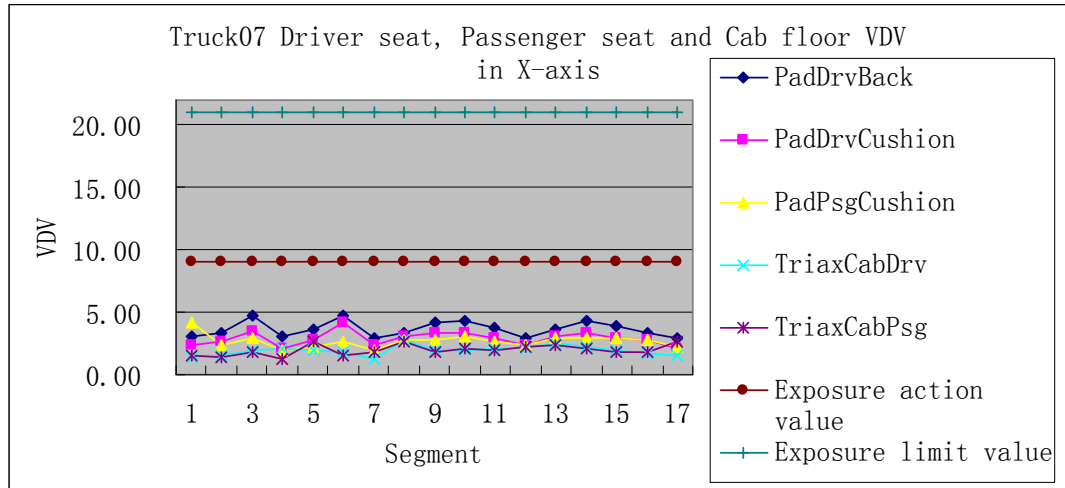


Figure A7.16: Truck07 driver seat, passenger seat and cab floor VDV in X-axis

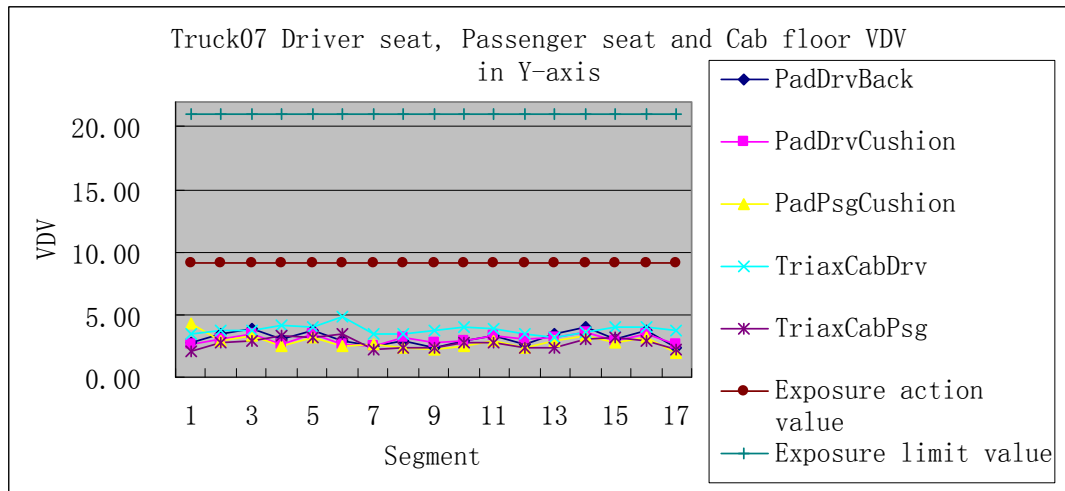


Figure A7.17: Truck07 driver seat, passenger seat and cab floor VDV in Y-axis

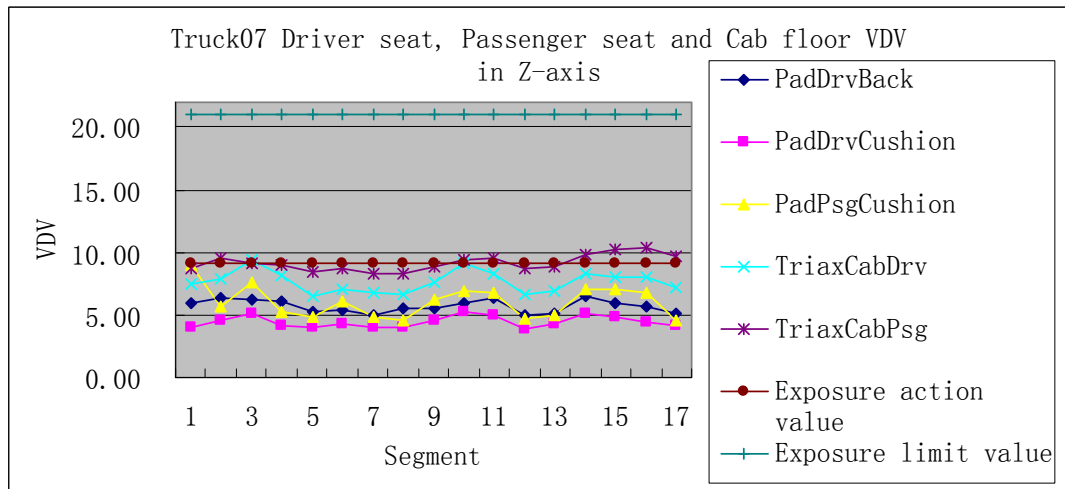


Figure A7.18: Truck07 driver seat, passenger seat and cab floor VDV in Z-axis

Appendix VIII: RMS jerk results for trucks

Table A8.1: RMS jerks for Truck02

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	24.6	83.4	101.3	102.4	121.3	33.2	99.1	139.0	39.8	111.6	151.7	294.5	106.9	149.7	340.4
2	26.0	100.1	115.5	78.1	124.9	41.5	107.4	134.9	70.5	117.8	168.8	344.1	106.9	166.6	389.7
3	26.1	102.5	111.4	95.4	130.6	35.1	140.0	142.7	74.2	116.5	208.8	350.8	134.2	208.4	364.8
4	22.8	101.6	110.4	128.3	143.9	43.4	173.4	179.0	103.5	142.6	236.6	361.6	174.8	239.1	473.9
5	30.6	94.5	101.6	89.5	124.0	32.6	154.8	168.0	63.8	131.7	212.2	268.6	155.2	217.6	347.7
6	20.1	65.5	75.7	64.0	103.8	23.0	126.0	137.6	48.9	105.9	161.0	168.4	124.4	163.7	260.0
7	27.8	94.9	115.7	85.1	121.2	27.2	97.6	147.3	24.3	110.4	180.6	244.0	140.1	183.3	271.3
8	24.3	65.0	28.1	59.4	99.5	23.4	84.7	115.3	30.6	84.9	120.4	163.7	91.6	123.9	157.0
9	29.0	85.0	126.3	74.7	106.5	33.0	106.7	128.8	65.1	102.9	141.0	256.0	98.8	144.1	253.4
10	26.6	73.4	105.6	69.4	103.3	27.6	106.8	134.2	49.1	91.3	126.0	209.4	96.1	128.9	211.8
11	30.0	82.5	116.7	61.2	104.2	31.8	100.7	135.7	34.5	106.4	129.1	254.2	97.3	131.9	235.4
12	22.2	76.7	91.5	72.9	100.5	25.9	117.5	132.9	48.8	98.0	148.2	199.9	109.7	149.0	202.5
13	29.7	91.9	120.7	86.6	115.1	33.6	131.9	130.0	81.7	104.3	160.0	273.8	120.9	160.1	261.7
14	31.7	91.5	119.9	79.2	116.3	34.1	123.0	132.0	73.6	106.0	147.3	277.5	113.8	148.9	250.0
15	26.2	93.7	100.2	79.9	100.2	28.4	128.2	153.7	53.5	124.9	193.0	244.8	141.2	196.6	239.6
16	31.0	103.4	123.6	79.0	125.0	33.7	116.3	143.1	44.4	105.4	182.5	280.4	122.6	184.3	243.3
17	35.2	86.9	114.1	78.7	110.8	32.4	115.3	133.0	58.8	108.6	152.3	251.6	125.3	154.7	241.6
Average	27.3	87.8	104.6	81.4	114.8	31.8	119.4	140.4	56.8	109.9	165.9	261.4	121.2	167.7	279.1

Table A8.2: RMS jerks for Truck03

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
2	39.5	81.1	213.5	97.5	162.7	49.1	88.2	214.2	36.6	96.1	208.0	354.4	122.9	206.9	226.5
3	29.1	83.6	147.1	103.5	151.7	67.3	131.2	238.0	43.6	125.0	291.1	211.6	150.0	278.5	236.8
4	37.4	106.6	202.1	118.0	181.1	71.3	129.1	297.6	42.7	114.0	302.3	270.4	145.5	293.1	222.4
5	30.2	63.2	144.3	79.3	123.9	44.9	81.0	175.8	30.8	77.1	175.1	216.5	100.0	168.9	152.3
6	31.0	78.8	153.3	86.1	127.4	53.5	119.6	179.7	48.2	95.1	221.0	230.0	120.8	213.1	173.1
7	22.1	60.4	93.6	69.7	101.8	39.0	95.0	124.9	37.2	80.2	153.6	161.6	91.0	148.5	151.3
8	22.9	64.0	105.8	76.7	113.8	41.6	107.0	142.1	41.1	86.1	161.2	208.4	96.8	158.2	163.0
9	21.4	51.4	68.8	61.4	99.3	28.6	87.5	100.7	30.7	80.9	140.8	148.9	82.1	137.9	121.3
10	31.3	71.4	124.1	84.4	119.1	50.5	111.1	142.7	41.2	98.6	189.9	251.1	103.9	183.2	181.4
11	32.1	73.4	144.0	90.2	128.2	50.1	107.6	159.3	44.1	98.1	180.3	270.9	105.3	174.9	196.5
12	27.3	63.6	80.2	74.2	114.2	39.4	101.5	119.3	40.0	88.5	160.4	179.2	107.4	156.2	174.4
13	29.6	73.3	116.2	88.1	116.7	55.8	99.7	159.0	31.5	94.4	204.4	193.4	115.7	195.8	160.4
14	35.9	76.3	177.6	89.1	133.4	59.1	81.2	190.9	42.0	86.6	172.0	310.6	115.8	172.2	176.9
15	33.5	70.0	148.3	82.5	126.9	57.3	97.1	149.4	25.5	24.8	174.8	262.8	108.4	170.8	165.9
16	33.7	44.0	71.7	48.9	78.9	88.6	60.1	83.1	28.4	45.8	70.0	114.5	46.5	70.0	92.4
Average	30.5	70.7	132.7	83.3	125.3	53.1	99.8	165.1	37.6	86.1	187.0	225.6	107.5	181.9	173.0

Table A8.3: RMS jerks for Truck04

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	43.5	104.4	210.6	100.0	138.2	44.6	135.8	158.6	48.9	24.6	174.5	282.5	119.6	172.2	227.2
2	38.9	103.4	196.1	105.3	150.6	57.7	149.1	188.2	53.7	98.8	257.9	280.5	150.1	257.4	227.0
3	36.2	109.8	178.7	108.4	168.5	67.6	145.2	212.5	56.6	117.2	300.0	278.2	167.2	301.8	234.8
4	35.8	112.1	175.6	96.2	154.0	56.3	135.4	204.9	144.8	100.3	261.7	279.9	162.9	262.8	240.9
5	32.0	90.7	147.7	96.3	154.9	63.6	126.8	175.6	55.6	107.5	264.4	246.1	144.5	267.6	223.1
6	30.5	74.9	123.1	80.1	135.1	49.7	103.0	161.0	43.8	93.7	224.4	199.0	123.4	228.1	184.0
7	43.6	103.7	212.7	100.0	150.7	36.1	137.3	169.3	52.1	94.8	215.3	277.1	133.9	215.6	222.7
8	37.5	70.5	155.4	77.7	119.3	29.4	109.5	140.4	41.4	83.3	160.2	217.5	106.9	159.3	187.1
9	36.3	67.8	152.8	69.9	116.7	29.4	104.9	126.2	38.6	81.0	142.9	218.7	95.0	142.5	190.5
10	31.1	77.2	143.8	73.5	116.5	30.1	118.5	127.2	43.0	78.2	147.6	209.0	99.5	148.3	183.6
11	37.6	62.9	151.3	59.7	121.6	28.4	95.2	114.5	43.0	87.7	127.4	249.0	83.5	123.9	200.6
12	29.1	65.6	124.3	75.7	120.4	32.2	105.6	127.2	41.4	92.1	180.7	212.6	113.2	180.3	193.2
13	31.9	65.0	139.6	69.7	109.5	32.0	95.0	122.6	38.1	80.7	171.7	196.0	101.6	170.8	177.7
14	37.8	84.7	170.4	84.8	137.8	37.3	128.1	140.8	51.1	102.6	200.9	253.6	117.7	198.7	200.9
15	45.5	99.9	212.2	93.7	148.4	35.9	150.4	135.1	49.1	91.2	168.5	287.1	106.5	166.2	203.0
16	34.0	88.9	141.7	86.3	127.4	37.8	113.0	145.9	53.8	97.1	224.9	223.5	136.1	220.1	211.0
17	50.9	127.6	267.8	114.2	144.8	48.8	167.7	129.7	51.1	93.4	173.4	323.1	111.9	171.6	219.9
18	34.6	89.1	155.6	83.6	134.3	37.7	133.0	147.7	44.8	93.7	185.1	228.7	114.9	180.9	206.6
Average	37.0	88.8	170.0	87.5	136.0	41.9	125.2	151.5	52.8	89.9	199.0	247.9	121.6	198.2	207.4

Table A8.4: RMS jerks for Truck05

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	30.9	85.4	154.2	76.0	98.7	22.8	93.1	125.9	37.2	91.4	170.7	257.9	119.0	172.9	197.0
2	33.4	86.4	185.0	87.8	113.2	24.6	107.6	159.2	51.5	114.7	202.8	287.2	141.1	208.3	224.1
3	25.9	85.0	165.8	97.6	121.7	24.8	116.3	207.3	66.1	156.9	259.6	225.0	177.2	260.7	219.5
4	31.6	98.6	190.1	107.0	134.9	25.8	143.4	187.4	69.2	154.5	257.7	286.1	173.0	257.1	254.3
5	35.8	85.2	192.3	98.8	124.0	24.1	123.6	175.2	60.3	135.5	224.5	232.1	150.8	228.1	209.6
6	25.9	71.0	165.7	102.2	109.6	28.3	89.4	187.8	59.9	132.1	214.9	210.9	137.4	216.3	201.0
7	21.5	56.8	126.5	82.3	93.1	23.6	84.4	129.0	41.1	96.7	153.8	203.5	107.6	153.3	153.6
8	27.3	59.4	130.0	104.1	103.3	23.9	98.8	133.7	52.3	89.0	157.7	216.4	113.9	158.4	166.0
9	28.8	59.5	158.6	68.2	101.0	31.2	100.7	122.0	42.7	91.7	149.5	283.4	96.7	149.6	205.2
10	25.4	57.8	133.4	75.8	100.9	26.2	102.9	127.4	39.1	91.5	144.8	233.1	109.5	146.1	179.0
11	24.6	46.1	94.8	60.0	75.3	18.0	72.1	102.0	33.2	71.1	120.2	139.4	81.2	119.3	130.9
12	26.1	68.3	127.1	76.9	99.1	20.5	98.8	127.4	43.6	96.6	162.7	201.5	119.5	160.4	175.3
13	29.0	76.2	163.3	78.6	100.3	23.5	93.3	120.4	52.2	96.8	166.3	248.7	113.5	163.6	204.6
14	30.7	67.4	120.6	79.6	99.8	22.4	99.5	151.4	47.2	117.6	191.0	181.6	125.8	186.3	172.3
15	26.2	73.3	158.5	85.1	110.0	26.5	102.5	129.4	49.7	100.3	174.1	260.8	133.6	176.5	173.3
16	36.8	74.9	162.5	85.4	105.2	26.2	100.1	121.8	52.6	93.7	163.7	270.0	120.7	160.2	178.0
17	25.7	66.9	153.8	75.2	95.4	26.1	96.9	125.2	52.9	100.0	166.9	248.4	117.0	167.2	181.5
Average	28.6	71.7	151.9	84.7	105.0	24.6	101.4	143.1	50.0	107.7	181.2	234.5	125.7	181.4	189.7

Table A8.5: RMS jerks for Truck06

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	39.2	80.5	285.7	360.8	154.3	39.3	380.7	152.6	88.8	92.1	227.3	435.0	124.0	197.8	392.6
2	37.4	80.3	289.1	358.1	168.1	42.5	434.1	184.8	91.1	113.5	285.1	462.4	146.7	249.3	390.1
3	48.8	86.4	346.4	418.2	195.3	46.4	522.3	228.1	102.7	140.7	376.7	582.0	189.0	326.3	440.5
4	40.8	86.0	271.7	349.4	182.4	41.5	455.7	198.4	92.7	120.6	311.1	432.3	157.9	270.2	391.5
5	33.7	56.9	226.1	277.9	162.8	35.7	301.5	165.9	60.8	122.0	317.1	351.8	150.3	282.0	284.8
6	27.8	59.9	217.7	293.6	173.6	35.5	337.6	183.7	60.2	117.4	289.7	401.8	140.1	256.9	300.5
7	30.7	51.2	193.7	253.0	125.1	30.2	269.8	130.2	58.1	80.4	175.8	323.9	95.8	158.4	259.4
8	36.9	55.9	237.5	367.8	126.0	38.9	344.9	129.6	68.9	82.5	185.3	413.1	102.0	165.3	325.2
9	38.3	64.8	219.6	351.5	142.4	35.3	327.7	134.9	77.9	86.1	194.3	430.9	109.7	171.6	333.1
10	67.6	67.7	218.8	349.6	113.4	31.3	309.3	121.4	79.6	78.1	138.7	442.7	89.7	123.6	313.0
11	38.7	67.6	231.5	368.3	133.5	34.2	362.2	131.1	90.2	89.8	171.4	455.1	104.5	150.8	344.6
12	44.0	64.4	234.6	353.5	151.5	36.8	354.6	142.9	71.8	104.9	227.3	452.7	127.9	199.7	364.9
13	40.6	62.0	218.8	331.6	144.6	29.8	382.7	135.5	78.7	109.6	211.4	401.9	121.1	184.4	329.5
14	38.8	53.1	184.1	248.7	131.3	33.4	291.5	138.0	66.9	107.9	250.7	355.0	131.8	219.4	245.5
15	39.3	66.3	223.8	337.1	148.6	37.1	385.3	155.8	99.1	99.9	231.0	421.5	128.0	198.0	371.7
16	35.6	61.2	239.3	357.4	179.0	39.9	351.7	168.8	75.0	126.8	290.4	452.6	142.3	255.5	342.1
17	44.4	64.8	211.8	321.5	149.3	32.4	338.9	144.6	81.5	96.6	231.6	422.2	122.0	200.3	327.8
Average	40.2	66.4	238.2	335.2	151.8	36.5	361.8	155.7	79.1	104.1	242.1	425.7	128.4	212.3	338.6

Table A8.6: RMS jerks for Truck07

Segment	PadDrvBack			PadDrvCushion			PadPsgCushion			TriaxCabDrv			TriaxCabPsg		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	71.4	149.1	400.8	280.5	116.0	31.9	551.8	152.0	109.1	105.6	218.4	507.0	137.3	206.4	325.8
2	36.9	151.5	383.9	278.4	175.9	34.4	549.0	167.3	93.0	144.1	341.1	487.1	181.9	321.4	429.2
3	34.8	119.8	274.7	269.4	160.9	33.2	536.9	166.6	90.8	157.5	383.8	517.6	195.2	363.9	423.9
4	36.5	131.8	313.2	287.7	148.9	39.0	530.8	183.6	74.1	157.3	398.7	549.8	190.6	348.7	364.6
5	35.5	105.2	241.4	266.5	144.0	33.8	418.0	182.7	55.6	153.7	364.3	373.7	168.1	374.5	363.3
6	58.8	112.2	237.6	275.0	122.7	32.7	361.1	168.6	97.3	153.9	349.0	446.1	175.7	337.4	387.6
7	50.7	78.5	192.5	245.0	101.0	31.9	294.5	151.5	79.2	107.8	227.8	410.2	121.1	222.0	259.2
8	66.5	89.4	268.6	248.0	111.9	35.5	317.6	155.5	78.0	112.4	248.2	391.6	129.1	241.5	306.0
9	89.2	81.8	229.7	216.8	96.7	31.1	317.7	130.1	73.3	100.3	185.4	367.6	113.2	178.8	266.5
10	52.5	66.4	162.2	200.1	108.4	27.1	374.9	155.6	64.1	113.6	238.2	290.6	124.7	226.3	287.1
11	52.8	81.6	199.7	230.0	114.4	34.9	402.5	172.4	73.3	125.8	274.3	346.8	148.4	262.9	319.8
12	60.3	78.1	197.2	233.4	111.6	36.2	388.9	134.4	77.2	111.6	260.6	314.5	139.0	245.1	315.8
13	51.1	78.7	170.3	200.5	100.1	29.2	412.0	114.7	71.5	119.3	248.9	302.3	135.1	230.9	309.3
14	46.1	79.1	191.0	215.7	107.4	28.8	421.5	174.2	72.6	138.3	281.2	332.2	143.5	265.5	308.0
15	81.9	101.8	227.9	246.6	107.4	32.1	374.9	134.4	95.2	122.6	250.0	420.3	135.4	236.6	276.6
16	75.8	93.0	276.9	244.8	128.1	33.3	474.8	161.3	108.1	141.8	294.3	470.8	166.7	276.0	348.3
17	45.9	84.5	199.9	219.9	95.9	29.6	375.5	120.8	67.6	98.2	196.8	367.8	115.3	185.2	269.1
Average	55.7	99.0	245.1	244.6	120.7	32.6	417.8	154.5	81.2	127.3	280.1	405.6	148.3	266.1	327.1

Appendix IX: RMS jerk plots for trucks

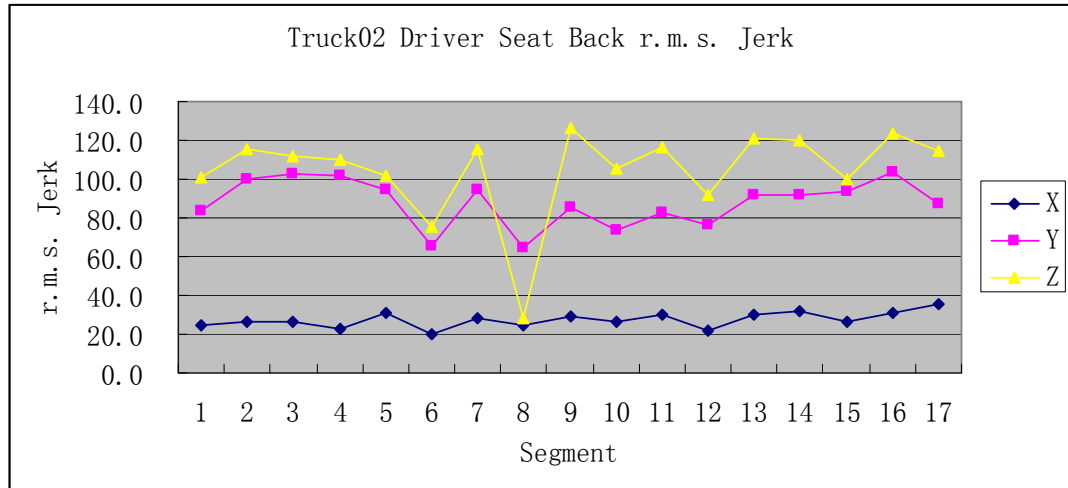


Figure A9.1: Truck02 driver seat back RMS jerk

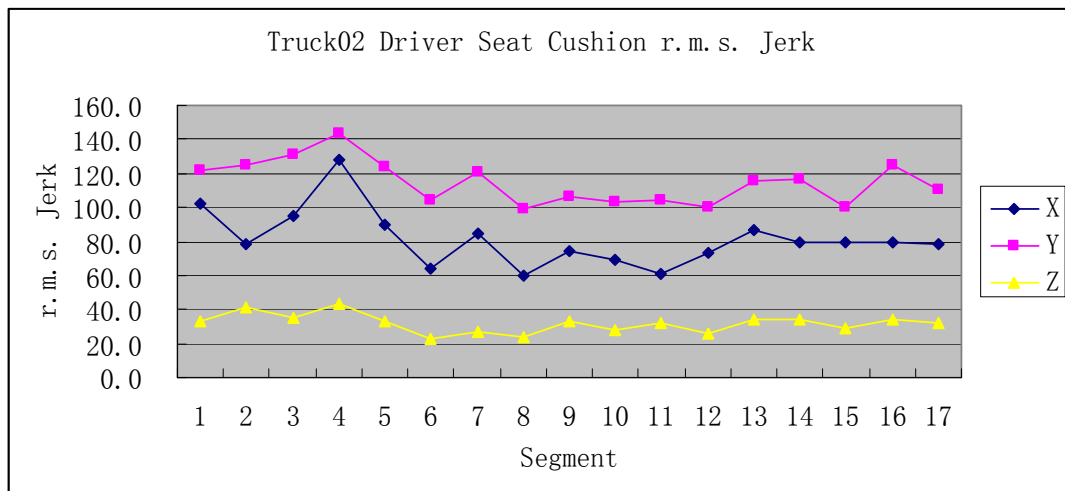


Figure A9.2: Truck02 driver seat cushion RMS jerk

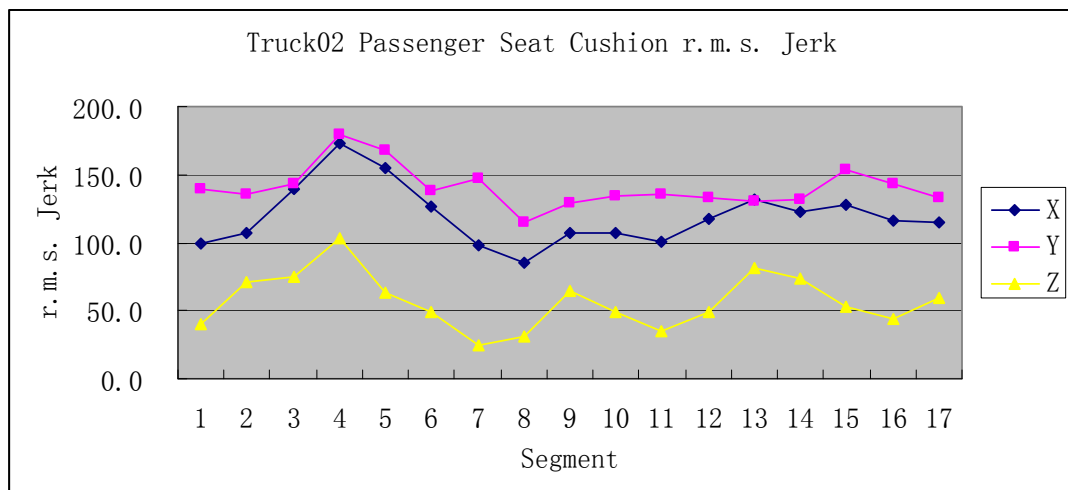


Figure A9.3: Truck02 passenger seat cushion RMS jerk

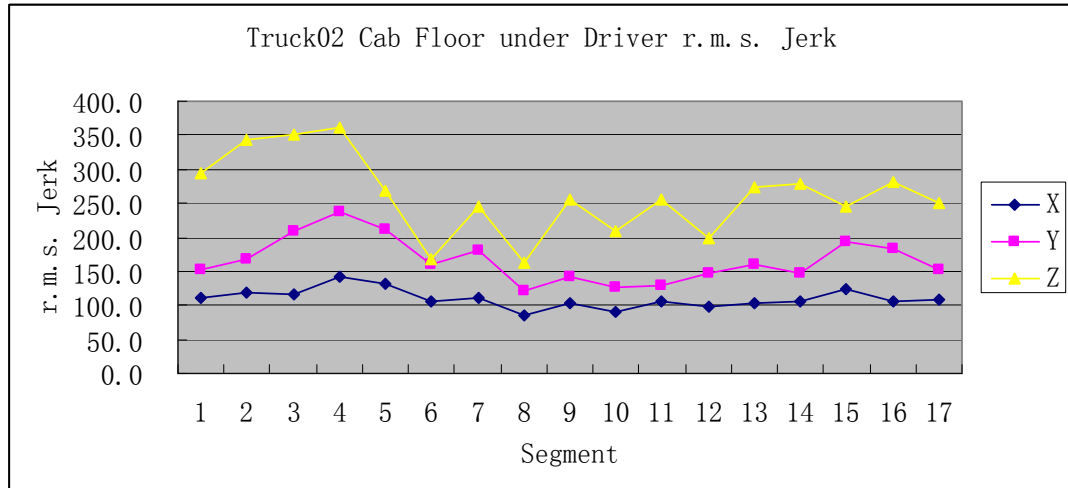


Figure A9.4: Truck02 cab floor under driver RMS jerk

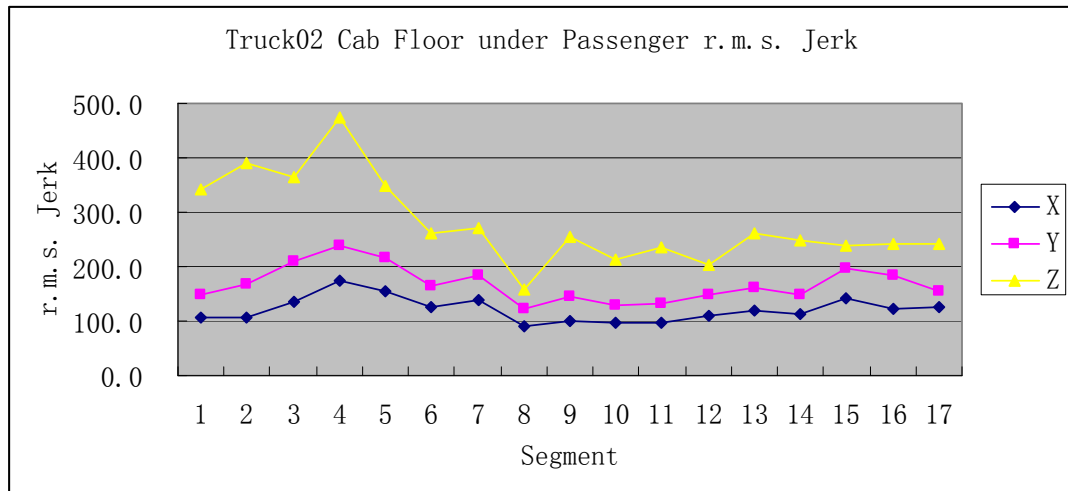


Figure A9.5: Truck02 cab floor under passenger RMS jerk

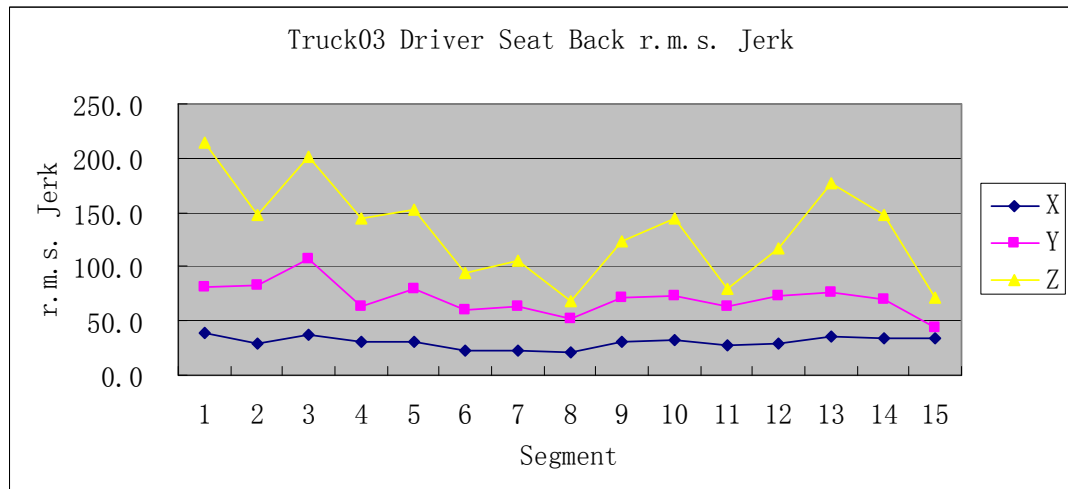


Figure A9.6: Truck03 driver seat back RMS jerk

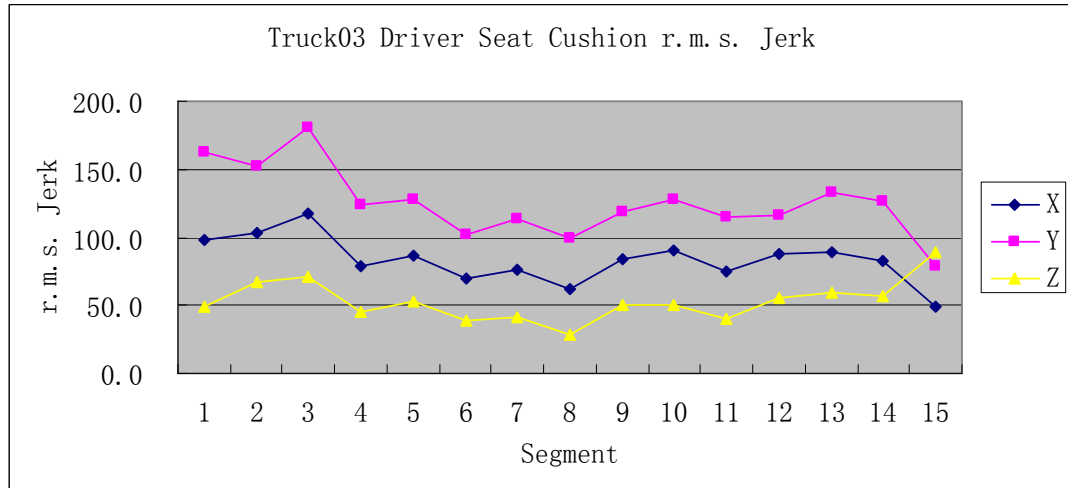


Figure A9.7: Truck03 driver seat cushion RMS jerk

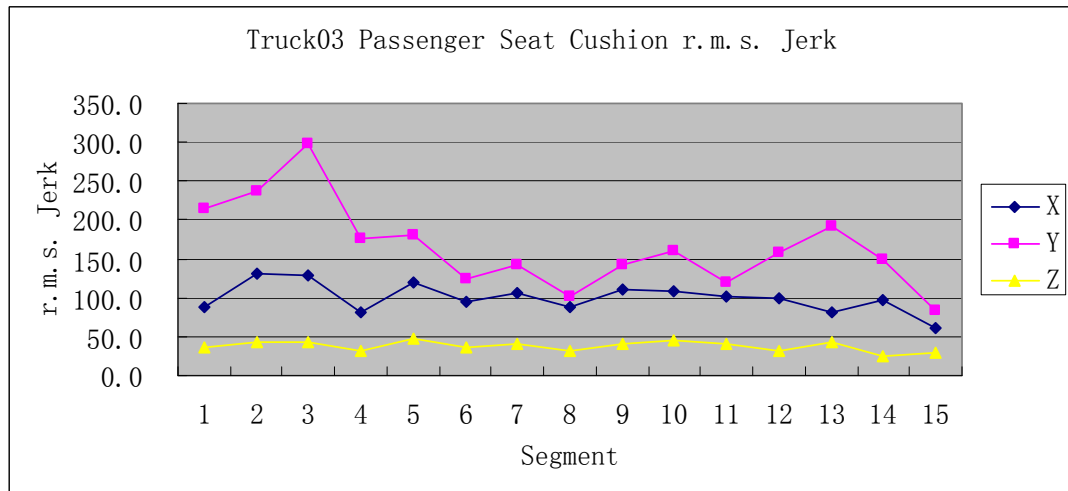


Figure A9.8: Truck03 passenger seat cushion RMS jerk

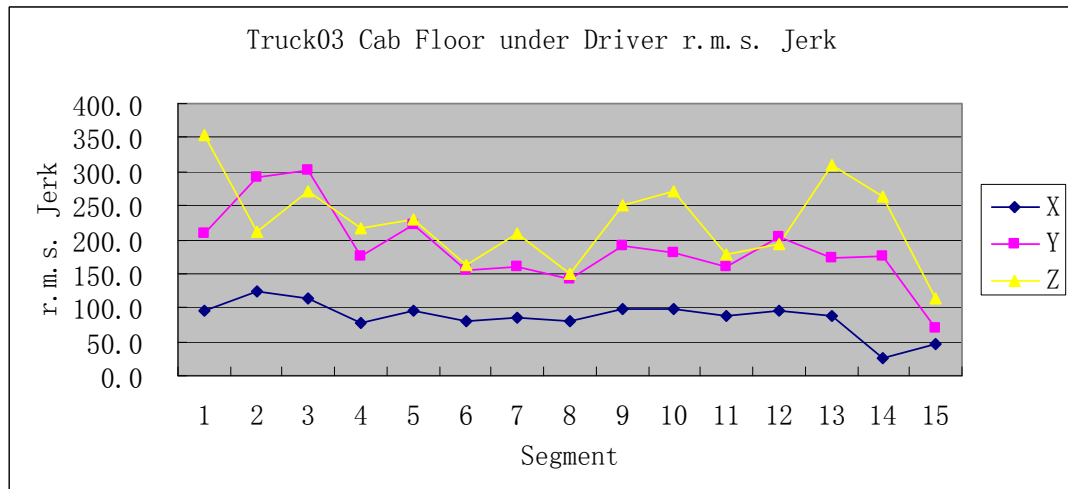


Figure A9.9: Truck03 cab floor under driver RMS jerk

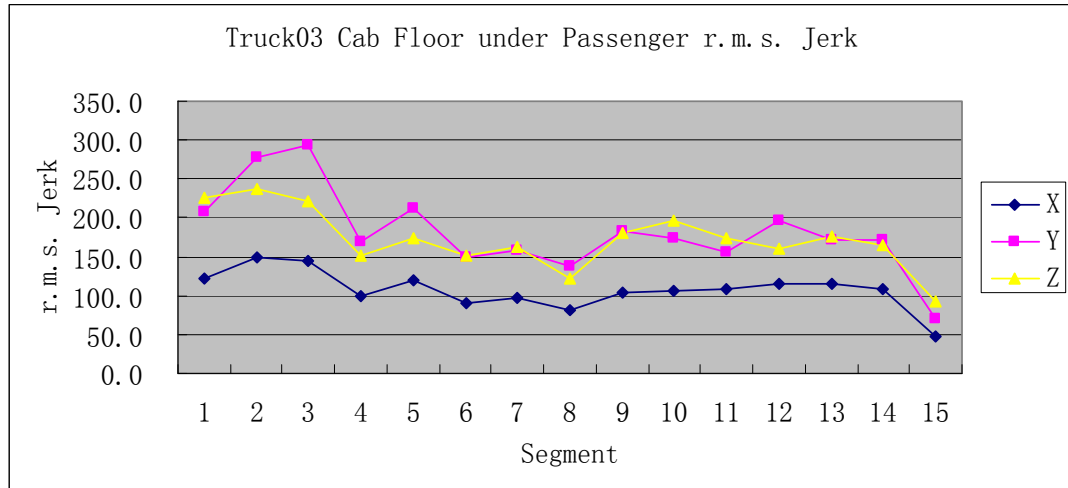


Figure A9.10: Truck03 cab floor under passenger RMS jerk

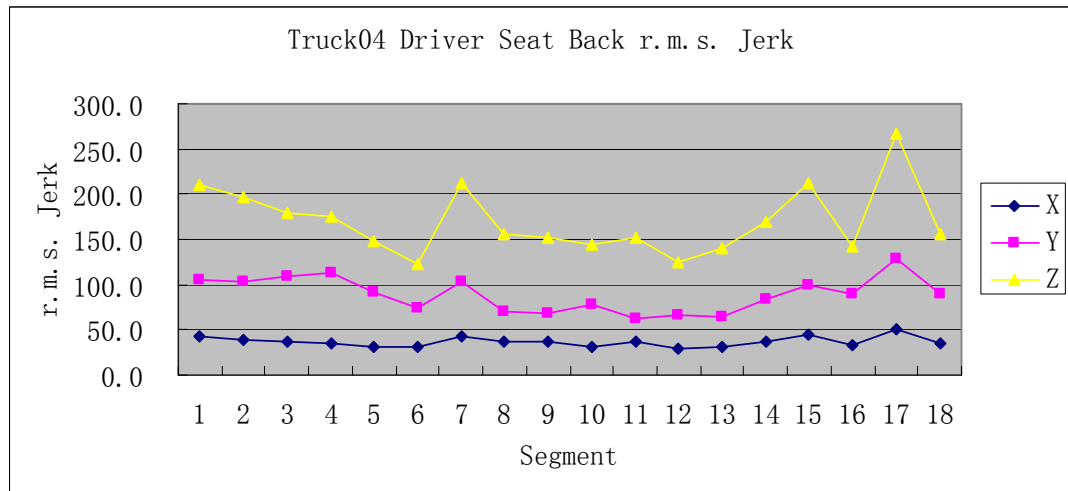


Figure A9.11: Truck04 driver seat back RMS jerk

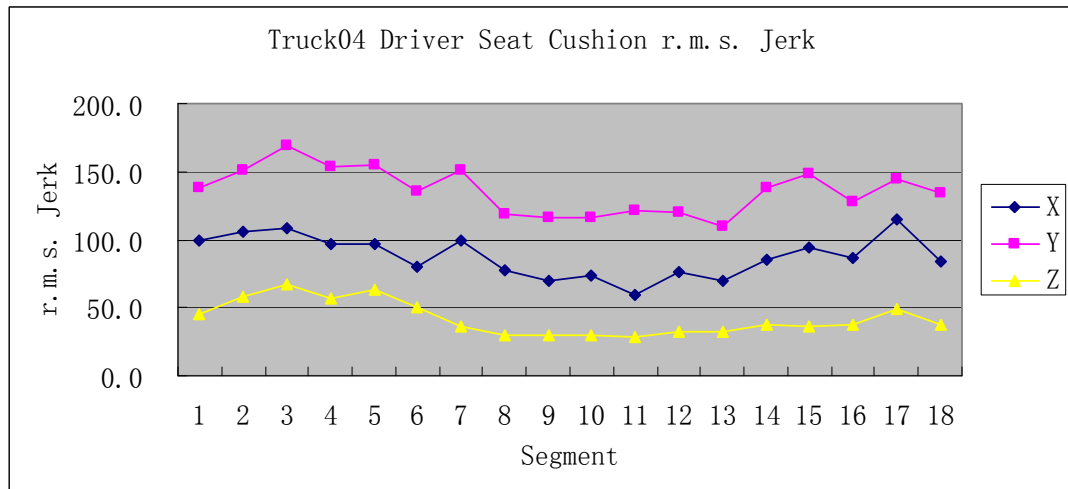


Figure A9.12: Truck04 driver seat cushion RMS jerk

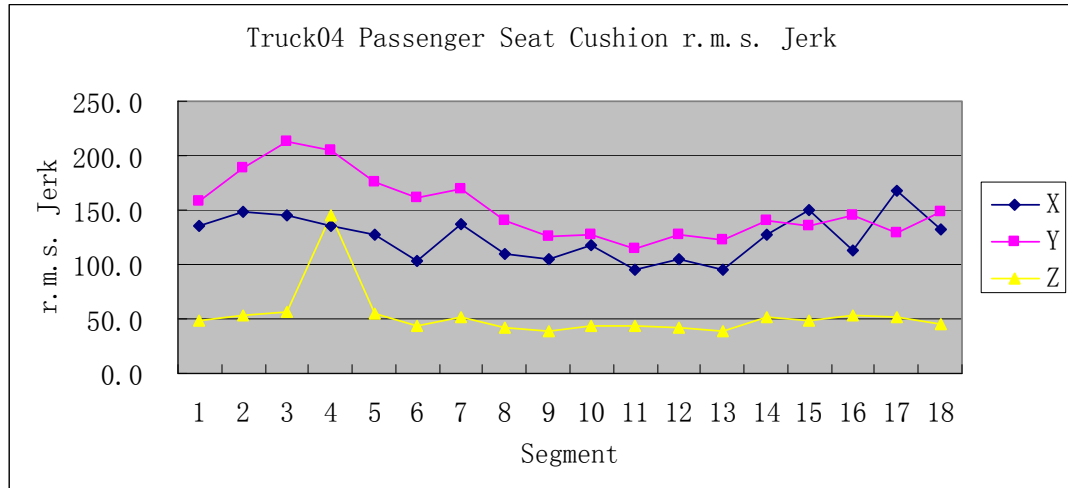


Figure A9.13: Truck04 passenger seat cushion RMS jerk

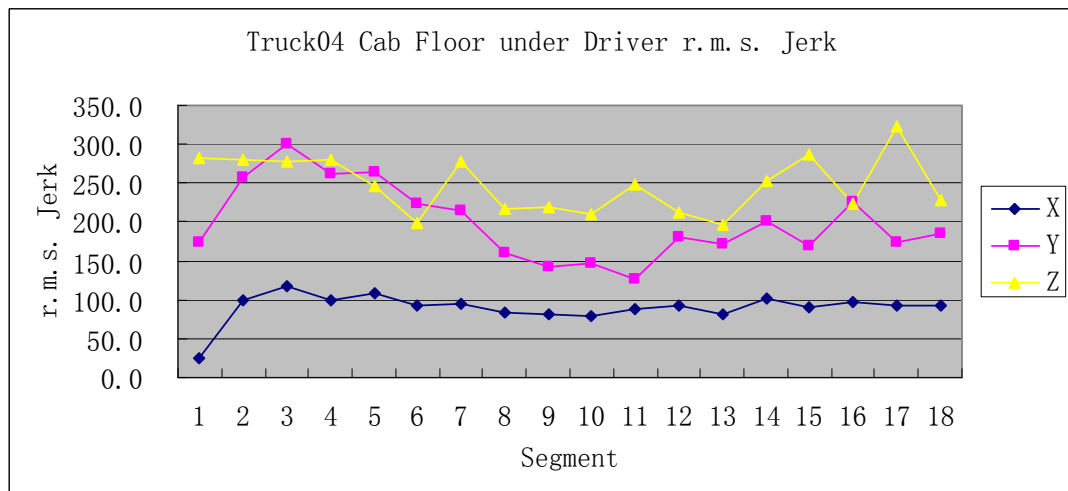


Figure A9.14: Truck04 cab floor under driver RMS jerk

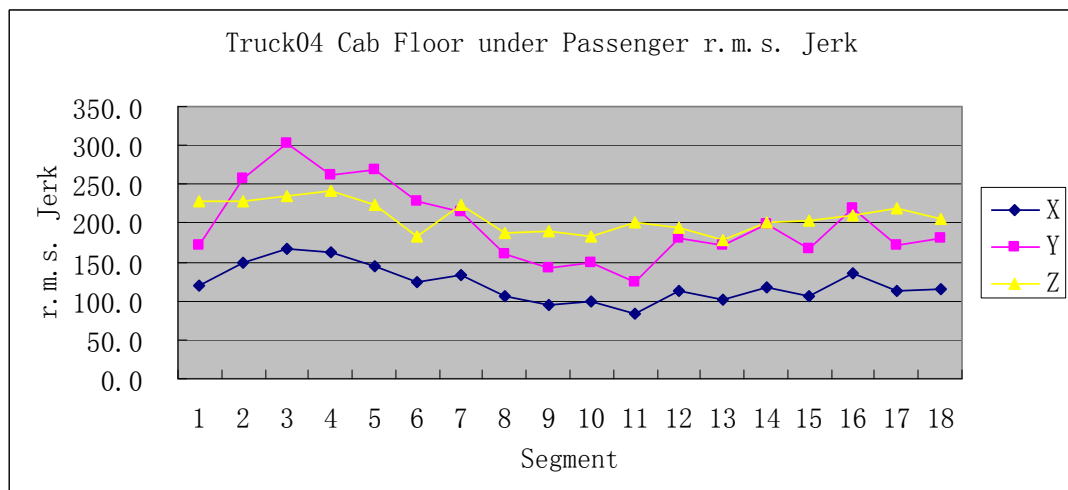


Figure A9.15: Truck04 cab floor under passenger RMS jerk

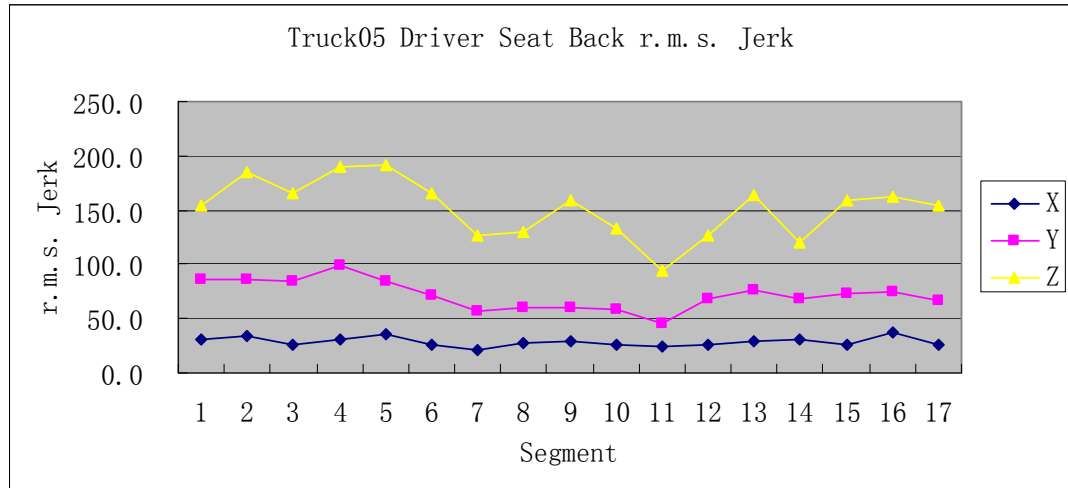


Figure A9.16: Truck05 driver seat back RMS jerk

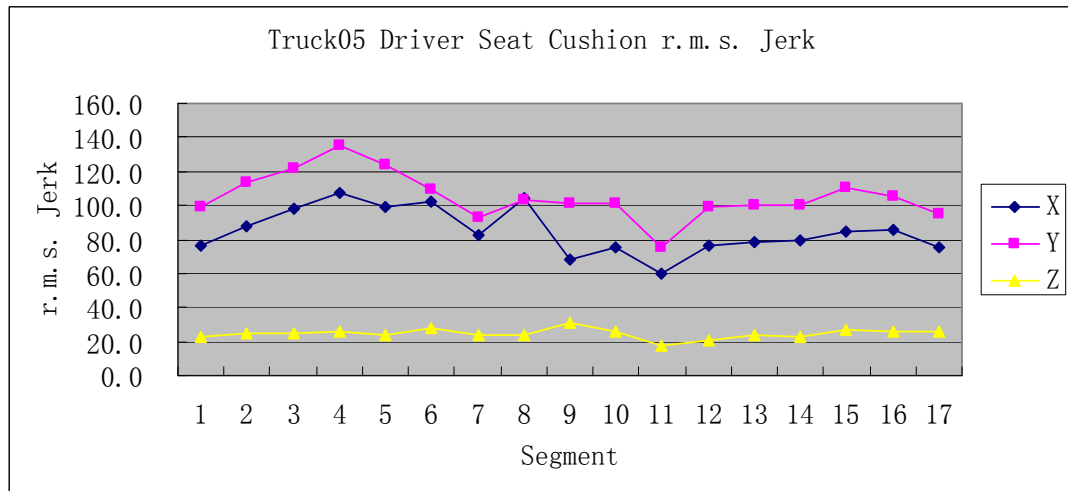


Figure A9.17: Truck05 driver seat cushion RMS jerk

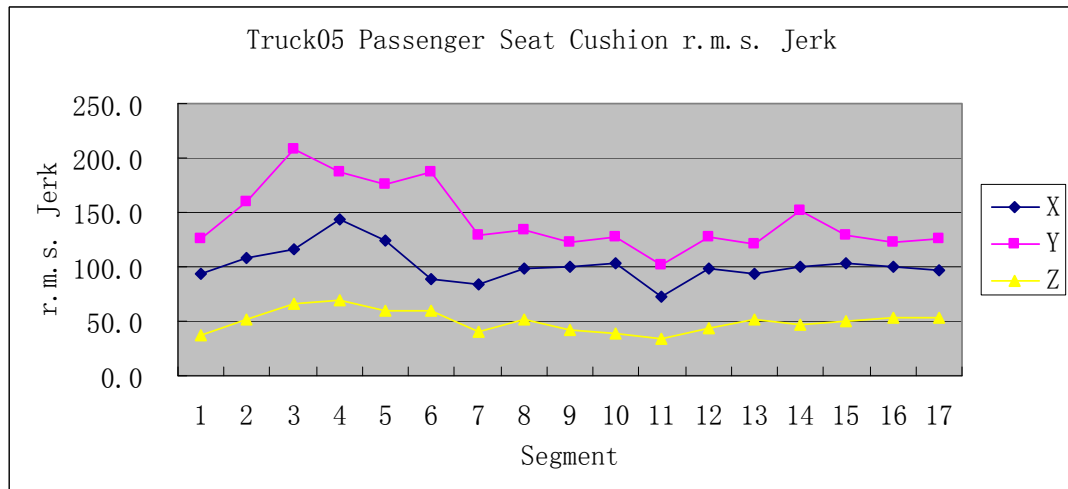


Figure A9.18: Truck05 passenger seat cushion RMS jerk

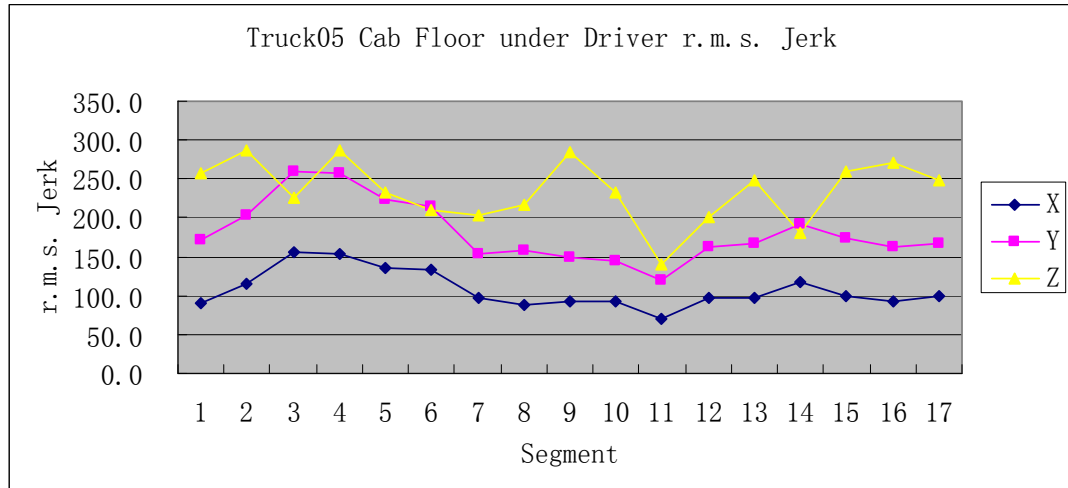


Figure A9.19: Truck05 cab floor under driver RMS jerk

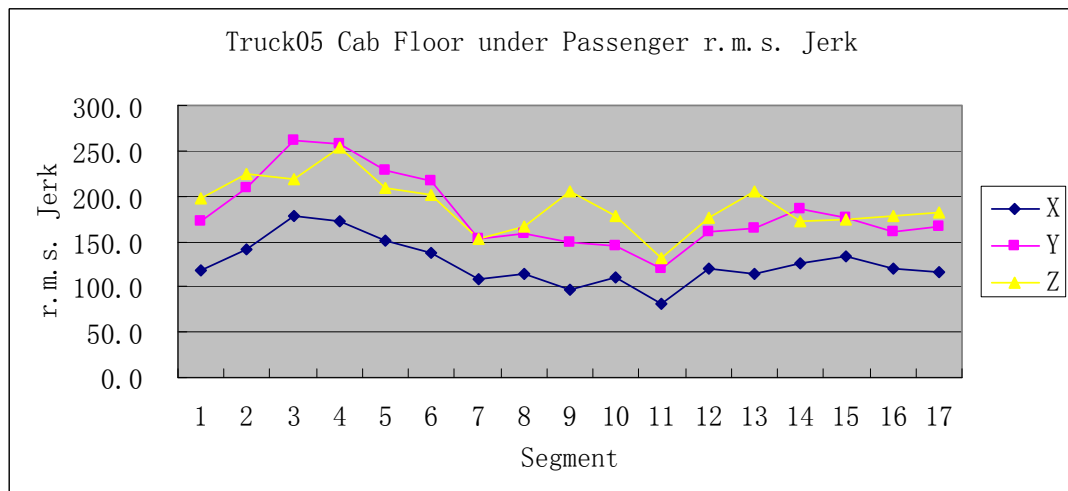


Figure A9.20: Truck05 cab floor under passenger RMS jerk

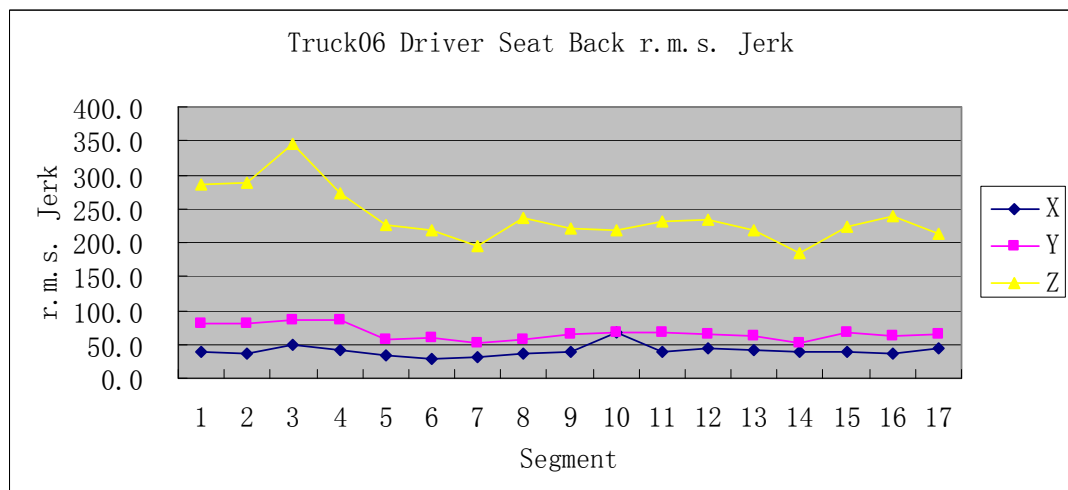


Figure A9.21: Truck06 driver seat back RMS jerk

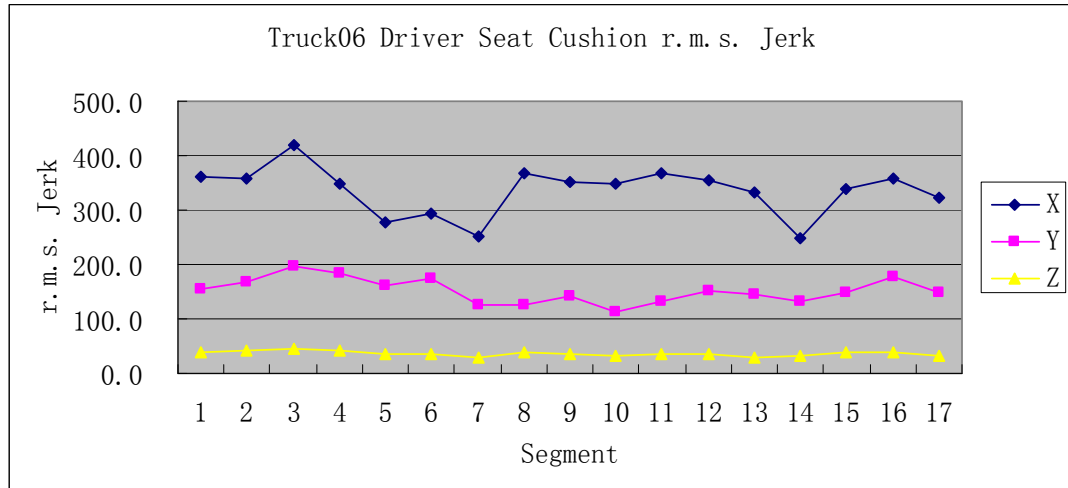


Figure A9.22: Truck06 driver seat cushion RMS jerk

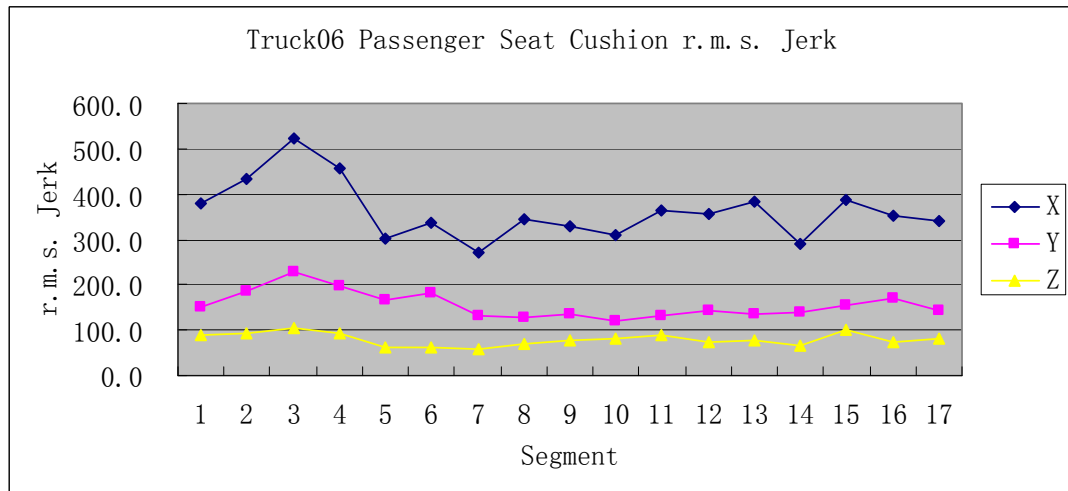


Figure A9.23: Truck06 passenger seat cushion RMS jerk

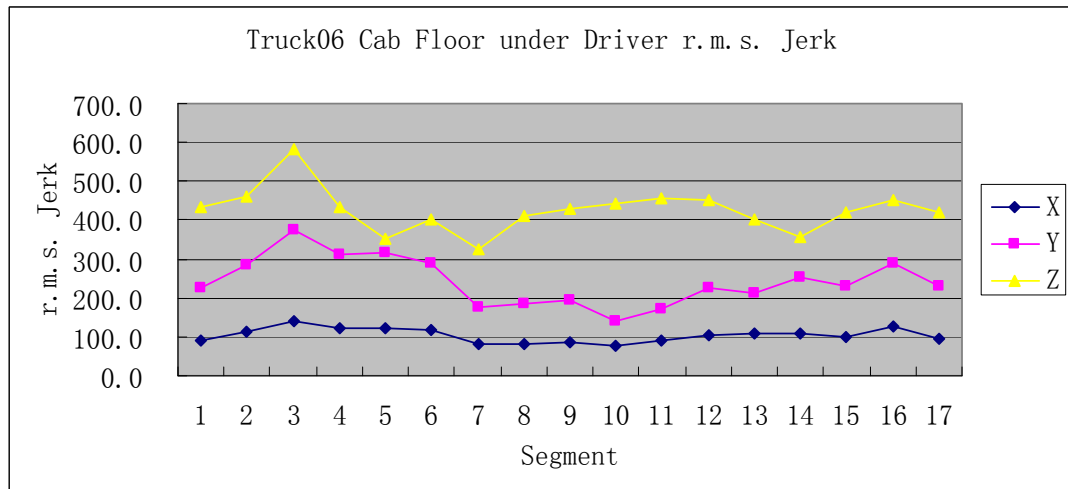


Figure A9.24: Truck06 cab floor under driver RMS jerk

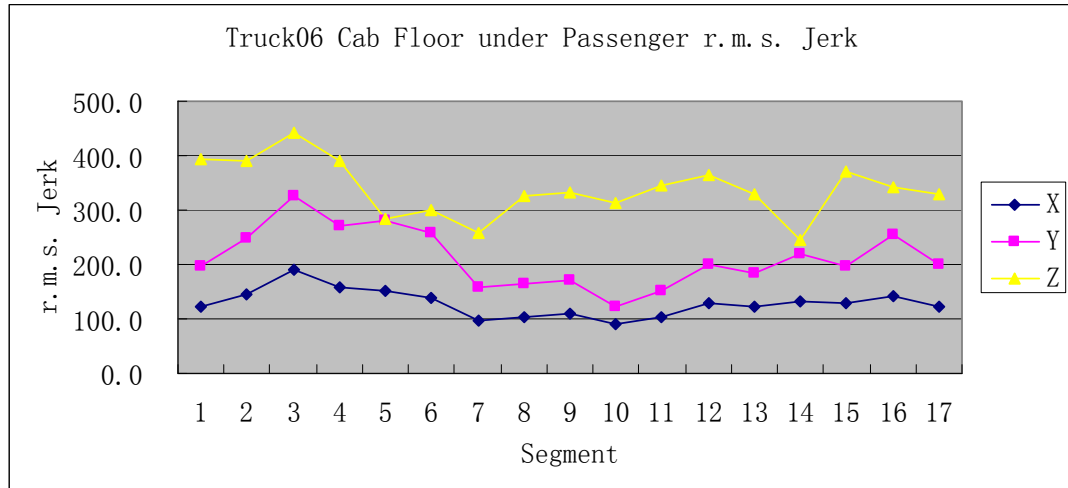


Figure A9.25: Truck06 cab floor under passenger RMS jerk

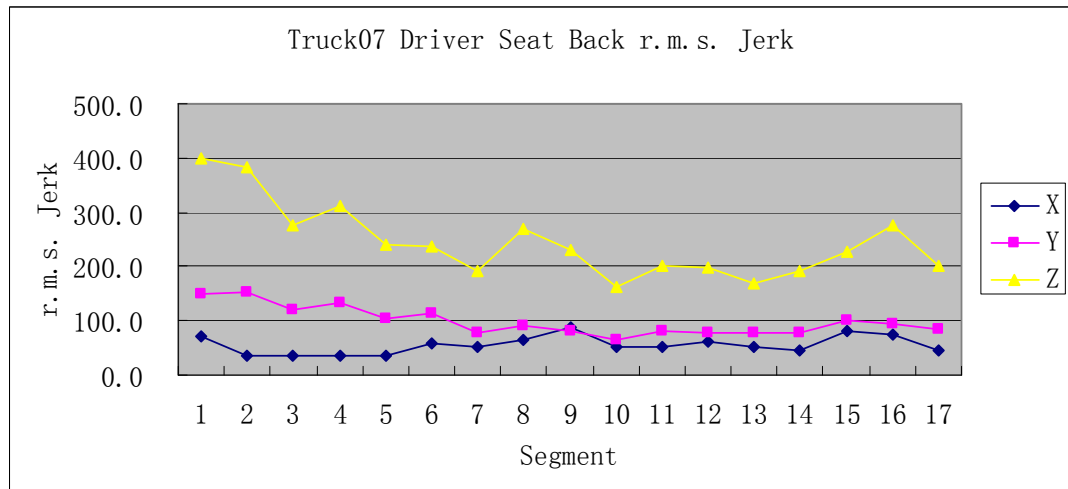


Figure A9.26: Truck07 driver seat back RMS jerk

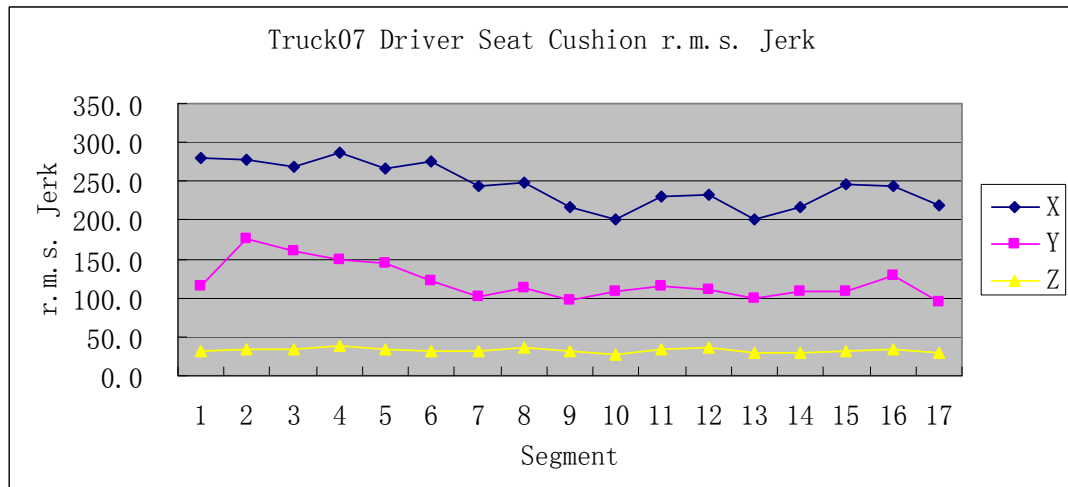


Figure A9.27: Truck07 driver seat cushion RMS jerk

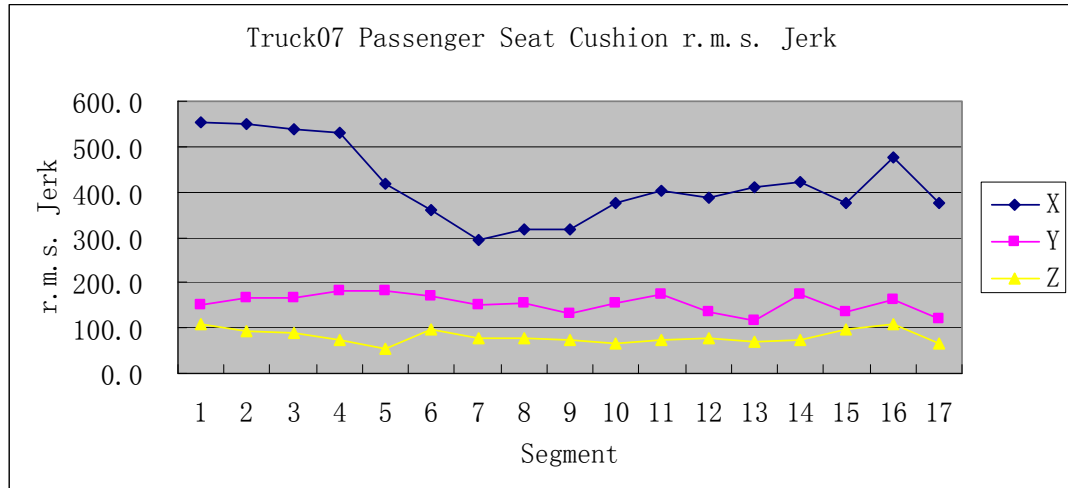


Figure A9.28: Truck07 passenger seat cushion RMS jerk

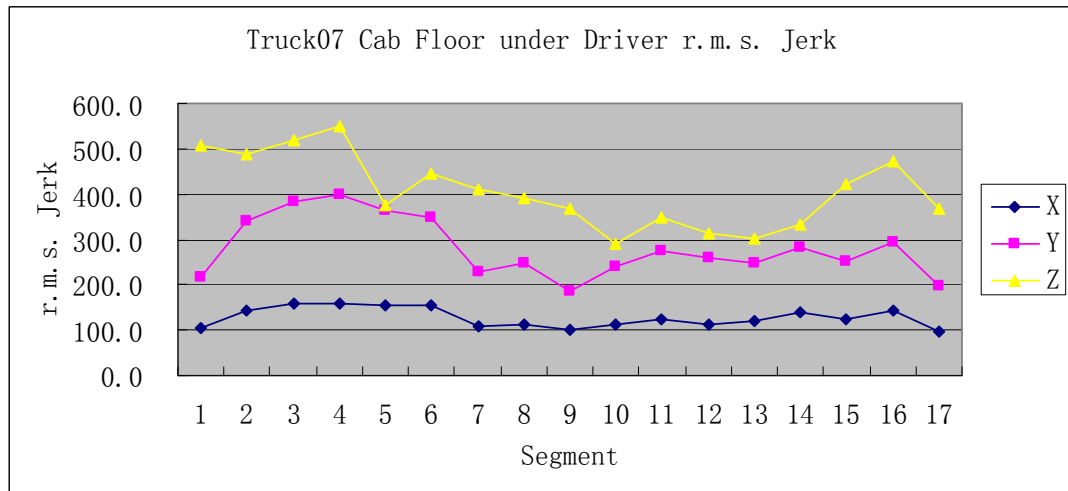


Figure A9.29: Truck07 cab floor under driver RMS jerk

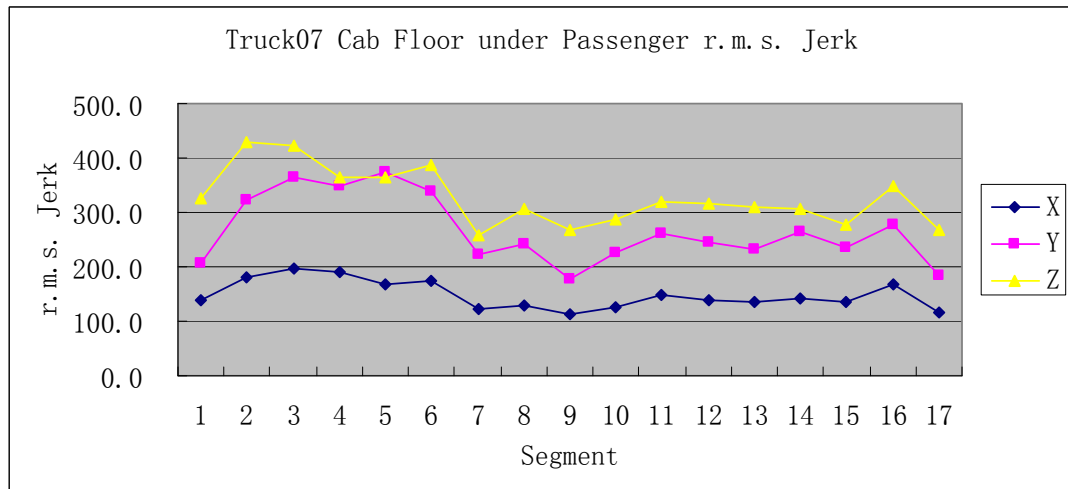


Figure A9.30: Truck07 cab floor under passenger RMS jerk

Vita

Liangming Pan was born in Zhejiang, China on April 22, 1980. He got his Undergraduate degree in Mechanical Engineering from Tongji University, China in 2002. He graduated from Tongji University, China with a Master's degree in Automotive Engineering in 2005. Then he joined the Shanghai Volkswagen Automotive Ltd. Co. as an engineer and continued to work there till attending UT in Fall 2006. He graduated from UT with a Master's degree in Biomedical Engineering in 2009.