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I am submitting herewith a thesis written by Shekhar Khanal entitled "Environmental Effects on Driver Acceleration Exposure". 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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ENVIRONMENTAL EFFECTS ON DRIVER ACCELERATION EXPOSURE

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

Shekhar Khanal
August, 2006

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DEDICATION

To my parents Hem Nath Khanal and Anuradha Khanal.

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ABSTRACT

The European Union has developed a set of standard for the exposure to whole body vibration measured by acceleration. For manufacturers to meet this directive, it is essential to understand the levels of exposures that are common among long-haul vehicle drivers.

Many factors can influence the exposure levels. Generally, all the European vehicles are the cab-over design. Each vehicle manufacturer has provided a combination of truck and cab suspensions in addition to the air-ride seating that is standard on the vehicles. The road quality, driver speeds, and time of daily work can have variation from country to country. The determination of the factors that influence the driver exposure and their level of effects are necessary.

Effect of road type, vehicle type, load, different drivers, and different environment on the whole body vibration exposure to the European truck drivers was investigated in this study. Data collected from Europe on different types of trucks were processed and analysed as per the methods set by the International standard ISO 2631-1 and the results were compared with the limits set by the directive of the European Community-2002/44/EC.

The first set of data was taken from driver's seat, passenger's seat and floor of 2 cab-over trucks (Volvo and Mercedes) in England on different roads and load conditions. A second set of data was collected from 6 different cab-over trucks (DAF, Volvo, Iveco, Mercedes, Renault and Scania) in Poland on a wider variety of roads, with the application of additional transducers on driver's & passenger's seat back as well as seat motion sensors. Further analysis on cab rotation and jerk was made.

The results were compared among different factors. Road type was the primary factor affecting the driver's exposure followed by the truck load. Choice of the proper processing equipment made some differences in the results. Discrepancies were also observed in assessing the WBV with different methods suggested in the standard.

The driver was found to be safe as per the ECE directive but the comfort levels were often exceeded. For both studies, the level of comfort was in 'fairly uncomfortable' range suggested by the ISO standard. Passenger was always exposed to higher level of vibrations. Significant amount of cab rotations and lots of jerks as well as greater levels of acceleration exposure were observed in the Poland test trucks.

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Nomenclature

m/s^2	meters per second square
Hz	Hertz (cycles/sec)
WBV	Whole Body Vibration
RMS	Root Mean Square
a_{RMS}	RMS acceleration
VDV	Vibration Dose Value
eVDV	Estimated Vibration Dose Value
FDP	Fatigue Decreased Proficiency
Dx, Dy, Dz	Driver seat acceleration along X, Y, and Z direction
Px, Py, Pz	Passenger seat acceleration along X, Y, and Z direction
Fx, Fy, Fz	Floor acceleration along X, Y, and Z direction
EAV	Exposure Action Value
ELV	Exposure Limit Value
ET	England Test Truck
PT	Poland Test Truck

Chapter-1 INTRODUCTION

Vibration is known as a physical occupational hygiene hazards in the workplace. There are two main types of vibrations related to human health: **Hand-Arm Vibration** (usually associated with the use of vibrating hand tools), and **Whole-Body Vibration** (usually associated with vehicles).

Whole-Body Vibration (WBV) has been found to be a significant factor of injury among the operators of trucks, buses, tractors, locomotives, subway, bulldozers, cranes, forklifts, helicopters, heavy equipments, farm vehicles, and other vibrating machineries. Low back pain is the most common and serious chronic effect of WBV. This is the primary reason for drivers reporting in sick and for early disability retirement.

In addition to health, comfort for the drivers will result in a better performance. It is important that the seat designed for each truck, coupled with the truck and cab suspensions, result in meeting the standards and the driver comfort. Although the designs may be adequate 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. Each environment can have differences in the amount of time the vehicle is being driven per day, the quality of the road structure being used, the size of the vehicles and the amount of weight that can be carried. [32]

This thesis is primarily about evaluation of vibration of truck drivers in Europe. There are several factors that affect the injury and comfort of the drivers. In the present study, the effect of road type, vehicle type, load, different drivers, and different environment on the WBV exposure to the truck drivers is being investigated. WBV exposure in passengers have also been evaluated and compared with the drivers.

This project is in fact a part of a larger project on design and optimization of truck seats. The main project also contains modelling of seat and spine with ADAMS. The goal of this project is to guide truck manufacturers to build seats providing optimal comfort and protection to the drivers.

Different trucks have different exposures based on design as well as the environment. European trucks are quite different from the American ones. Trucks in Europe are dominantly cab-over, which are subjected to more vibration because of the fact that the engine is directly below the seat. We are concerned with the rotation as well as translation along all three directions (X, Y&Z axes) to better understand how a driver feels when the seat is rocking.

Two sets of data were collected for this study-one from England and other from Poland. Different types of trucks were tested on different kinds of roads. The data was processed with different processors and analysed as per ISO 2361-1, ECE directive 2002/44/EC.

Chapter-2 BACKGROUND

2.1 Whole Body Vibration and its Effects

Whole-Body Vibration is experienced when the operator or driver sits on a vibrating surface, usually a vehicle or standing on a vibrating floor. It is transmitted via the feet, buttocks or supporting areas. It can be experienced either through an instantaneous shock with a high peak level or through repeated exposure to low peaks. WBV affects the entire body.

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 lumbar 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.

The most common effect of WBV is low back pain. Short term effects include headache, blurred vision, chest pain, abdominal pain, nausea and loss of balance. Chronic exposures may irritate spinal tissues, degenerate the intervertebral discs, cause lumbar scoliosis and disorders of the gastrointestinal system. Other 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. Long-term WBV exposure may lead to disorders in the digestive system as well as cardiovascular system and can probably contribute to the pathogenesis of disorders of female reproductive organs and disturbances of pregnancy. Animal experiments suggest harmful effects on the fetus. [29]

Muscle fatigue also occurs as the muscles try to react to the vibrational energy to maintain balance and protect and support the spinal column, but these are often too slow as the muscular and nervous system cannot react fast enough to the shocks and loads being applied to the body.

The immediate treatment for any WBV exposure is to stop the exposure. Persons chronically exposed to WBV should be periodically evaluated to check if changes in exposure or health status have occurred. To compensate for the discomfort from vibration, drivers could change their position correctly.

Tilting back of the seat at 110º from the leg reduces disc pressure. By properly adjusting seat and steering wheel (so that the driver can press the pedals without moving his low back forward off the back of the seat), using a lumbar support, adding extra padding over

the seat, taking regular breaks, avoiding lifting immediately after driving, and avoiding being overweight are some of the tips to avoid health hazards of driving. [Website 2]

While being exposed to vibration, human body reflexes try to protect organs that are sensitive to resonance through a tightening of the muscles. Lengthy exposure to vibration often results in high muscular tonicity which is dangerous to health on many accounts. It would be desirable if the vibrations could be totally eliminated, but on the other hand, reducing vibrations at the floor, may suppress vibrations that are positive -vibrations that inform drivers about the movement of their vehicle e.g. driving over zebra crossing, feel of puncture on the wheel. [1]

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

In a survey done by the CVG (Commercial Vehicle Group) at 2005 Mid-America Trucking Show, Kentucky Fair & Exposition Center, it was found that maximum number (265) had lower back problem followed by neck problems (132), high blood pressure (96), shoulder (76), upper back (56), elbow (46), diabetes (42), carpal tunnel (31), hemorrhoids (26) and lastly blood in urine (10). Figure 1 shows the distribution of the ailments against different trucks.

While driving, 108 reported stiffness, 80 soreness, 64 pain (shoulder, knee back, elbow, abdomen, chest and legs) 63 numbness and 40 routine drowsiness. There were 509 drivers participated, 448 males and 43 females (rest kept their gender secret!), average age being 43, average height 5’10” and weight 217 lbs. 202 were company driver and 269 independent (owner/operator).

Whole-body vibration has many more widespread and varied effects and these effects are not particularly clear, as the body does not have one receptor for this energy. Figure 2 shows the various effects of WBV.

In addition to health, comfort for the drivers is also of great concern as it could result in better performance. The discomfort produced by the whole-body vibration depends on various factors like magnitude, frequency, input position, direction & duration of vibration as well as physical characteristics (weight, age, gender, transmissibility etc), posture and orientation of the body, and the seat design. At low frequencies (below 1 or 2 Hz) the body responds as a virtually rigid system and discomfort tends to be proportional to acceleration but at slightly higher frequencies, various body resonances tend to amplify the motion and overall discomfort is influenced by sensations in different parts of the body. At high frequencies, small postural changes can greatly reduce the vibration to the body whereas at low frequencies, posture has less effect. [10]

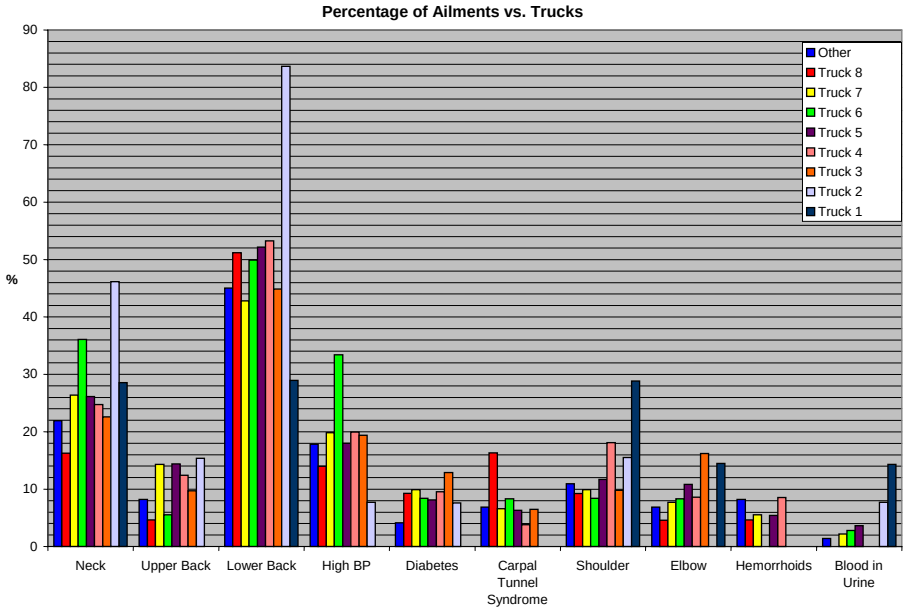


Figure 1 Trucker's Survey result

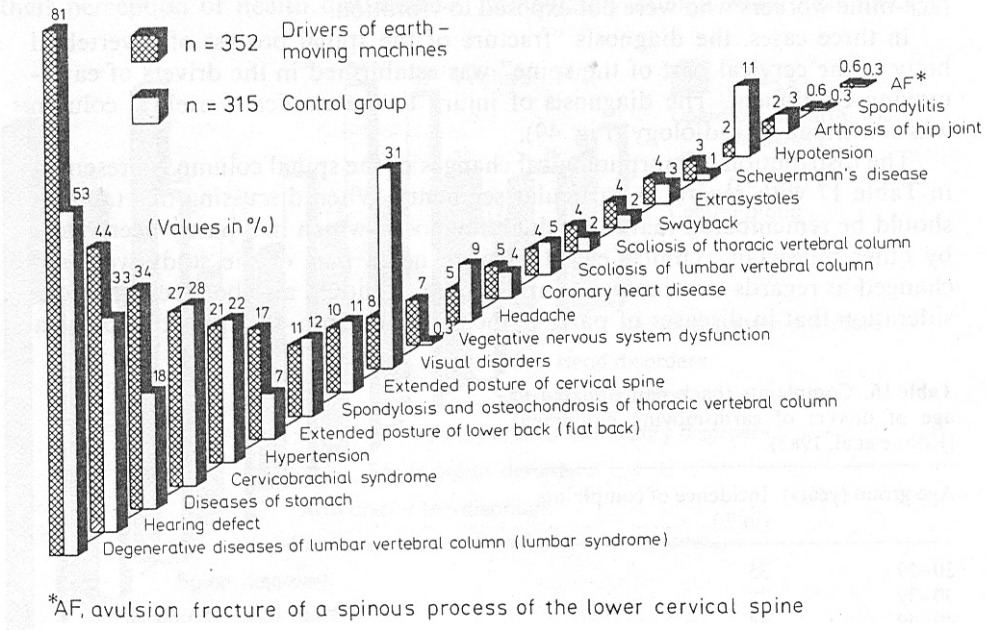


Figure 2 Various Effects of WBV [33]

Table 1: Comfort Reactions to Vibration Environments, ISO 2631-1, 1997

Vibration Level	Passenger Perception
Less than 0.315 m/s^2	Not uncomfortable
0.315 to 0.63 m/s^2	a little uncomfortable
0.500 to 1.00 m/s^2	fairly uncomfortable
0.800 to 1.6 m/s^2	Uncomfortable
1.25 to 2.5 m/s^2	very uncomfortable
Greater than 2 m/s^2	extremely uncomfortable

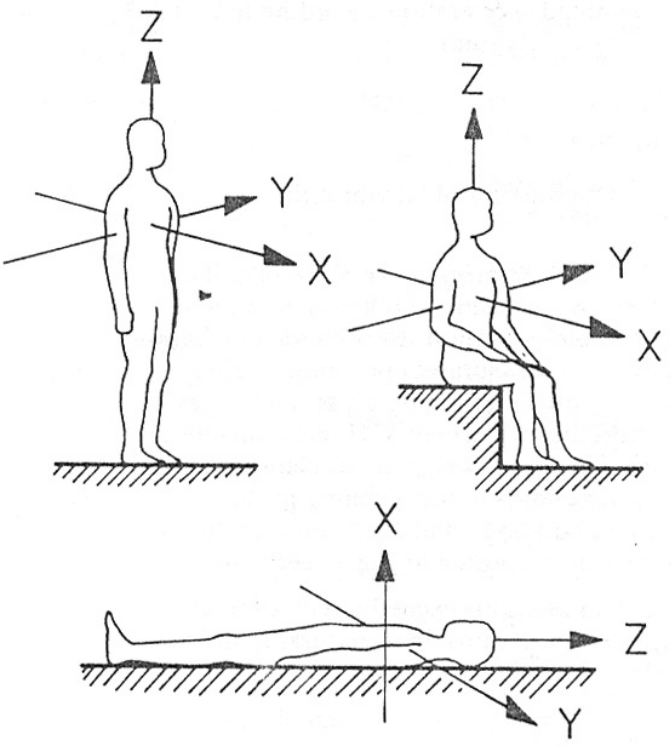
The seat provided for each truck should meet the standards for health as well as comfort. Table 1 shows the passenger perception of the comfort reactions set by the standard ISO 2631-1.

2.2 Vibration Measurement

The primary quantity of vibration magnitude is acceleration. It should be measured according to a coordinate system originating at a point from which vibration is considered to enter the human body. Transducers located at one measurement location should be positioned orthogonally, with X forward to back, Y side by side and Z in the vertical direction (Figure 3), as defined by the ISO 2631. [13]

Transducers should be located so as to indicate the vibration at the interface between the human body and the source of its vibration.

The duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed.



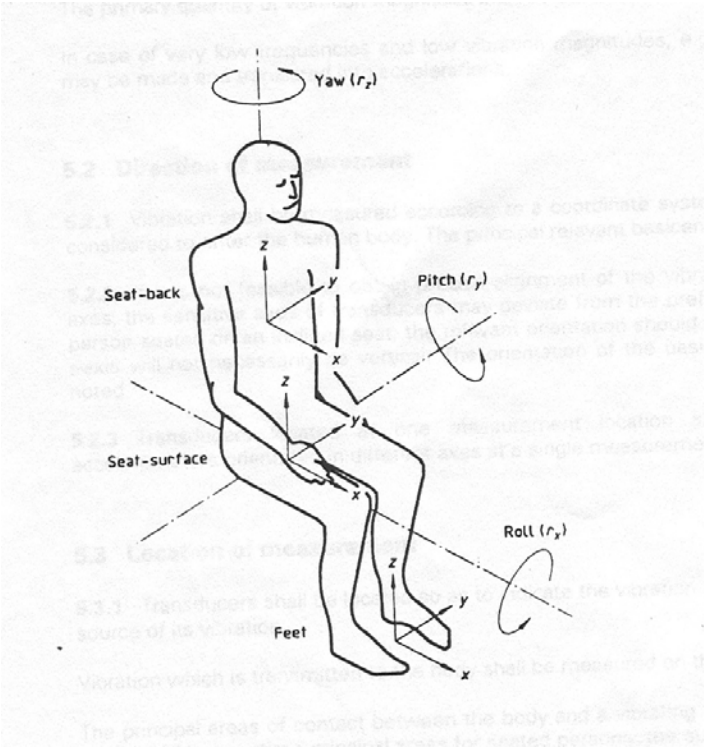


Figure 3 Transducer Orientation

2.3 Frequency Weighting

The human body reacts to different frequencies in different ways. The manner in which vibration affects health, comfort, perception and motion sickness is dependent on the vibration frequency content. The effect of the frequency is reflected in the frequency weightings. More weight is applied to the frequencies to which the body is more sensitive. In other words, the frequency-weightings mimic the human sensitivity to vibration of different frequencies. Also, different frequency weightings are required for different axes of the body. Tables 2 and 3 show which frequency weighting is applied to which direction for health, comfort, perception as well as motion sickness.

The weighting factors used can be visualized by the Figure 4. For vertical direction, the acceleration weighting W_k has greatest sensitivity in the range 4-13 Hz, whereas for horizontal direction (X and Y-axes), the acceleration weighting W_d has the greatest sensitivity in the range 0.5-2 Hz. The frequency-weighted acceleration is multiplied by the weighting factor before its effect is assessed.

$$a_w = \sqrt{\sum (w_i a_i)^2}$$

where,
a_w is the frequency-weighted acceleration,
w_i is the weighting factor for the i^{th} one-third octave band,
a_i is the weighted RMS acceleration for the i^{th} octave band.

2.4 Evaluation of WBV

Following are the methods specified in the International Standard ISO 2631-1 to quantitatively measure the whole body vibration exposure.

2.4.1 Weighted root-mean-square acceleration

$$a_W = \left[\frac{1}{T} \int_0^T a_W^2 (t)\, dt \right]^{1/2}$$

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

The Crest Factor, defined as the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration to its RMS value determines if the data recorded for the time can be considered valid to predict safety. It states that the highest peak cannot exceed the RMS value by 9.

Table 2 Guide for the Application of Frequency-Weighting Curves for Principal Weightings, ISO 2631 - 1:

Frequency Weighting	Health	Comfort	Perception	Motion Sickness
W_k	*z*-axis, seat surface	*z*-axis, seat surface *z*-axis, standing vertical recumbent (except head) *x*-, *y*-, *z*-axes, feet (sitting)	*z*-axis, seat surface *z*-axis, standing vertical recumbent	-
W_d	*x*-axis, seat surface *y*-axis, seat surface	*x*-axis, seat surface *y*-axis, seat surface *x*- *y*-axes, standing horizontal recumbent *y*-, *z*-axes, seat back	*x*-axis, seat surface *y*-axis, seat surface *x*-, *y*-axes, standing horizontal recumbent -	-
W_f	-	-	-	vertical

Table 3 Guide for the Application of Frequency-Weighting Curves for Additional Weighting Factors, ISO 2631 - 1: 1997

Frequency Weighting	Health	Comfort	Perception	Motion Sickness
W_c	*x*-axis, seat back	*x*-axis, seat back	*x*-axis, seat back	-
W_e	-	r_x-,r_y-r_z-axes, seat surface	r_x-,r_y-r_z-axes, seat surface	-
W_j	-	vertical recumbent (head)	vertical recumbent	-

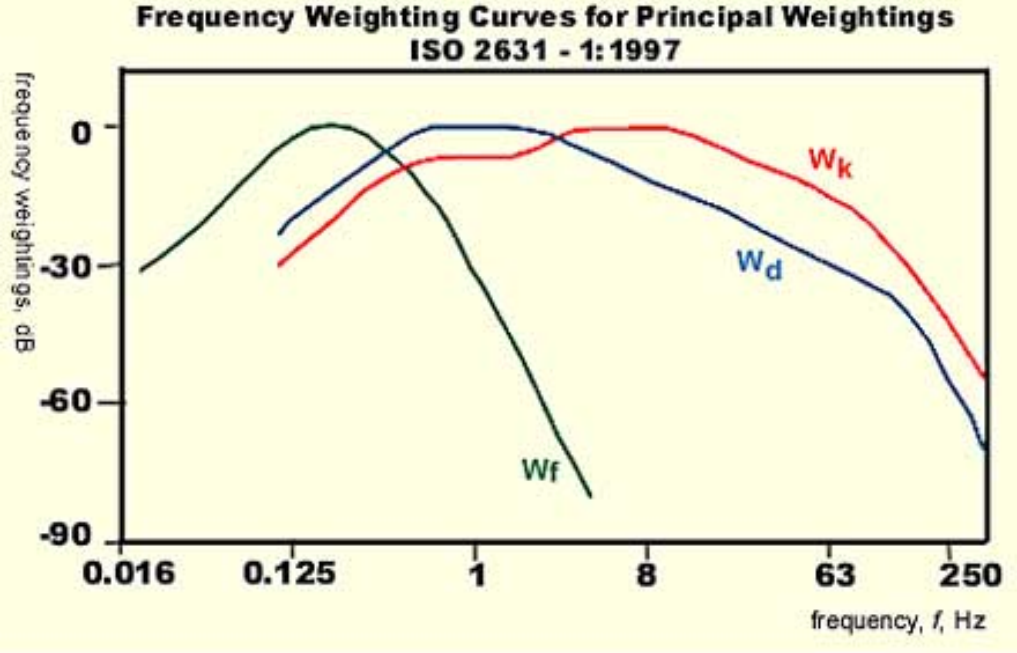


Figure 4 Frequency Weighting Curves
*****Source: Website [6]

2.4.2 Running r.m.s. method

This method takes into account occasional shocks and transient vibration by using a short integration time constant. The vibration magnitude is defined as a maximum transient vibration value (MTVV) given as the maximum in time.

$$a_w(t_0) = \left\{ \frac{1}{\tau} \int_{t_0-\tau}^{t_0} \left[a_W(\tau) \right]^2 dt \right\}^{1/2}$$

where

$a_w(t)$ is the instantaneous frequency-weighted acceleration

τ is the integration time for the running average

t is the time (integration variable)

t_0 is the time of observation (instantaneous time)

$$MTVV = \max\left[a_W(t_0) \right]$$

2.4.3 The fourth power vibration dose method

Here, the fourth power of acceleration is used as the basis for averaging.

$$VDV = \left\{ \int_0^T \left[a_W(t) \right]^4 dt \right\}^{1/4}$$

where

$a_W(t)$ is the instantaneous frequency-weighted acceleration;

T is the duration of measurement;

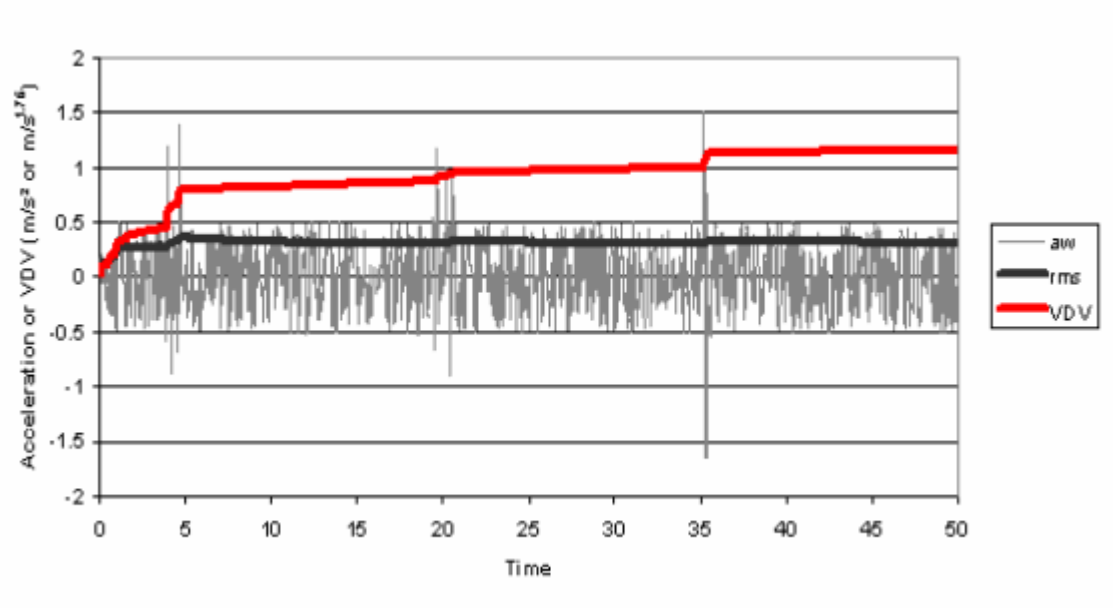
$$VDV_{total} = \left(\sum_i VDV_i^4 \right)^{1/4}$$

Further, the following ratios are used for comparison of basic and additional methods of

$$\frac{MTW}{a_W} = 1.5$$

$$\frac{VDV}{a_W T^{1/4}} = 1.75$$

This method is sensitive to individual high acceleration events and produces a cumulative dose over a (working) day. The graph in Figure 5 illustrates how the VDV responds more readily to shock than RMS.



.

Figure 5 VDV vs. RMS acceleration
*Source: website [9]

2.4.4 Combining vibrations in more than one direction

The vibration total value of weighted RMS acceleration, determined from vibration in orthogonal coordinates is calculated as-

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

where,
a_{wx}, a_{wy} and a_{wz} are the weighted RMS accelerations with respect to the orthogonal axes X,Y and Z respectively.

k_x, k_y and k_z are multiplying factors.

For health,	For comfort,
$k_x = k_y = 1.4$, $k_z = 1.0$	$k_x = k_y = k_z = 1.0$

2.5 Octave Band Analysis

The pitch perception of the ear is proportional to the logarithm of frequency rather than to frequency itself. Therefore the frequency axis of acoustic spectra is expressed on a logarithmic frequency axis.

Octave band, where the upper frequency is twice that of the lower, has been defined as a standard for acoustic analysis. Each band is denoted by its centre frequency and each octave band has a bandwidth equal to about 70% of it center frequency.

If we need to have more detailed information than the octave band analysis, we can select narrower bands, the most common being **one-third octave bands** whose filter bandwidths are about 27 % of their center frequencies. Table 4 shows the comparison between 1-octave and 1/3rd -octave bands.

If f_n is the lower cutoff frequency and f_{n+1} is the upper cutoff frequency, the ratio of band limits is given by:

$$\frac{f_{n+1}}{f_n} = 2^k$$

Where, $k = 1$ for full octave bands and $k = 1/3$ for one-third octave bands. An octave has a centre frequency that is √2 times the lower cutoff frequency and has an upper cutoff frequency that is twice the lower cutoff frequency.

$Bandwidth = f_{n+1} - f_n$

Table 4 octave band frequencies: Comparison of 1 and 1/3rd –octave bands

TABLE 4.

Comparison of 1-octave and ⅓-octave bands

1 Octave			⅓ Octave		
Lower cutoff frequency (Hz)	*Center frequency (Hz)*	*Upper cutoff frequency (Hz)*	*Lower cutoff frequency (Hz)*	*Center frequency (Hz)*	*Upper cutoff frequency (Hz)*
11	16	22	14.1	16	17.8
			17.8	20	22.4
			22.4	25	28.2
22	31.5	44	28.2	31.5	35.5
			35.5	40	44.7
			44.7	50	56.2
44	63	88	56.2	63	70.8
			70.8	80	89.1
			89.1	100	112
88	125	177	112	125	141
			141	160	178
			178	200	224
177	250	355	224	250	282
			282	315	355
			355	400	447
355	500	710	447	500	562
			562	630	708
			708	800	891
710	1,000	1,420	891	1,000	1,122
			1,122	1,250	1,413
			1,413	1,600	1,778
1,420	2,000	2,840	1,778	2,000	2,239
			2,239	2,500	2,818
			2,818	3,150	3,548
2,840	4,000	5,680	3,548	4,000	4,467
			4,467	5,000	5,623
			5,623	6,300	7,079
5,680	8,000	11,360	7,079	8,000	8,913
			8,913	10,000	11,220
			11,220	12,220	14,130
11,360	16,000	22,720	14,130	16,000	17,780
			17,780	20,000	22,390

*Source: Website [7]

2.6 WBV Standards

2.6.1 ISO 2631-1

ISO (the International Organization for Standardization) *2631* was first published in 1974 and republished in 1985 with a revised title "*Evaluation of human exposure to whole body vibration*". It was based on weighted RMS acceleration and two frequency weightings defined from 1-80Hz by straight lines on a logarithmic graph of acceleration versus frequency and a time dependency from 1 min to 24 hr. It differs for the three vibration axes, as the critical frequencies with respect to health are different for the vertical (4-8Hz) and two horizontal (1-2 Hz) axes. Each axis is compared individually to its respective standard. Alternatively, it suggests averaging the three axes after calculating RMS values to create the vector sum, which could then be directly compared to ISO standard for Z-axis.

The ISO 2631 provides three exposure standards: the level at which fatigue decreases proficiency (FDP), the exposure level, and the "reduced-comfort boundary" in the fore-aft, lateral and vertical axes of standing, sitting and recumbent persons. The 8-hr FDP for the Z-axis at 4-8 Hz is 0.315m/s^2.

New ISO was published in 1997 with more general title "*Mechanical Vibration and Shock-Evaluation of human exposure to whole body vibration*". It incorporates new experience and research results from literature. It specifies direction and location of measurements, equipments to be used, duration of measurements, frequency weighting, methods of assessment of measurements and evaluation of weighted root-mean-square acceleration. The frequency range is extended below 1 Hz and evaluation is based on frequency weighting of the RMS acceleration rather than the rating method. Different frequency weightings are given for the evaluation of different effects.

RMS acceleration methods continue to be the basis for measurement for crest factors less than 9 and alternative methods are presented for vibration with high peaks beyond that. It defines a health caution zone as can be seen in Figure 6.

ISO 2631-1(1997) consists of two parts:

- General requirements
- Continuous and shock-induced vibration in buildings

The first part is concerned with WBV and excludes hazardous effects of vibration transmitted directly to the limbs. It defines methods of quantifying WBV in relation to human health and comfort, the probability of vibration perception, and the incidence of motion sickness.

Testing/Evaluation methods have been defined which may be used as the basis for limits. The degree to which a vibration exposure will be acceptable is given as-

- 0.5 to 80 Hz for health, comfort and perception, and
- 0 .1 to 0.5 Hz for motion sickness

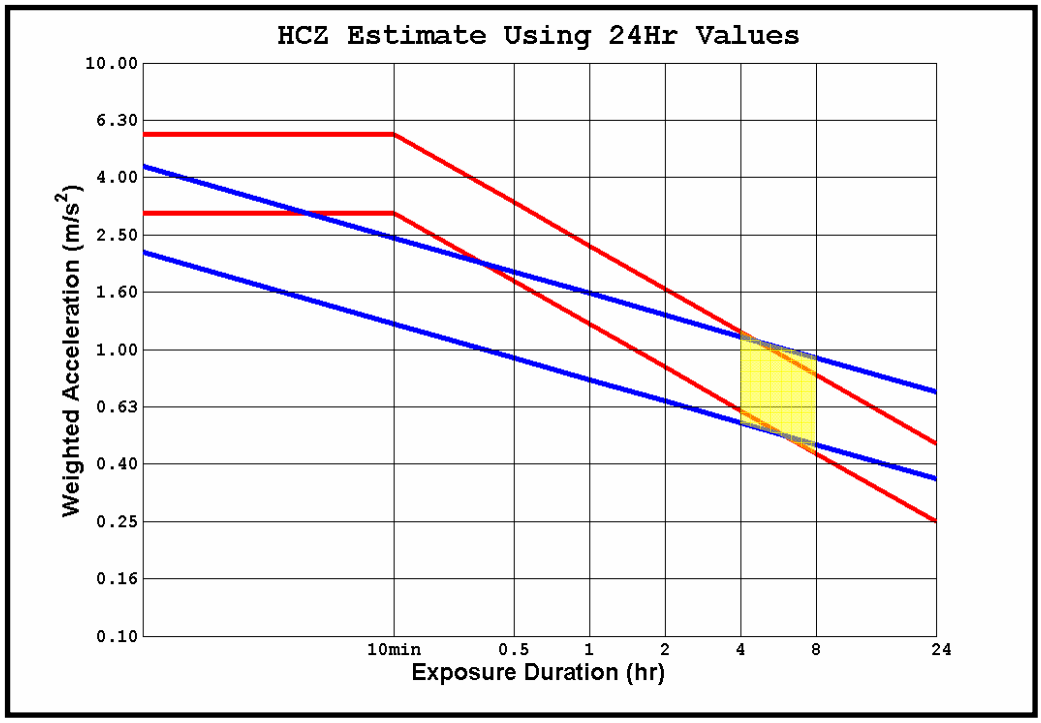


Figure 6 Health Caution Zone

Following Normative references are given:

- ISO 2041:1990 Vibration and Shock – Vocabulary
- ISO 5805:1997 Mechanical vibration and shock
- ISO 8041: 1990 Human response to vibration

2.6.2 BS 6841(1987)

(*Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*)

British Standard states that the primary quantity for expressing vibration magnitude is the weighted a_{RMS}. However, it recommends the use of vibration dose value procedure when either the crest factors exceed 6.0, or the vibration has variable magnitude, or the motion contains occasional peaks, or the motion is intermittent. This method more heavily weights higher acceleration levels which are considered to have greater effect on health.

The VDV may be calculated using the above mentioned formula (averaging after raising the acceleration to the fourth power), or alternatively, from the a_{RMS} using the 'estimated vibration dose value' eVDV (for crest factors below 6.0):

$$eVDV = \sqrt[1/4]{(1.4 * a_{RMS})^4 * t}$$

Table 5: Comfort Reactions to Vibration Environments, BS 6841

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

(Source: Griffin, 1990)

The eVDV will underestimate the true VDV where shocks and jolts occur.
For higher crest factors, the VDV is estimated directly from the frequency weighted Acceleration time history. This standard states that VDVs in the region of $15m/s^{1.75}$ will usually cause severe discomfort and this is considered as an action level.
Intermittent vibration is evaluated by using the fourth root of the sums of the fourth powers of the vibration dose values determined during each period.

Table 5 shows the semantic labels for the comfort according to this standard.

2.6.3 ANSI and ACGIH

These are the WBV guidelines currently being used in the USA. The ISO 2631 guidelines have not yet been accepted legally to be used in the USA. Instead, ISO 2631 has been modified to form ANSI standard. ANSI S 3.18 is based on ISO 2631(85) and ANSI 2000 is based on the latter version of ISO 2631.

Figures 7 and 8 explain these standards. A set of parallel U shaped curves in Figure 7 shows the acceleration limits as a function of frequency and daily worker exposure time for the vertical (Z) axis. This information is tabulated in Table 6.Similar curve for horizontal axes are given in Figure 8.

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.

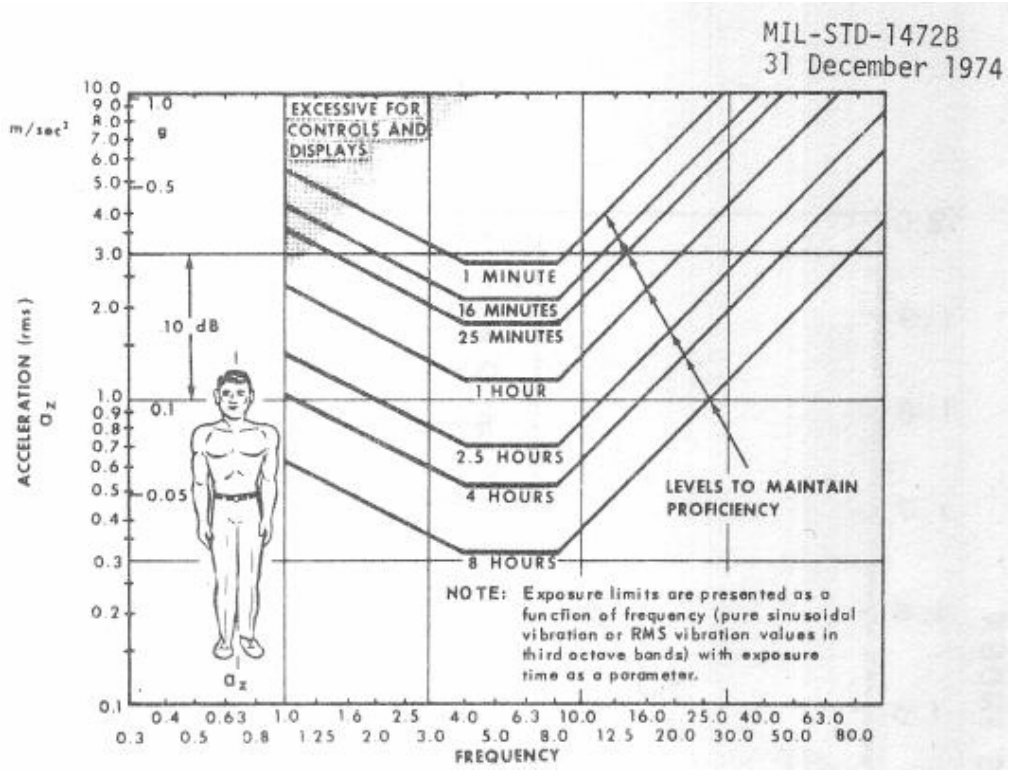


Figure 7 FDP boundary-Z axis

Table 6: FDP boundary-Z axis, ISO 1985

Acceleration (rms) m/s^2 Fatigue-decreased Proficiency Boundary (Z-Direction)									
Freq	**24**	**16**	**8**	**4**	**2.5**	**1**	**25**	**16**	**1**
1	0.280	0.425	0.630	1.060	1.400	2.360	3.550	4.250	5.600
1.25	0.250	0.375	0.560	0.950	1.260	2.120	3.150	3.750	5.000
1.6	**0.224**	**0.335**	**0.500**	**0.850**	**1.120**	**1.900**	**2.800**	**3.350**	**4.500**
2	0.200	0.300	0.450	0.750	1.000	1.700	2.500	3.000	4.000
2.5	0.180	0.265	0.400	0.670	0.900	1.500	2.240	2.650	3.550
3.15	0.160	0.235	0.355	0.600	0.800	1.320	2.000	2.350	3.150
4	0.140	0.212	0.315	0.530	0.710	1.180	1.800	2.120	2.800
5	0.140	0.212	0.315	0.530	0.710	1.180	1.800	2.120	2.800
6.3	0.140	0.212	0.315	0.530	0.710	1.180	1.800	2.120	2.800
8	0.140	0.212	0.315	0.530	0.710	1.180	1.800	2.120	2.800
10	0.180	0.265	0.400	0.670	0.900	1.500	2.240	2.650	3.550
12.5	0.224	0.335	0.500	0.850	1.120	1.900	2.800	3.350	4.500
16	0.280	0.425	0.630	1.060	1.400	2.360	3.550	4.250	5.600
20	0.355	0.530	0.800	1.320	1.800	3.000	4.500	5.300	7.100
25	0.450	0.670	1.000	1.700	2.240	3.750	5.600	6.700	9.000
31.5	0.560	0.850	1.250	2.120	2.800	4.750	7.100	8.500	11.200
40	0.710	1.060	1.600	2.650	3.550	6.000	9.000	10.600	14.000
50	0.900	1.320	2.000	3.350	4.500	7.500	11.200	13.200	18.000
63	1.120	1.700	2.500	4.250	5.600	9.500	14.000	17.000	22.400
80	1.400	2.120	3.150	5.300	7.100	11.800	18.000	21.200	28.000

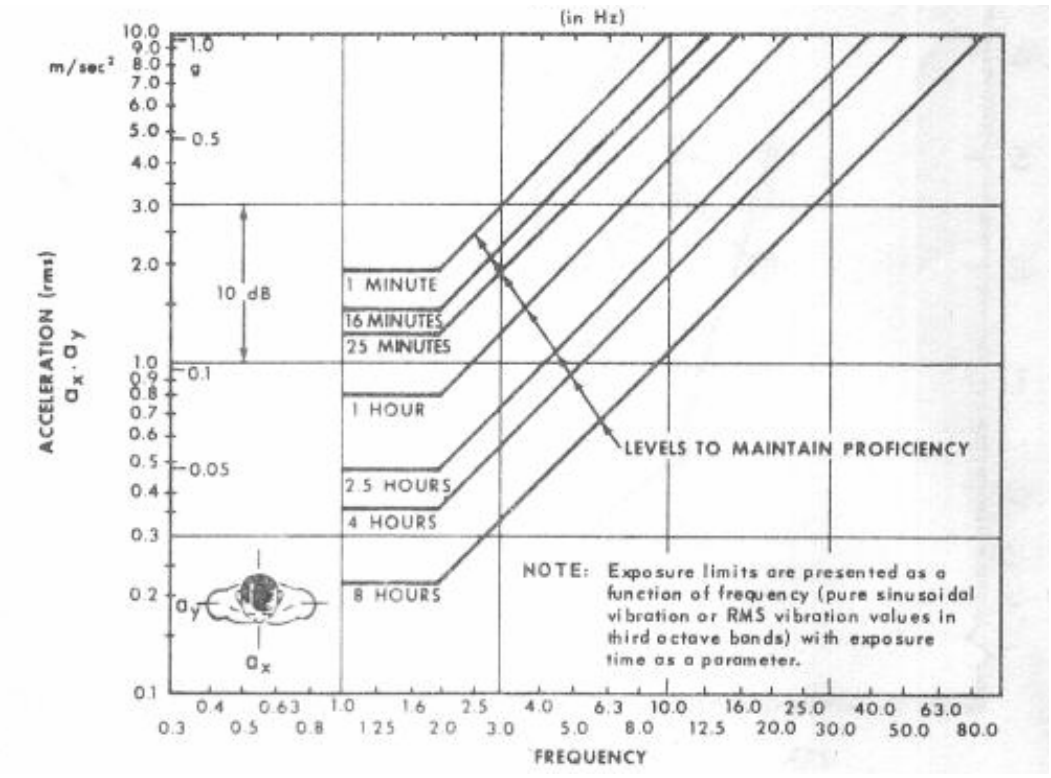


Figure 8 FDP boundary-X&Y axes

2.6.4 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 to establish a legal limitation of Human Vibration Exposure starting in July of 2005. It places specific limitations for the average amount of vibration a truck driver can experience for an 8 hour day. For Whole Body Exposure, the directive is based on the ISO 2631. According to this directive,

the daily exposure limit value standardized to and 8-hr reference period shall be 1.15m/s^2 or, a VDV of 21m/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 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.

2.6.5 Comparison among standards

A comparison among three current standards: ISO 2631-1(1974,1985),BS 6841(1987) and ISO 2631-1(1997) to predict the hazards of WBV and repeated shocks has been done by Lewis and Griffin in 1998.They measured the seat accelerations in nine different transport environments and found out differences due to variations in the shapes of the frequency weightings, the phase responses of the frequency weighting filters, the method of combining multi-axis vibration, the averaging method, and the assessment method. There was 31% difference in a_{RMS} between the old and new ISO 2631 and 14% difference between BS 6841 and ISO 2631.The largest variations arose from differences between evaluations based on a_{RMS} and those based on VDV. The difference varied up to 70% while comparing eVDV and VDV. The differences tended to be greatest for more severe motions. ISO 2631-1 does not clearly identify when the a_{RMS}, eVDV or VDV measures should be used, leading to large differences in limiting daily exposure. The true VDV provided more cautious assessment of safe exposure durations. [16]

In another study by Paddan and Griffin, the vibration in 100 different vehicles was measured, evaluated and assessed according to BS 6841 (1987) and ISO 2631 (1997). The measurements indicated that the 17 $m/s^{1.75}$ "health guidance caution zone" in ISO 2631 was less likely to be exceeded than the 15 $m/s^{1.75}$ "action level" in BS 6841. Consequently, ISO 2631 "allows" appreciably longer daily exposures to whole-body vibration than BS 6841. [22]

In a similar study, Griffin has concluded that the latest version of ISO 2631-1 causes unnecessary confusion because it is unclear in several important areas, e.g. 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 a_{RMS} in all directions, why a 1.4 factor for health but not for comfort, how to choose between overall a_{RMS}, running RMS, VDV and no time-dependency; inclusion of two very different health guidance caution zones for interpreting RMS and VDV measures; allowing use of either the maximum value of a running RMS (MTVV) or the VDV etc. ISO 2631-1(1997) can however be interpreted as being consistent with BS 6841. 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. [9]

2.7 Literature Survey

There have been lots of studies but limited information concerning the levels of WBV experienced by the truck drivers.

Road condition and truck type were found to be the key predictors to WBV experienced by the transport operators. Other predictor variables included driver experience, truck

mileage and seat type. In the test conducted on two different types of trucks (cab-over and cab-behind) on four different highways it was found that WBV levels on average did not exceed the ISO 2631-1 guidelines for health caution zone. [5]

In another study by the same group, mobile equipments were found to be associated with greater levels (221%) of WBV than the stationary ones**.** 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.
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. [4]

A study done in Sweden (Kjell Ahlin,et al) to investigate the relationship between road condition, vehicle properties, driver behavior and ride quality 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. [1]

In an another study (Shrawan Kumar, Canada), 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 on heavy haul truck drivers in mining. The study was done on a new and an old truck of two different makes and different carrying capacities and 14 different drivers (8 males, 6 females) being instrumented with triaxial accelerometer at C7 and L3 spinous processes. The vibration at seat pan, C7 and L3 levels were recorded which frequently exceeded the ISO standards. [15]

The frequency response was found to be affected by posture, seating, seat back inclination and largely by the rocking of the pelvis. The career vibration exposure was found to be related to low back, neck, and shoulder pain. Vehicle driving might be the reason for low back pain or herniated nucleus pulposus. Muscle fatigue also occured under WBV and the response of the muscle to a sudden load had greater latency after WBV exposure. The authors recommend to reduce prolonged seating exposure along with WBV by means of using improved seats and correct ergonomic layout of the cabs. [27]

Palmer, Griffin et al 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 $m/s^{1.75.}$
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. [24]

Sarah Atkinson, Martin Robb and Neil J Mansfield 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. [2]

In a study by Corbridege and Griffin 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. [6]

In another study by Griffin along with Matsumoto, it was found that the dynamic responses of seated subjects are non-linear with respect to vibration magnitude.
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 m/s^2 RMS accelerations. 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 (transmissibility and apparent mass) were used to represent the responses of the body. Non-linear characteristics were observed in the apparent mass and in the transmissibility to most measurement locations. Resonance frequencies in the frequency response functions decreased with increases in the vibration magnitude. [8]

In a similar study by the same authors, the principal resonance in the apparent mass was 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. [36]

In another study by Bovenzi & Zadini, it was 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

(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. [3]

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). [18]

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 $0.5m/s^2$.[7]

Ronnie Lundstrom, Patrik Holmlund and Lennart Lindberg 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 an 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. [17]

In another study, 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. [21]

A field study was conducted in order 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. [19]

The effect of phase angle was found to be important with low magnitude of vibration at lower frequencies. Jang and Griffin 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. [14]

Huston, Zhao and Johnson talk 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. [12]

Epidemiological studies to determine whether there is support for a casual link between exposure to WBV and back disorders 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-vibrational factors related to back disorders.

Reducing prolonged sitting and improving the seats, cabs and suspensions are the possible ways to reduce the WBV exposure.

Not much of the information was found on exploring the better ways to assess the vibration exposure taking into account the effect of rotations and the jerk. An attempt to throw some light on these aspects has also been made in this thesis work.

Chapter-3 Methodology

3.1 Data Collection

3.1.1 ENGLAND

First set of data was collected from the driver's seat, the passenger's seat and the floor of two different cab-over trucks-Volvo and Mercedes (Fig 9) in England, and recorded in the tapes. Trucks were supplied by the DFDS Transport Company located at a Harwich. A seat pad containing triaxial accelerometer was attached to the driver's seat, one to the passenger's seat and a triaxial accelerometer to the seat base (Figure 10, 11).

The data was collected in nine channels for the entire operating time, with 3 channels along the 3 orthogonal directions [X-forward on truck, Y-side and Z-vertical] for the driver, passenger and the floor. The testing was done on a variety of roads: A 120(2-Lane segments), A12 (4-lane highway) and M-25 (6 or more lanes) within 100 miles of London with the unloaded loaded (maximum 44 tons) and removed trailer.

The data was then processed using a HVM-100 (hand-held vibration meter) as well as the analyzer from LMS-Pimento .The Y-data for the passenger (which was found to be quite less significant than the other two) was omitted as the Pimento contained only eight channels. The tapes containing the recorded data were played on the data recorder which was connected to Pimento. The data was recorded, processed and analyzed for every 4 minute with the help of Pimento.

After processing the data, frequency weighted RMS accelerations were calculated at each interval of time. The values were compared with the ISO standard and the ECE directive. Acceleration vs. time as well as $1/3^{rd}$ octave charts in the frequency domain was plotted. Natural frequencies were predicted from the ratio charts.



Volvo FH-12,420



Mercedes Actros, 2546

Figure 9 England Test Trucks



Seatpad-Driver's seat



Seatpad-Passenger's seat

Figure 10 England Test- Seatpads





Figure 11 England Test- Floor Transducers

3.1.2 POLAND

The second data collection segment was based from Warsaw, Poland in January 2006. The testing was done on cab-over trucks manufactured by 6 different companies. Trucks tested were DAF XF, IVECO ST, Mercedes ACTROS, SCANIA 420, RENAULT MAG and VOLVO FM in alphabetical order, all being cab-over (Figure 12). We don't have the picture of DAF as the camera used to photograph DAF was stolen in an airport in Detroit.

The routs of the trucks had a significantly wider range of road quality. The instrumentation for the trucks was much more extensive with a new type of electronic based recording system. The instrumentation consisted of 10 mounded triaxial accelerometers, 4 triaxial seat pads, 2 biaxial rotation sensors and 2 translational sensors. The system also recorded locations and speed using GPS system.

The purpose of the extended transducers were to better understand the accelerations and motions of the truck frame, the cab suspension system and the combination of translational and rotational accelerations. The driver's set motion was monitored using the translational sensors. The complexity of the cab designs resulted in a number of different mounting configurations in the initial testing, while a fixed pattern developed on the later testing. Based on the ISO 2631-1997 standard, a triaxial seat pad was used on both the seat pad cushion and the seat pad back for the driver's and passenger's seats.



Volvo



Iveco



Mercedes



Scania



Renault

Figure 12 Poland Test Trucks

To allow an adequate simulation on a vibration shake table, accelerometers were mounted on the cab floor in a manner that allowed sufficient distance that the same transducers could be mounted on the shake table. The combination of the data and neural network analysis would allow accurate simulations of the truck motions.

The data processing method was also different from that for the England data. This time, the recorded data were converted to Matlab files by using FlexPro software. The files were then extracted at smaller time segments and then processed using a Matlab program. Besides acceleration, VDV, jerk and rotation were also calculated in this analysis.
Due to various errors while running the Matlab code, the preliminary analysis was done with the help of available alternative processor, i.e. FAMOS. But we were not able to break the time interval into smaller sections here. Bad data were omitted in the analysis.

Transducers list is given in table 7. Figures 14 and 15 show the transducer mountings at different locations and the detail instrumentation layout respectively.

3.2 Data Processing Equipments

The data was processed with different equipments and softwares. A brief description to each of them is given below.

3.2.1 TEAC RD 145T Data Recorder

This is a data recorder (Figure 13) containing 16 channels with voltage or IPC accelerometer inputs. Data recorded on a digital tape is processed by connecting this recorder to HVM or Pimento via output connectors. Some of its features include Dual speed, PCM (Pulse Code Modulation data recording system to ensure high signal definition and signal to noise ratio), time base conversion capability (reduces analysis time), computer control via the GP-IB interface, built-in microphone and speaker, high speed data search, mains or external 12 - 28 VDC operation and BNC output connectors. Each BNC input may be switched between voltage or charge amplifier mode suitable for using IPC accelerometers directly. The drive voltage is 18 - 28 VDC, with constant current 4 - 20 mA.

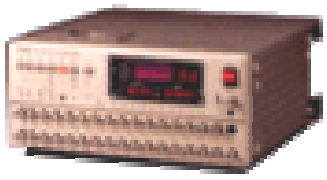


Figure 13 TEAC RD Data Recorder
*****Source: Website [8]

Table 7: Transducer list-Poland test

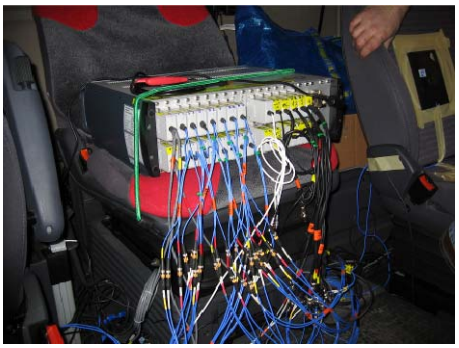
Transducer	Details	Transducer	Details
LDX	Linear (String Pot) Driver X direction	ASCDX	Acceleration Seat Cushion (pan) Driver (seat) X direction
LDZ	Linear (String Pot) Driver Z direction	ASCDY	Acceleration Seat Cushion (pan) Driver (seat) Y direction
LPX	Linear (String Pot) Passenger X direction	ASCDZ	Acceleration Seat Cushion (pan) Driver (seat) Z direction
LPZ	Linear (String Pot) Passenger Z direction	ASBPX	Acceleration Seat Base Passenger (seat) X direction
AFFCX	Acceleration Floor Front Center X direction	ASBPY	Acceleration Seat Base Passenger (seat) Y direction
AFFCY	Acceleration Floor Front Center Y direction	ASBPZ	Acceleration Seat Base Passenger (seat) Z direction
AFFCZ	Acceleration Floor Front Center Z direction	ASCPX	Acceleration Seat Cushion (pan) Passenger (seat) X direction
AFRRX	Acceleration Floor Rear Right X direction	ASCPY	Acceleration Seat Cushion (pan) Passenger (seat) Y direction
AFRRY	Acceleration Floor Rear Right Y direction	ASCPZ	Acceleration Seat Cushion (pan) Passenger (seat) Z direction
AFRRZ	Acceleration Floor Rear Right Z direction	TSOX	Tilt Sensor Outside (around) X-axis
AFRLX	Acceleration Floor Rear Left X direction	TSOY	Tilt Sensor Outside (around) Y-axis
AFRLY	Acceleration Floor Rear Left Y direction	TSIX	Tilt Sensor Inside (around) X-axis
AFRLZ	Acceleration Floor Rear Left Z direction	TSIY	Tilt Sensor Inside (around) Y-axis
ABPDX	Acceleration B-Pillar Driver (side) X direction	SPCDX	Seat Pad Cushion Driver X direction
ABPDY	Acceleration B-Pillar Driver (side) Y direction	SPCDY	Seat Pad Cushion Driver Y direction
ABPDZ	Acceleration B-Pillar Driver (side) Z direction	SPCDZ	Seat Pad Cushion Driver Z direction
AOFRX	Acceleration Outside Frame Right (passenger side) X direction	SPBDX	Seat Pad Back Driver (z-prime) X direction
AOFRY	Acceleration Outside Frame Right (passenger side) Y direction	SPBDY	Seat Pad Back Driver (y-prime, negative) Y direction
AOFRZ	Acceleration Outside Frame Right (passenger side) Z direction	SPBDZ	Seat Pad Back Driver Z direction
AOFLX	Acceleration Outside Frame Left (driver side) X direction	SPCPX	Seat Pad Cushion Passenger X direction
AOFLY	Acceleration Outside Frame Left (driver side) Y direction	SPCPY	Seat Pad Cushion Passenger Y direction
AOFLZ	Acceleration Outside Frame Left (driver side) X direction	SPCPZ	Seat Pad Cushion Passenger Z direction
ASBDX	Acceleration Seat Base Driver (seat) X direction	SPBPX	Seat Pad Back Passenger (z-prime) X direction
ASBDY	Acceleration Seat Base Driver (seat) Y direction	SPBPY	Seat Pad Back Passenger (y-prime, negative) Y direction
ASBDZ	Acceleration Seat Base Driver (seat) Z direction	SPBPZ	Seat Pad Back Passenger Z direction



1. Driver's seat and back- PT6



2. B-Pillar-PT4



3. IMC data acquisition system



4.Seat Suspension-PT3



5. Truck frame-PT5



6.Seat Base-PT5



7. Seat Base-PT2



8. Truck frame PT3

Figure 14 Poland test-Transducers at various locations

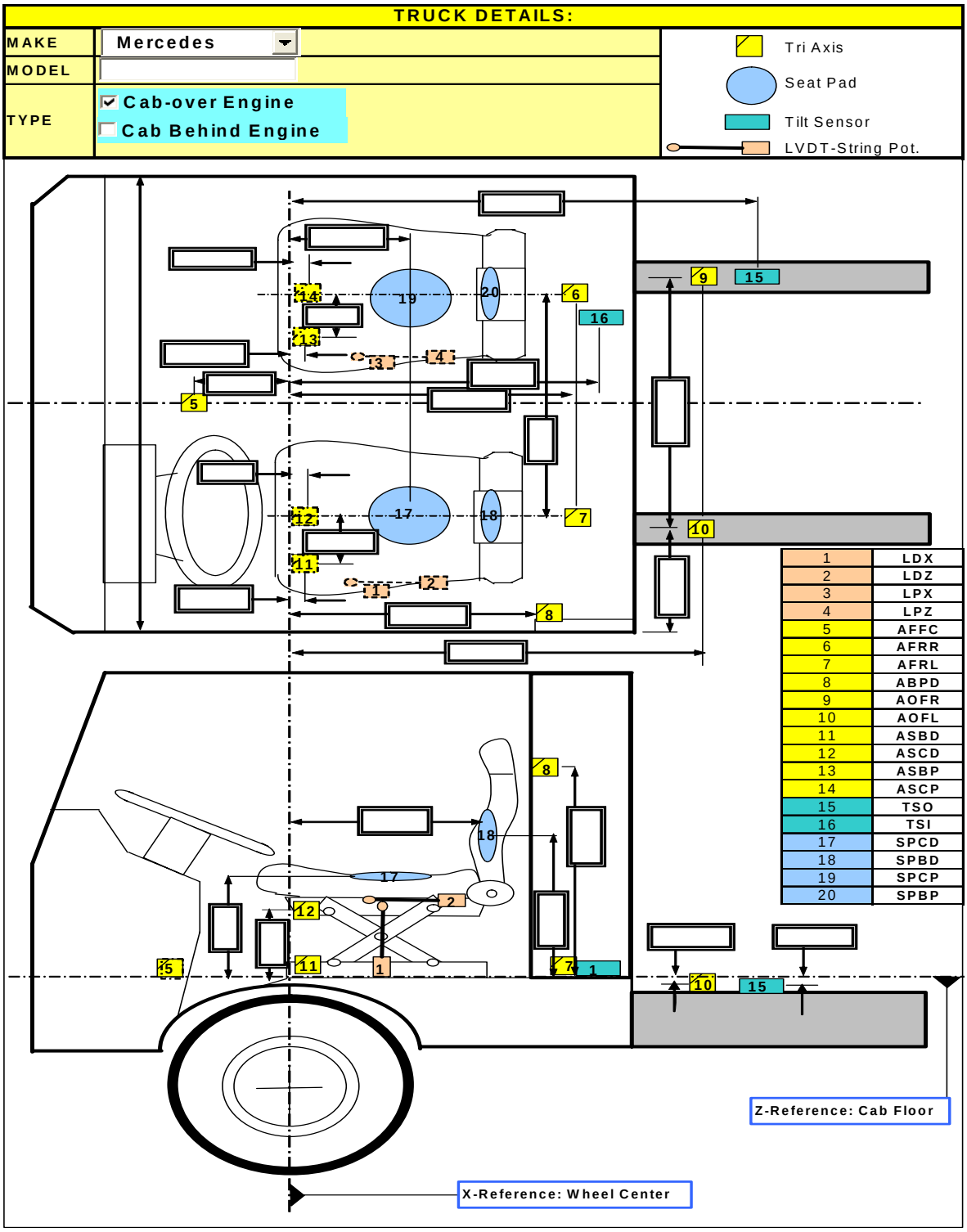


Figure 15 Poland test-Instrumentation Locations

3.2.2 HVM 100

The HVM 100 (Figure 16) is a hand-held instrument for measuring human exposure to vibration, performing the relevant calculations and providing overall results on the LCD display. It can perform simultaneous 3-channel measurements: X Y and Z and can store up to 200 hours of time histories for each channel. Both peak and RMS levels of the 3-axis may be stored together with the important vector sum which the HVM 100 also calculates. Frequency weightings is automatically done fulfilling BS ISO 2631, 5349, 6841 and 8041 standards, both for hand-arm and whole-body vibration. The results, current and recalled from the memory may be downloaded to a PC.

3.2.3 PIMENTO

Pimento (Figure 17) can handle most tasks in general data acquisition & DSP, rotating machinery, structural analysis and acoustics, including sound power and sound intensity measurements. Pimento's human body vibration applications cover both whole-body and hand-arm vibrations. They comprise of the implementation of ISO standards. Total RMS value and Vibration Dose Value (VDV) can be obtained as well as detailed results per 1/3rd octave band. It is also possible to change weighting functions. The results can then be listed in Microsoft Excel.
Starting with 4 channels, Pimento is expandable up to 24 channels, all with 24-bit ADCs. It also offers up to 40 kHz bandwidth per channel (MSP424 module) and over 1 Megasample /sec in.



Figure 16 Larson Davis HVM 100
*Source: Website [11]



Figure 17 LMS Pimento
*Source: Website [1]

3.2.4 FAMOS

FAMOS (**F**ast **A**nalysis and **M**onitoring **o**f **S**ignals) is a software program for analysis and evaluation of measurement results. With FAMOS, large waveforms can be processed, data can be displayed in charts or tables and can be printed in individually designed reports. FAMOS is able to read various binary and ASCII data formats in addition to process data recorded using an **imc** system (e.g. MUSYCS or µ-MUSYCS) and existing in the FAMOS data file format.

Data Processing with FAMOS

To process the data, the raw data files to be processed are loaded. These are displayed in the variable box (Figure 18). In the editor window, the analysis codes are typed.

e.g. PT1_D_seat_X_1191510 = OctA (SPCDX, 0.1, 100)

OctA ( ) performs the third octave analysis. Inside the parentheses, the lower and upper ends of the frequency range are specified in Hz, preceded by the data filename.
Then the entire sequence is run by pressing ctrl+F7.
After processing these data, the files with the corresponding names appear on the left window (under variables).The result files are saved together in XL format (as the excel sheet).Further analysis are carried out with the third octave accelerations from those sheets.

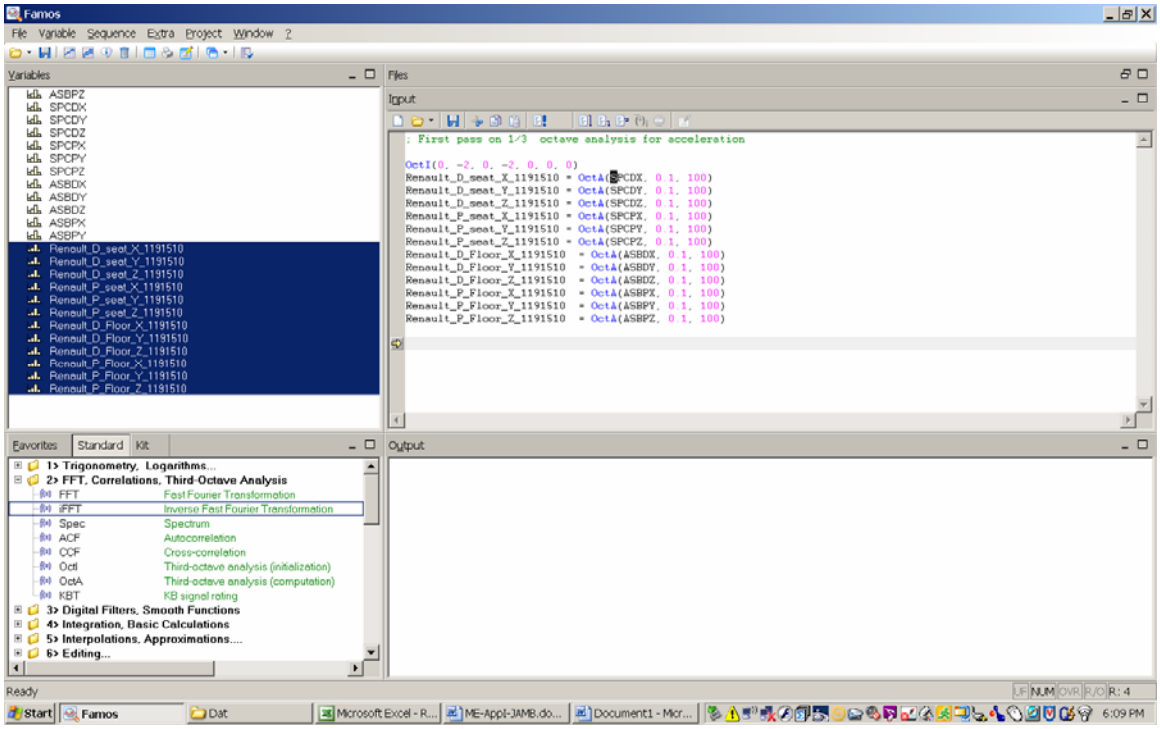


Figure 18 Data processing with FAMOS

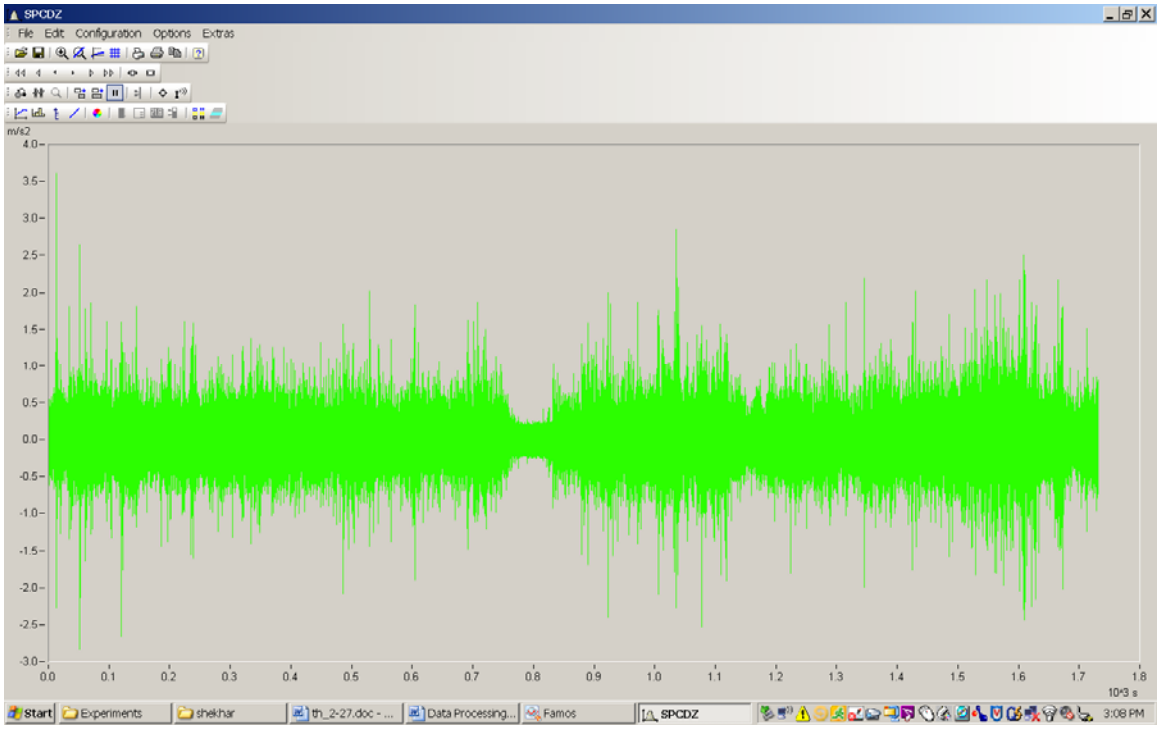


Figure 19 Waveform example with FAMOS

The waveforms for each of the variables can be seen individually or together from the variables menu, or using Look software which is a built-in program in FAMOS. Figure 19 shows one typical waveform.

3.2.5 FlexPro

FlexPro is a software package developed by Weisang GmbH & Co. KG for analysis and presentation of technical data. Large amounts of data can be imported into FlexPro's object database (Figure 20) using a variety of binary formats. It has got more than 200 analysis functions as well as additional special modules for spectral analysis, acoustics, counting procedures, order tracking analysis and statistics.

Using this software, Poland test data was processed as follows:

- First of all, the FlexPro files were converted to Matlab files (to be used as input)
- The Matlab files were reduced/extracted to smaller intervals (intervals were selected looking at the waveforms in Famos)
- The extracted files were then processed using ISHV (International Standard Human Vibration) code.

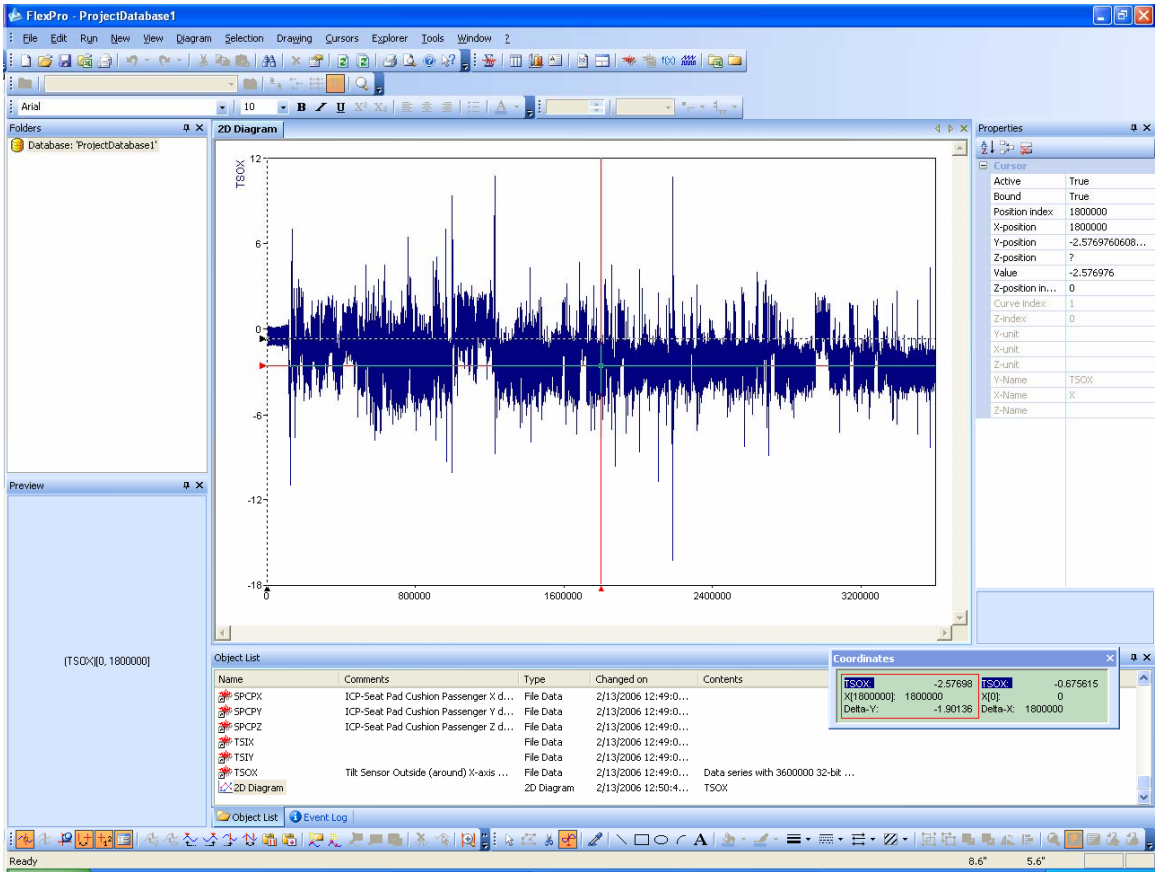


Figure 20 Flexpro software

3.3 Processing the Extracted Files in Matlab

Here are the steps to process the extracted files in Matlab:

- Create a new folder in C. e.g. “PT1 4.20” (Truck name followed by the date)
- Create subfolders “DataFiles”, “MatFiles”, “Analysis Results” and “Plot” under that folder.
- Copy Matlab files [1]AnalysisHeader, [2]ExtractData2.m and [3]ImcMatHeader.m under “Matfiles” and “DataFiles”.
- Open Matlab. Set the working directory to the “DataFiles” subfolder.
- Type the command to extract the data for the required time interval.
  e.g. ExtractData2([700],[1700],500,3,{'SPCDX1' 'SPCDY1' 'SPCDZ1'},[]);
- Select the data file (created using FlexPro) to process (from MatFiles folder).
  e.g. [4]PT1STD01S01
- The extracted data will seat in “PT1STD01S01IdxReduced” folder created automatically inside the “MatFiles” subfolder.
- Copy the data file inside the reduced folder to “DataFiles”.
- Copy the extracted/reduced data files to process in the “DataFiles” folder.
- Type ISHV[5] Code ('WholeBody','ImcMatWBV',500,0,1,1,60); select the reduced data file to process.
- The results and the plots will be saved in ‘Plots’ and ‘AnalysisResults’ folders.

[1] Defines the processing for each channel.
[2] Extracts a smaller time-segment of the data.
[3] File for data structure.
[4] Test Truck 1: Day1, Segment1.
[5] The Institute for the Study of Human Vibration.

Chapter-4 Results

4.1 England Study

Table 8 lists the average weighted RMS acceleration results for the driver seat, passenger seat and the floor for all the tapes. Vertical a_{RMS} values are plotted in Figure 21.
On average, the action value of 0.5m/s^2 was exceeded only by passenger seat on tape 5 and that was when the trailer was removed. However, if we look at the individual time segments, this value was exceeded couple of times by both trucks.

The overall a_{RMS} for all the tapes are tabulated in Appendix-I with the acceleration exceeding the "action value" being highlighted with bold numbers. Individual a_{RMS} plots are given in Appendix-II. The RMS accelerations for the driver's and the passenger's seat along Z-direction is plotted in Figure 22.

It can be seen that:

- Passenger seat is always higher than the driver seat
- Driver seat a_{RMS} values are mostly below the action level
- Passenger seat a_{RMS} values cross the action limit couple of times
- Maximum exposure is observed for ET1-Tape5 where the trailer is removed
- None has reached the limit value of 1.15m/s^2

Table 8 England Test Result-average weighted a_{RMS}

Truck	Tape	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz
ET1	2	0.1596	0.148	0.2262	0.0705	0.3501	0.1194	0.1365	0.2947
	3	0.1564	0.1463	0.3079	0.1786	0.3497	0.1244	0.1254	0.3452
	4	0.1556	0.132	0.3199	0.1729	0.3868	0.1149	0.1155	0.3669
	5	0.2053	0.2276	0.3666	0.2644	**0.5268**	0.171	0.1963	0.4363
ET2	6	0.1938	0.1474	0.2926	0.1817	0.3791	0.1529	0.117	0.328
	7	0.1468	0.1661	0.3233	0.1806	0.369	0.1735	0.1321	0.3202
	8	0.1896	0.1389	0.3268	0.1979	0.3918	0.1836	0.0999	0.3502
	9	0.2196	0.1593	0.2968	0.2206	0.3448	0.175	0.118	0.3073
	10	0.1746	0.156	0.3428	0.1709	0.3909	0.1243	0.1095	0.2952
	12	0.1692	0.1602	0.3737	0.1751	0.4312	0.1393	0.1195	0.3302

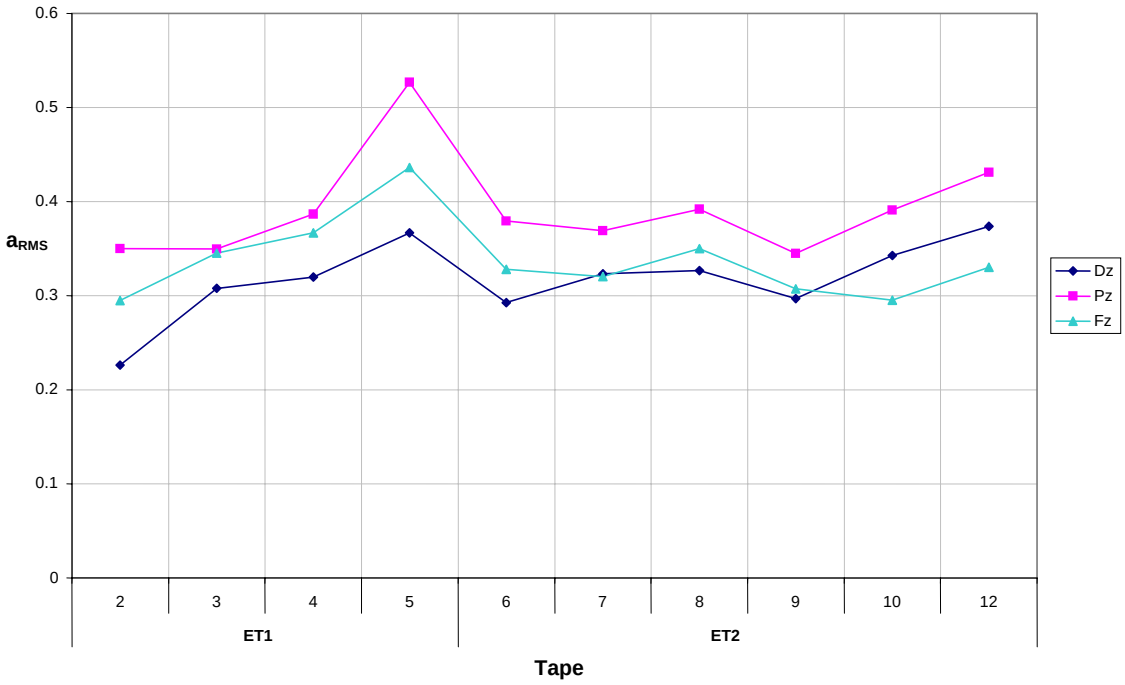


Figure 21 England-average weighted a_{RMS} -Z axis

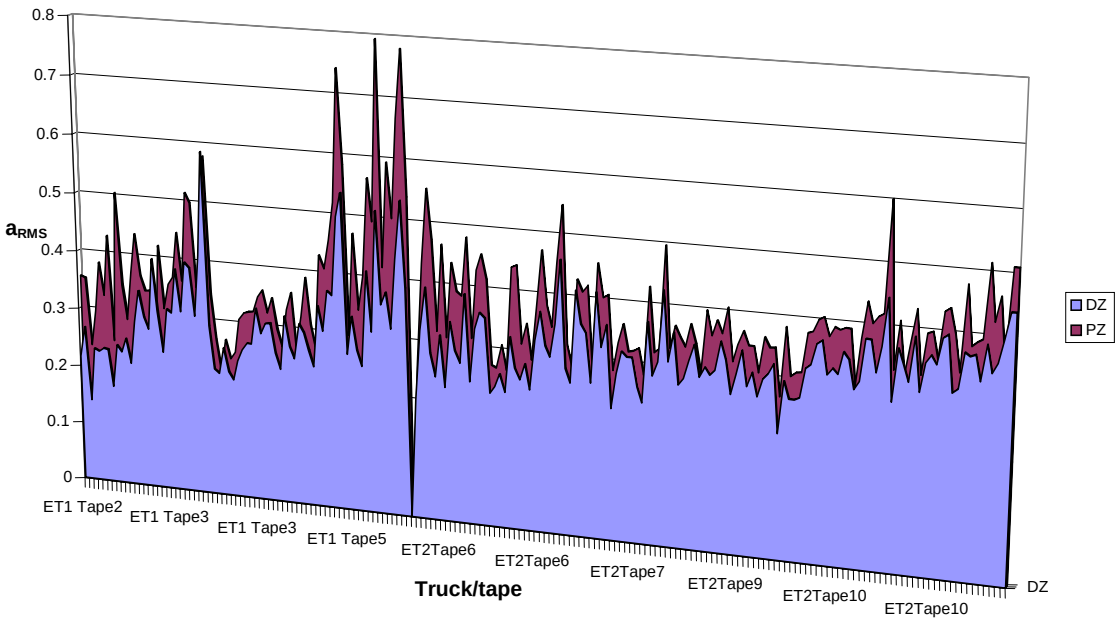


Figure 22 England-Driver and Passenger seat weighted a_{RMS} -Z axis

Table 9 Comparison-England test results

Truck	Comparison	Roads	Load	Higher exposure & direction	difference
ET1	road	M-25/ 2-lane	unloaded	2-lane, all	1-21%
	road	M-43/ 2-lane	loaded	2-lane, all	10-27%
	load	2-lane	loaded/unloaded	loaded, vertical	11-23%
ET2	road	A-2,228/ M-2,23,26	unloaded	M-26, vertical	20-47%
	road	A-130/ M-25	loaded	A-130, all	2-8%
	load	A-14	loaded/unloaded	unloaded, vertical	0-5%
	driver	A-120	loaded	D2[6], all	15-54%
	truck	2-Lane	unloaded	ET2, vertical	13-18%
		M-25	loaded	ET1,all	4-51%

Table 9 shows the comparisons between various roads, load and trucks (Volvo vs. Mercedes) based on the a_{RMS} vs. time plots given in Appendix-II.

Comfort analysis is done by combining the weighted a_{RMS} in all directions and calculating the Vibration Total Value (a_v).

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

$$k_x = k_y = k_z = 1.0$$

The results are plotted in Figure 23.While looking at the chart, it can be seen that the driver may feel a little uncomfortable whereas the passenger is more uncomfortable, crossing the limit of "fairly uncomfortable" a couple of times, maximum in tape 5 where the trailer has been removed.

Table 10 compares the a_{RMS} values for health as well as comfort with the action value set by the standard.

[6] Second driver on ET2

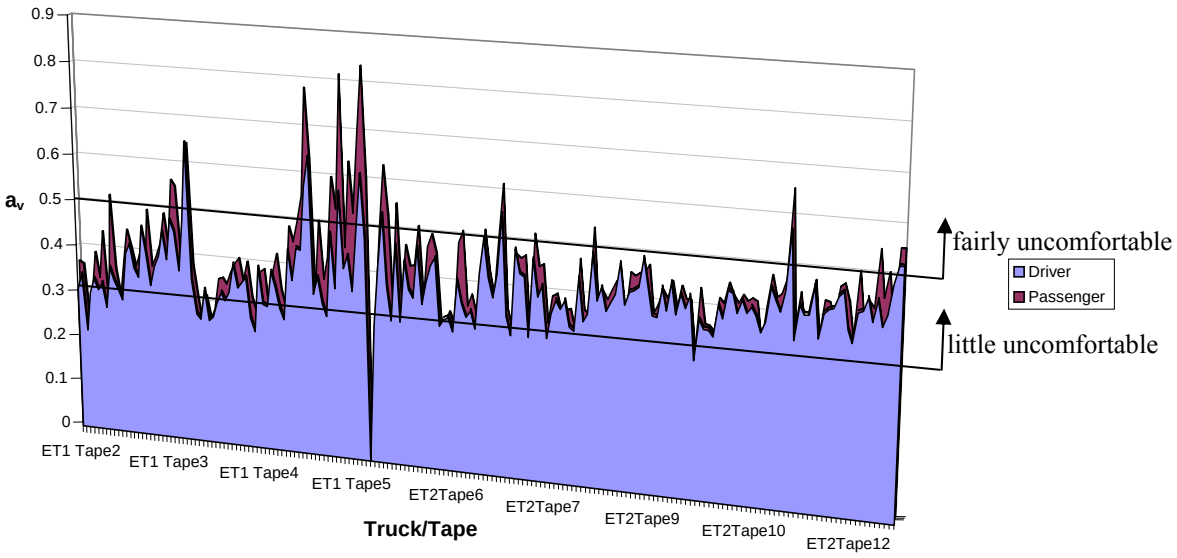


Figure 23 England- Comfort Plot

Table 10: England test results-Comparison with ECE directive-Z axis

	Truck	over the action value (weighted a_{RMS})			over the action value (weighted a_{RMS})			
		Health(instances)	Max(m/s^2)	Road	Comfort	Max(m/s^2)	Road	Remarks
Driver	ET1	2	0.54	M-25	5	0.65	M-25	
	ET2	0	0.48	2-lane	7	0.63	2-lane	
Passenger	ET1	10	0.79	M-25	14	0.83	M-25	cab only
	ET2	6	0.554	2-lane	15	0.66	2-lane	

4.2 Poland Study

For Poland study, Table 11 shows the initial average a_{RMS} values for the driver's seat measured by hand held HVM 100 during vehicle operation. There is no initial data for PT2 since the observer was not allowed to seat inside the truck. The results obtained by processing the data are given in Appendix-IV. Average a_{RMS} values are listed in Table 12. As per ECE directive, over the action values are highlighted as bold. The value is 0.5m/s^2 for the standard time of 8-hr drive. In Europe, driver is allowed to drive up to 11 hrs. The action value would then be scaled accordingly:

- 8 Hours – 0.5 m/s^2
- 9 Hours – 0.47 m/s^2
- 10 Hours – 0.45 m/s^2
- 11 Hours – 0.43 m/s^2

None of the trucks, except 2nd day of PT1 drove more than 8hrs, however the factor need to consider a possible 11hrs per day.

For X and Y axes, EAV has been scaled as:

- 8 Hours - 0.375 m/s^2
- 11 Hours - 0.31 m/s^2

Individual a_{RMS} plots are given in Appendix-V. Driver and passenger seat a_{RMS} along Z-direction could be compared in Figure 24. Passenger is higher almost all the time. Except for PT1, all have crossed the EAV value a couple of times but never reached 0.8m/s^2. PT2 and PT3 show the highest exposure among all the trucks. PT6 is above EAV only once.

Table 11: Poland Test Result-Observer HVM 100 ISO 2631 Values for Driver Seat, Z axis

Truck	Range - $a_{X,}$ m/s^2	Range - $a_{Y,}$ m/s^2	Range - $a_{Z,}$ m/s^2	a_Z –avg., m/s^2
PT1	0.11 – 0.508	0.07 – 0.36	0.24 – 0.96	0.48
PT3	~0.31	~0.25	0.36 – 0.68	0.68
PT4	0.13 – 0.31	0.14 – 0.33	0.30 – 0.79	0.51
PT5	0.26 – 0.71	0.09 – 0.28	0.33 – 0.84	0.58
PT6	0.10 – 0.34	0.10 – 0.15	0.21 – 0.58	0.34

Table 12 Poland Test Result-average weighted a_{RMS}

Truck	Driver Seat			Passenger Seat			Driver Floor			Passenger Floor			Driver Back			Passenger Back		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
PT1	0.16	0.13	0.35	0.24	0.16	0.39	0.15	0.14	0.24	0.1	0.9	0.26	0.25	0.19	0.39	**0.31**	**0.43**	**0.44**
PT2	0.15	0.25	**0.52**	-	-	-	0.12	0.16	0.42	0.08	0.12	**0.49**	0.29	0.25	0.39	-	-	-
PT3	0.19	0.16	**0.43**	0.19	0.17	**0.55**	0.16	0.15	**0.48**	0.18	0.15	**0.48**	**0.31**	0.19	**0.49**	**0.36**	0.21	**0.47**
PT4	0.12	0.1	0.38	0.18	0.13	0.39	0.12	0.1	0.32	0.12	0.1	0.34	0.18	**0.33**	0.37	0.22	0.12	0.38
PT5	0.2	0.11	0.26	0.21	0.27	0.35	0.21	0.18	0.35	0.14	0.09	0.3	0.25	0.12	0.42	0.23	0.1	0.38
PT6	0.14	0.08	0.36	0.14	0.07	0.36	-	-	-	-	-	-	0.24	0.08	0.4	0.27	0.1	**0.5**

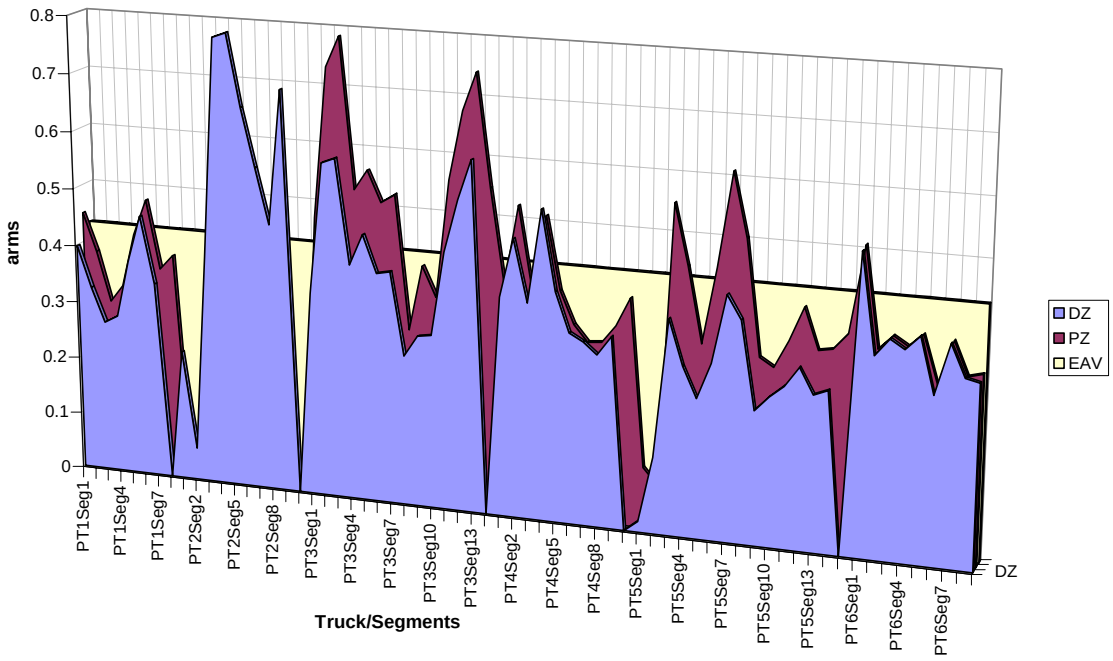


Figure 24 Poland-Driver and Passenger seat weighted a_{RMS} -Z axis

For Comfort, Figure 25 shows that both driver and passenger are fairly uncomfortable in this study. Both have crossed the action limit (EAV) a lot of time but never reached the exposure limit (ELV). Passenger is higher almost all the time. As per the driver's comfort, PT2 seems to be bad and as per the passenger, PT3 followed by PT5 are bad. The ride on PT6 is most comfortable. Appendix-VI contains the individual comfort charts for all the trucks.

"Total Vibration Value" for health, calculated using the same formula as for comfort, but by taking constants as $k_x = k_y = 1.4$ and $k_z = 1.0$ gives little higher a_{RMS} values which are shown in Figure 26. Here, even PT6 is little above the EAV lots of time, passenger seat in PT1 reaching up to ~0.9 at a time. Driver seat in PT2 and passenger seat in PT3 go up to 0.96m/s^2 but none reach the ELV.

The details of the comparisons of the driver's and the passenger's seat pad as well as the seat back values with the ECE directives are given in table 13 and 14 respectively. On average, both driver and passenger were exposed to greater level of vibration on rougher and smaller roads. Though they have crossed the action values a couple of times, they have never reached the upper limit as specified by the standards.

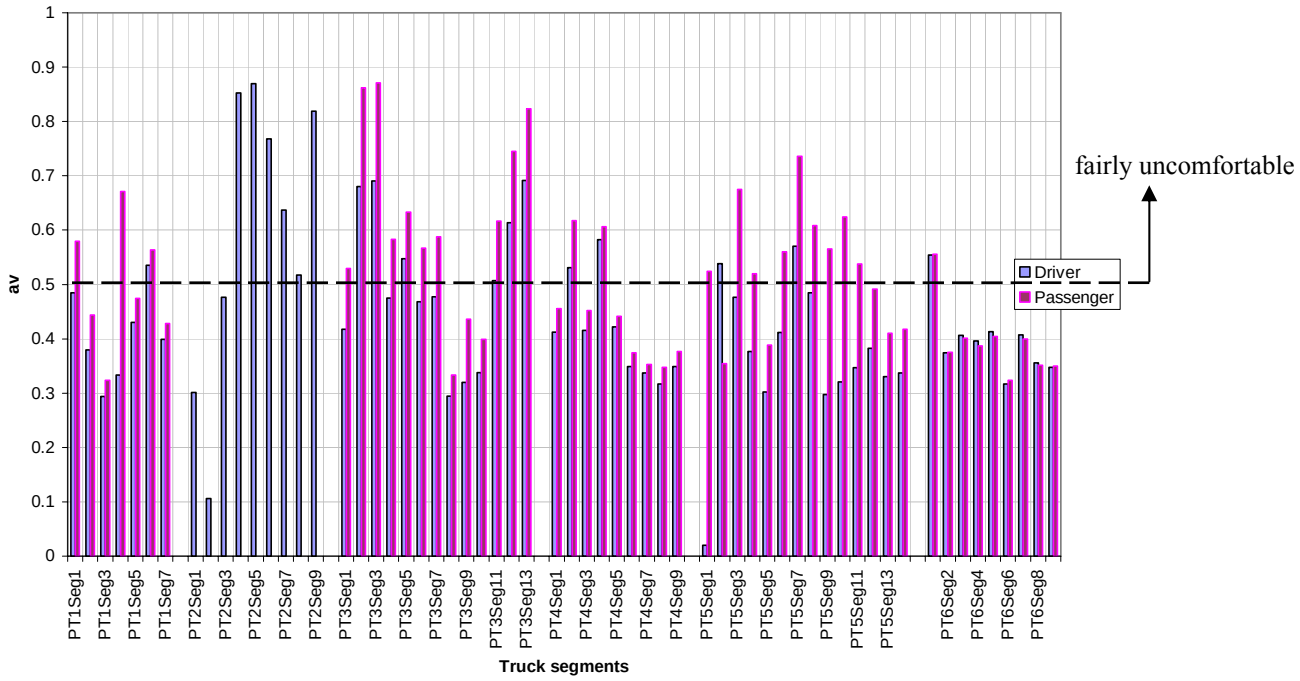


Figure 25 Poland Test- 'Total Vibration Value' for Comfort

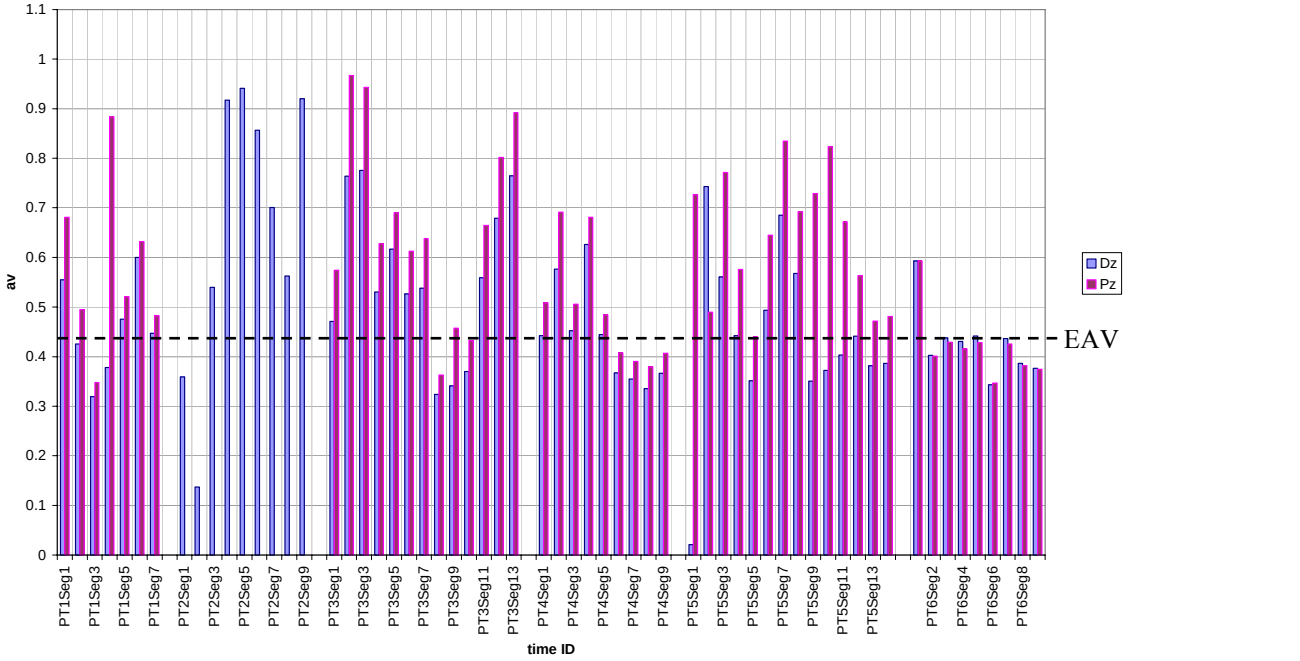


Figure 26 Poland Test-'Total Vibration Value' for Health

Table 13 Poland Test Result-Comparison with ECE standard-Driver& Passenger Seatpad

	Truck	over the EAV- weighted RMS acceleration					
		Health	Max (m/s^2)	Road	Comfort	Max(m/s^2)	Road
Driver	PT1	1	0.4596	E-30,2-lane	2	0.5996	E-30,2-lane
	PT2	6	0.7873	-	7	0.9415	
	PT3	6	0.6054	E-67,2-lane	6	0.7755	E-67,2-lane
	PT4	2	0.533	sE67/8, 4-lane	2	0.6264	sE67/8, 4-lane
	PT5	0	0.4191	sE67/8, 4-lane	4	0.7427	sE67/8, 4-lane
	PT6	1	0.5101	4-lane	1	0.5930	4-lane
Passenger	PT1	2	0.4828	E-30,2-lane	3	0.8835	E-30,2-lane
	PT2	-	-	-	-	-	-
	PT3	10	0.7459	E-67,2-lane	7	0.9668	E-67,2-lane
	PT4	2	0.5293	sE67/8, 4-lane	2	0.6808	sE67/8, 4-lane
	PT5	5	0.6157	sE67/8, 4-lane	10	0.8347	sE67/8, 4-lane
	PT6	1	0.5144	4-lane	1	0.5926	4-lane

Table 14 Poland Test Result-Comparison with ECE standard-Driver& Passenger Seatback

	Truck	Over the EAV	Max($m/s^{2)}$	Road
Driver Seatback	PT1	3	0.55	E-30,2-lane
	PT2	5	0.66	-
	PT3	9	0.7	E-67,2-lane
	PT4	3	1.1	1/E75
	PT5	7	0.66	sE67/8, 4-lane
	PT6	0	0.31	4-lane
Passenger Seatback	PT1	3	0.59	E-30,2-lane
	PT2	-	-	-
	PT3	9	0.67	E-67,2-lane
	PT4	3	0.52	sE67/8, 4-lane
	PT5	6	0.61	sE67/8, 4-lane
	PT6	0	0.38	4-lane

Chapter-5 Discussion

Observations from the a_{RMS} as well as the 1/3rd octave plots for all the trucks are summarized in this section. Additional analysis on Poland data with *VDV* and jerk, cab rotation as well as some comparison among different processors and different trucks are also included.

The original standards ISO 2631 – 85 and earlier used 1/3rd octave values to judge potential for driver risk factors. It was found that the frequency range of 4 Hz to 8 Hz was the most sensitive region, which related to the fundamental vertical spinal mode. The spine, like other physical systems, has a sensitivity related to the driving force and the critical natural frequency. This concept related to the risk values at other 1/3 octave frequency values. The current standard, ISO 2631, uses a combined set of values, but this concept is not beneficial for understanding the needed seat frequency requirements. The acceptable level of acceleration in the 4 Hz to 8 Hz region is 0.5 m/s^2 for an 8 hour day.

Rotation of the cab can be estimated looking along the X and Y directions. Transducer mounted on the floor, being near to the center of rotation, does not say much about the rotation but as we go up, the effect of rotation will start increasing. We can thus measure the rocking of the driver's and the passenger's seat with respect to the floor. Accelerations along X are primarily due to rotation around Y axis and vice versa. Range of the frequencies can be observed from the ratio charts.

5.1 England Data

5.1.1 Observations from the RMS acceleration plots

The seat in the vehicle 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 standards. In other words, driver exposure is safe but he may feel bit uncomfortable while driving on the highway which can affect end of the day performance.

Table 9 shows the comparison among different roads, loading conditions, drivers and the trucks themselves. For unloaded as well as loaded ET1, average a_{RMS} was found to be up to 27% higher in 2-lane road than the 4 or 6 lane highways . While comparing loaded vs. unloaded, higher values were obtained for loaded case on a 2-lane road whereas on M-25, values were higher for unloaded case. The multidimensional suspension system in ET1 helped prevent the extra vibrations in unloaded 2-lane road.

Similarly for loaded ET2, little higher values were obtained while driving on A-130 but for unloaded one, M-26 gave 20-47% higher values. This may be due to higher speed on M-26. While making comparison between loaded and unloaded, unloaded one gave higher values in most of the cases. Comparing different drivers on A-120, second driver

was exposed to up to 54% higher vibration. It was Saturday and the driver was in hurry to finish and go resulting in higher speed.

Finally comparing different trucks for the vertical exposure, while loaded- ET1 gave up to higher values driving on M-25 and while unloaded-ET2 gave 13-18% higher values driving on a 2-lane road.

Table 10 compares the a_{RMS} results with the ECE standard. In ET1, the driver crossed the EAV just twice whereas for passenger, there were 10 instances when the limit was crossed; maximum being 0.79m/s^2 on M-25.For ET2 however, there was not a single instance where the driver seat a_{RMS} crossed the limit. For passenger there were 6 instances when the limit was crossed (maximum 0.55m/s^2 on a 2-lane road). Here also, the passenger had higher exposure to vibration. This suggests that the seat was good enough to protect the driver whereas the passenger was exposed to some high level of vibration but not consistent and strong enough to violate the standard.

Looking at the levels of comfort, the passenger seat in both trucks were above the action value a number of times .There were 14 such instances in ET1, with a maximum of 0.83 m/s^2 in M-25 when trailer was removed, and 15 in ET2 with a maximum of 0.66 m/s^2 in a 2-lane road. Driver was also above EAV 5 times (maximum of 0.65 m/s^2 on M-25) in ET1 and 7 times (maximum of 0.63 on a 2-lane road) in ET2. Levels of exposure were however below the limit value set by the standard.

Looking at X and Y axes we can see constant rocking of the driver and the passenger seat along these directions, magnitudes being higher in 2- lanes and unloaded/trailer removed conditions. Passenger seat is subjected to little more rocking than the driver's.
ET2 is subjected to more rocking than ET1 and the rocking is more along fore-aft than the sideways direction. Though a_{RMS} values are not too high, significant amount of rocking might be a cause for the driver's uncomfort.

Below is the brief description of the observations along X, Y and Z axes (Appendix-II) for both trucks.

X-axis
In ET1, Passenger is about 20% higher than driver and driver is also about 20% higher than the floor in all the tapes except tape 2 (unloaded, M-25&2-lane) where the passenger is the lowest. All values are however well within the limit.
In ET2, Floor is lowest in all the cases. Driver and passenger are around 30% above and about the same levels having alternative peaks crossing the limit only once.

Y-axis
The values of Y-axis acceleration ($a_{Y\text{-}RMS}$) for the passenger seat were seldom recorded, due to an equipment limitation. The Y – Axis also reflects the effects of turns, and cab suspension.

In ET1, Driver is about 15% above the floor, almost all within 0.2 m/s^2.In tape 5, passenger is in between the driver and the floor. The value is increased (but still below 0.3 m/s^2) when the trailer is removed.
For ET2, Driver is about 20% higher than floor in all cases. Mostly they were under 0.2 m/s^2 and in couple of occasions exceeded that but still within 0.25 m/s^2.
Z-axis
The Z – axis accelerations are the primary focus of the seating design, which has resulted in the air spring suspension for all the driver's seats.
In ET1, there were just two instances where a_{RMS} value in Z-direction exceeded 0.5m/s^2, maximum being 0.54m/s^2. For comfort however, there were 10 instances- maximum 0.75m/s^2 on M-43.

5.1.2 Observations from the third octave plots

1Hz –8Hz range is of our primary focus, though the data is collected in the range 0.1-100Hz.Vertical natural frequency of the human spine is found to be around 5Hz. Accelerations of the seat are supposed to be decreasing in the range 4-8Hz.For ET2, the plot is first decreasing and then increasing while for ET2 it is first increasing and then decreasing. Though the accelerations remained pretty low, different natural frequencies of the seat suspension, the foam and the cab suspension as well as rotation of the cab suspension might have played important role in altering the pattern along this critical zone.

For ET1, passenger seat is vibrating with higher acceleration than the driver's, almost all the time in 4-8Hz range. In that range, the accelerations are pretty low, mostly below 0.15 m/s^2, except for Tape 5, cab-only case where the values are almost the double.
As per ratio pattern, driver to floor and passenger to floor ratio is mostly decreasing from 4 to 6.3 Hz and then increasing (except for tape 4, loaded M-25, where both are decreasing from 4-8Hz). Driver to passenger ratio is mostly below 1, decreases from 4 to 6.3 Hz and increases in two cases whereas in other, it is almost constant.
All the ratios were averaging around 1.
The average natural frequency of driver seat is 1.8Hz and passenger seat is 4Hz.

Similarly for ET2, except in the range 4-8Hz, passenger seat is greater than the driver. High peaks occur at 1-2Hz. Maximum acceleration of driver seat is around 0.33 m/s^2 and passenger seat is around 0.39 m/s^2. At the 4-8Hz zone, driver is either greater than or equal to passenger. Looking at the driver to floor ratio in the 4-8 Hz range, the ratio mostly increases from 4-5 or 6.3 Hz and then decreases. (In contrast to ET1), whereas P/F ratio first decreases and then increases, even decreasing along the whole range in some cases. D/P ratio follows the same pattern as D/F. The ratios averaged around 1.0.
The natural frequency of driver seat was around 2.5Hz and Passenger seat around 5Hz.

Below is the summary of the observations for all the tapes along Z axis, based on the plots in Appendix-III.

ET1: Tape 2 [unloaded 2-lane]
Passenger has high peaks at 4-5 Hz, in the magnitude of 0.3m/s^2.
Driver is always below 0.153m/s^2, and below 0.1 m/s^2 between 4-8Hz.Both driver and passenger decrease from 4 to 6.3Hz and increase little bit at 8Hz.
Driver to Floor, Passenger to Floor as well as Driver to Passenger ratios are decreasing from 4 to 6.3Hz and increasing after that.
From peaks, it can be predicted that natural frequencies of driver seat is between 2.5 Hz and Passenger seat at 4Hz.
Passenger is greater than driver till 8Hz.After that, driver leads.
The ratios average around 0.5 for D/F and D/P (passenger and floor both are greater than the driver) and 1 for P/F.

ET1: Tape 3 [loaded M-43]
Driver peaks with a high value of ~0.6 m/s^2 at 2Hz.Passenger has also maximum peak at the same frequency with little less acceleration. Values are low between 4-8Hz (0.1-0.15 m/s^2) for both. D/F and D/P ratios decrease from 4 to 6.3Hz but after that increase till 10Hz. D/P decreases till 5 Hz and then increases till 10Hz.Natural frequencies of driver seat could be 1.6Hz and passenger seat 4Hz.
The ratios average around 1.

ET1: Tape 4 [loaded M-25]
Lots of high peaks are seen at 1.25-1.6Hz.Driver has maximum peak at 1.25 Hz (~0.28 m/s^2).Passenger's maximum is at 1.6 m/s^2 which is little higher than driver's (below 0.3 m/s^2).In 4-8Hz range, driver is below 0.12 m/s^2,passenger is little higher.
D/F and P/F are decreasing between 4-8Hz.D/P is almost constant. Natural frequencies of the driver seat could be 2 Hz and passenger seat 4Hz.
The ratios average around 1.2.

ET1: Tape 5 [M-25, cab only]
Most of the time (1-10Hz), passenger is greater than the driver. High peaks are observed at 1.6Hz, driver's Acceleration being 0.55 m/s^2 and passenger's 0.62 m/s^2. All other peaks are below 0.4 m/s^2. At 4-8Hz, driver is below 0.3 m/s^2 and passenger is little higher.
D/F decreases from 4-5Hz and then keeps increasing. P/F decreases from 4-6.3Hz and then increases till 10Hz. D/P keeps on decreasing and increasing at each frequency interval. Natural frequency of the driver seat seems to be 1.25 Hz and passenger seat 4 Hz.

ET2: Tape 6 [loaded M-120]
Lots of peaks are seen at around 1-2 Hz and again between 10-12.5Hz.Maximum peaks occur at 1.25Hz, driver's acceleration being around 0.35 m/s^2 and passenger's in between 0.4-0.45 m/s^2. At 4-8Hz, values are too low-driver is below 0.07and passenger little higher but below 0.12 m/s^2. Driver and floor are exactly same at 4 and 8Hz.Between 4-8, driver is higher than floor.

Driver to Floor ratio is increasing from 4 to 6.3Hz, and then decreasing till 10Hz. Passenger to Floor is decreasing from 4 to 5 Hz and then increasing till 10 Hz. Driver to Passenger ratio is first constant between 4-5Hz, and increases till 6.3Hz and then decreases till 10Hz.
From peaks, it can be predicted that natural frequencies of driver seat may be at 2.5 Hz and Passenger seat at 5Hz.

ET2: Tape 7 [unloaded A-2]
Maximum peaks are seen around 1.25&1.6Hz. Maximum acceleration for the passenger seat is around 0.4 m/s^2 and for the driver is around 0.35 m/s^2. In 4-8Hz range, driver is greater than the passenger (being equal at 8Hz), all values being less than 0.2 m/s^2.
Driver to Floor ratio keeps on increasing and decreasing at each frequency interval from 4 to 8Hz. Passenger to Floor decreases from 4 to 6 Hz, increases till 8 and then decreases. Driver to Passenger ratio increases till 5Hz and then decreases till 8Hz.During 4-8Hz, driver is greater than passenger; while at other times it is smaller.
The natural frequency of driver seat seems to be at 5Hz and Passenger seat at 4Hz.

ET2: Tape 9 [loaded A-14]
Lots of high peaks are seen in between 1 to 2 Hz, maximum being at 1.6Hz where both driver and passenger are little larger than 0.25 m/s^2.Between 4-8Hz, driver goes below 0.1 m/s^2 and passenger below 0.15 m/s^2.Both start decreasing from 4 Hz to 6.3Hz and then increase.
D/F as well as P/F ratio increases from 4Hz to 5Hz and then decreases till 10Hz.D/P ratio increases till 6.3Hz and then remains almost constant till 12.5Hz.
Passenger seat acceleration is mostly greater than the driver (except at 6.3-12.5Hz).
The natural frequency of driver seat may be at 2 or 3.15 Hz and Passenger seat at 5Hz.

ET2: Tape 10 [unloaded A-14]
Maximum peaks are seen around 1-2Hz.At 1.25Hz, passenger has maximum acceleration of ~0.54 m/s^2 and driver ~0.36 m/s^2.Passenger is greater than driver at almost all the time except between 5-8 Hz. Between 4-8Hz,driver is below 0.2 m/s^2,decreases till 6.3Hz and increases.
D/F ratio increases from 4 to 6.3Hz and decreases till 12.5Hz.P/F ratio decreases from 4-8Hz.D/P ratio increases from 4 to 6.3 Hz and then decreases till 12.5Hz.
The natural frequency of driver seat may be at 2.5 Hz and Passenger seat at 3.15Hz.

ET2: Tape 12 [unloaded 2-lane]
First set of high peaks are observed at 1.25&1.6Hz, maximum being at 1.25.(Driver =0.32 m/s^2 and passenger=0.36m/s^2).Passenger is greater than the driver at all time except at 8Hz where both are equal. Between 4-8Hz, driver is below 0.17 m/s^2 and passenger below 0.23 m/s^2; decreasing till 6.3Hz and increasing at 8Hz, as seen with other tapes.
D/F ratio decreases from 4 to 5Hz, increases till 8Hz.P/F ratio decreases from 4 to 8Hz.D/P ratio decreases from 4 to 5Hz and then increases till 8Hz.
The natural frequency of driver seat may be at 4Hz and Passenger seat at 2Hz.

Table 15 England Test Result-Estimated Natural Frequencies

Seat	Direction	ET1	ET2
Driver	Horizontal (X-axis)	1.25Hz	1.25Hz
Driver	Horizontal (Y-axis)	2Hz	1.25Hz
Driver	Vertical (Z-axis)	2Hz	2.5Hz
Passenger	Horizontal (X-axis)	2Hz	1.25Hz
Passenger	Horizontal (Y-axis)	1.6Hz	2.5Hz
Passenger	Vertical (Z-axis)	4Hz	5Hz

Table 15 shows the estimated vertical and horizontal natural frequencies for both trucks.

5.2 Poland Data

5.2.1 Individual Vehicle Observations

For all but one vehicle, the passenger provided observations on the type of road condition. Following are the main points from these observations.

PT1: On the first day (Poland), the ride in the truck from the passenger seat was only slightly uncomfortable on 2-Lanes whereas it was comfortable with reasonable acceleration values on 4-lane highway. When the truck stopped for dinner at a truck stop, the drive through the rough parking lot resulted in extreme rocking motion in the seats. On the second day (Germany), the ride was on 4-6 lane highways and was comfortable with reasonable acceleration values.

PT2: The perception of the truck motion was not possible since an operator was not allowed on the truck.

PT3: The trip on this vehicle was the most severe one. An initial segment of the road in Wroclet produced extreme rocking motions as it traveled over brick and stone roads. A one minute value of acceleration was 1.5 m/s^2. The driver had the steering wheel to provide upper body support during the extreme times.

PT4: Though this was one of the best rides, on rougher roads the truck was rough. Within an hour of starting, the passenger's legs got numb. The truck traveled on probably the best section of highway in Poland and the driver had no deadlines that pressed him for time. The vibration levels were as high or higher as any other trucks. The truck had a more uniform ride in the lateral and fore-aft directions.

PT5: It was one of the roughest riding trucks. The truck hit up to 10 degrees of pitch and 7 degrees of roll. The driver had the damper set at the mid-range setting and a lot of relative motion of the driver was noticed. The passenger seat damper was on a low setting and on rougher sections of road the response was high .The lumbar on the passenger seat

felt like it was located too high and the feel was too hard. It's possible the dampers were adjusted to allow relative motion to try to create softer ride.

PT6: It had the lowest numbers overall (with better vertical numbers) but was rougher in the fore-aft directions. The driver drove very conservatively. The passenger seat was a static seat which made the fore-aft ride harsh.

5.2.2 Observations from the data analysis

From the initial data taken from inside the vehicle, the vertical accelerations were found to exceed the EU standards lower value at various times but did not exceed the EU maximum value. The result indicates that drivers can be at risk under certain circumstances and there will be levels of discomfort.

Equipment failure resulted in a loss of driver and passenger floor data on truck PT6. Too high values were found for Passenger floor, exceeding the upper limit in all the cases, whereas the driver floor values were too low. There might have been something wrong in mounting the device itself. These results for PT6 therefore are omitted for the analysis. Floor values in PT1 were also too low in most of the sections thus being discarded. However, good sections have been used in the 1/3rd octave plots to have some idea about the natural frequency and the rotation of the cab.
Though there is not much difference in the overall results processed by these two different processes, with Matlab, however, we were able to cut the files into smaller time segments, thus being able to select only those portions having good data. Therefore, the results from Matlab are considered as the final to be taken for the further analysis.

PT1 was driven on E-30 only (2&4-lane road) on the first day. Road condition varied from rough in the beginning, normal, smoother and then again rougher. Maximum exposure was obtained on the rougher road on the 2-lane. Day 2 data could not be processed due to some error. PT3 was driven on E-67, also 2 and 4- lane road. Again the greater exposures were obtained on the 2-lane roads. PT4 was driven primarily on 4-lane sE-67/8 and later on another 4-lane 1/E75. Maximum exposures were obtained in the beginning, on the asphalt road. PT5 was also driven on sE67/8 (4-lane) and A4 (4, 6-lane), all Asphalt. Higher exposures were on sE67/8, 4-lane.
PT6 day 1 data was omitted due to bad segments. On day 2, it drove mainly on A-9 (4 and 6-lane, mainly concrete) and little bit on A-10 (6-lane, pavement). Higher values were obtained on the 4-lane concrete road.

5.2.2A Observations from the RMS acceleration plots

RMS accelerations along X and Y axes are mostly smaller than the Z axis. However, the passenger seat-X in PT1 suddenly jumps up to 0.55 m/s^2 at the middle suggesting the sudden rise in passenger's rocking motion around Y axis.

Table 13 compares the seat pad weighted a_{RMS} results with the ECE standard. Driver in PT2 and PT3 has crossed the EAV maximum number of times, both for health as well as comfort. PT5 is always below the EAV whereas PT1 and PT6 are above the limit just once.
Talking about passenger, we don't have the data for PT2. Among the rest, PT3 is above the EAV 10 times for health and 7 times for comfort. PT5 is above the EAV 10 times for comfort. None have however reached the upper limit of 1.15m/s^2.
For most of the trucks, seat back exposure is greatest along Z direction and least along Y. For all the trucks, passenger seat back values are little higher than the driver's and also these values are above the seat pad values. Looking at table 14, the driver seat back in PT3 is above the limit maximum number of times (maximum a_{RMS} being 0.7 m/s^2 on a 2-lane road) followed by PT5 (0.66 m/s^2) and PT2 (0.66 m/s^2). Though PT4 is above the EAV only thrice, it has once reached a_{RMS} value of 1.1 m/s^2. The driver seatback is least while driving in sE67/8, but after starting in the next highway (1/E75), it suddenly rises, reaching up to 1.1m/s^2.
For the passenger seat back also, PT3 is above the limit maximum number of times followed by PT5.

We cannot make any comparison between different loading conditions here as most of the trucks were loaded all through. PT2 was loaded and unloaded throughout the night. That may be a reason behind higher exposure in this truck. PT5 was loaded on the first day and unloaded on the next day.

Floor data for PT6 has been discarded and we don't have good results for PT1 either. However, from the 1/3rd octave plots, we can see significant amount of rocking in the passenger seat for PT1. Rest are subjected to rocking of both driver and passenger seat, passenger seat giving higher values in most cases. PT3 shows greater rocking motion in both seats.

The Z-axis has always been critical because of the vertical spinal motion. Z-axis a_{RMS} plots from the Appendix-IV for the Poland test has shown the following information.

PT1: Passenger seat is higher than the driver's (~10-12%) all the time, but never reaches EAV. Seatback values are lower then the seat pads and the driver's back is lower than the passenger's.

PT2: Driver seat crosses the EAV almost half the time reaching up to 0.8 m/s^2. Floor Accelerations are always below the seat pad but they also cross the EAV a couple of times. Passenger seat data is not available as no passenger was allowed to seat. The values crossed the lower limit a couple of times. Driver back was always below 0.4m/s^2.

PT3: The passenger's seat is the highest all the time (up to 33% greater than the driver's), crossing the EAV most of the times. Driver's seat is below 0.6 m/s^2 but goes above 0.5 m/s^2 a couple of times. Floor values are almost equal, little above driver's seat. Seat back values are the lowest; passenger seatback above the EAV once.

We can see higher exposure in 2-lane and lower in 4-lane highway.

PT4: Here the driver's seat is almost double the passenger's seat but it goes above the EAV just once. Passenger is below 0.3 m/s^2 all the time while the floor values lie between 0.3-0.45 m/s^2, passenger floor always leading the driver floor. Seatback values are the lowest.

PT5: Here the passenger's seat is the highest and driver's seat the lowest. Driver floor is in between these two but suddenly goes up to 1m/s^2 at the second segment. Passenger floor and driver's seat are almost same, always below EAV. Seatbacks are the lowest as with other trucks.
Accelerations are little higher in 4-lane highway than the 6-lane highway.

PT6: Driver's and passenger's seat are interestingly the same, mostly below 0.4 m/s^2.Passenger back is the highest, crossing the EAV almost haft the time whereas the driver's back is always below the limit.

5.2.2B Observations from the third octave plots

To better understand the characteristic of the cab that results in the single value of aceleration, the $1/3^{rd}$ octave plots show what frequencies are dominantly causing the weighted singular value, the observations from the plots along Z-axis in Appendix-VII are summarized below:

PT1: Passenger acceleration is higher than the driver almost all the time (both seat and the floor). Acceleration is always below 0.35 m/s^2.Between 4-8Hz, both driver and passenger seat accelerations are below 0.15 m/s^2. Both D/F and P/F ratios decrease from 4-8 Hz. D/P ratio increases from 4Hz to 7Hz and then decreases. The ratio is below 1 till 10Hz.
Looking at the D/F and P/F charts, vertical natural frequency of both driver's seat and passenger's seat could be around 2 Hz.
Looking at the seatback accelerations, driver is higher till 2 Hz and then passenger leads, maximum being around 8Hz. All the values are well below 0.25m/s^2.

PT2: Driver seat is mostly higher than the floor or back. Accelerations are pretty low, all below 0.2 m/s^2.D/F ratio first decreases from 4 Hz and then increases little bit from 7Hz. Vertical natural frequency of the driver's seat seems to be around 2.5 Hz.

PT3: Beyond 2Hz passenger seat is higher than the driver's all the time, staying below 0.3. Passenger and driver floor are mostly equal. D/F ratio first decreases from 4 Hz , remains constant from 5-7HZ and then increases little bit. P/F ratio also decreases till 7Hz and again increases. D/P ratio remains almost constant between 4-8 Hz and is below 1 almost all the time (from 2-70Hz). Vertical natural frequencies of the driver's seat and passenger's seat could be around 1.6 Hz and 4Hz.

Table 16 Poland Test Result -Estimated Vertical Natural Frequencies

Truck	Driver seat	Passenger seat
PT1	2 Hz	2Hz
PT2	3 Hz	-
PT3	1.6Hz	4 Hz
PT4	4-5Hz	2Hz
PT5	1.6Hz	2Hz
PT6	4 Hz	4 Hz

PT4: Here the driver's and passenger seats are almost equal, all below 0.25.Passenger floor is little higher than the driver floor most of the times. D/F ratio decreases from 5-8Hz, whereas P/F decreases from 4-7Hz and then increases a bit. D/P decreases from little beyond 4 Hz to 8 Hz. This ratio is above 1 from 4-6Hz and then remains at 1 till 7 and then decreases below 1.
Vertical natural frequency of the driver's seat could be around 4-5Hz while that of the passengers seat around 2 Hz.

PT5: Till about 2Hz, driver's seat is higher than the passenger's and then the passenger's leads till 10Hz. Both become equal after that. Between 1-2 Hz they have high peaks, driver's acceleration reaching 0.5m/s^2 and passenger 0.4 m/s^2, and then suddenly drop to below 0.2 m/s^2. Seatback values are below 0.25 m/s^2 all the time.
D/F value drops from 4-7Hz. P/F decreases from 4 to 5 and then increases. D/P ratio decreases from 4 Hz to 7 Hz, staying below 1 from 2-10 Hz.
Vertical natural frequencies of the driver's seat and passenger's seat could be around 1.6 Hz and 2 Hz respectively.

PT6: Driver seat is below 0.22 all the time, maximum being around 4Hz. Similar with the passenger's seat. Till 5Hz driver seat is little higher than the passenger and then the passenger leads. Looking at the seatback accelerations, passenger always leads the driver maximum reaching around 0.37 at 4 Hz. D/P ratio decreases from 4-8 Hz. Floor values are discarded for the analysis and so we don't have D/F or P/F plots.
From the seat pad plots however, vertical natural frequencies of the driver's seat and passenger's seat could both be estimated to be around 4 Hz.

Table 16 lists the estimated natural frequencies of the driver's and the passenger's seat based on the ratio charts.

5.2.3 Rotation

Cab suspension resulted in constant rotation. The rotational transducer's data was not processed but from the waveforms via Famos we could see the significant amount of rotation (up to ±25 degrees) in X and Y directions.
Higher rotations have been observed in X direction. Figure 27 illustrates an example of the rotation waveform along X direction.

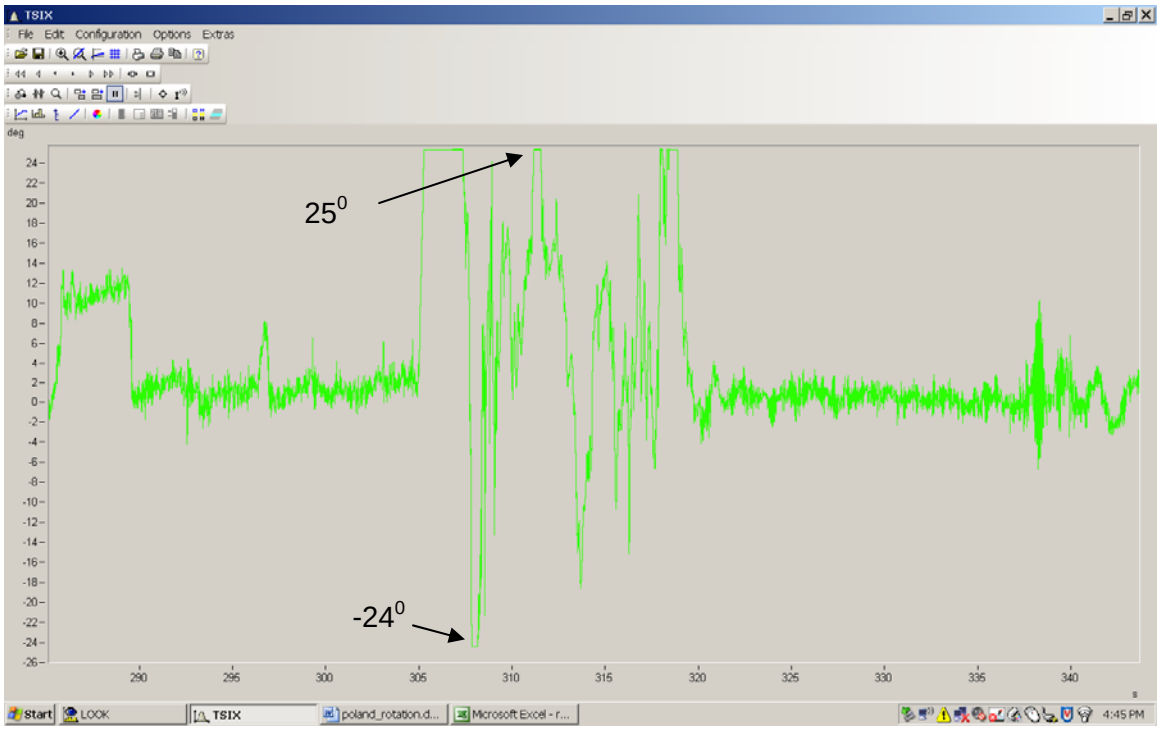


Figure 27 Cab Rotation

Selected rotation plots are given in Appendix-IX. Based on those plots, the natural frequency of the cab suspension was below or equal to 1Hz in most of the cases.
It has been found that trucks often have their axle suspension natural frequencies between 1 and 2 Hz and the cab suspension natural frequency is usually designed to be between 2 and 3 Hz. [26]
In our case, it seems that the natural frequencies of the suspensions were close together, thus amplifying the road input at the same frequency range giving rise to such level of rotations and jerks.

5.2.4 VDV analysis

VDVs for all the trucks average between 4-5 $m/s^{1.75}$(after scaling up the values to 8-hr). Average weighted VDVs for all the trucks are given in table 17. Figure 28 and 29 show the variation of the driver and the passenger seat VDV along the time segments for all the trucks. Looking at these plots, driver seat is above the EAV of 9.1 $m/s^{1.75}$ a couple of times in PT2, PT3 and once in PT5. Passenger seat is above this limit quite a lot of time in PT3. PT1 and PT5 have crossed the EAV along horizontal direction too. None have however reached the upper limit of 21 $m/s^{1.75}$ specified by the ECE directive. Selected individual VDV plots for all the trucks are given in Appendix-VIII.

Figure 30 compares the estimated VDV with the real VDV for the driver seat.

Table 17 Poland Test Result-Average Weighted VDV

Truck	Driver seat			Passenger Seat		
	X	Y	Z	X	Y	Z
PT1	4.2	4.3	3.9	7.2	4.2	4.0
PT2	4.7	4.8	7.2	-	-	-
PT3	4.0	3.8	7.8	4.0	4.0	11.5
PT4	3.9	3.8	3.8	4.5	3.9	3.7
PT5	4.0	3.9	4.7	3.9	5.5	3.9
PT6	3.4	3.8	3.6	3.5	3.5	3.4
Average	*4.0*	*4.0*	*5.2*	*4.6*	*4.2*	*5.3*

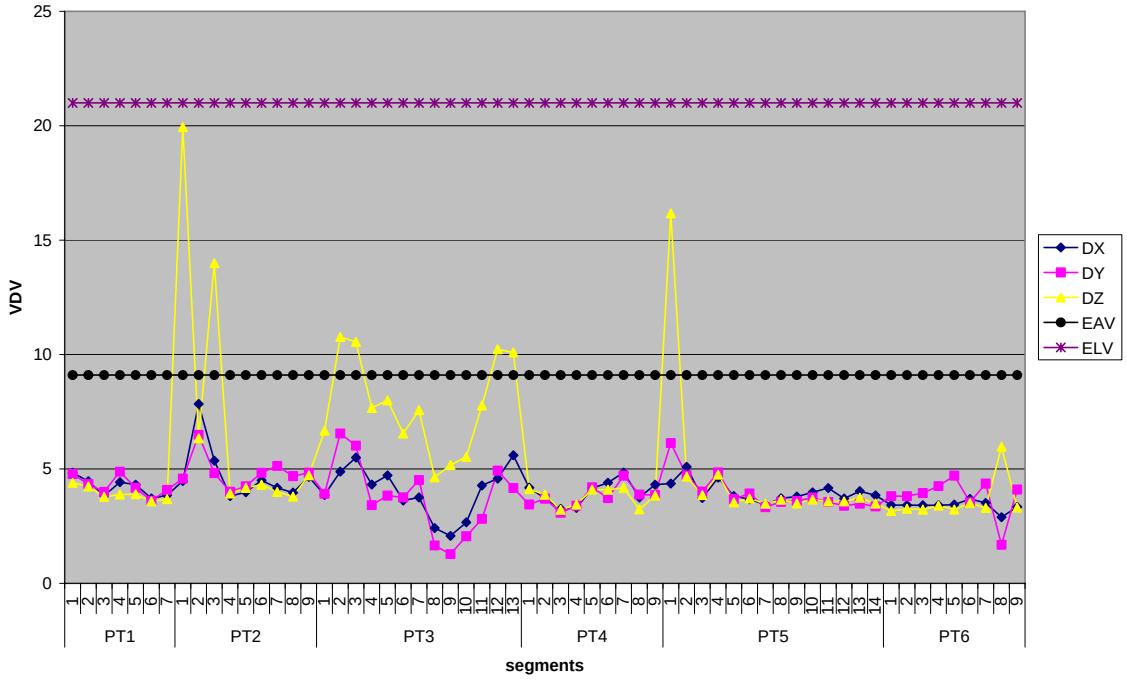


Figure 28 Driver Seat's weighted VDV-Poland test

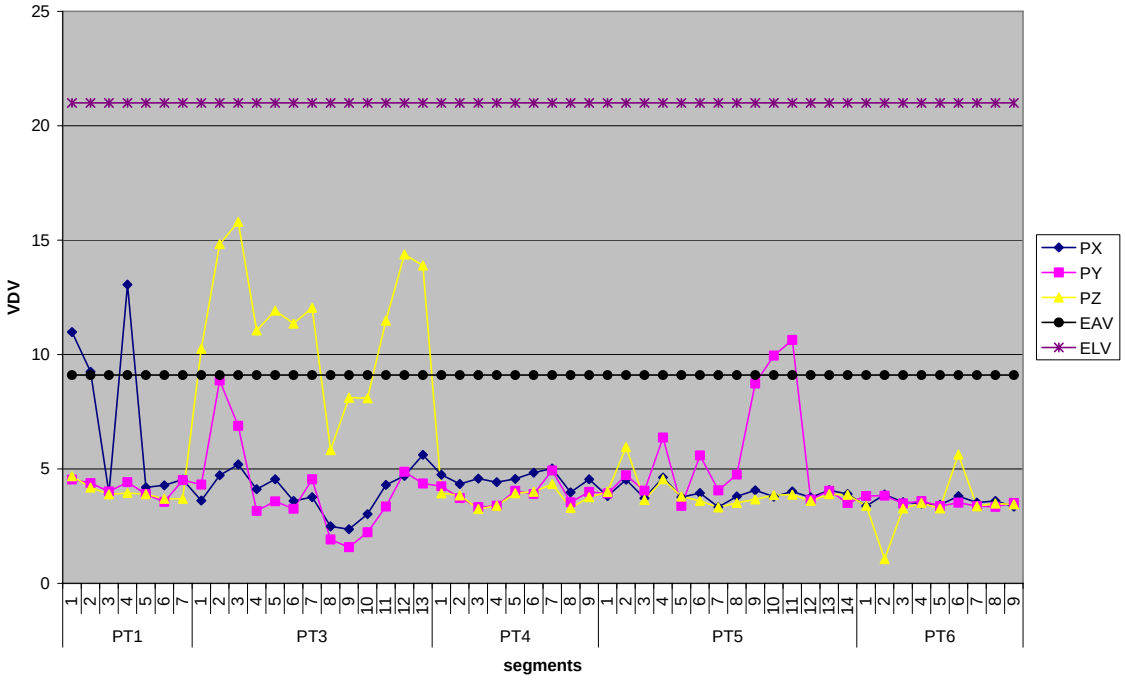


Figure 29 Passenger seat's weighted VDV

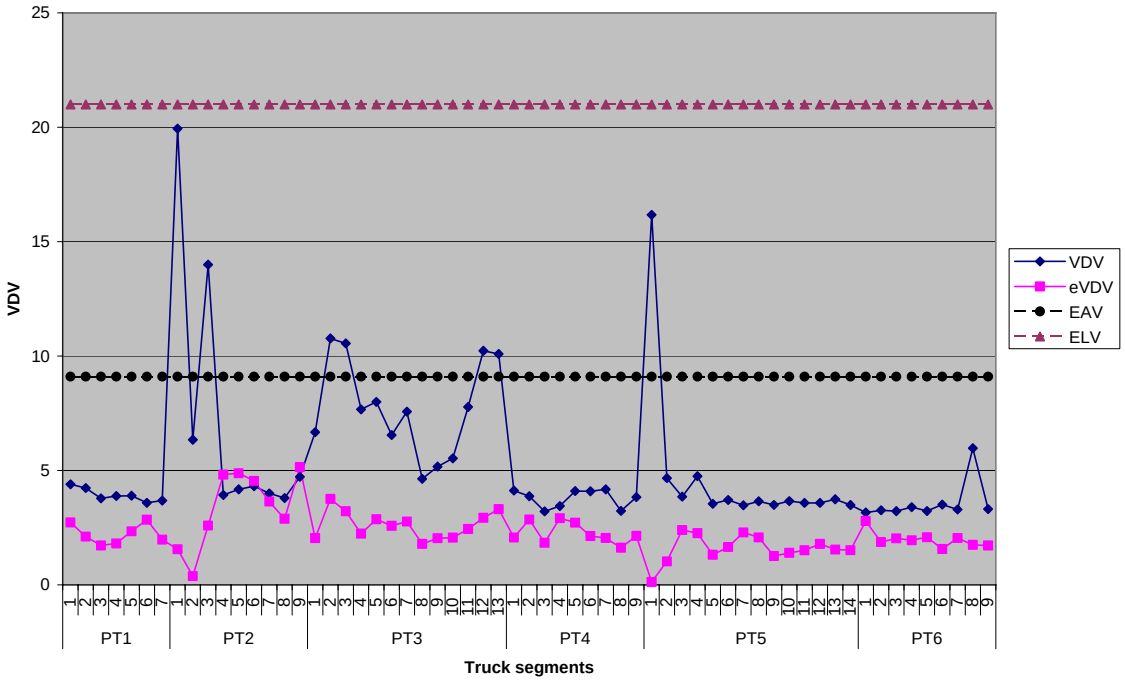


Figure 30 VDV vs. eVDV comparison

The estimated VDVs are too low as compared to the real VDVs. The average vertical eVDV is almost half the real VDV, averaging around 2.3-2.5 $m/s^{1.75}$. PT2 and PT5 show some high peaks suggesting shocks. Lower eVDV values at those points suggest that the driver was driving cautiously with low speed but got sudden jolts resulting in high VDV peaks.

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. [18]

Table 18 shows the average jerk values for all the trucks that are plotted in Figure 31 and 32. Looking at the driver's seat , X axis is the highest and Z is the least for all but PT5. This means that there is more fore-aft followed by side to side jerk than up down.
PT6, PT5 and PT2 show comparatively higher jerks in all directions.
Passenger seat also gives higher jerk along X and least along Z for all except PT5 and PT4. PT5 and PT4 show higher jerk in the vertical direction.

Individual jerk plots in Appendix-X show too much variation in the rate suggesting that the driver might have decreased muscular ability to bear the continuous vibration exposure.

Table 18 Poland Test Result-Jerk

Truck	Driver seat			Passenger seat		
	X	Y	Z	X	Y	Z
PT1	65.8	50.8	21.9	97.5	51.8	23.2
PT2	124.9	98.4	58.1	-	-	-
PT3	71	66.7	24.6	86.3	62.3	37.1
PT4	58.2	50.8	22.6	33.9	52.3	90.5
PT5	94.4	111.9	36.7	85	35.2	126.8
PT6	144.3	108.7	52.1	135.4	74	73

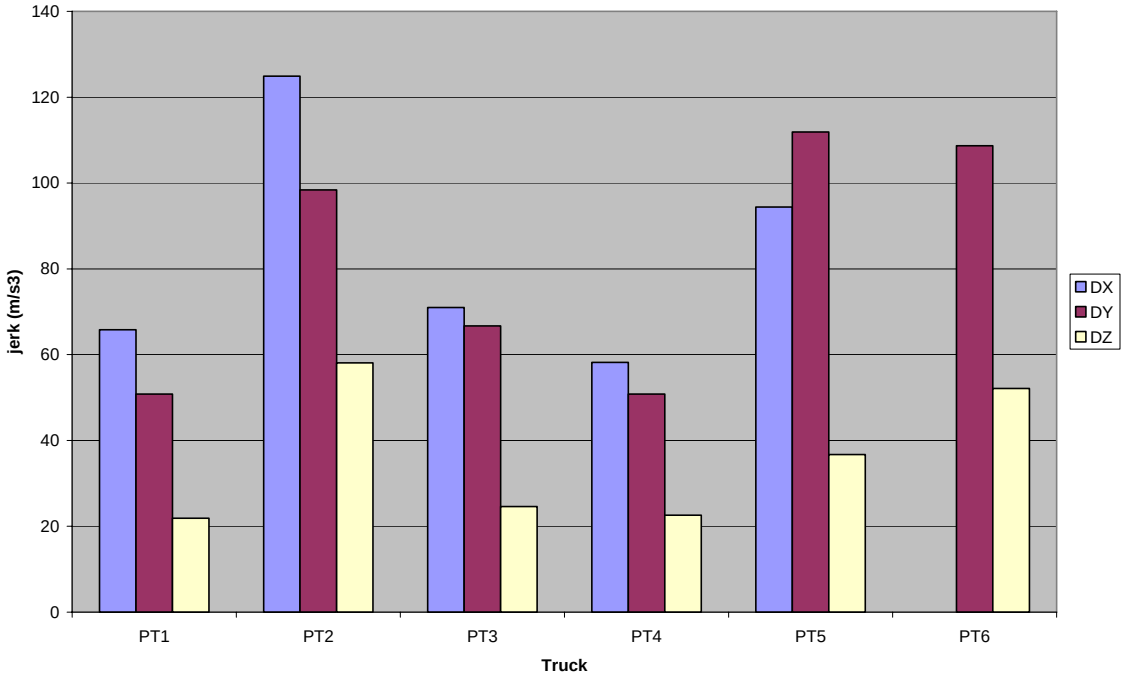


Figure 31 Driver Seat average jerk-Poland

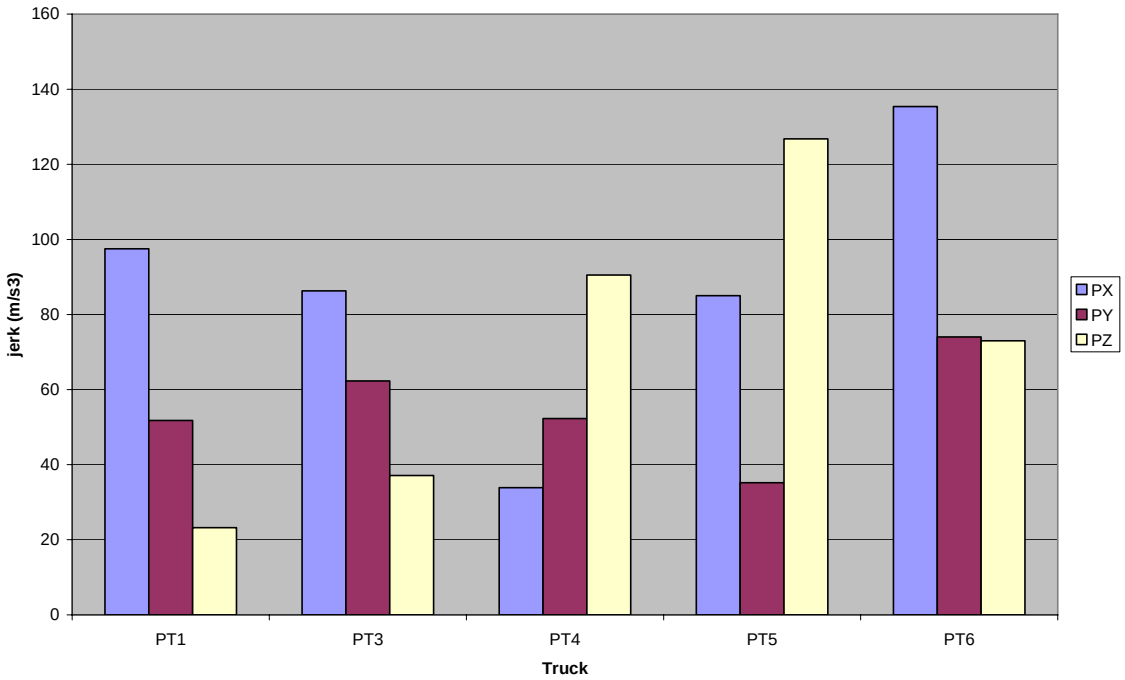


Figure 32 Passenger seat average jerk-Poland

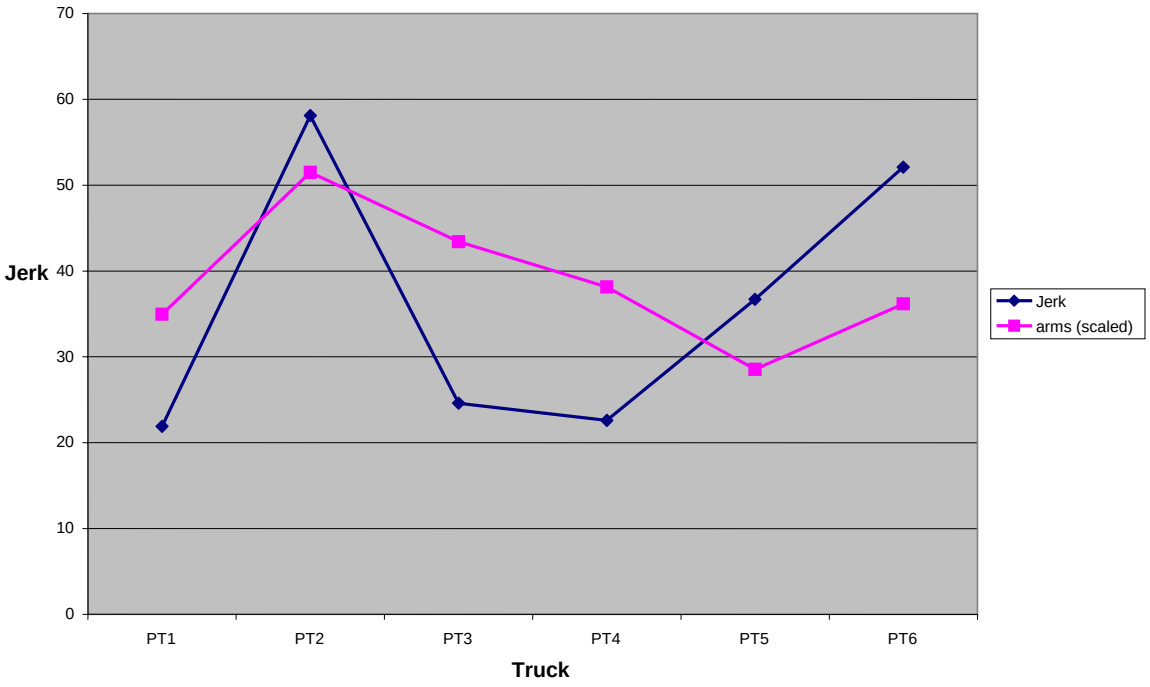


Figure 33 Jerk vs. weighted a_{RMS} comparison-Poland

If we compare the average jerk values with the weighted a_{RMS} (scaled up by 100) values for different trucks, it can be seen (Figure 33) that a_{RMS} is more or less proportional to the jerk. Thus, the higher jerk rate means greater exposure. This can be another way of measuring the exposure but no reference is available as per the limit of the jerk value that is acceptable.

5.2.6 Comparing results from different processors

In Poland we have used three different processors to process the test data. Figure 34 shows a comparison among them for the driver seat a_{RMS}.

In all cases HVM gave the highest values. Even for the England data, we had got similar results (Figure 35). This was because of the use of a modified filtering in HVM which is not in the current acceptable level. For PT1, PT2 and PT4, Famos results are higher than Matlab whereas for the rest, Matlab result is little higher.

However, we cannot really conclude on the basis of this as each of the processors had its own limitations and the sizes of the data processed were also different.
With Matlab, however, we were able to cut the files into smaller time segments, thus being able to select only those portions having good wave pattern.

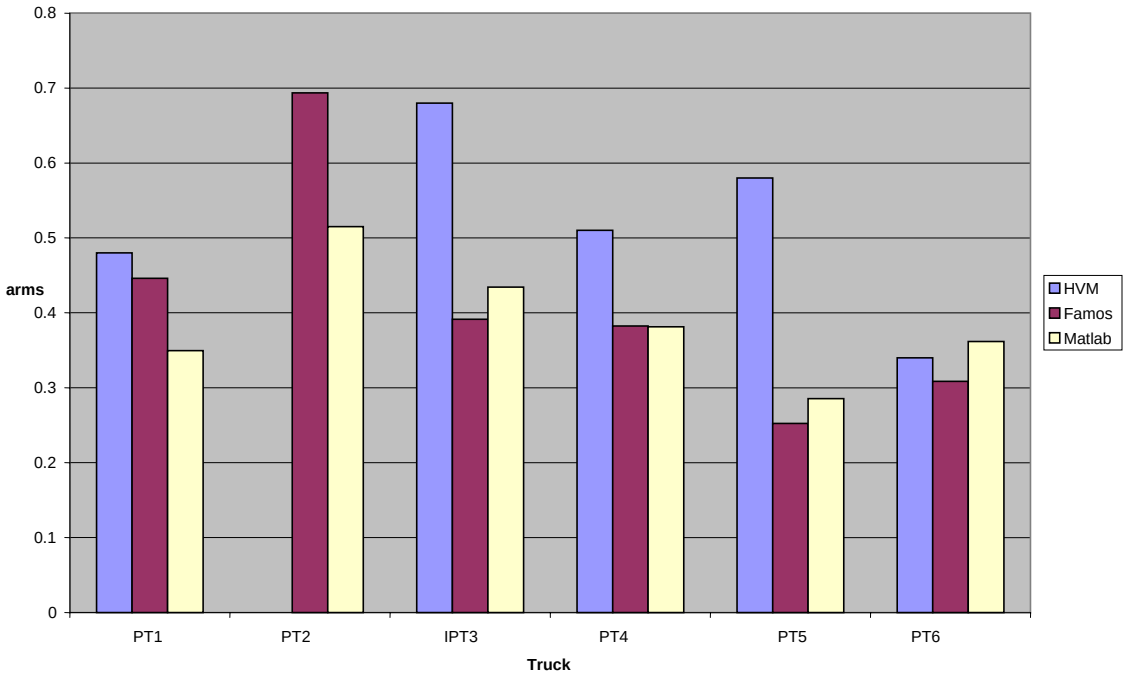


Figure 34 Driver seat pad weighted a_{RMS} with different processors-Poland test

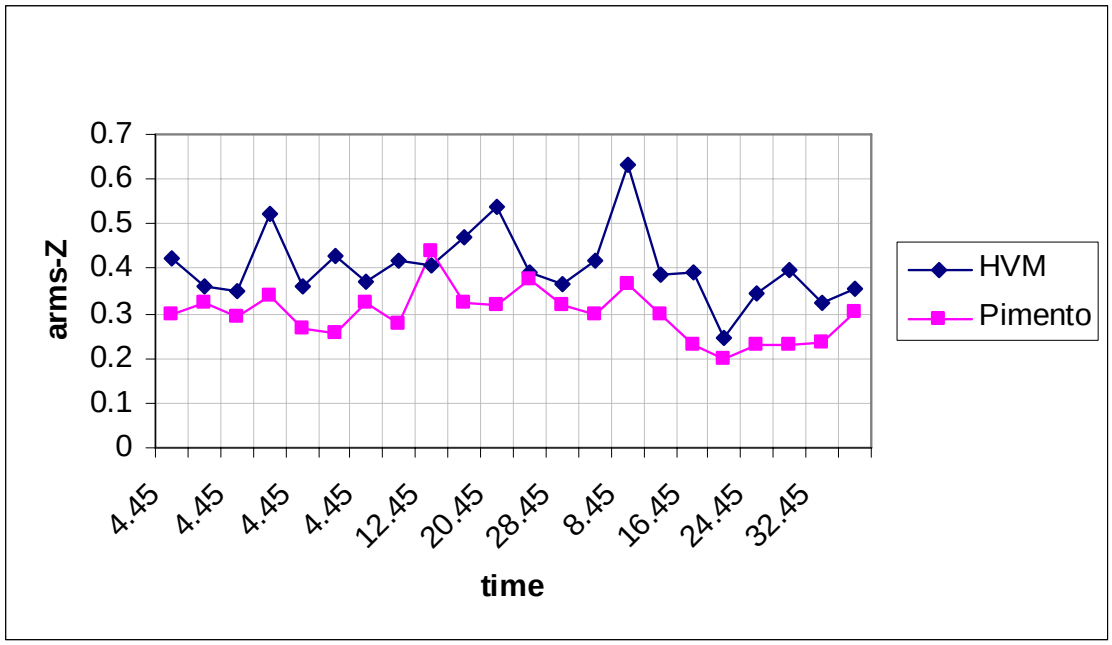


Figure 35 HVM vs. Pimento Comparison-ET3 England test

5.3 Comparing Trucks in England and Poland

One of the trucks used in Poland was by the same manufacturer in England, but the trucks were different. The truck in Poland had been made to deliver only gasoline whereas the truck in England was a typical long hail configuration. Figure 36 shows the driver and passenger exposure in this truck at two different test sites.

Though the average accelerations may be little less, we can see that, the passenger seat for the Poland truck has crossed the action value a couple of times and it has steeper curves suggesting more severe exposure. It seems that the Poland truck had a rougher ride.

In overall, driver was exposed to higher levels of vibration in Poland. England data showed little more instances where the passenger seat exceeded the EAV for comfort but it did not reach the values as high as Poland. England data was processed for every 4 minute time interval resulting in numerous data for each tape. Poland data had much less segments for each truck and also lots of bad segments were removed.

To conclude, Poland data gave higher vibration exposure than the England data which correlated to the much wider range of road roughness

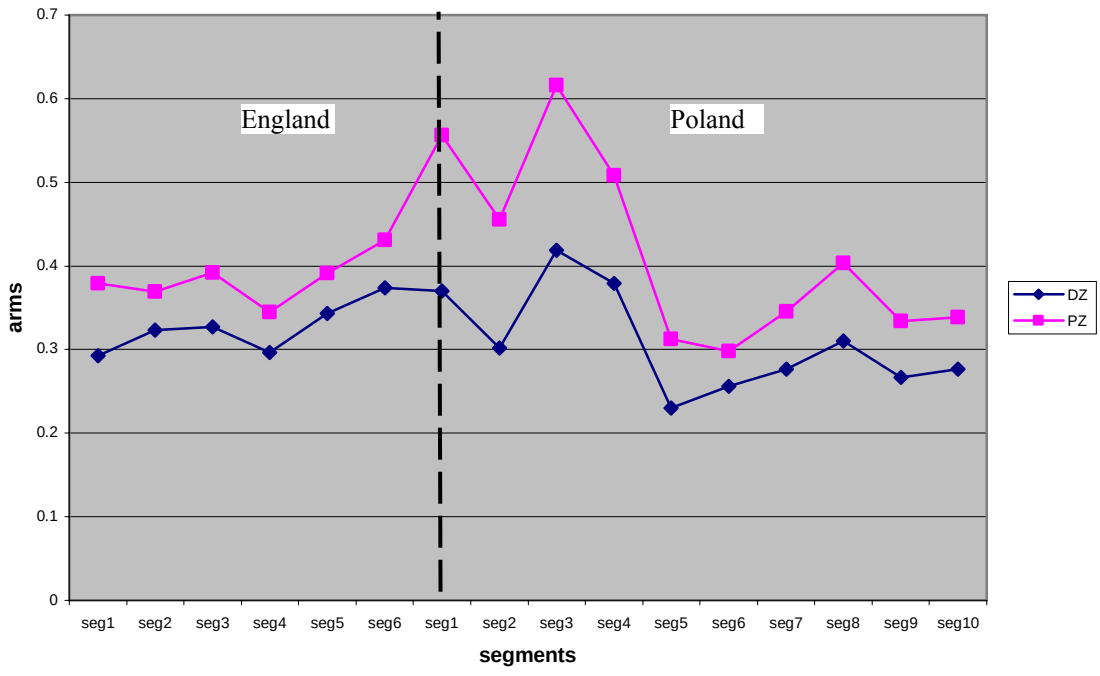


Figure 36 England vs. Poland truck comparison

Chapter-6 Conclusion and Recommendations

The type of road was found to be a primary factor, which influences the driver's vibration exposure. As expected, smoother roads gave a lower level of acceleration exposure. Ride on the 2-lane roads transmitted greater exposures in all cases. Load was another factor. Most of the time, increase in truck load dampened the vibration.

Driver was found to be safe as per ECE directive but the comfort levels were often exceeded. For both studies, the level of comfort was in 'fairly uncomfortable' range. Though safe with respect to health, the feeling of uncomfortable may hamper the driver's performance and ability to control the vehicle. So the necessary action should be taken to increase the comfort.

Various factors could lead to driver's uncomfort besides the aforementioned ones. A survey on the European trucks could provide better understanding in this matter.

In overall, the vibration exposure was found to be little higher in Poland data. The level of exposure could be more, given to the fact that the driver was trying to minimize the exposure by changing his sitting posture, stiffening his body and sometimes firmly holding the steering. Also, lots of bad data have been discarded in the analysis.

Significant amount of cab rotations have been found. This could be due to improper orientation of the center of rotation or the natural frequency of the cab suspension being close to that of the truck suspension itself. These rotations, along with the vibration exposure adds to the injury and discomfort to the driver. Better orientation of the cab suspensions may help to reduce the rotation.

While collecting data, proper positioning of the various transducers was a major problem. Transducers capable of measuring all 6 DOF would be the best way to measure the translational as well as rotational exposure due to vibration. However, validity of the rotational sensors above 2-3 Hz is still under study.

Similarly, lots of jerk have been found in the Poland trucks mainly in fore-aft followed by side to side direction. Severe jerks might have reduced the ability of the muscles to bear the high vibration exposures. Jerk, mostly being proportional to the 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.

Data can be processed in different ways, with different processors. Selection of the suitable processor depends on many things like frequency range, sensitivity, and of course price. However, each of them could give different error and thereby different results. So we can't really compare the results from England study with the Poland study as they were analyzed with completely different type of processors. Poland results may be compared but again, each of the processors had its own limitations and the sizes of the data processed were different.

In the Poland study, we obtained some strange a_{RMS} values for some trucks, but when we went back and looked at the waveforms, it showed erroneous peaks suggesting that there was something wrong in the recorded data itself. This resulted in a loss of some important data. It would be better to look at the waveforms and discard the bad data before processing. Even better idea would be to check the waveforms during recording the data itself, if possible.

WBV exposure to the passenger has been found higher in all cases. In most of the cases, passenger did not have air-ride seat. There should be concern to reduce these levels and increase comfort for the passenger seat as well. Use of multiple drivers is also being thought of.

Though the study was done with different kinds of trucks and variety of roads, seat suspensions and type of seats didn't vary much. These could be some of the major factors affecting the vibration exposure. Climate, which affects the road condition, could also be another significant factor. Both sets of data were recorded in comparatively cold climates. If we can get next set of data from a warmer place, a comparison could be done between totally different climates and some conclusion could be made as per the role of climate on the levels of exposure.

A lot of study has been done to relate WBV with low back pain. But a recent survey has shown that majority of drivers have problems on their neck and shoulder too. So it is equally important to give focus on those parts and try to seek remedy to minimize the complaints.

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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   Link: http://www.dliengineering.com/vibman/

6. "Online Lectures on Frequency Analysis& Human Vibration" SafetyLine Institute -visited on June 2006.
   Links:
   http://www.safetyline.wa.gov.au/institute/level2/course18/lecture54/l54_08.asp
   http://www.safetyline.wa.gov.au/institute/level2/course18/lecture54/l54_09.asp
   http://www.safetyline.wa.gov.au/institute/level2/course19/lecture61/l61_02.asp

7. "Spectrum and Octave band"-visited on July 2006.
   Link: http://personal.cityu.edu.hk/~bsapplec/spectrum.htm

8. "TEAC RD 145T" Gracey& Associates Hire - visited on Feb 06.
   Link: http://gracey.com/descriptions/teac-145-d1.htm

9. "The Physical Agents (Vibration) Directive", Health and Safety Executive (HSE) -visited on June 2006.
Link: http://www.hse.gov.uk/vibration/

10. "Vibration - Measurement, Control and Standards" Canada's National Occupational Health& Safely Resources - visited on July 06.
Link:
http://www.ccohs.ca/oshanswers/phys_agents/vibration/vibration_measure.html

11. "Vibration Meter HVM 100" Larson Davis -visited on Jan 06.
Link: http://www.larsondavis.com/

12. "Whole body Vibration", Association of Societies for Occupational Safety and Health (ASOSH) -visited on Jan 2006.
Link: http://www.asosh.org/TopicSpecific/wholebody_vibration.htm

APPENDICES

Appendix I: RMS acceleration results- England

Table 19 England Test Results-Driver, Passenger and Floor weighted a_{RMS}

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET1	2	4.45	1	0.1529	0.156	0.2157	0.0761	0.3546	0.1202	0.1362	0.3099	M-25	unloaded
		12.45	1	0.1481	0.1473	0.2675	0.0617	0.3513	0.1132	0.1403	0.3601		
		16.45	1	0.1208	0.1138	0.1398	0.062	0.2349	0.1089	0.1021	0.1702		
		20.45	1	0.1365	0.1363	0.2316	0.0621	0.2951	0.1229	0.1254	0.3181		
		24.45	1	0.1604	0.1812	0.2273	0.062	0.3804	0.1118	0.1244	0.3346		
		28.45	1	0.149	0.1363	0.2337	0.062	0.3237	0.1038	0.1249	0.2561		
		36.45	1	0.1577	0.163	0.2323	0.0616	0.428	0.1151	0.1444	0.3301		
		40.45	1	0.1544	0.1489	0.1681	0.0874	0.246	0.1187	0.1391	0.2309		
		4.45	2	0.2008	0.175	0.2416	0.1066	**0.5034**	0.1451	0.1747	0.3139	2 lane	unloaded
		8.45	2	0.1893	0.1477	0.2306	0.0759	0.345	0.1196	0.1521	0.2954		
		12.45	2	0.1481	0.1054	0.2546	0.0619	0.2854	0.0957	0.1205	0.2499		
		16.45	2	0.1519	0.1321	0.2119	0.0616	0.3688	0.1062	0.1215	0.2724		
		4.45	3	0.205	0.1816	0.286	0.0761	0.4351	0.1708	0.1695	0.3892		
ET1	3	4.45	1	0.1809	0.1579	0.3399	0.1687	0.3637	0.1055	0.1316	0.3479	2 lane	unloaded
		8.45	1	0.1636	0.1367	0.2955	0.1229	0.339	0.1	0.1371	0.2928		
		4.45	2	0.1547	0.1393	0.2751	0.1944	0.3399	0.1287	0.126	0.2855		
		8.45	2	0.1731	0.1432	0.3973	0.1959	0.2317	0.1267	0.1553	**0.5665**		
		8.45	6	0.1599	0.1985	0.3077	0.2532	0.4187	0.1464	0.1693	0.3786		
		12.45	6	0.1563	0.1688	0.237	0.1916	0.3112	0.1397	0.1345	0.2391		
		4.45	7	0.1525	0.1317	0.3131	0.1616	0.3542	0.121	0.1082	0.3373	2 lane	loaded
		8.45	7	0.1513	0.1979	0.3075	0.1988	0.3664	0.1305	0.1457	0.345		
		12.45	7	0.1657	0.1678	0.3832	0.1929	0.444	0.1361	0.1376	0.4826		
		16.45	7	0.1783	0.1547	0.3109	0.206	0.3619	0.1376	0.1362	0.3691		
		20.45	7	0.1907	0.1833	0.3967	0.2216	**0.5132**	0.1549	0.1528	0.4197		
		24.45	7	0.1713	0.1551	0.3878	0.2261	0.497	0.1474	0.1304	0.4476		
		28.45	7	0.1404	0.1504	0.3055	0.1808	0.3533	0.1261	0.1403	0.4032		
		4.45	8	0.2087	0.1286	0.4104	0.1881	0.4379	0.1342	0.1162	0.4228	M-43	loaded
		8.45	8	0.2106	0.1718	**0.5873**	0.28	**0.5777**	0.1854	0.1326	**0.5486**		
		12.45	8	0.1403	0.1384	0.2918	0.1566	0.3443	0.1269	0.1218	0.3599		
		16.45	8	0.1211	0.1237	0.2178	0.1434	0.2665	0.1072	0.1088	0.2826		
		20.45	8	0.1075	0.1243	0.2112	0.1229	0.2106	0.0916	0.1071	0.2201		

Table 19 contd…

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET1	3	24.45	8	0.1568	0.1425	0.2561	0.1634	0.2678	0.1063	0.1142	0.2589	M-43	loaded
		28.45	8	0.1071	0.1159	0.2152	0.1179	0.2356	0.0957	0.111	0.259		
		32.45	8	0.1351	0.1313	0.2021	0.1393	0.2477	0.1077	0.1131	0.2306		
		36.45	8	0.1399	0.1359	0.2362	0.1753	0.3051	0.1135	0.1006	0.2523		
		40.45	8	0.1707	0.12	0.2559	0.161	0.3173	0.1119	0.1019	0.2426		
		44.45	8	0.1101	0.1213	0.2677	0.1214	0.3197	0.1054	0.1101	0.3037		
		48.45	8	0.1569	0.1222	0.2674	0.1854	0.3208	0.116	0.0981	0.3045		
		52.45	8	0.1637	0.1429	0.3293	0.1758	0.3472	0.1319	0.1205	0.3744		
ET1	4	4:45	1	0.1477	0.1187	0.2874	0.1818	0.3592	0.1311	0.1469	0.4065	M-43	loaded
		8:45	1	0.1477	0.1112	0.3053	0.1479	0.3211	0.1069	0.1047	0.3276		
		12:45	1	0.151	0.1358	0.3065	0.1899	0.3477	0.1086	0.1124	0.3679		
		4:45	3	0.0866	0.0787	0.2565	0.1198	0.295	0.0881	0.0796	0.2633		
		8:45	3	0.0771	0.0772	0.2291	0.1097	0.2663	0.0732	0.0723	0.2593		
		12:45	3	0.1907	0.1215	0.3212	0.1812	0.3297	0.1164	0.1062	0.3454		
		16:45	3	0.1162	0.1101	0.2701	0.1349	0.3598	0.0967	0.1037	0.3281		
		20:45	3	0.1428	0.1166	0.2503	0.1255	0.2657	0.0971	0.1017	0.2621		
		24.45	3	0.2035	0.1063	0.3107	0.2053	0.3206	0.1219	0.1069	0.35		
		28.45	3	0.1632	0.0975	0.2963	0.1608	0.3873	0.1055	0.0799	0.3514		
		32.45	3	0.1188	0.1015	0.2671	0.1489	0.3082	0.0919	0.0885	0.288		
		36.45	3	0.1026	0.1188	0.2394	0.1442	0.2712	0.1026	0.1043	0.3012		
		40.45	3	0.2311	0.1344	0.3442	0.2212	0.4279	0.1571	0.1363	0.4949		
		44.45	3	0.1596	0.1454	0.3024	0.1919	0.4057	0.1197	0.1123	0.3731		
		4:45	4	0.1498	0.1881	0.3714	0.1899	0.4553	0.1304	0.1579	0.4271		
		8:45	4	0.1564	0.1872	0.3644	0.1829	**0.519**	0.1127	0.145	0.4354		
		12:45	4	0.2313	0.1682	0.4977	0.2391	**0.7413**	0.1624	0.1484	**0.5406**		
		4:45	5	0.2252	0.2591	**0.5384**	0.2382	**0.5824**	0.1467	0.1715	0.4833		
ET1	5	4.45	1	0.1771	0.1349	0.267	0.1629	0.2972	0.1574	0.1143	0.2987	M-25	loaded
		8.45	1	0.1247	0.1475	0.3319	0.1713	0.4695	0.1189	0.1427	0.3872		
		12.45	1	0.1131	0.1384	0.2755	0.1546	0.3411	0.0855	0.1075	0.2999		

Table 19 contd…

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET1	5	16.45	1	0.1163	0.1285	0.2487	0.1366	0.3995	0.1042	0.1101	0.2706	M-25	loaded
		20.45	1	0.1485	0.2009	0.4107	0.1903	**0.5637**	0.1293	0.1675	0.4898		
		24.45	1	0.1299	0.1411	0.3092	0.1879	0.4923	0.0935	0.1173	0.3454		
		28.45	1	0.1924	0.1557	**0.5129**	0.1789	**0.7927**	0.1479	0.139	**0.613**		
		32.45	1	0.1368	0.1451	0.3565	0.1593	0.4168	0.0948	0.1139	0.3527		
		36.45	1	0.1238	0.1797	0.3785	0.2172	**0.5924**	0.1315	0.1808	0.4805		
		40.45	1	0.1049	0.1364	0.3174	0.1496	**0.5003**	0.0749	0.1184	0.3787		
		44.45	1	0.1778	0.1619	0.4357	0.1915	**0.6657**	0.1311	0.154	**0.6178**		
		48.45	1	0.2066	0.2149	0.5334	0.2949	**0.7796**	0.1579	0.1725	**0.6441**	M-25	Cab only
		52.45	1	0.1546	0.2286	0.3884	0.2606	**0.5377**	0.1613	0.1848	0.4933		
ET2	6	4.45	1	0.1289	0.1682	0.2022	0.1593	0.2608	0.1366	0.1731	0.194	A-120	loaded
		8.45	1	0.2324	0.1463	0.3202	0.2369	0.4308	0.1999	0.1369	0.3285		
		12.45	1	0.292	0.2103	0.393	0.2977	**0.5545**	0.2316	0.1814	**0.5255**		
		4.45	2	0.1971	0.1581	0.2836	0.2304	0.4712	0.185	0.1586	0.4637		
		8.45	2	0.1595	0.0992	0.2437	0.1202	0.3189	0.1303	0.0772	0.3078		
		12.45	2	0.2897	0.1922	0.3149	0.2973	0.4647	0.1926	0.1569	0.4655		
		16.45	2	0.1692	0.1156	0.2281	0.1448	0.3099	0.1216	0.1007	0.2786		
		20.45	2	0.2248	0.1563	0.3391	0.1629	0.4357	0.1559	0.1066	0.3287		
		24.45	2	0.1731	0.1655	0.2916	0.1615	0.389	0.1324	0.1215	0.3122		
		28.45	2	0.1563	0.1773	0.2714	0.1809	0.3819	0.1256	0.131	0.3075		
		32.45	2	0.2272	0.1277	0.3885	0.1647	0.4799	0.1763	0.0915	0.3763		
		36.45	2	0.1987	0.1548	0.2421	0.1556	0.3126	0.1304	0.1068	0.2556		
		40.45	2	0.1793	0.1214	0.3317	0.1829	0.4278	0.1618	0.0972	0.452		
		44.45	2	0.2036	0.1256	0.3596	0.191	0.4544	0.1679	0.1087	0.41		
		48.45	2	0.2326	0.1562	0.351	0.1867	0.4133	0.1723	0.1213	0.4132		
		52.45	2	0.1475	0.1456	0.2264	0.1606	0.2709	0.113	0.1035	0.239		
		56.45	2	0.1391	0.1652	0.2383	0.1502	0.2672	0.124	0.1128	0.2101		
		60.45	2	0.1613	0.1146	0.2599	0.1285	0.3066	0.1337	0.0824	0.2719	M-25	loaded
		64.45	2	0.1459	0.1203	0.2301	0.1526	0.2647	0.1051	0.0955	0.2122		

Table 19 contd…

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET2	6	68.45	2	0.2068	0.1321	0.3237	0.1959	0.4377	0.1613	0.1105	0.3127	M-25	loaded
		72.45	2	0.1464	0.1816	0.2726	0.2469	0.4414	0.1574	0.1449	0.3		
		80.45	2	0.1737	0.123	0.2541	0.1538	0.3116	0.1516	0.099	0.2937		
		84.45	2	0.1574	0.1231	0.2814	0.1386	0.3466	0.1462	0.097	0.3033		
		88.45	2	0.1476	0.1278	0.2388	0.167	0.2869	0.134	0.1037	0.2781		
		92.45	2	0.242	0.1362	0.3233	0.1726	0.3831	0.1474	0.1054	0.3432		
		96.45	2	0.283	0.1809	0.3708	0.2055	0.47	0.182	0.1361	0.3703		
		100	2	0.2215	0.1664	0.315	0.197	0.3794	0.1654	0.1224	0.3338		
		104	2	0.19	0.1361	0.2975	0.146	0.3449	0.1398	0.0937	0.298		
ET2	7	4.45	1	0.1792	0.1641	0.3531	0.1887	0.4528	0.2152	0.1345	0.3817	M-25	loaded
		8.45	2	0.2101	0.2272	0.46	0.2732	**0.5467**	0.2619	0.1797	0.49	M-25	unloaded
		12.45	2	0.13	0.1452	0.2811	0.1507	0.3173	0.139	0.109	0.2857	M-23	unloaded
		16.45	2	0.099	0.1237	0.2578	0.1298	0.2802	0.1075	0.1016	0.2454		
		20.45	2	0.1652	0.1938	0.4115	0.1876	0.4274	0.1912	0.1373	0.3483		
		24.45	2	0.1704	0.1788	0.357	0.2121	0.4079	0.1713	0.1388	0.353		
		28.45	2	0.1727	0.19	0.3425	0.2053	0.4188	0.2096	0.131	0.3438		
		32.45	2	0.1047	0.1124	0.2612	0.1274	0.2817	0.1177	0.088	0.242		
		36.45	2	0.1777	0.1292	0.412	0.2338	0.4571	0.1752	0.1001	0.3828	M-26	unloaded
		40.45	2	0.1523	0.1581	0.3216	0.1928	0.4013	0.1479	0.1257	0.3242		
		44.45	2	0.1379	0.1485	0.3597	0.1948	0.4066	0.1593	0.1222	0.3758		
		4.45	3	0.1226	0.1677	0.2223	0.1665	0.2828	0.1527	0.1429	0.2806	A-228	unloaded
		8.45	3	0.1378	0.1723	0.2811	0.2001	0.3303	0.1613	0.1447	0.3007		
		4.45	4	0.1313	0.1727	0.3184	0.1526	0.3614	0.146	0.1228	0.2836	M-2	unloaded
		4.45	5	0.1379	0.1434	0.31	0.1583	0.3165	0.1629	0.1161	0.2961	A-2	unloaded
		8.45	5	0.1431	0.1824	0.31	0.167	0.3187	0.1864	0.1489	0.2723		
		12.45	5	0.1349	0.1561	0.2625	0.1635	0.3238	0.1826	0.1163	0.2651		
		16.45	5	0.1389	0.1755	0.2368	0.1501	0.28	0.1644	0.1411	0.2553		
		20.45	5	0.1475	0.1751	0.3709	0.1968	0.4265	0.1862	0.147	0.3643		
		4.45	6	0.1402	0.1455	0.283	0.1721	0.3195	0.1421	0.1142	0.3346		
		8.45	6	0.1252	0.1478	0.3074	0.1454	0.3269	0.149	0.1105	0.3117		
		12.45	6	0.1591	0.1858	0.4249	0.2065	0.4959	0.2031	0.1388	0.4186		
		16.45	6	0.1744	0.1691	0.3091	0.1894	0.3293	0.2408	0.1321	0.2739		

Table 19 contd…

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET2	7	20.45	6	0.1387	0.1737	0.3578	0.1773	0.3666	0.1909	0.1946	0.3232	A-2	unloaded
		4.45	7	0.1396	0.2137	0.2723	0.1727	0.349	0.1757	0.165	0.253		
ET2	9	4.45	1	0.2217	0.1558	0.2842	0.2402	0.3334	0.1692	0.1136	0.3186	A-14	loaded
		8.45	1	0.2162	0.1475	0.3151	0.2175	0.3722	0.1561	0.1089	0.3302		
		12.45	1	0.2922	0.1556	0.3415	0.2632	0.3402	0.1933	0.1215	0.3284		
		16.45	1	0.2136	0.1511	0.2888	0.2132	0.2928	0.156	0.125	0.2599		
		20.45	1	0.2259	0.1715	0.3063	0.2171	0.3969	0.2057	0.1194	0.3368		
		24.45	1	0.2285	0.1975	0.2939	0.2658	0.3565	0.2021	0.1367	0.3148		
		28.45	1	0.2448	0.1795	0.3024	0.2414	0.3823	0.1933	0.1146	0.3444		
		32.45	1	0.2908	0.1824	0.3506	0.2728	0.3614	0.1871	0.137	0.3191		
		36.45	1	0.2347	0.166	0.3218	0.2407	0.4044	0.2167	0.1247	0.4575		
		40.45	1	0.2217	0.1388	0.2665	0.193	0.3172	0.1457	0.1073	0.2531		
		4.45	2	0.16	0.1499	0.2994	0.1784	0.3463	0.1867	0.1149	0.2873		
		8.45	2	0.1974	0.1822	0.3395	0.2038	0.3688	0.1919	0.1308	0.3014		
		12.45	2	0.1997	0.1738	0.2813	0.2092	0.3461	0.1697	0.1308	0.2654		
		16.45	2	0.2666	0.1869	0.3049	0.2749	0.346	0.1776	0.1237	0.2867		
		20.45	2	0.2242	0.1541	0.2669	0.242	0.3032	0.1528	0.1008	0.2765		
		24.45	2	0.2567	0.1605	0.2963	0.2384	0.3624	0.1973	0.1283	0.3146		
		28.45	2	0.2128	0.1338	0.3056	0.2141	0.346	0.1594	0.1019	0.3139		
		32.45	2	0.2138	0.1693	0.3225	0.2113	0.347	0.1702	0.1282	0.3037		
		36.45	2	0.1557	0.1277	0.2101	0.1408	0.268	0.1368	0.0976	0.2753		
		40.45	2	0.1758	0.1488	0.2968	0.2029	0.3825	0.1639	0.1171	0.2908		
		44.45	2	0.2053	0.1156	0.2681	0.1947	0.3026	0.15	0.0955	0.2626		
		48.45	2	0.1726	0.1576	0.2679	0.1775	0.3095	0.1695	0.1186	0.3207		
ET2	10	4.45	1	0.1453	0.1523	0.2717	0.1514	0.3107	0.2209	0.1059	0.2611	A-14	unloaded
		4.45	3	0.1937	0.1641	0.3205	0.1798	0.3755	0.1201	0.1268	0.2909	A-14	loaded
		8.45	3	0.1468	0.1313	0.3276	0.146	0.3786	0.1039	0.0922	0.2671		
		12.45	3	0.185	0.1712	0.3616	0.2069	0.3987	0.1199	0.1148	0.306		
		16.45	3	0.1521	0.1768	0.3682	0.1319	0.4037	0.1194	0.1297	0.2788		
		20.45	3	0.1671	0.1739	0.3138	0.1668	0.3736	0.1163	0.1236	0.2792		
		24.45	3	0.2058	0.1764	0.3251	0.1771	0.3893	0.1202	0.1026	0.2876		
		28.45	3	0.1895	0.1497	0.3159	0.154	0.3854	0.1427	0.1077	0.3151		

Table 19 contd…

Truck	Tape	Time	Event	Dx	Dy	Dz	Px	Pz	Fx	Fy	Fz	Road	Remarks
ET2	10	32.45	3	0.1644	0.1331	0.353	0.1617	0.3896	0.1162	0.095	0.2872	A-14	unloaded
		36.45	3	0.1478	0.1272	0.342	0.1488	0.3888	0.1025	0.0965	0.2862		
		40.45	3	0.1562	0.1398	0.2945	0.1474	0.2969	0.1	0.0955	0.2546		
		44.45	3	0.1736	0.149	0.3088	0.1584	0.3759	0.1164	0.1147	0.285		
		48.45	3	0.1874	0.1726	0.3778	0.1876	0.435	0.1238	0.107	0.3092		
		52.45	3	0.1633	0.1244	0.377	0.1506	0.4009	0.1167	0.0941	0.287		
		56.45	3	0.157	0.1891	0.3245	0.1416	0.4126	0.1267	0.1095	0.2714		
		60.45	3	0.2054	0.1561	0.3681	0.2095	0.418	0.1138	0.1051	0.3208		
		64.45	3	0.2692	0.2389	0.4463	0.2535	0.6	0.164	0.1547	0.412		
		68.45	3	0.1652	0.1357	0.2803	0.1716	0.3296	0.1099	0.0915	0.2497		
		72.45	3	0.1484	0.1548	0.3676	0.1747	0.4089	0.1064	0.098	0.2937		
		76.45	3	0.1746	0.1302	0.343	0.1645	0.3221	0.1033	0.0959	0.2831		
		80.45	3	0.2075	0.1536	0.3149	0.1892	0.3795	0.1489	0.1145	0.2839		
		84.45	3	0.1984	0.1664	0.389	0.1937	0.4301	0.1296	0.1147	0.3316		
		88.45	3	0.1515	0.1318	0.3004	0.1556	0.3253	0.1107	0.0903	0.251		
		92.45	3	0.1672	0.1429	0.3491	0.1784	0.3931	0.1213	0.1062	0.3112		
		96.45	3	0.1539	0.1513	0.3616	0.164	0.397	0.1307	0.1099	0.2995		
		100	3	0.1808	0.1653	0.3473	0.1746	0.3535	0.1253	0.1112	0.2908		
		104	3	0.1726	0.1419	0.3905	0.1693	0.4303	0.13	0.1171	0.3369		
		108	3	0.1696	0.1581	0.3969	0.1729	0.4365	0.1299	0.1184	0.3168		
		112	3	0.1639	0.1669	0.3046	0.1761	0.3966	0.1142	0.1334	0.3142		
ET2	12	4.45	1	0.1429	0.105	0.3119	0.1364	0.3356	0.1115	0.0836	0.2535	A-14	unloaded
		8.45	1	0.1454	0.1338	0.3712	0.145	0.4764	0.1145	0.0902	0.3385		
		4.45	2	0.1579	0.149	0.3654	0.1434	0.3793	0.1079	0.0983	0.2775	A-12	unloaded
		8.45	2	0.2034	0.1628	0.369	0.2094	0.3866	0.1189	0.1084	0.3033		
		12.45	2	0.1546	0.1812	0.3275	0.1644	0.3917	0.1125	0.1008	0.278		
		16.45	2	0.1753	0.1463	0.3871	0.1838	**0.5133**	0.13	0.0913	0.4106		
		20.45	2	0.1528	0.1303	0.3421	0.151	0.421	0.1351	0.0992	0.3131		
		24.45	2	0.178	0.1318	0.3589	0.1938	0.4623	0.1407	0.0935	0.3497	A-120	unloaded
		28.45	2	0.1776	0.213	0.3965	0.1801	0.3585	0.1687	0.1747	0.345		
		32.45	2	0.187	0.2043	0.441	0.2092	0.5092	0.1963	0.1875	0.3819		
		34.6	2	0.187	0.2043	0.441	0.2092	0.5092	0.1963	0.1875	0.3819		

Appendix II: RMS acceleration plots- England

1. ET1

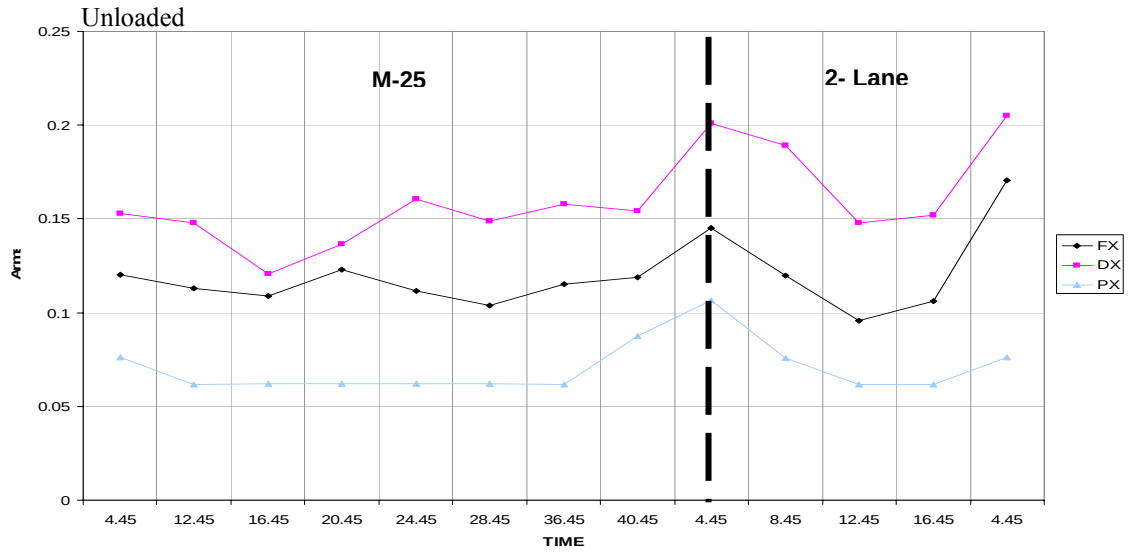


Figure 37 ET1 Tape 2 Driver, Passenger &Floor Weighted RMS acceleration-X axis

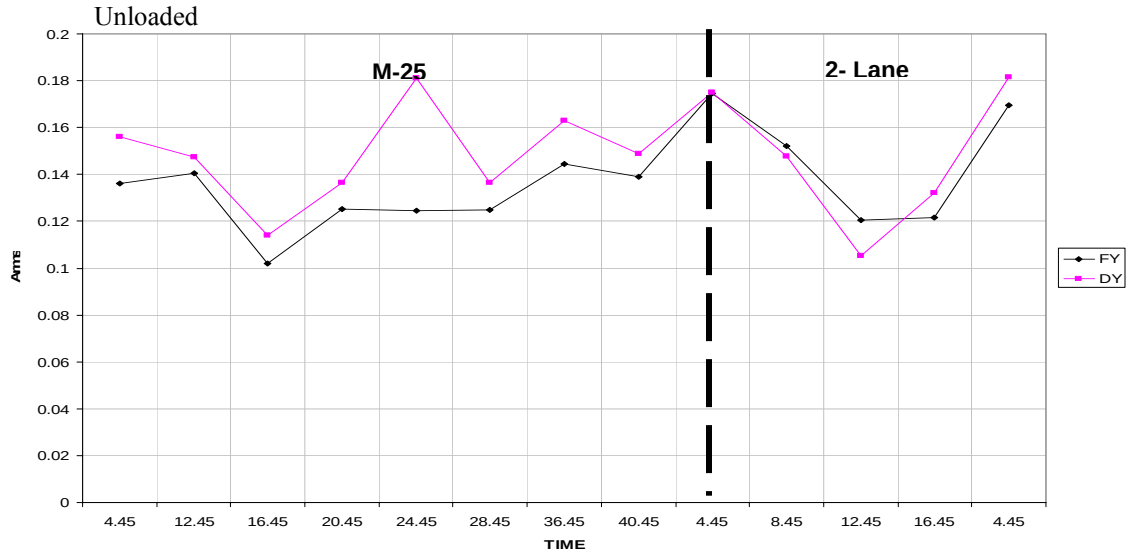


Figure 38 ET1 Tape 2 Driver & Floor Weighted RMS acceleration-Y axis

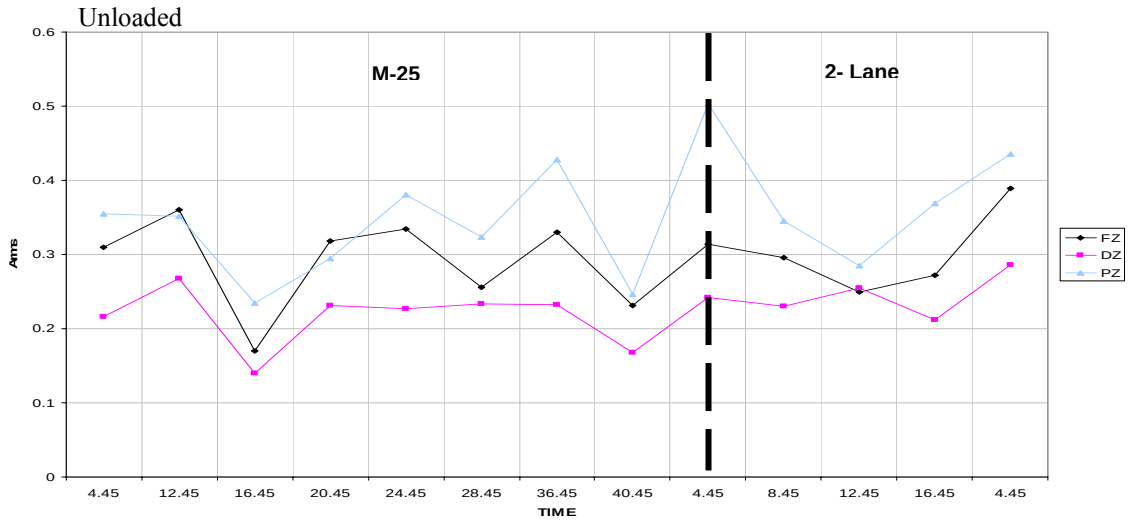


Figure 39 ET1 Tape 2 Driver, Passenger &Floor Weighted RMS acceleration-Z axis

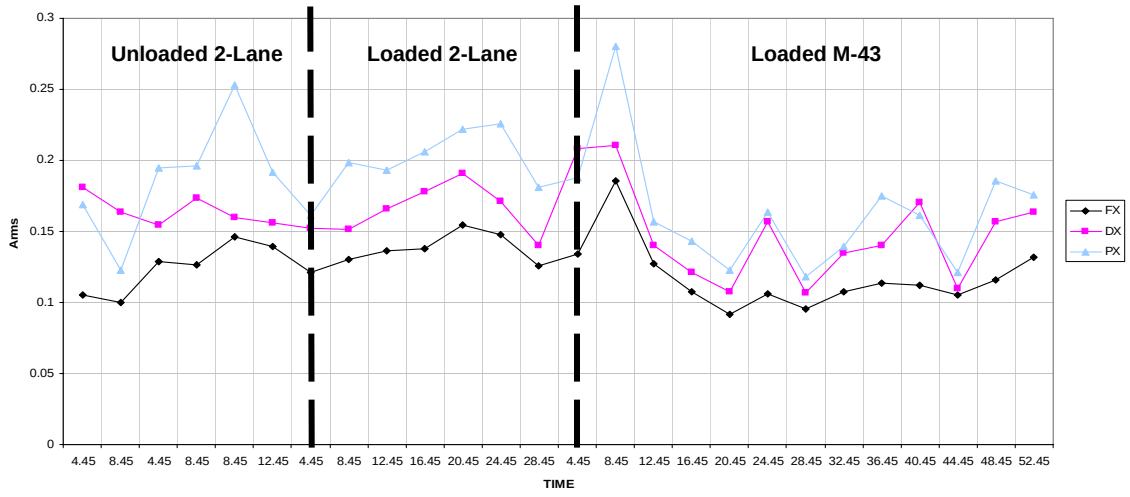


Figure 40 ET1 Tape 3 Driver, Passenger &Floor Weighted RMS acceleration-X axis

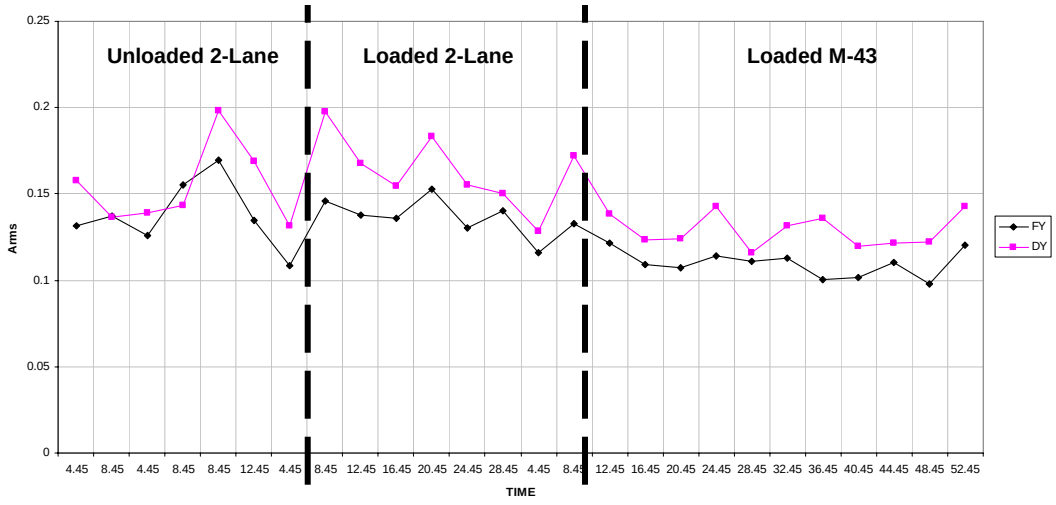


Figure 41 ET1 Tape 3 Driver &Floor Weighted RMS acceleration-Y axis

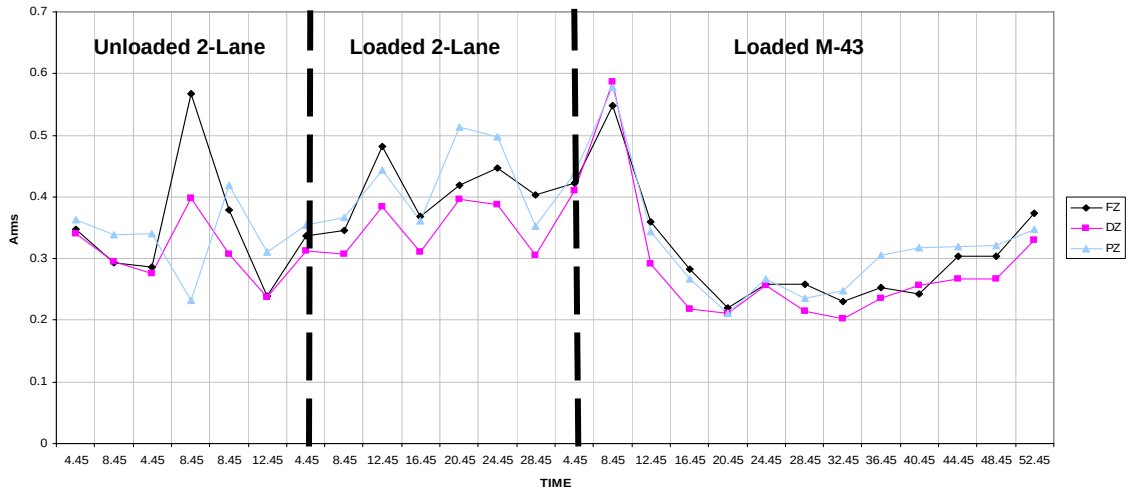


Figure 42 ET1 Tape 3 Driver, Passenger &Floor Weighted RMS acceleration-Z axis

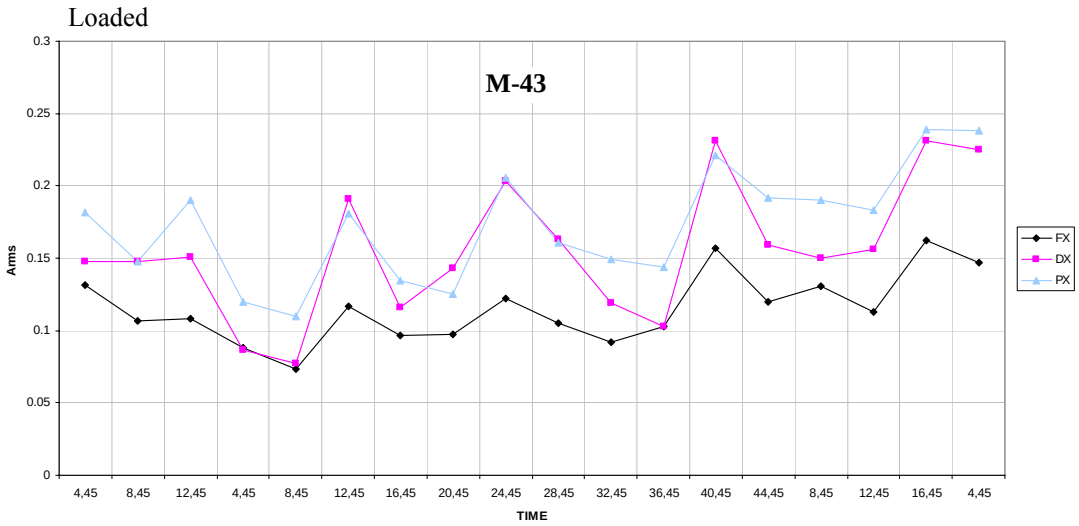


Figure 43 ET1 Tape 4 Driver, Passenger &Floor Weighted RMS acceleration-X axis

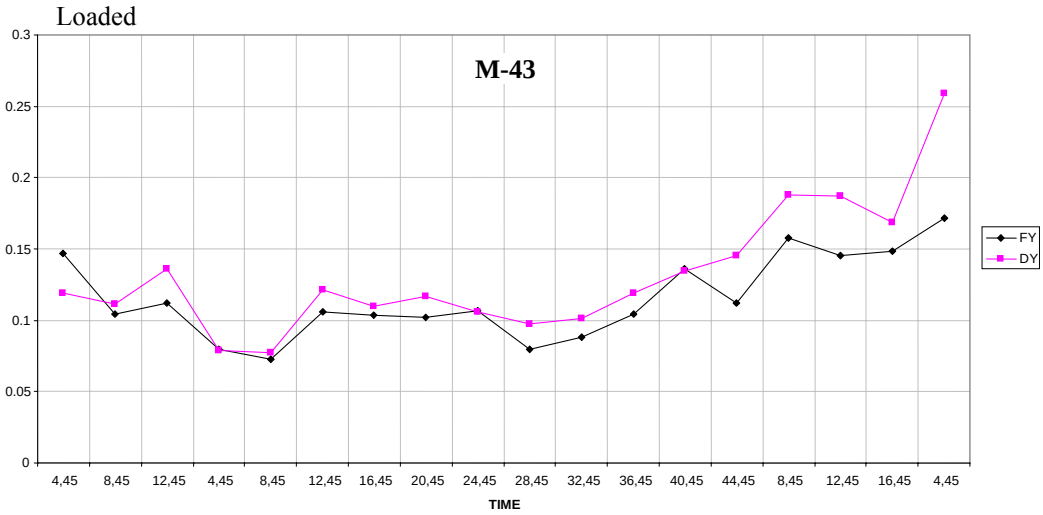


Figure 44 ET1 Tape 4 Driver & Floor Weighted RMS acceleration- Y axis

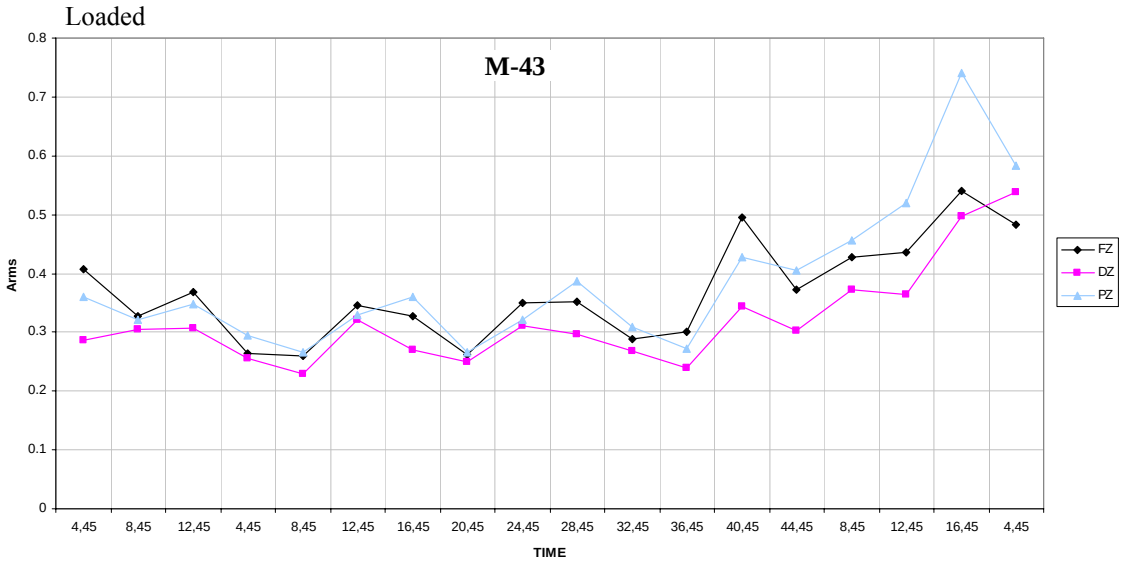


Figure 45 ET1 Tape 4 Driver, Passenger & Floor Weighted RMS acceleration-Z axis

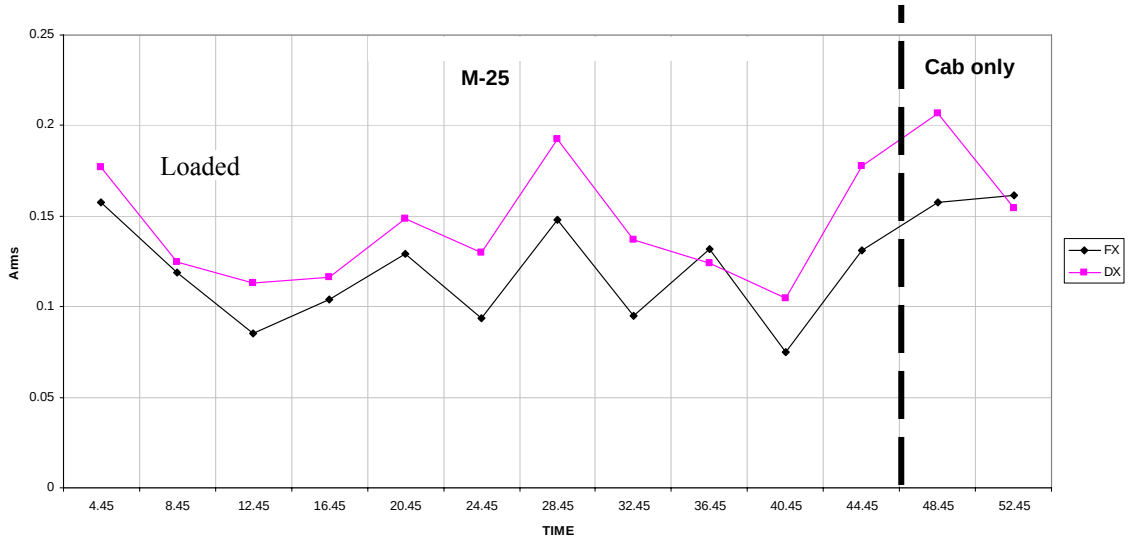


Figure 46 ET1 Tape 5 Driver & Floor Weighted RMS acceleration-X axis

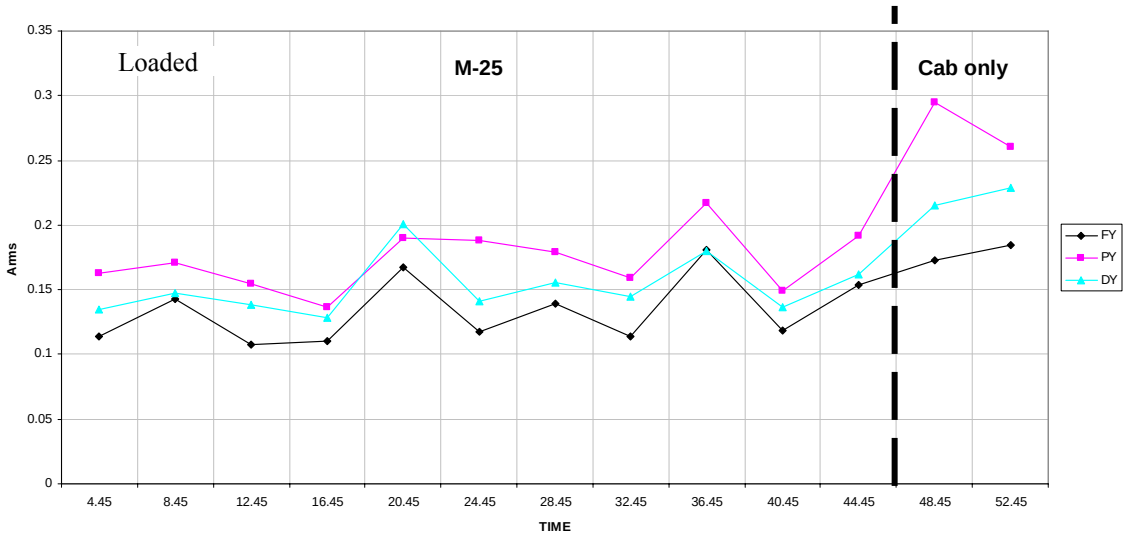


Figure 47 ET1 Tape 5 Driver, Passenger &Floor Weighted RMS acceleration-Y axis

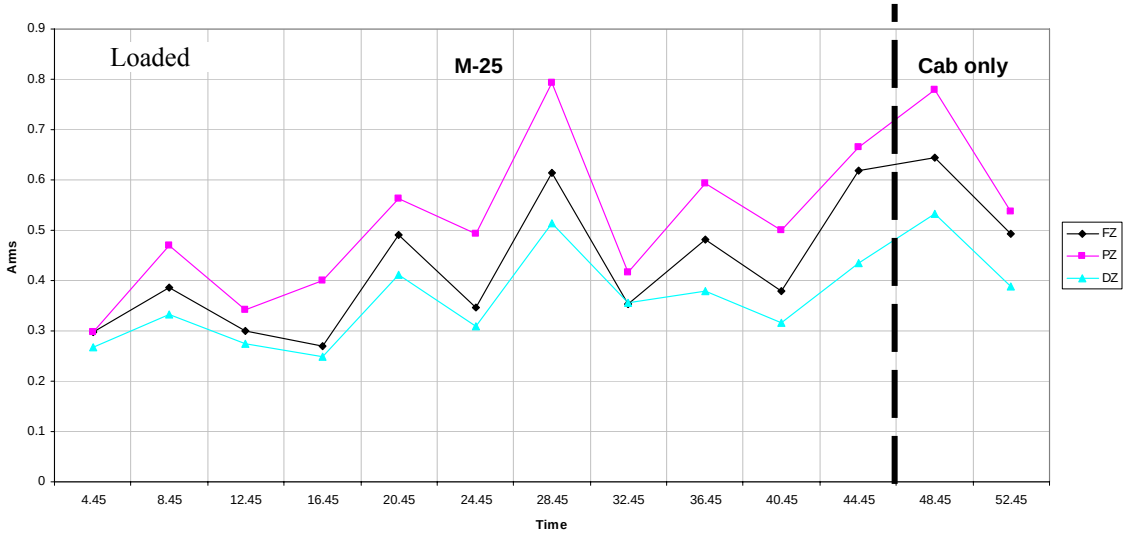


Figure 48 ET1 Tape 5 Driver, Passenger &Floor Weighted RMS acceleration-Z axis

2. ET2

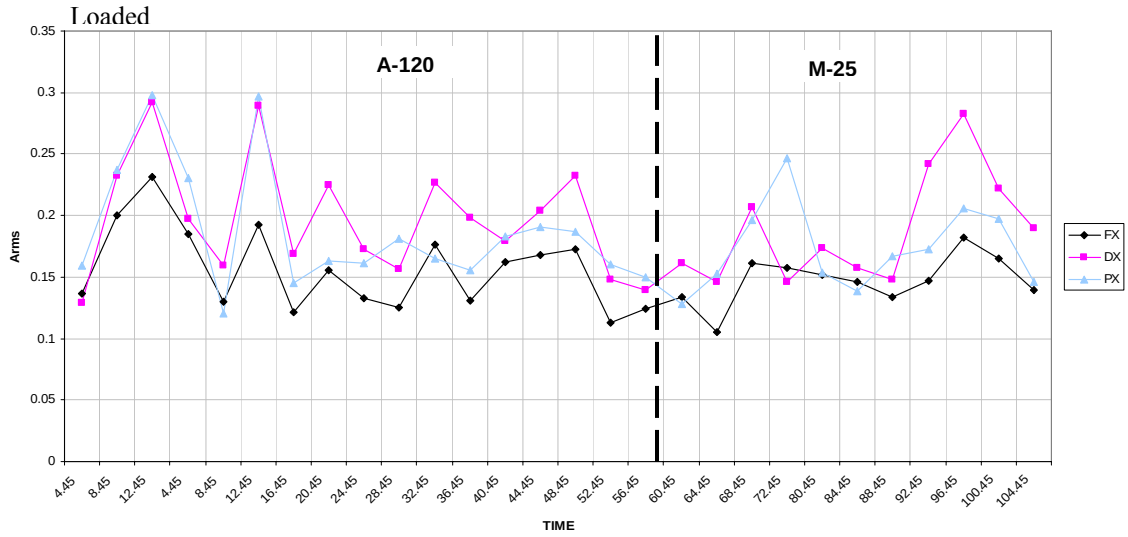


Figure 49 ET2 Tape 6 Driver, Passenger &Floor Weighted RMS acceleration-X axis

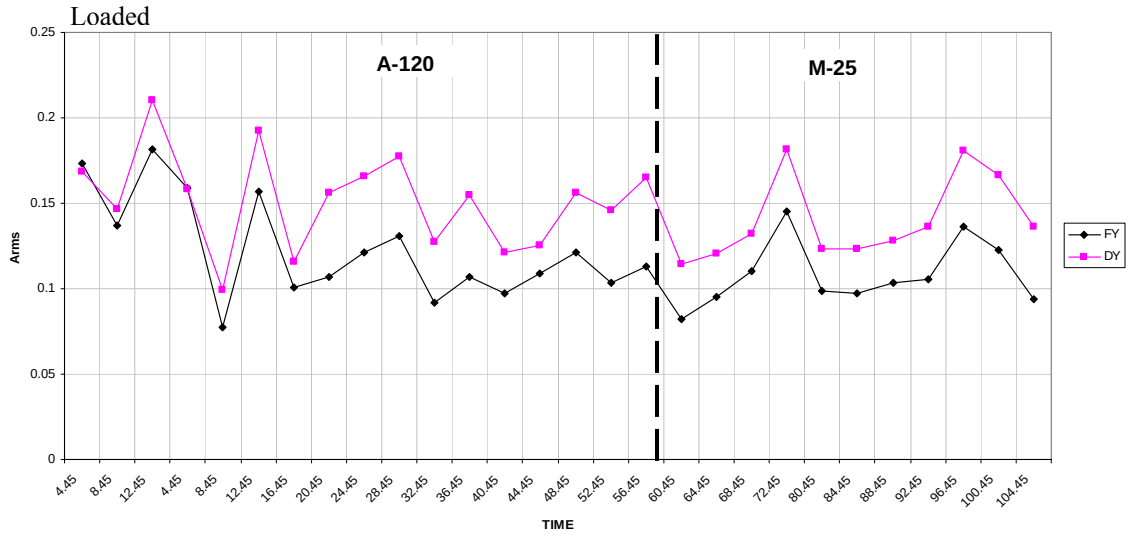


Figure 50 ET2 Tape 6 Driver &Floor Weighted RMS acceleration-Y axis

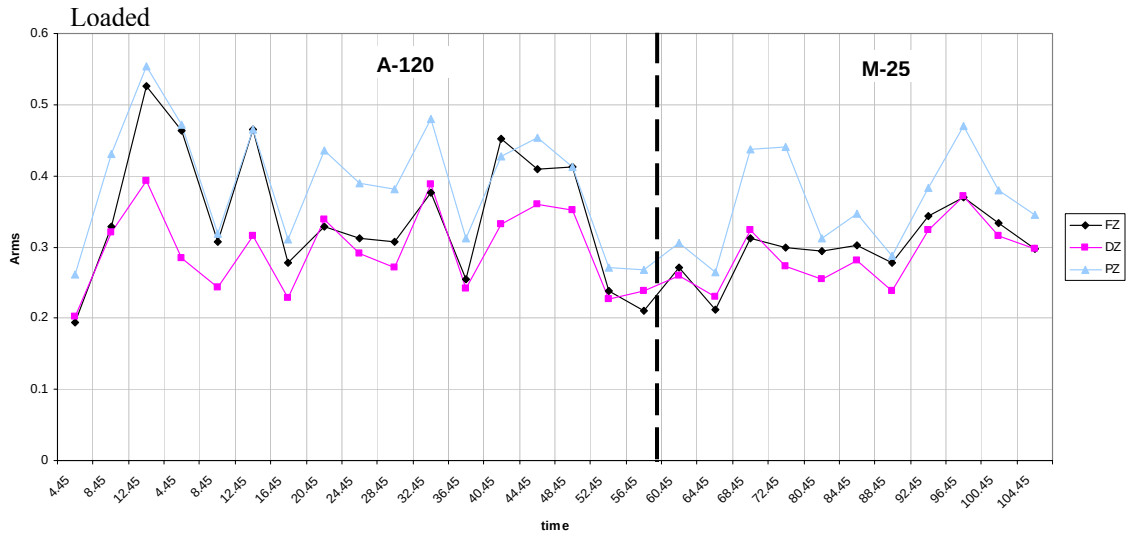


Figure 51 ET2 Tape 6 Driver, Passenger &Floor Weighted RMS acceleration-Z axis

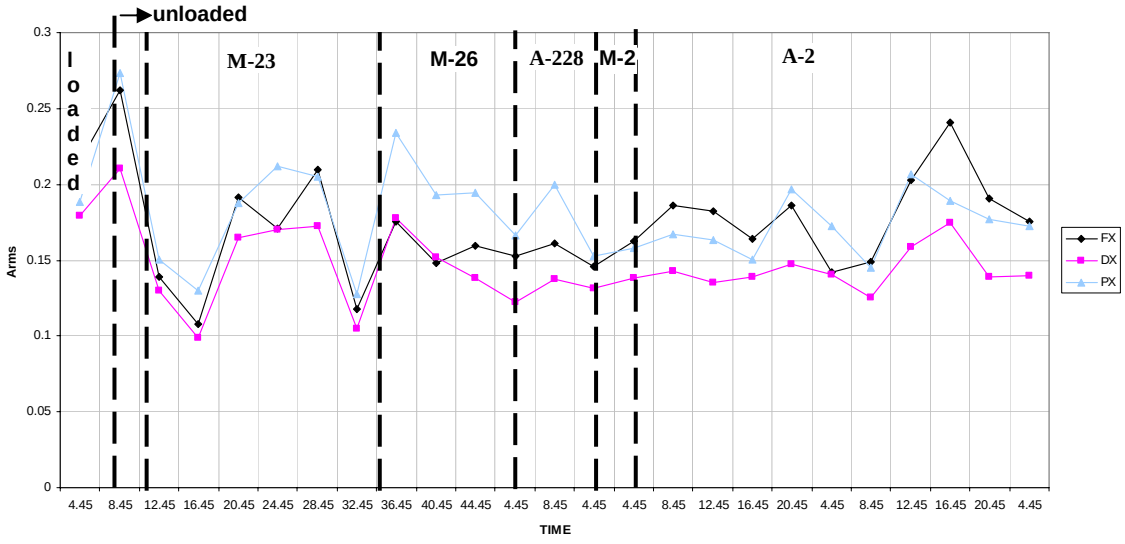


Figure 52 ET2 Tape 7 Driver, Passenger &Floor Weighted RMS acceleration-X axis

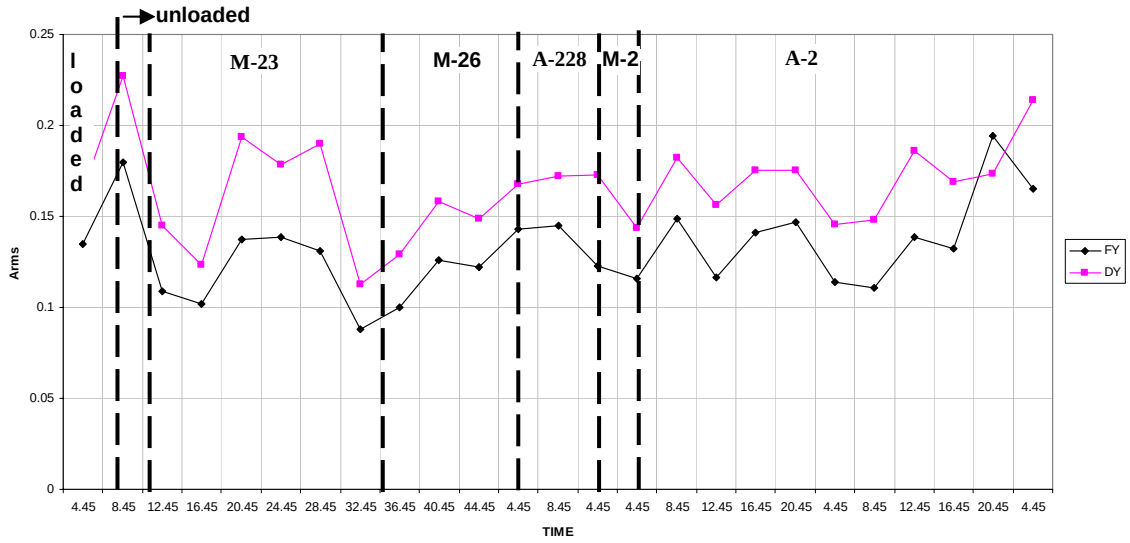


Figure 53 ET2 Tape 7 Driver& Floor Weighted RMS acceleration-Y axis

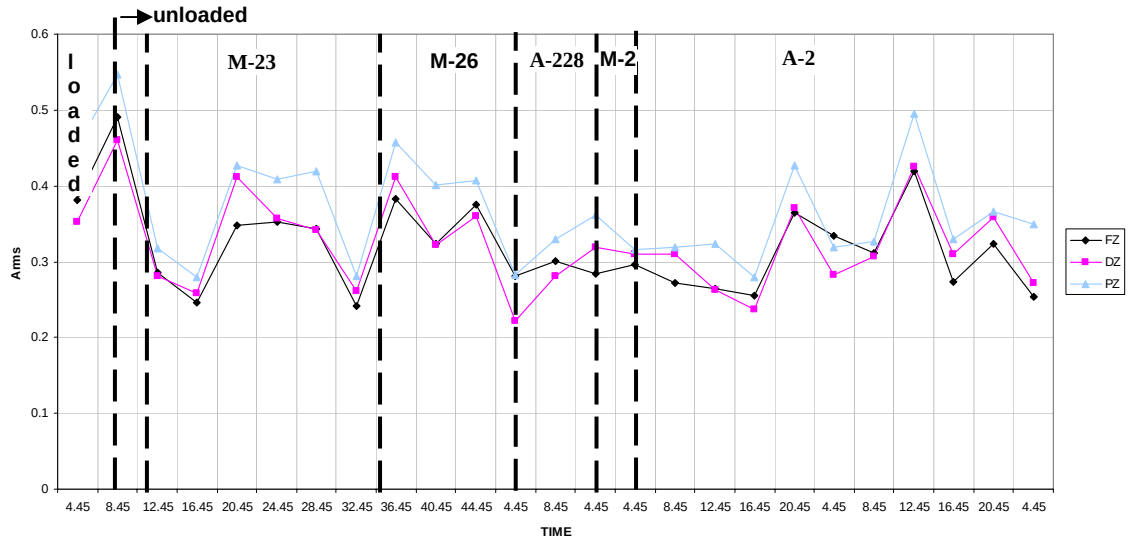


Figure 54 ET2 Tape 7 Driver, Passenger &Floor Weighted RMS acceleration- Z axis

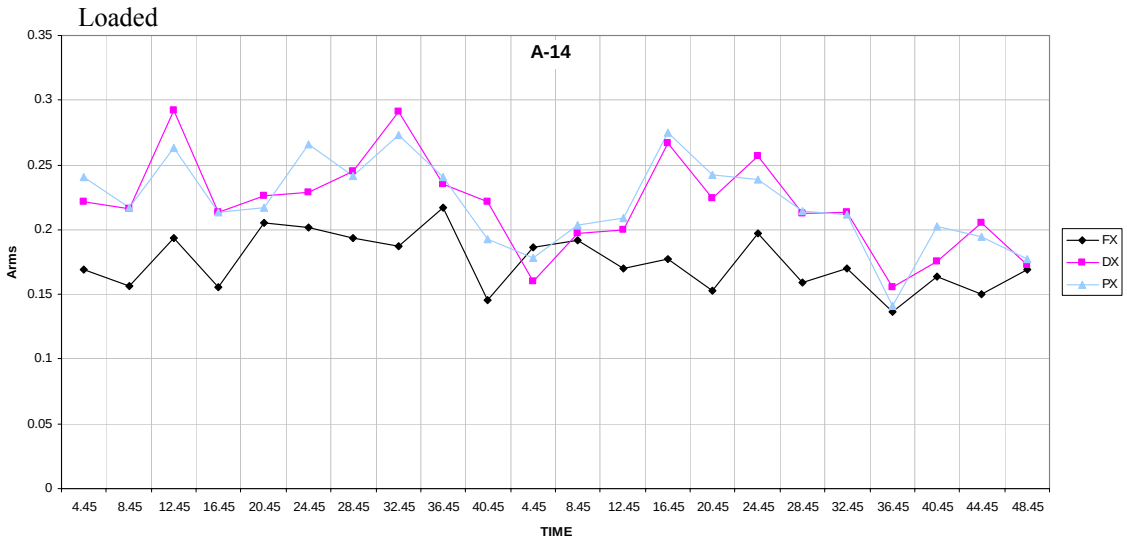


Figure 55 ET2 Tape 9 Driver, Passenger &Floor Weighted RMS acceleration-X axis

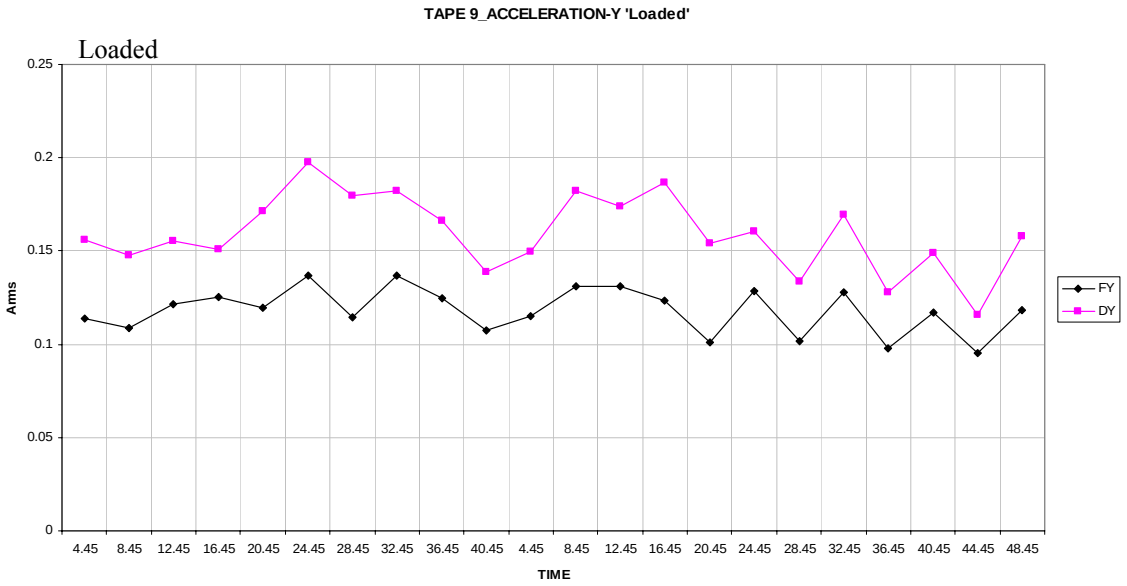


Figure 56 ET2 Tape 9 Driver &Floor Weighted RMS acceleration-Y axis

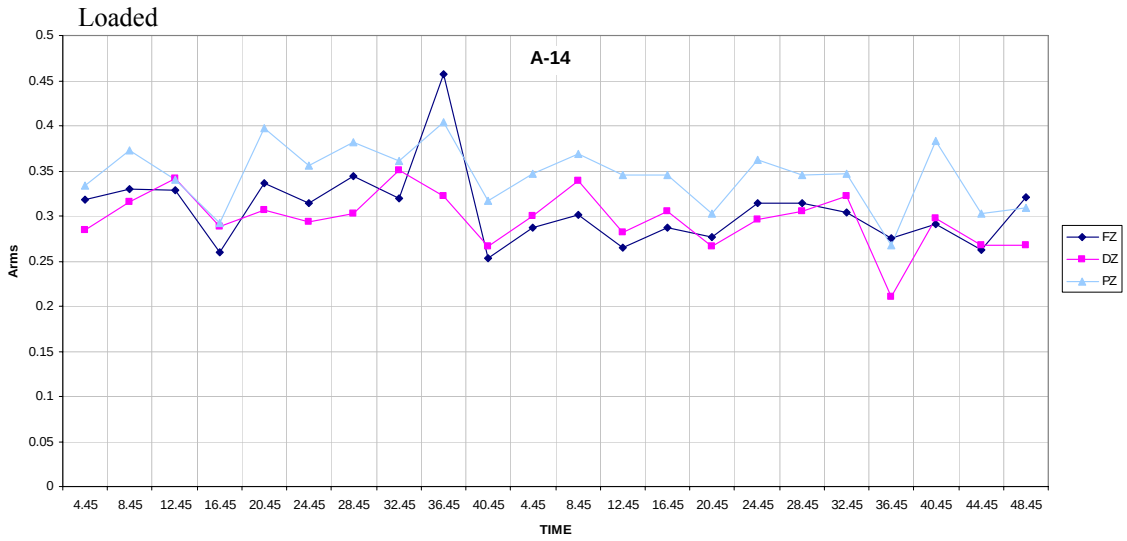


Figure 57 ET2 Tape 9 Driver, Passenger &Floor Weighted RMS acceleration-Z axis

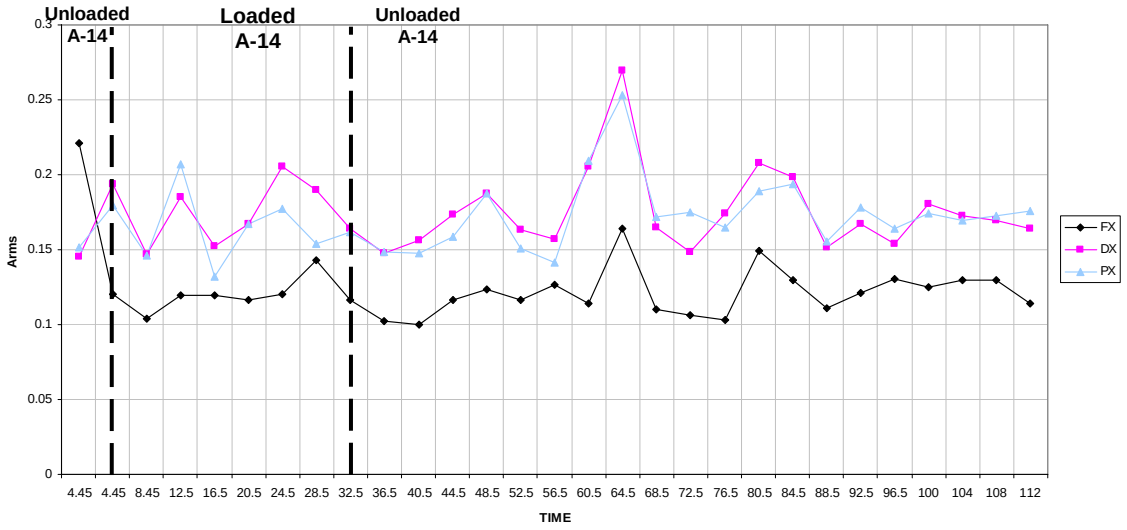


Figure 58 ET2 Tape 10 Driver, Passenger &Floor Weighted RMS acceleration-X axis

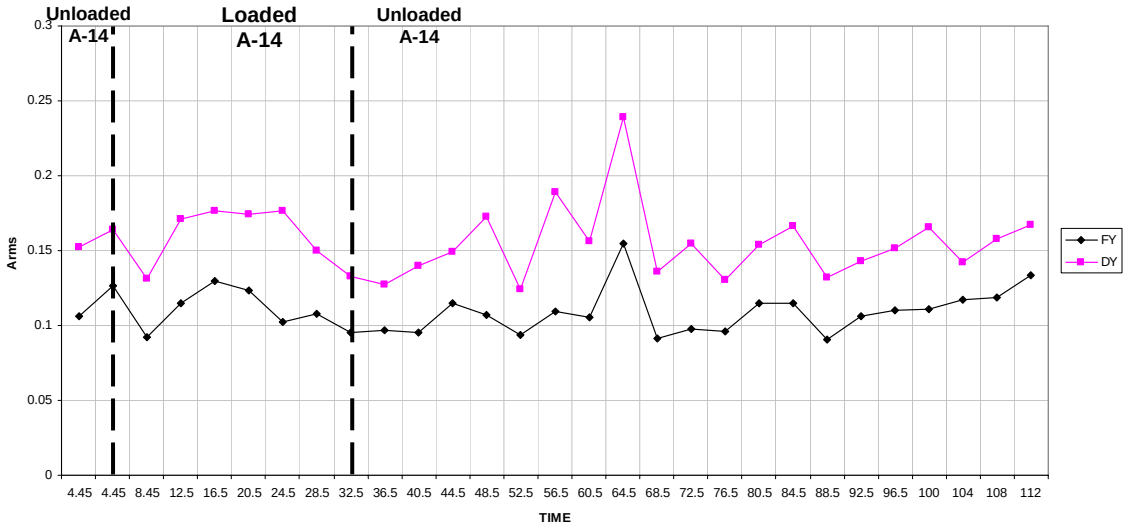


Figure 59 ET2 Tape 10 Driver &Floor Weighted RMS acceleration-X axis

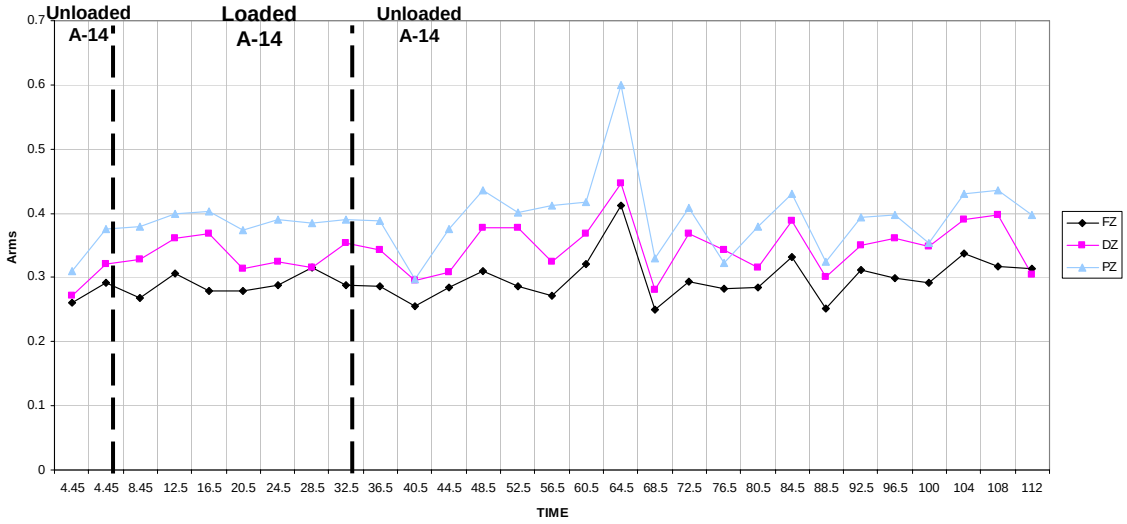


Figure 60 ET2 Tape 10 Driver, Passenger & Floor Weighted RMS acceleration-Z axis

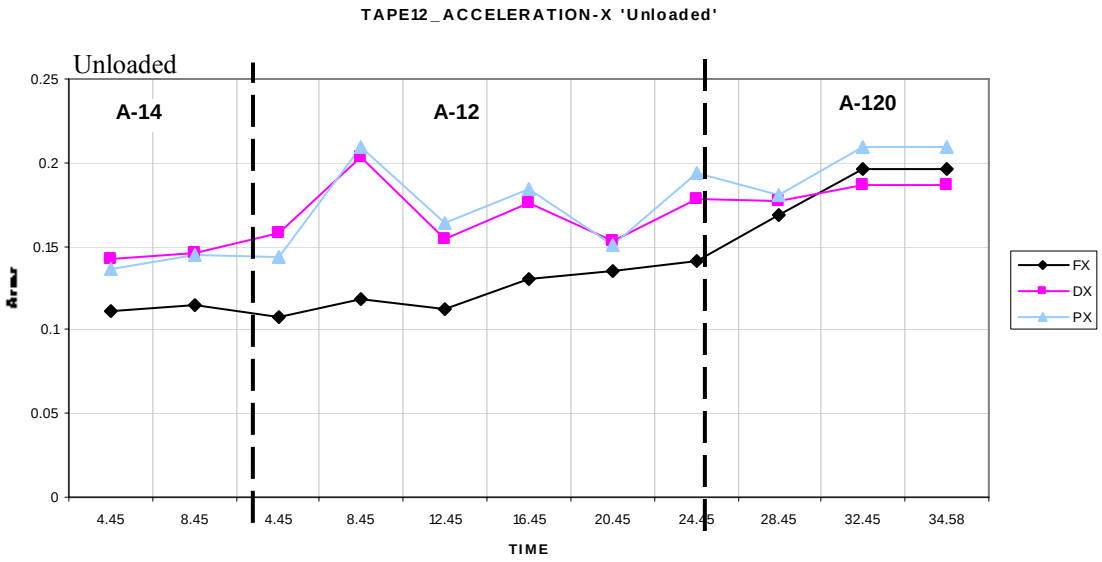


Figure 61 ET2 Tape 12 Driver, Passenger & Floor Weighted RMS acceleration-X axis

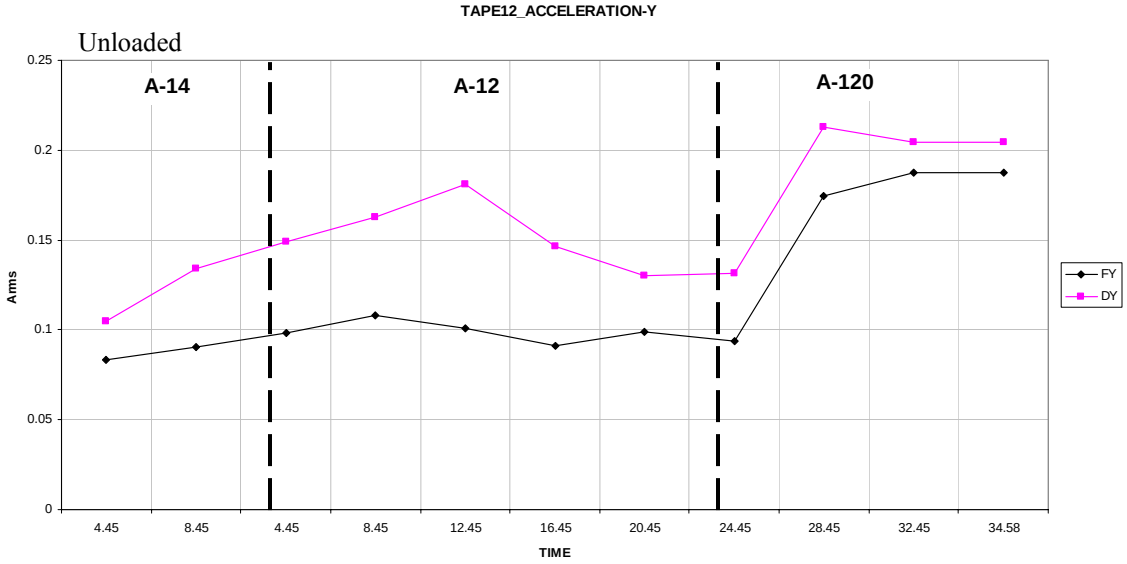


Figure 62 ET2 Tape 12 Driver &Floor Weighted RMS acceleration-Y axis

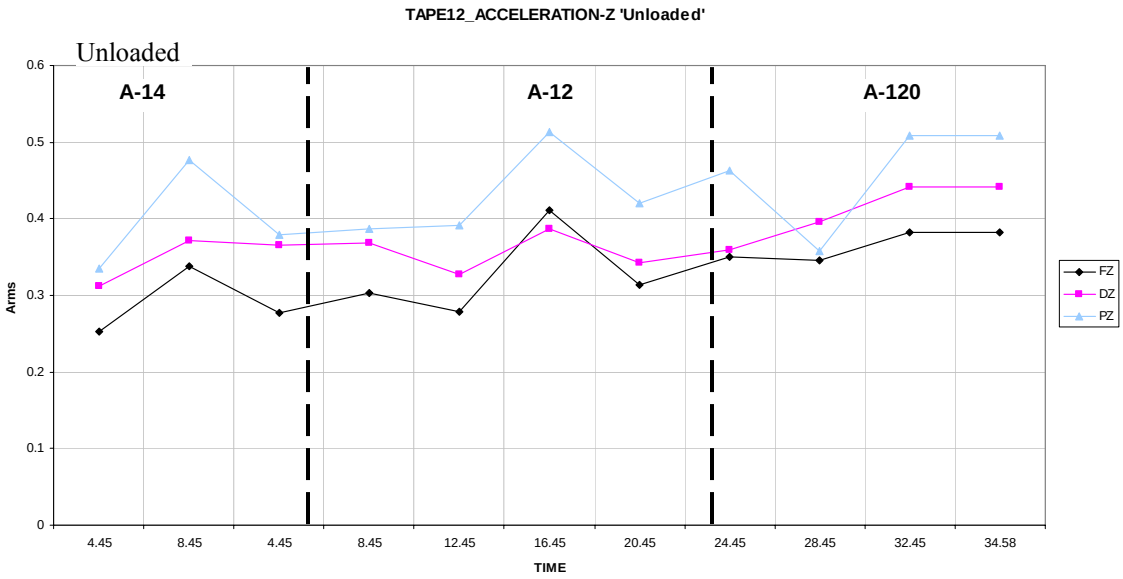


Figure 63 ET2 Tape 12 Driver, Passenger &Floor Weighted RMS acceleration- Z axis

Appendix-III: Selected 1/3rd octave plots- England

1. ET1

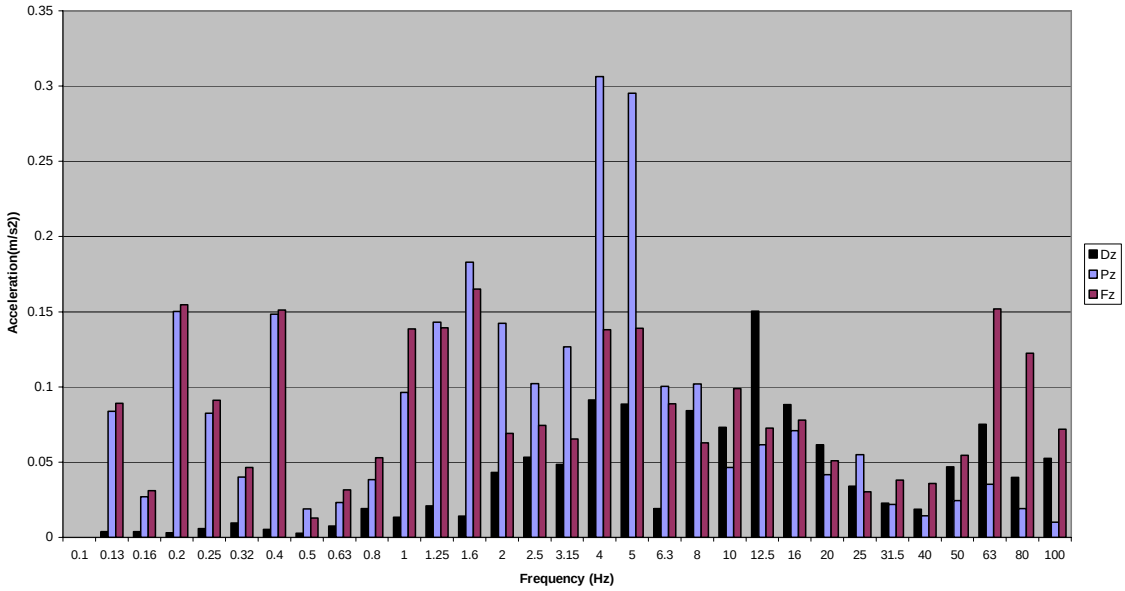


Figure 64 ET1 Tape 2: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

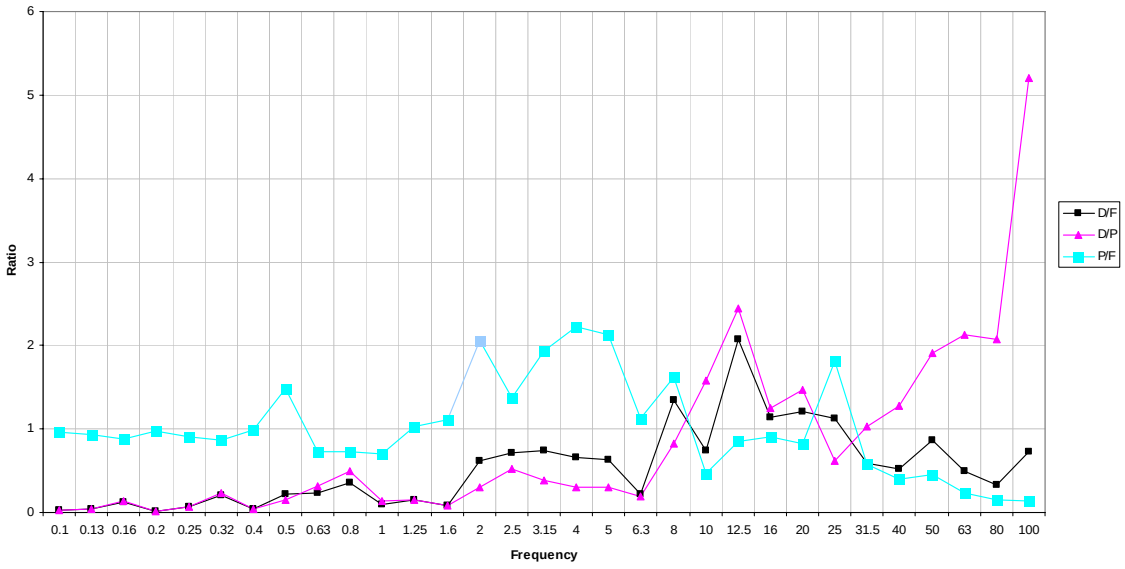


Figure 65 ET1 Tape 2: 1/3rd octave Driver/Floor, Driver/Passenger &Passenger/Floor ratio-Z axis

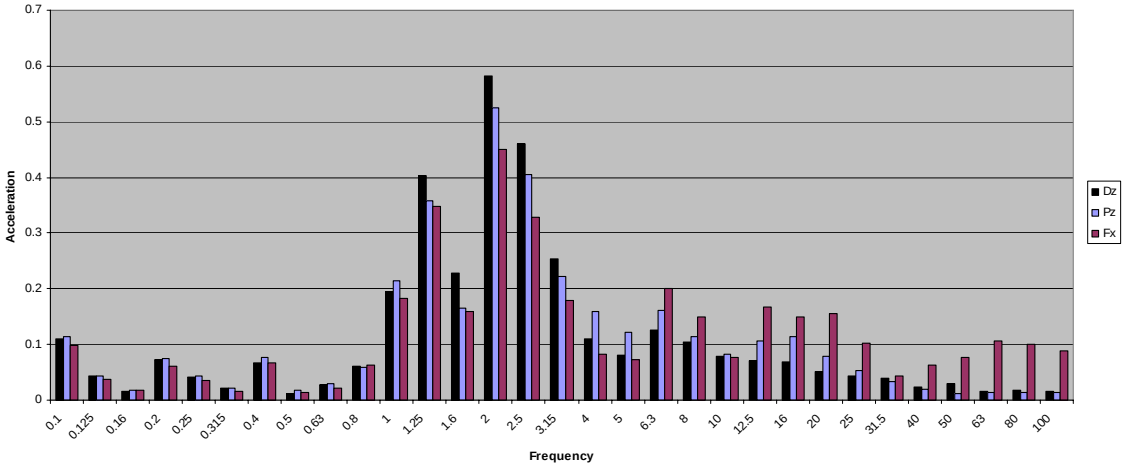


Figure 66 ET1 Tape 3: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

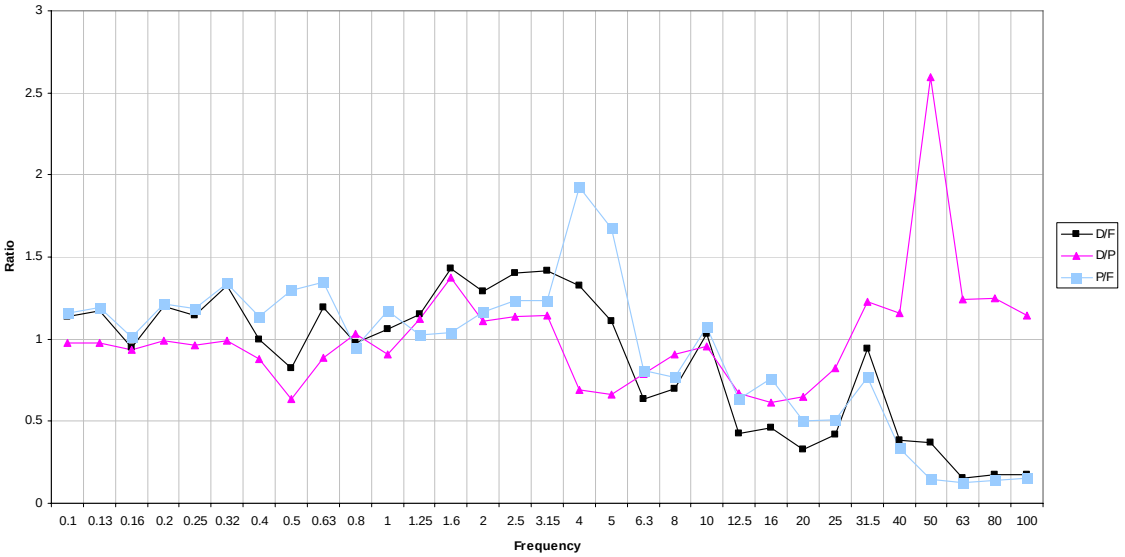


Figure 67 ET1 Tape 3: 1/3rd octave Driver/Floor, Driver/Passenger &Passenger/Floor ratio-Z axis

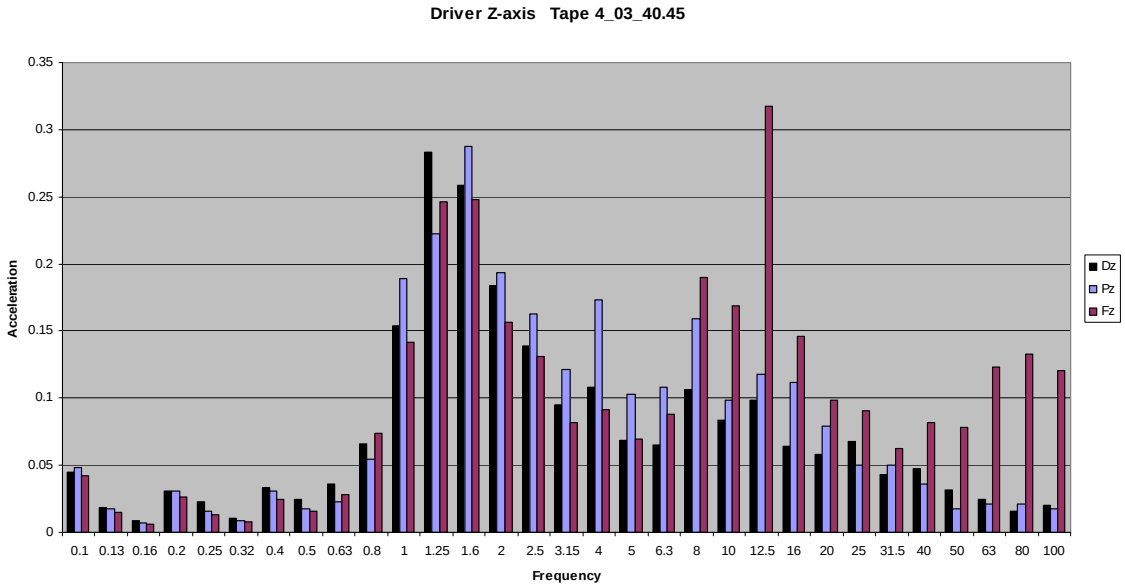


Figure 68 ET1 Tape 4: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

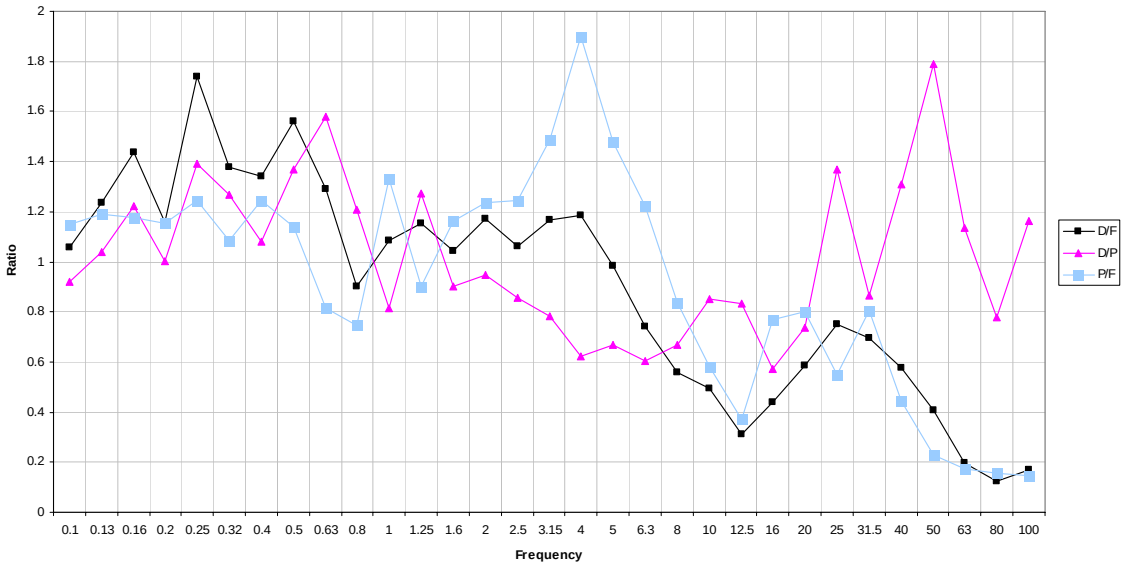


Figure 69 ET1 Tape 4: 1/3rd octave Driver/Floor, Driver/Passenger &Passenger/Floor ratio-Z axis

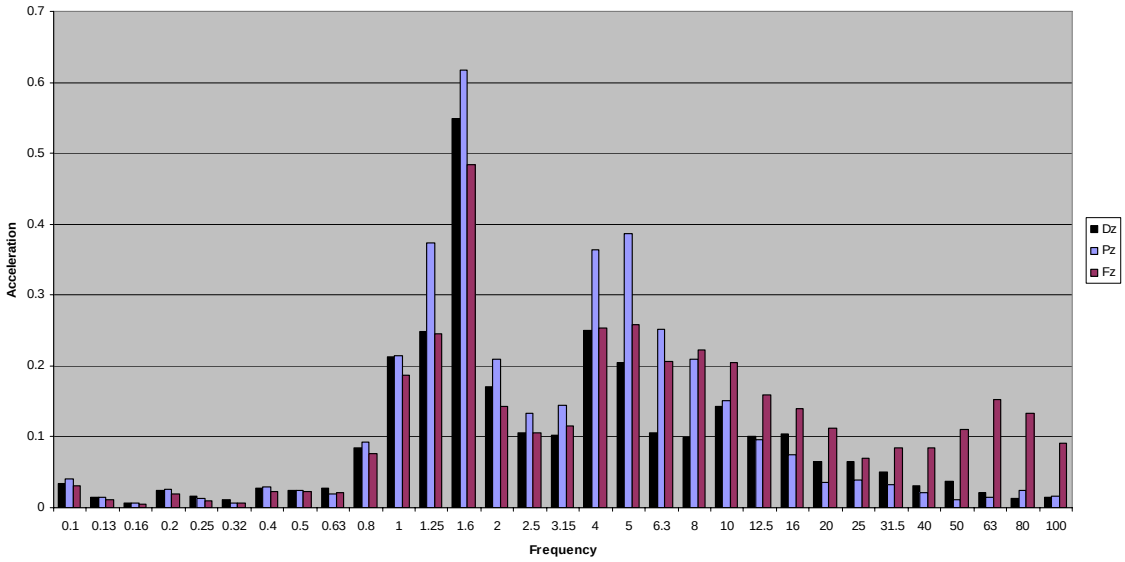


Figure 70 ET1 Tape 5: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

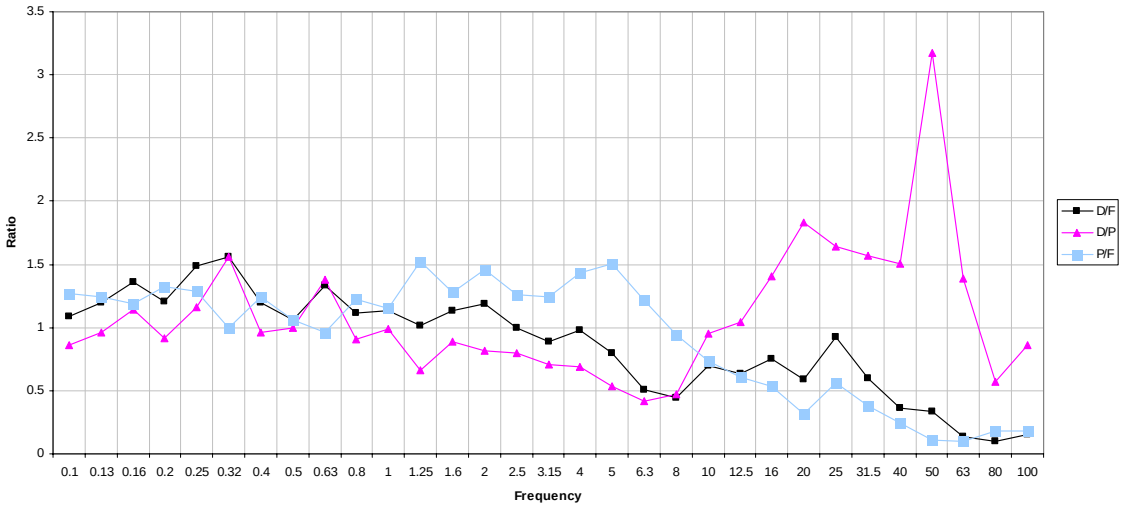


Figure 71 ET1 Tape 5: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

2. ET2

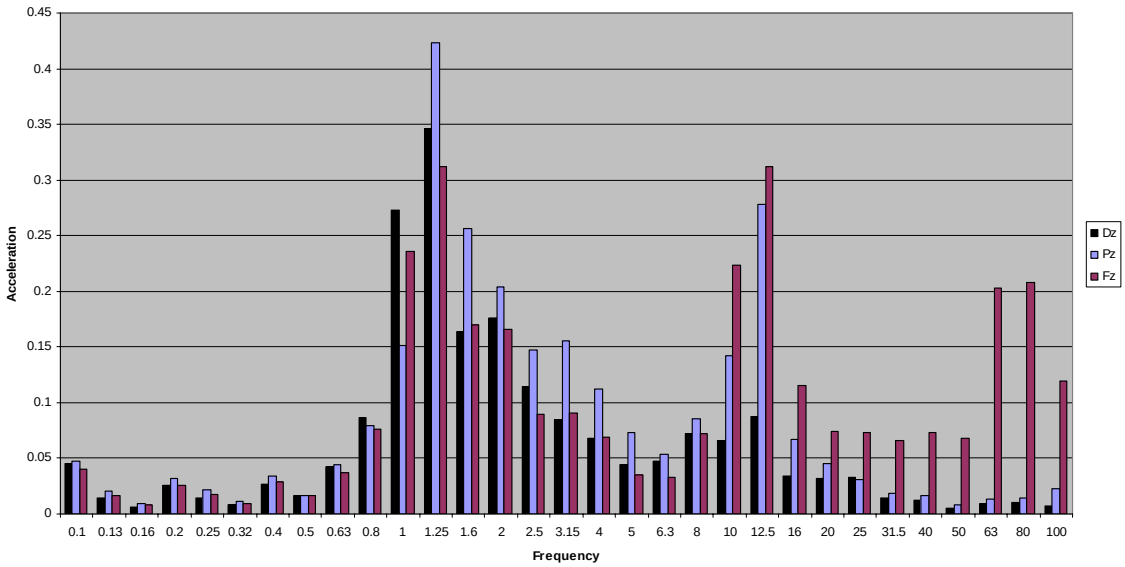


Figure 72 ET2 Tape 6: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

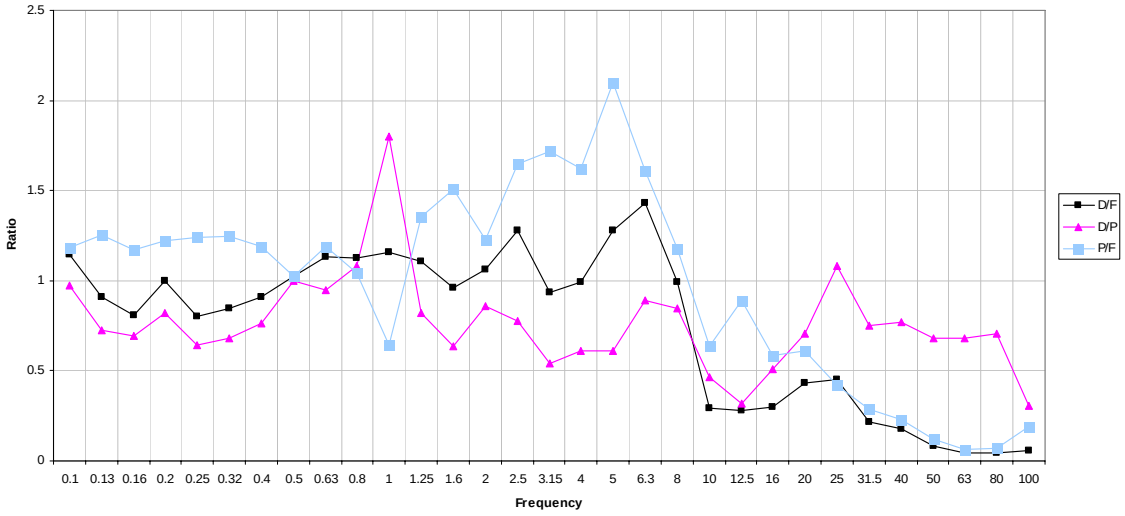


Figure 73 ET2 Tape 6: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

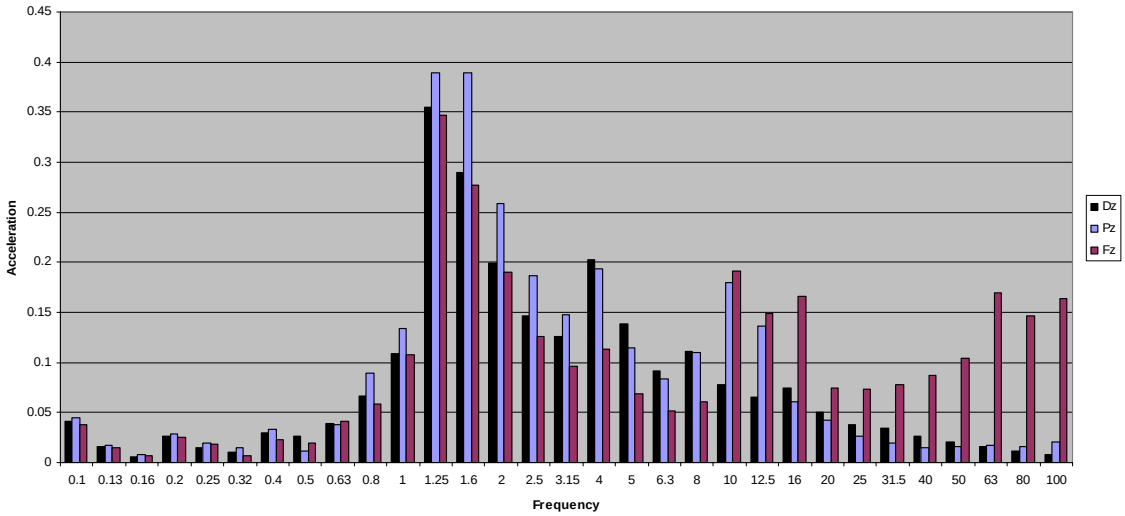


Figure 74 ET2 Tape 7: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

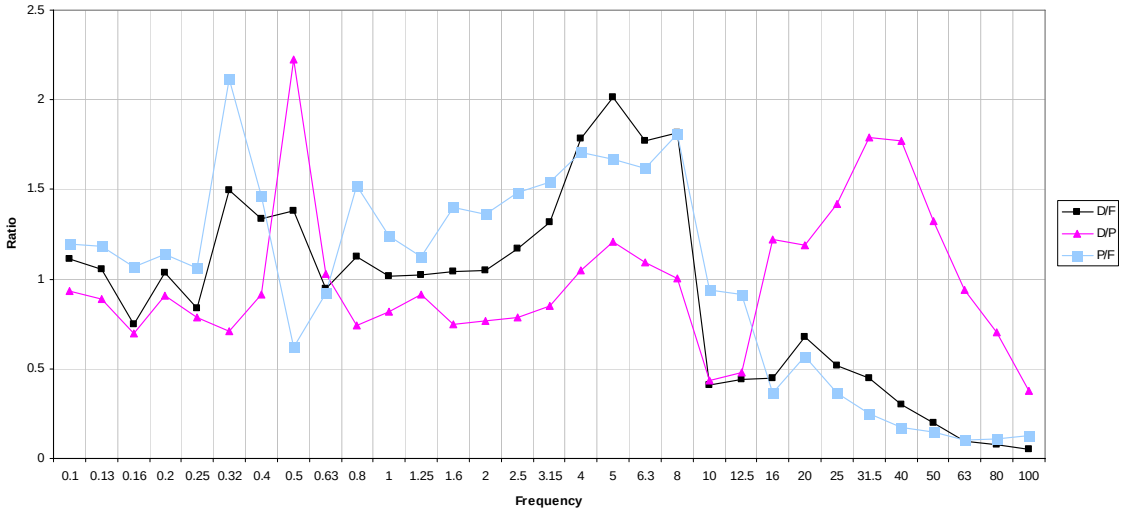


Figure 75 ET2 Tape 7: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

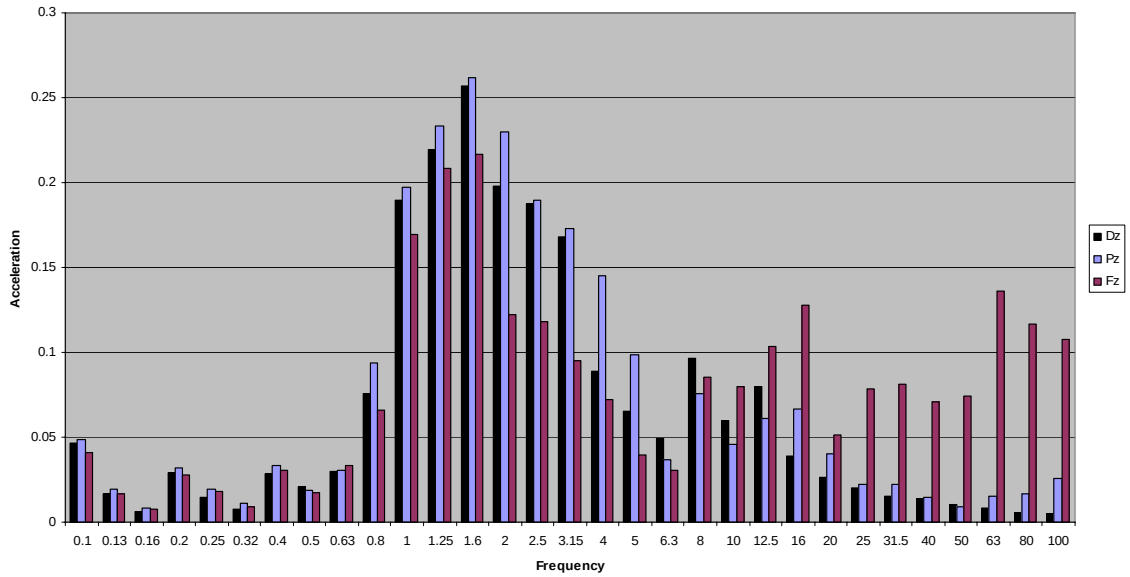


Figure 76 ET2 Tape 9: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

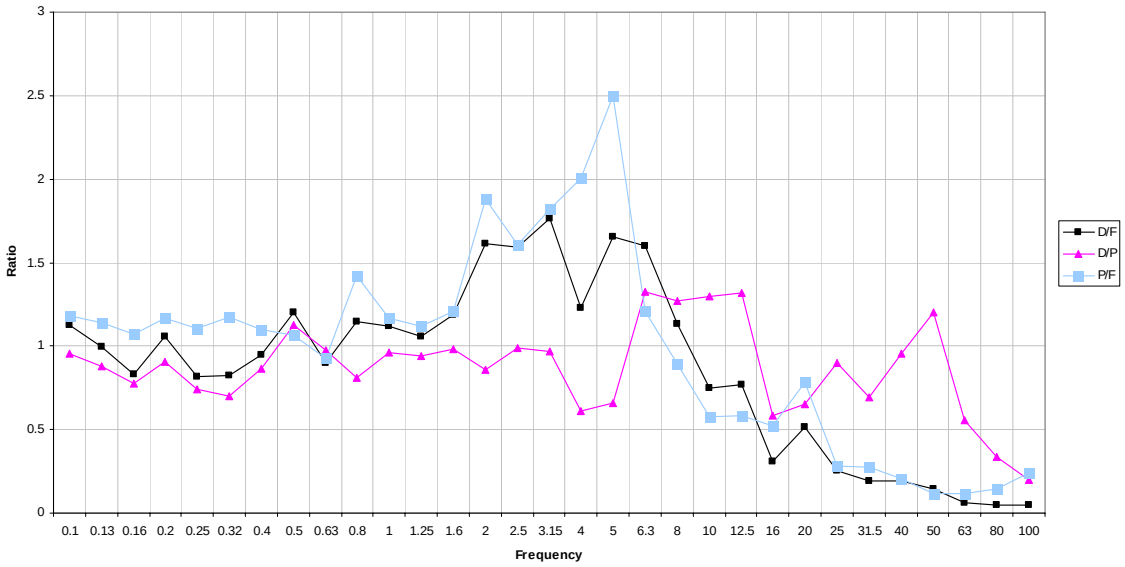


Figure 77 ET2 Tape 9: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

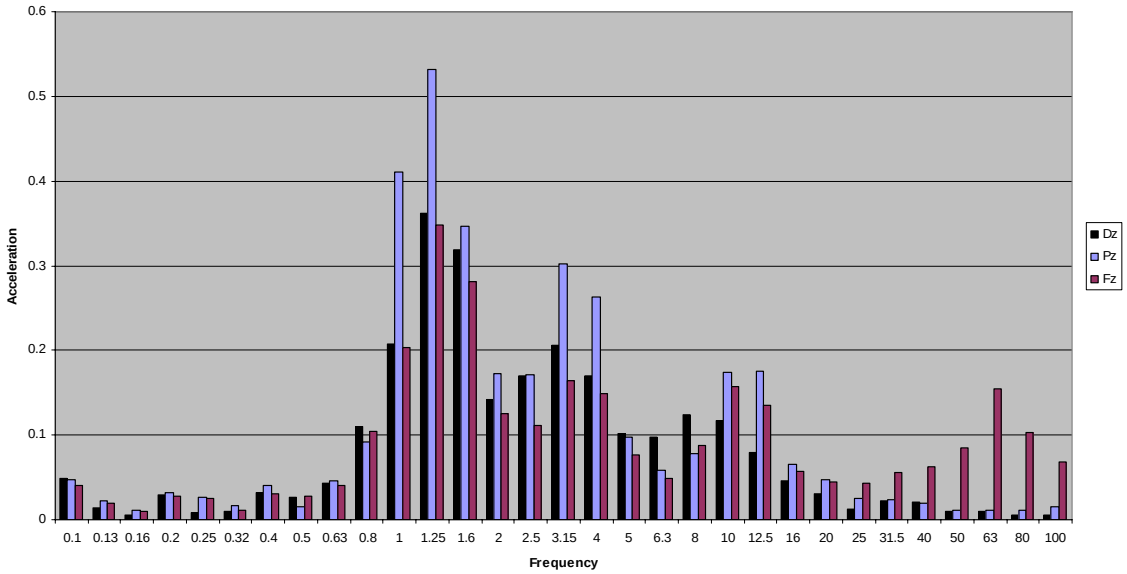


Figure 78 ET2 Tape 10: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

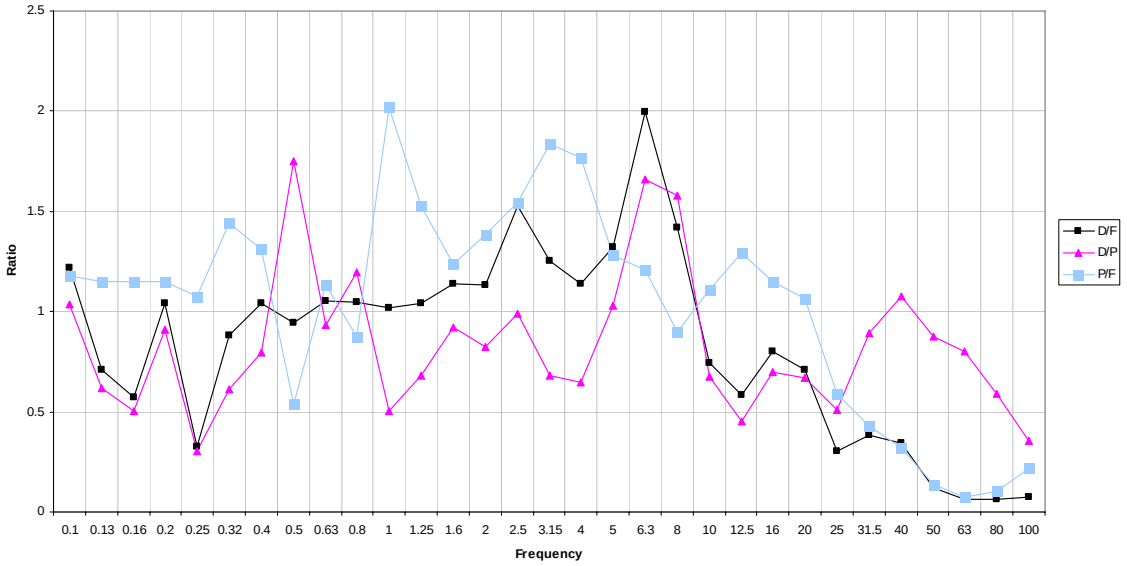


Figure 79 ET2 Tape 10: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

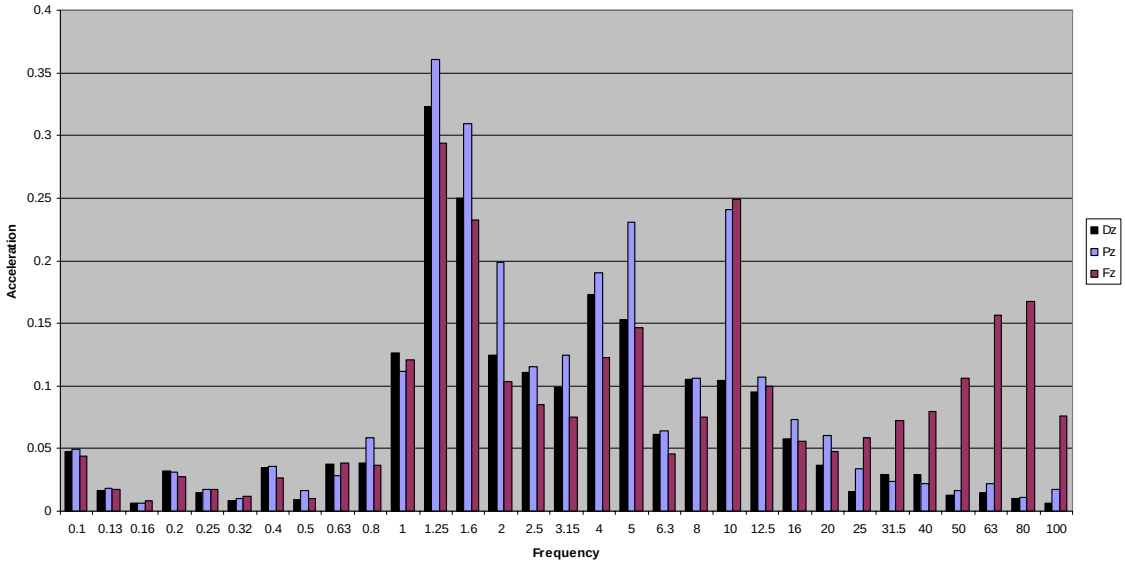


Figure 80 ET2 Tape 12: 1/3rd octave Driver, Passenger &Floor acceleration-Z axis

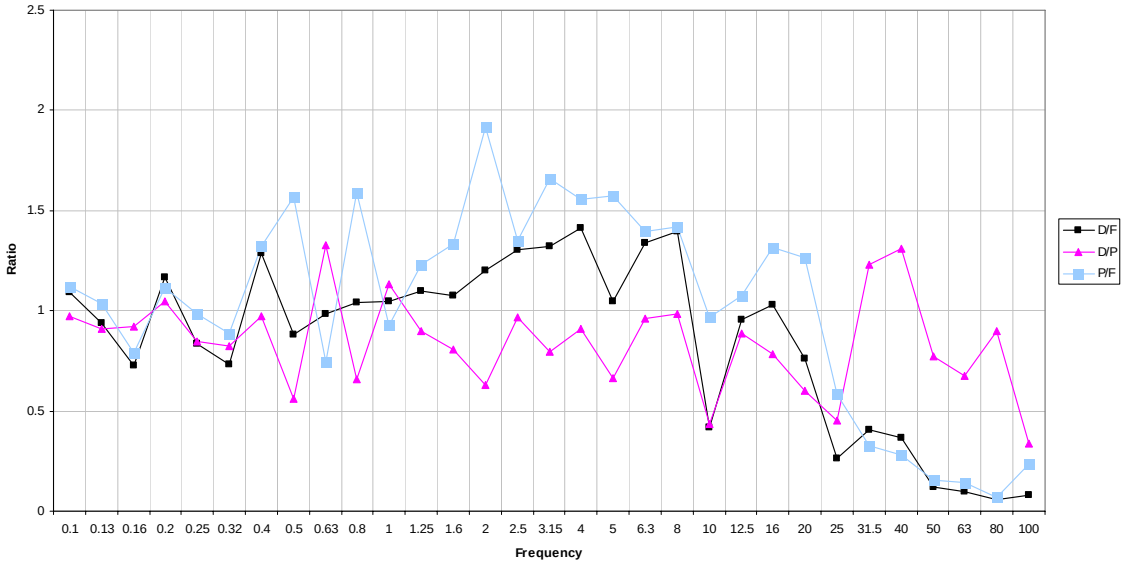


Figure 81 ET2 Tape 12: 1/3rd octave Driver/Floor, Driver/Passenger& Passenger/Floor ratio-Z axis

Appendix-IV: RMS acceleration results-Poland

Table 20 Poland Test Results-Driver &Passenger seat pad, floor and seat back weighted a_{rms}

Truck	Seg	Driver Seat			Passenger Seat			Driver Floor			Passenger Floor			Driver Back			Passenger Back		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
PT1	1	0.2016	0.189	0.3979	0.2741	0.2406	0.4503	0.1956	0.1883	0.4443	0.2009	0.1871	0.4951	0.4618	0.2711	0.29	**0.5231**	**1.7314**	0.3869
	2	0.1564	0.1175	0.3255	0.1753	0.1374	0.384	-	-	-	-		-	0.348	0.1666	0.2461	0.3941	0.213	0.3373
	3	0.1079	0.0664	0.2653	0.1052	0.0754	0.2969	-	-	-	-	-	-	0.2936	0.1061	0.169	0.3272	0.1283	0.2247
	4	0.1335	0.1238	0.2791	**0.5594**	0.1758	0.3267	-	-	-	-	-	-	0.2989	0.1827	0.2119	0.3291	0.2269	0.2714
	5	0.1716	0.1155	0.3775	0.175	0.1333	0.4203	0.1431	0.1207	0.3886	0.151	0.1192	0.4226	0.4386	0.1628	0.2615	0.4848	0.2026	0.3196
	6	0.2175	0.1684	0.4596	0.2127	0.199	0.4828	0.1841	0.1715	0.4807	0.1873	0.1685	**0.5118**	**0.5496**	0.235	0.3316	**0.5896**	0.2943	0.3647
	7	0.1613	0.1274	0.3424	0.1602	0.1614	0.3631	0.1422	0.1366	0.3545	0.1442	0.1334	0.37	0.3882	0.1785	0.2374	0.4175	0.222	0.2632
PT2	1	0.0988	0.1721	0.2268	-	-	-	0.0109	0.028	0.0468	0.0143	0.0443	0.2958	0.0526	0.0739	0.1569	-	-	-
	2	0.1355	0.2206	0.3996	-	-	-	0.1113	0.168	0.2894	0.0838	0.1137	0.3549	0.2734	0.2329	0.257	-	-	-
	3	0.1634	0.3067	0.7781	-	-	-	0.1502	0.237	**0.6273**	0.0998	0.1531	**0.5557**	**0.5161**	0.354	0.3832	-	-	-
	4	0.1824	0.3205	0.7873	-	-	-	0.1752	0.2411	**0.6632**	0.117	0.1719	**0.5999**	**0.5982**	0.3838	0.3574	-	-	-
	5	0.2118	0.3252	**0.6626**	-	-	-	0.1613	0.2052	**0.6284**	0.093	0.1419	**0.6638**	**0.6652**	0.3458	0.3958	-	-	-
	6	0.1435	0.263	**0.5616**	-	-	-	0.1343	0.1556	0.4538	0.0926	0.1125	0.4303	0.4243	0.248	0.2559	-	-	-
	7	0.1274	0.1857	0.4657	-	-	-	0.1178	0.1245	0.4217	0.0684	0.1328	0.4995	0.3304	0.1674	0.2766	-	-	-
	8	0.2223	0.3657	**0.6982**	-	-	-	0.1779	0.2492	**0.6442**	0.1157	0.1789	**0.704**	**0.6088**	0.4023	0.4417	0.7333		
PT3	1	0.1628	0.1515	0.3536	0.1589	0.1616	0.4785	0.1428	0.1485	0.4113	0.1524	0.1451	0.4156	0.3789	0.1828	0.272	0.379	0.194	0.312
	2	0.2322	0.2693	**0.5797**	0.2187	0.3901	**0.7366**	0.2151	0.269	**0.6498**	0.2272	0.2613	**0.6845**	**0.7024**	0.3564	0.4084	**0.6703**	0.3534	**0.5505**
	3	0.263	0.2461	**0.5892**	0.2464	0.2739	**0.7896**	0.2327	0.2418	**0.6718**	0.2461	0.2352	**0.6941**	**0.6688**	0.3199	0.4098	**0.6625**	0.3299	0.4802
	4	0.2008	0.134	0.4091	0.1961	0.1323	**0.5327**	0.1587	0.1302	0.4466	0.1803	0.1281	0.4476	0.4705	0.1543	0.3194	0.4491	0.1819	0.3349
	5	0.2358	0.1706	0.4633	0.2284	0.162	**0.5675**	0.1878	0.1671	**0.5159**	0.2088	0.1646	**0.5094**	**0.5608**	0.2033	0.3586	**0.5246**	0.2149	0.4022
	6	0.187	0.1594	0.3986	0.1868	0.1464	**0.5147**	0.1552	0.1562	0.4658	0.1753	0.1546	0.4623	0.4465	0.1814	0.3123	0.434	0.1887	0.3743
	7	0.1723	0.1868	0.4036	0.1692	0.1892	**0.5298**	0.1528	0.1809	0.4575	0.1628	0.1788	0.4711	0.4508	0.2237	0.2973	0.4392	0.2288	0.3296
	8	0.1124	0.0781	0.2609	0.1208	0.0829	0.2995	0.0886	0.0698	0.2575	0.1004	0.069	0.2633	0.2916	0.0977	0.1863	0.2894	0.1048	0.2248
	9	0.0996	0.0652	0.2972	0.1172	0.0812	0.412	0.0903	0.0645	0.2989	0.1033	0.0639	0.2967	0.2186	0.0797	0.2103	0.2278	0.0904	0.298
	10	0.1255	0.0887	0.3009	0.1385	0.1001	0.3605	0.0983	0.0762	0.3042	0.1154	0.0755	0.3049	0.34	0.0999	0.2053	0.328	0.1101	0.2491

Table 20 continued..

Truck	Seg	Driver Seat			Passenger Seat			Driver Floor			Passenger Floor			Driver Back			Passenger Back		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
PT3	11	0.2059	0.1236	0.4465	0.2119	0.1391	**0.5623**	0.161	0.1222	0.476	0.1807	0.1211	0.4731	**0.5238**	0.145	0.343	0.4804	0.1621	0.3374
	12	0.2209	0.1997	**0.5365**	0.2245	0.2039	**0.6802**	0.196	0.1904	**0.6016**	0.2117	0.1881	**0.5993**	**0.5849**	0.2416	0.3647	**0.5518**	0.2599	0.393
	13	0.2758	0.1877	**0.6054**	0.2797	0.2081	**0.7459**	0.2282	0.1787	**0.6392**	0.2485	0.1746	**0.6529**	**0.6745**	0.2373	0.403	**0.6421**	0.2619	0.4136
PT4	1	0.1281	0.1007	0.3787	0.188	0.1323	0.3932	0.1209	0.1003	0.3129	0.1216	0.1022	0.339	0.1122	0.3284	0.1841	0.38	0.1337	0.2105
	2	0.1819	0.1393	0.4791	0.2629	0.1791	**0.5293**	0.1605	0.1455	0.4077	0.1577	0.1482	0.4447	0.1564	0.4447	0.2443	0.4915	0.1699	0.2894
	3	0.1499	0.1049	0.3729	0.1911	0.1321	0.3878	0.1179	0.104	0.3055	0.1156	0.1057	0.3317	0.1158	0.327	0.1832	0.3656	0.1322	0.2357
	4	0.194	0.1328	**0.533**	0.2679	0.1689	**0.5166**	0.1596	0.1386	0.4179	0.1638	0.142	0.474	0.1625	0.4446	0.2448	**0.5242**	0.1656	0.2912
	5	0.1138	0.0874	0.3966	0.1665	0.1163	0.3923	0.115	0.0856	0.3176	0.1137	0.0886	0.3482	0.1291	0.3373	0.1756	0.396	0.1116	0.2155
	6	0.0894	0.0738	0.3294	0.1338	0.0935	0.3373	0.1066	0.0747	0.2837	0.1022	0.0777	0.2977	**1.1079**	0.2953	0.1522	0.3311	0.091	0.1943
	7	0.0783	0.0838	0.3167	0.1297	0.1102	0.3092	0.0953	0.0829	0.2685	0.0942	0.085	0.2846	**0.669**	0.265	0.1405	0.3009	0.1003	0.1926
	8	0.0728	0.0848	0.2965	0.1179	0.0991	0.3118	0.0968	0.0835	0.2598	0.0945	0.0986	0.2736	0.4195	0.2732	0.1387	0.3036	0.1051	0.1723
	9	0.0759	0.0845	0.3301	0.1208	0.1009	0.3419	0.1043	0.0797	0.2807	0.1054	0.0906	0.2924	0.4697	0.2991	0.1417	0.3392	0.1123	0.1807
PT5	1	0.0033	0.0055	0.0191	0.3125	0.4076	0.1046	0.2182	0.1771	0.4244	0.1801	0.1133	0.4127	**0.618**	0.1523	0.3462	0.0011	0.0032	0.0384
	2	0.2141	0.4761	0.1325	0.2092	0.2748	0.078	0.1332	0.107	0.2802	0.115	0.0725	0.2766	0.4391	0.1093	0.1874	0.4748	0.1088	0.2324
	3	0.2222	0.0838	0.2921	0.2033	0.1515	0.4534	0.1654	0.1395	0.3195	0.1254	0.0833	0.302	0.4567	0.1217	0.2181	0.4538	0.1183	0.2304
	4	0.1706	0.0662	0.2405	0.1601	0.1383	0.3257	0.2054	0.1881	0.3123	0.1162	0.0638	0.2535	0.3125	0.0893	0.2305	0.3255	0.0921	0.2031
	5	0.2641	0.0903	0.3021	0.241	0.2193	0.4554	0.2042	0.1781	0.3659	0.1457	0.094	0.324	0.4539	0.1226	0.2637	0.4627	0.1164	0.3054
	6	0.3665	0.1246	0.4191	0.2975	0.2712	**0.6157**	0.2613	0.2278	0.4781	0.1944	0.1211	0.4333	**0.6594**	0.1732	0.3359	**0.6105**	0.1355	0.3261
	7	0.2807	0.1117	0.3791	0.2161	0.2568	**0.508**	0.2694	0.2386	0.4583	0.1806	0.1111	0.3791	**0.5198**	0.1418	0.3273	**0.5001**	0.1245	0.3019
	8	0.176	0.0678	0.2304	0.1497	0.446	0.3128	0.1512	0.1309	0.2616	0.1042	0.0555	0.2198	0.3039	0.0826	0.2096	0.296	0.0761	0.1937
	9	0.1797	0.0712	0.2557	0.1495	**0.5273**	0.2984	0.27	0.2605	0.3585	0.1108	0.0636	0.2467	0.2909	0.0967	0.2433	0.2906	0.0914	0.218
	10	0.1927	0.0823	0.2763	0.1494	0.3834	0.3456	0.3164	0.3087	0.4274	0.1238	0.0804	0.2788	0.3376	0.11	0.2374	0.3349	0.0995	0.192
	11	0.2057	0.0895	0.3101	0.2288	0.1625	0.4035	0.1793	0.1563	0.3181	0.1316	0.0894	0.2829	0.4152	0.1288	0.255	0.4252	0.1258	0.2658
	12	0.1706	0.0935	0.267	0.1909	0.1416	0.3343	0.1502	0.1322	0.2735	0.1169	0.0896	0.2531	0.331	0.1255	0.2207	0.3486	0.1189	0.2278
	13	0.1703	0.0896	0.2769	0.1932	0.1493	0.3384	0.1704	0.1463	0.2931	0.1272	0.0837	0.2646	0.3209	0.1236	0.2337	0.3547	0.1226	0.2767

Table 20 continued..

Truck	Seg	Driver Seat			Passenger Seat			Driver Floor			Passenger Floor			Driver Back			Passenger Back		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
PT6	1	0.1846	0.1123	**0.5101**	0.1882	0.0938	**0.5144**	0.0498	0.0507	0.0564	**2.2224**	**2.0637**	**3.0188**	0.3143	0.0944	0.4421	0.376	0.142	**0.6437**
	2	0.1307	0.078	0.342	0.128	0.0668	0.3459	0.0447	0.0454	0.0508	**2.0808**	**1.9618**	**2.8365**	0.2271	0.0786	0.3937	0.256	0.093	0.4756
	3	0.1443	0.0797	0.3717	0.1388	0.0668	0.3705	0.0401	0.0409	0.0458	**1.9225**	**1.8339**	**2.6302**	0.2534	0.0815	0.4244	0.2835	0.0941	**0.5123**
	4	0.1514	0.0836	0.3563	0.1396	0.0652	0.3554	0.0396	0.0404	0.0459	**1.9922**	**1.9436**	**2.685**	0.2717	0.0788	0.3875	0.3078	0.0945	0.4427
	5	0.1419	0.074	0.381	0.1318	0.06	0.377	0.0386	0.0395	0.0448	**2.1798**	**2.1317**	**2.8394**	0.2268	0.0733	0.4507	0.2505	0.0832	**0.5677**
	6	0.1134	0.0729	0.2869	0.1044	0.071	0.298	0.0397	0.0407	0.0463	**2.1885**	**2.1377**	**2.8657**	0.1722	0.0864	0.3578	0.1965	0.0958	0.4183
	7	0.1421	0.0747	0.3741	0.1309	0.068	0.3717	0.0392	0.0403	0.0459	**2.2823**	**2.2433**	**2.9413**	0.2308	0.0795	0.4387	0.2674	0.0991	**0.5256**
	8	0.1384	0.0706	0.3196	0.1386	0.0658	0.3156	0.0367	0.0377	0.043	**2.2488**	**2.2158**	**2.9082**	0.2548	0.0782	0.3322	0.2843	0.091	0.43
	9	0.1262	0.078	0.3139	0.1234	0.0604	0.3217	0.036	0.0371	0.042	**2.1792**	**2.1948**	**2.7902**	0.2155	0.0725	0.3483	0.2382	0.0828	0.477

Appendix-V: RMS acceleration plots-Poland

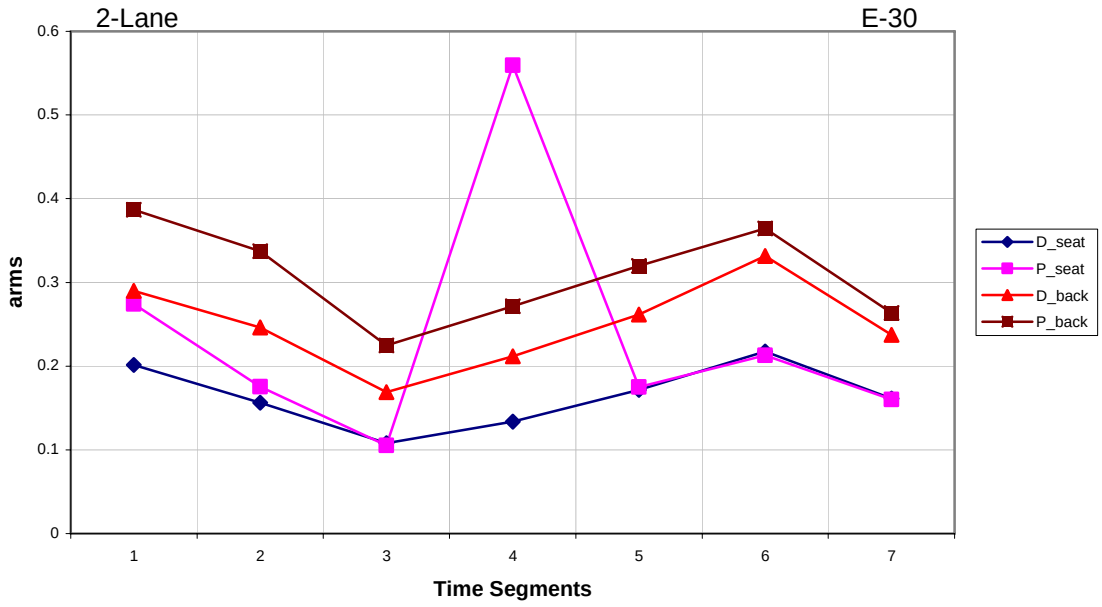


Figure 82 PT1 Driver, Passenger seat pad and seat back Weighted RMS acceleration- X axis

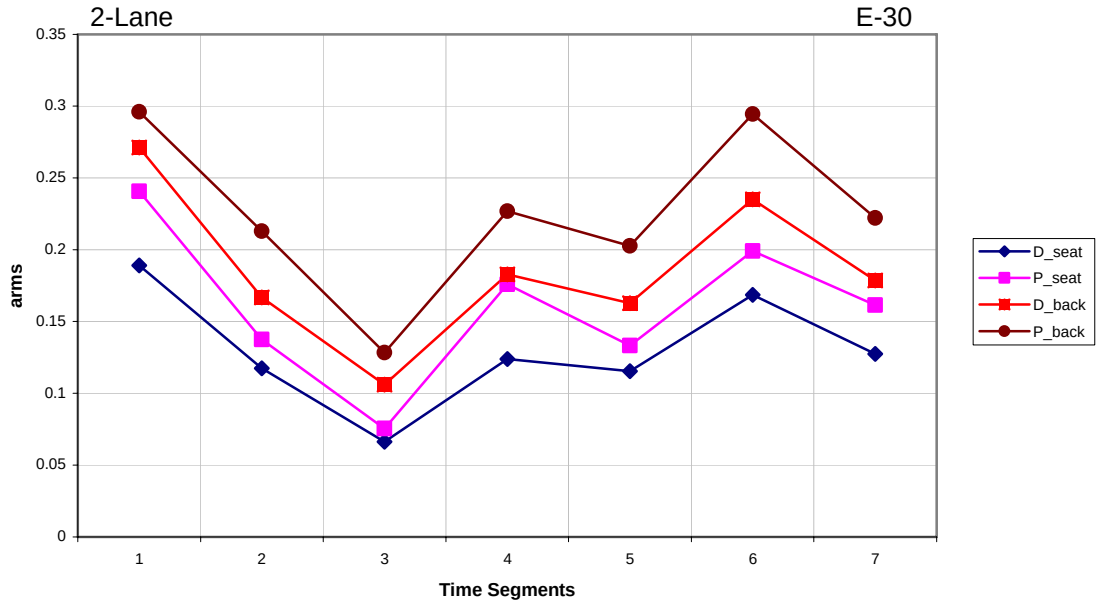


Figure 83 PT1 Driver, Passenger seat pad and seat back Weighted RMS acceleration- Y axis

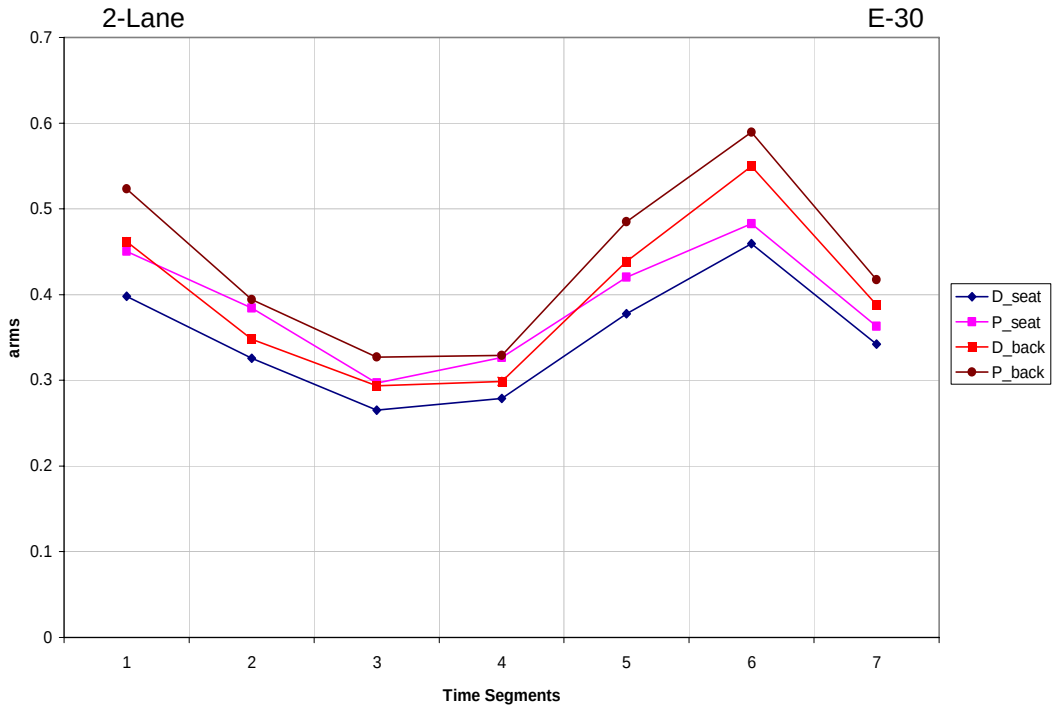


Figure 84 PT1 Driver, Passenger seat pad and seat back Weighted RMS acceleration-Z axis

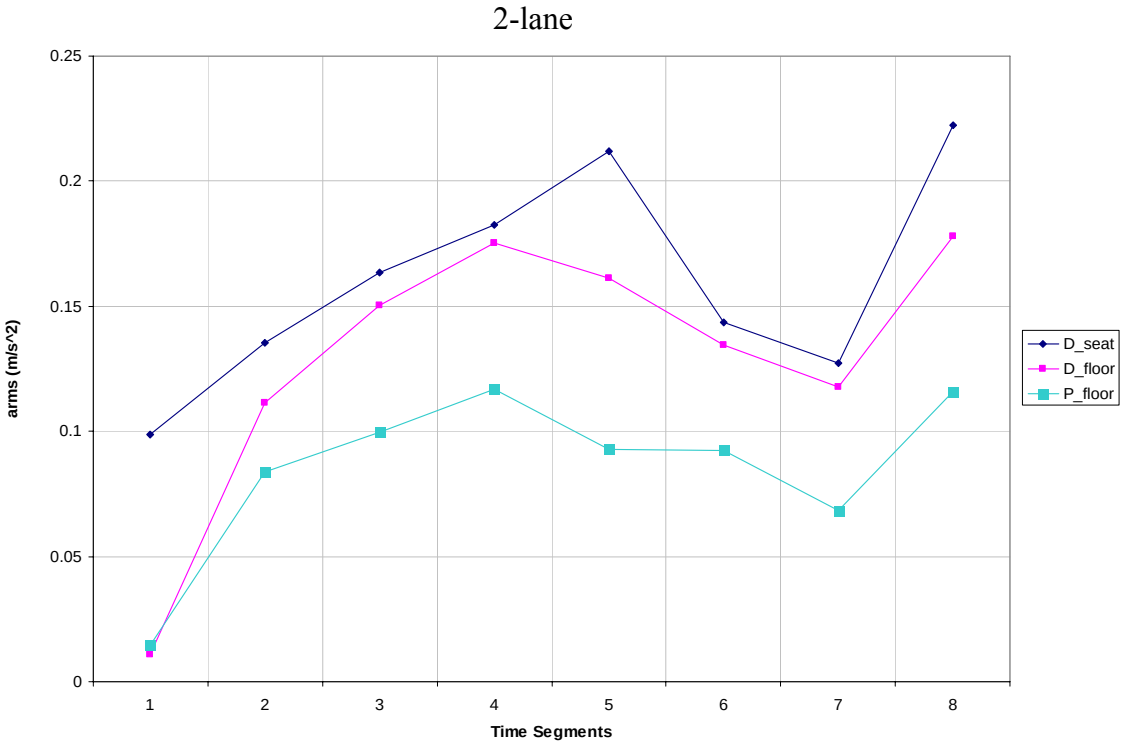


Figure 85 PT2 Driver seat pad, floor and Passenger floor Weighted RMS acceleration-X axis

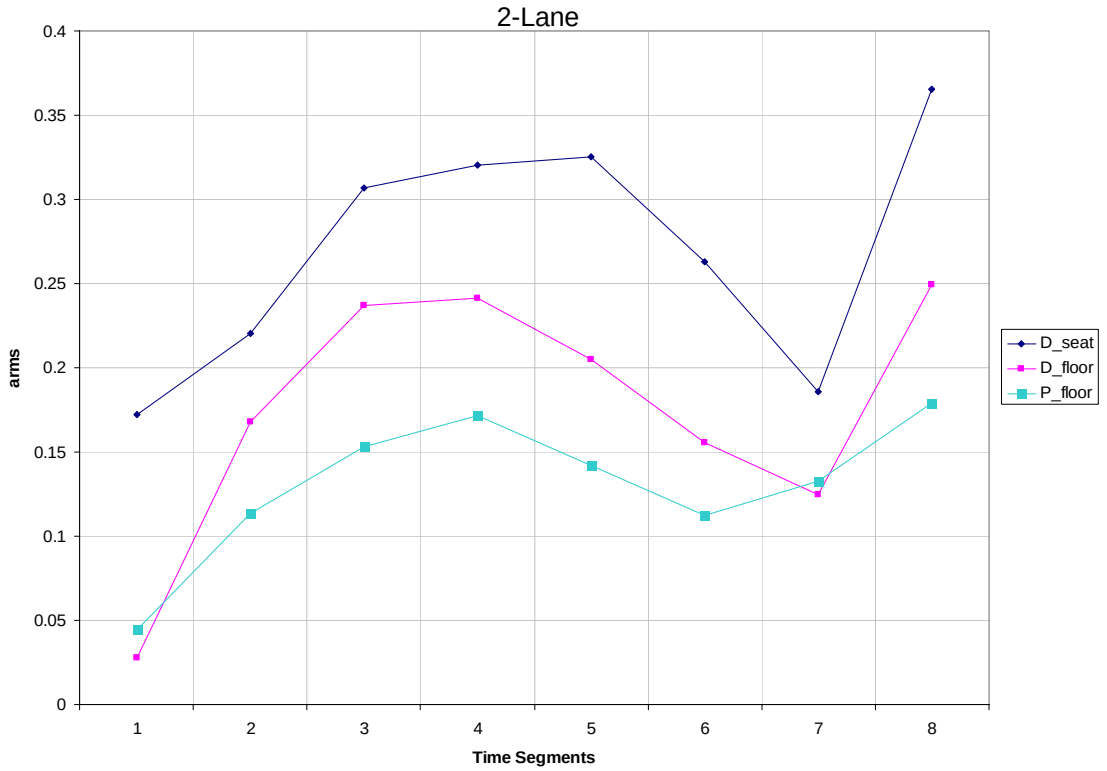


Figure 86 PT2 Driver seat pad, floor and Passenger floor Weighted RMS acceleration-Y axis

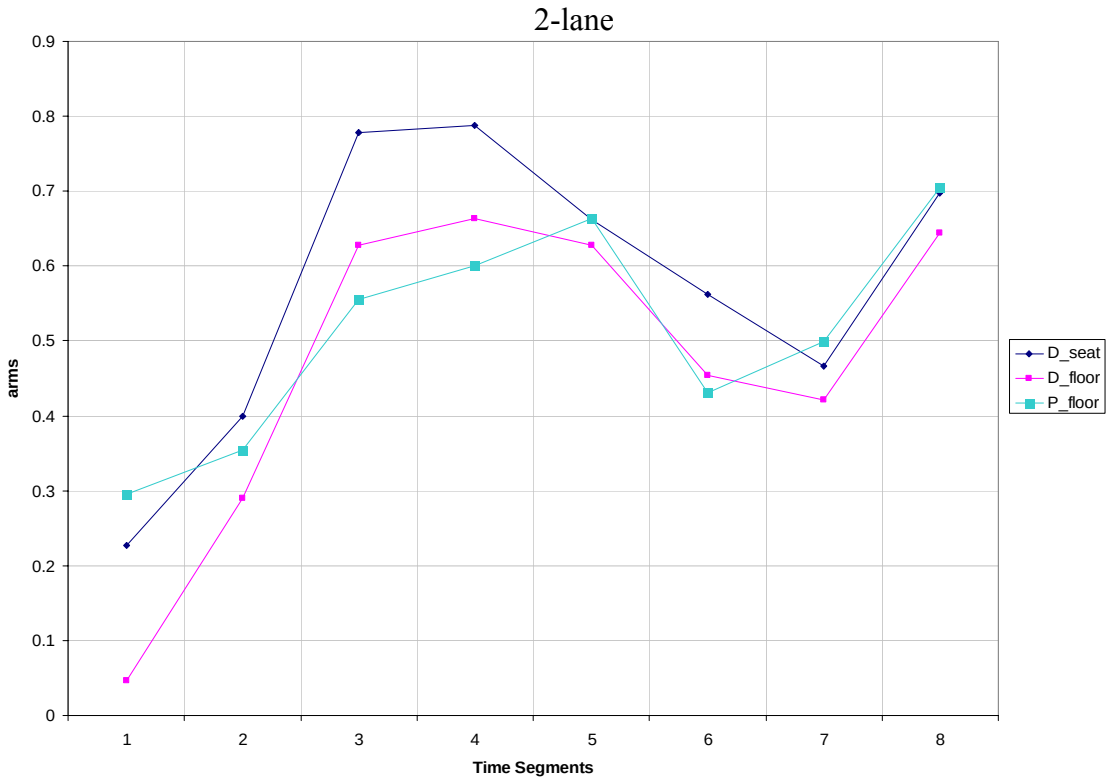


Figure 87 PT2 Driver seat pad, floor and Passenger floor Weighted RMS acceleration-X axis

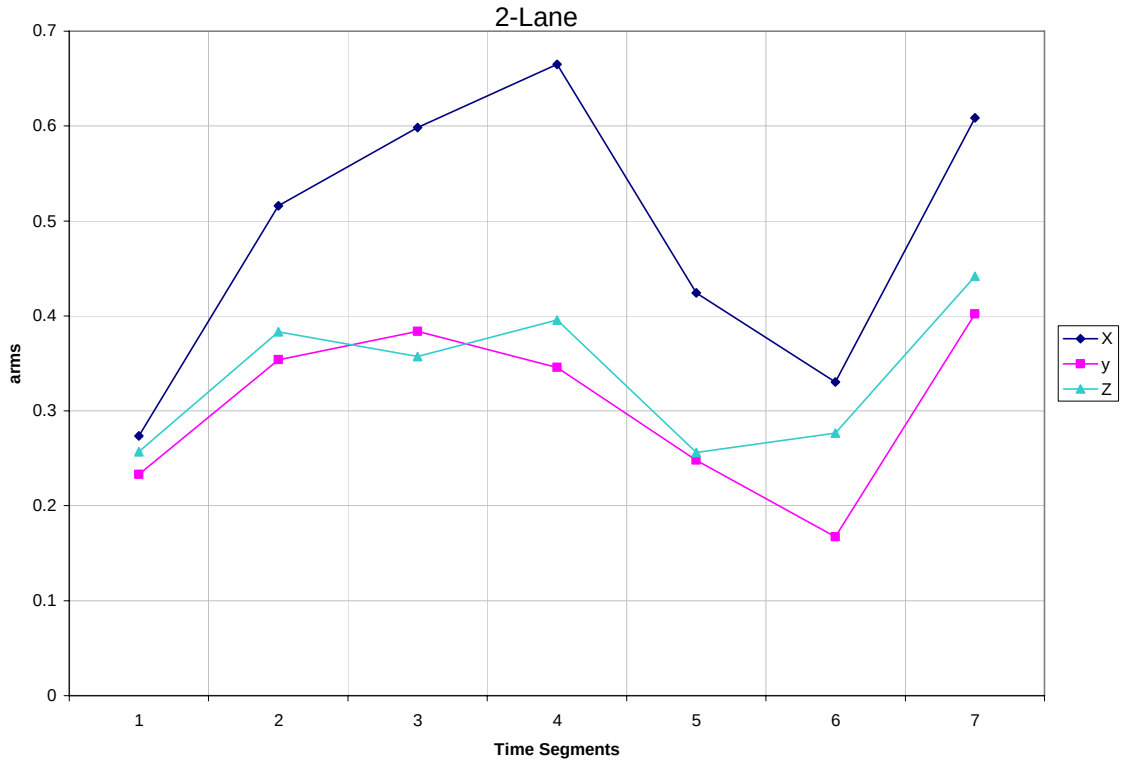


Figure 88 PT2 Driver seat back Weighted RMS acceleration

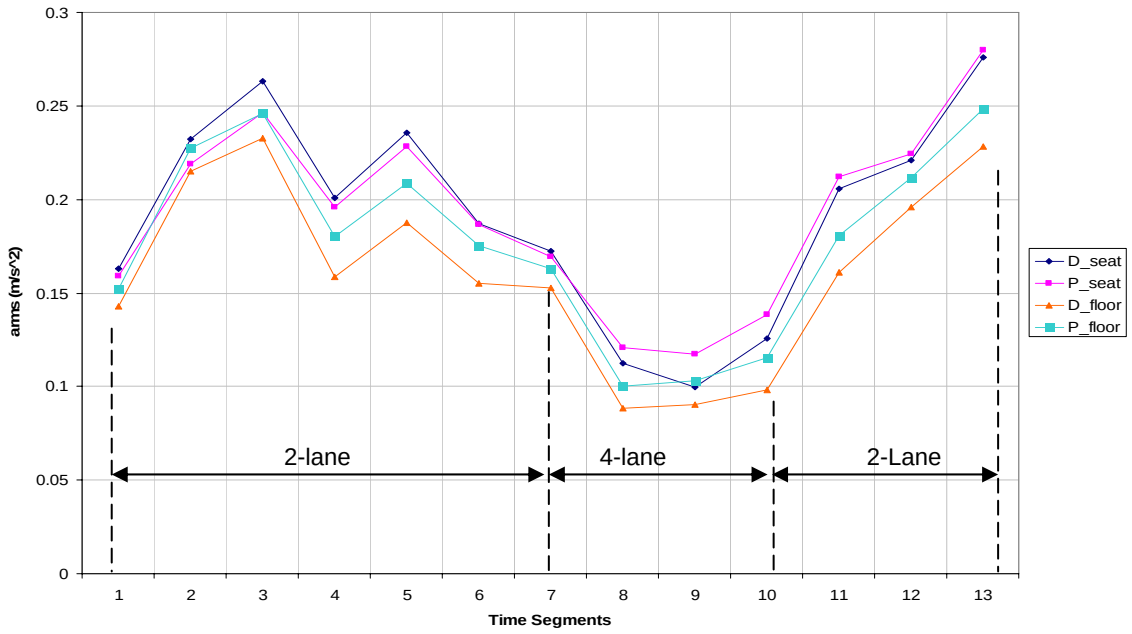


Figure 89 PT3 Driver, Passenger seat pad and floor Weighted RMS acceleration-X axis

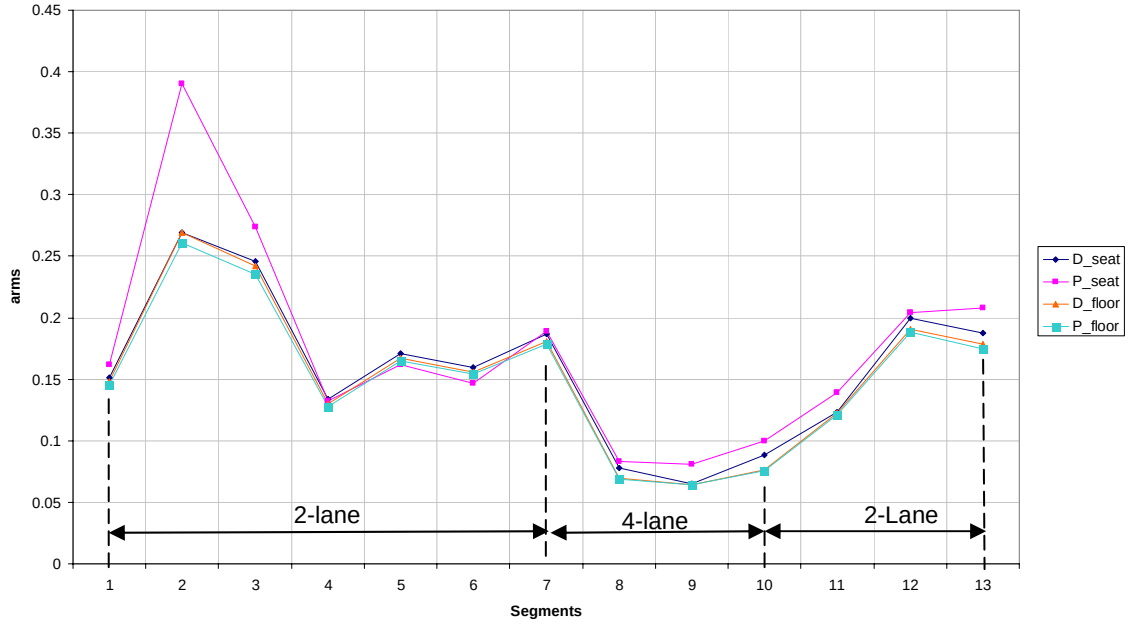


Figure 90 PT3 Driver, Passenger seat pad and floor Weighted RMS acceleration- Y axis

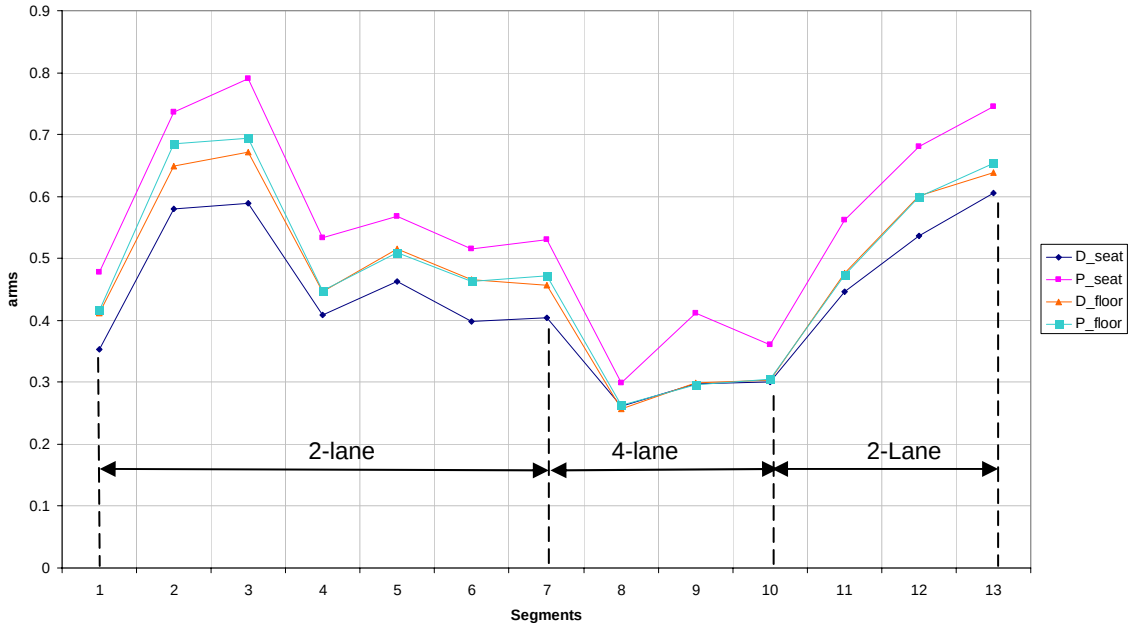


Figure 91 PT3 Driver, Passenger seat pad and floor Weighted RMS acceleration- Z axis

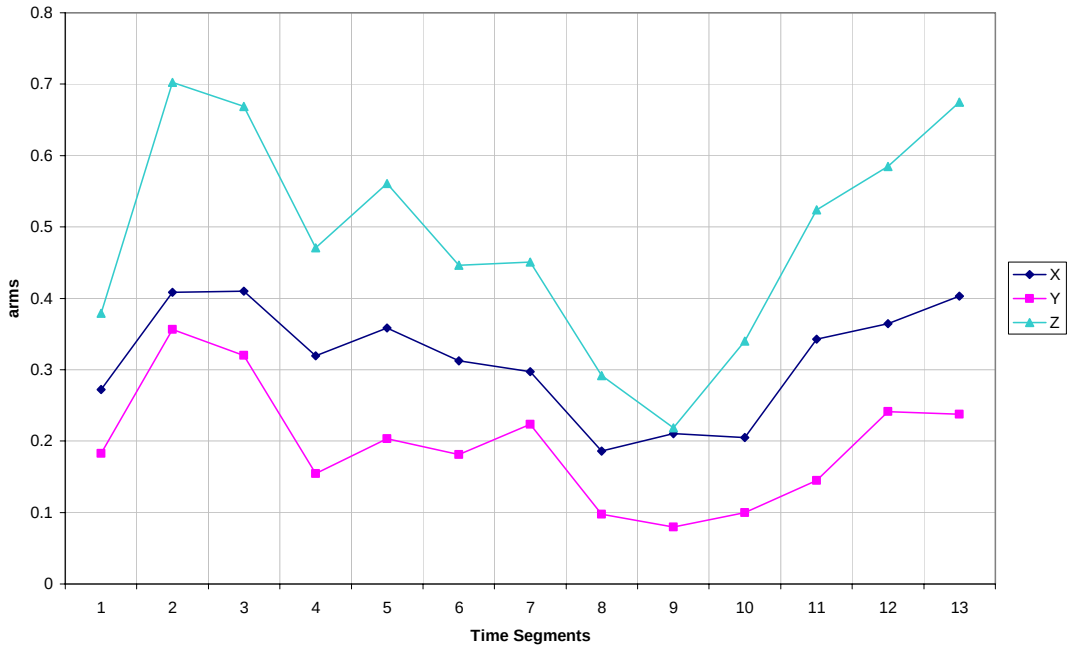


Figure 92 PT3 Driver seat back Weighted RMS acceleration

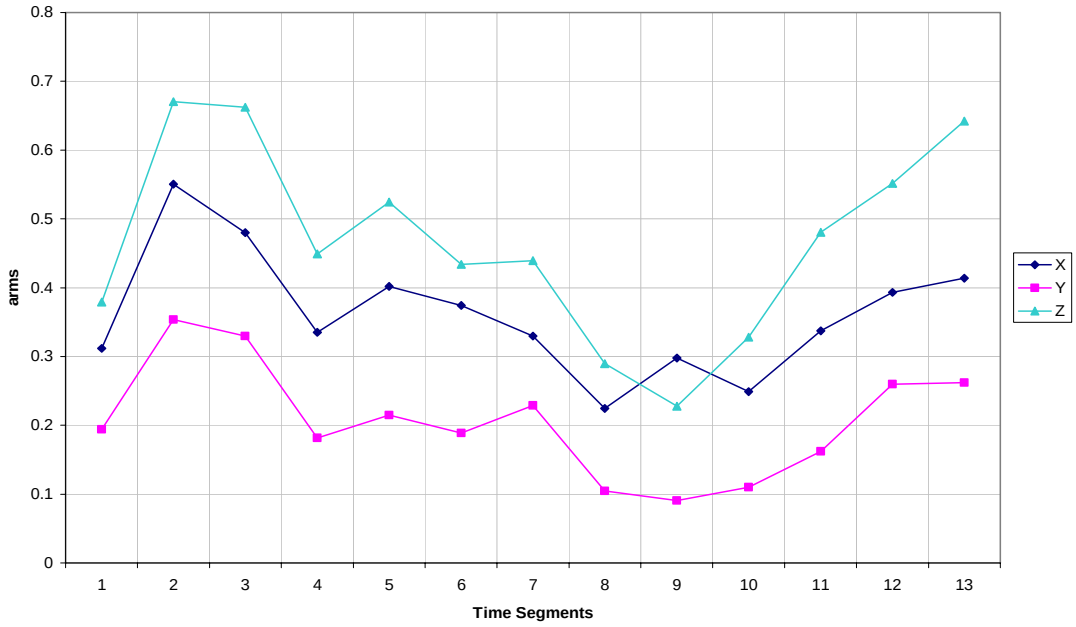


Figure 93 PT3 Passenger seat back Weighted RMS acceleration

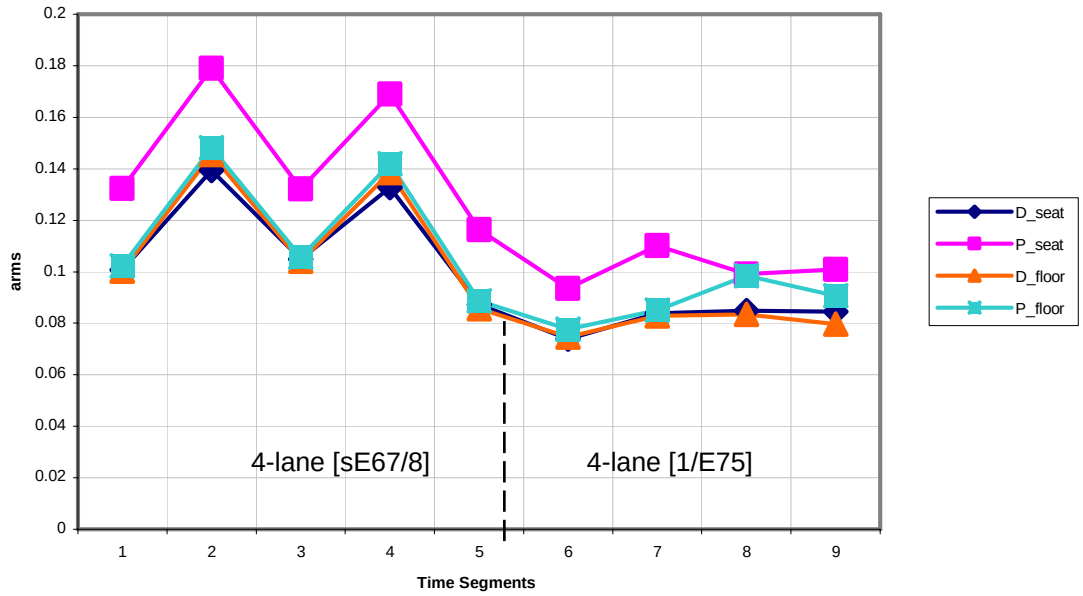


Figure 94 PT4 Driver, Passenger seat pad and floor Weighted RMS acceleration-X axis

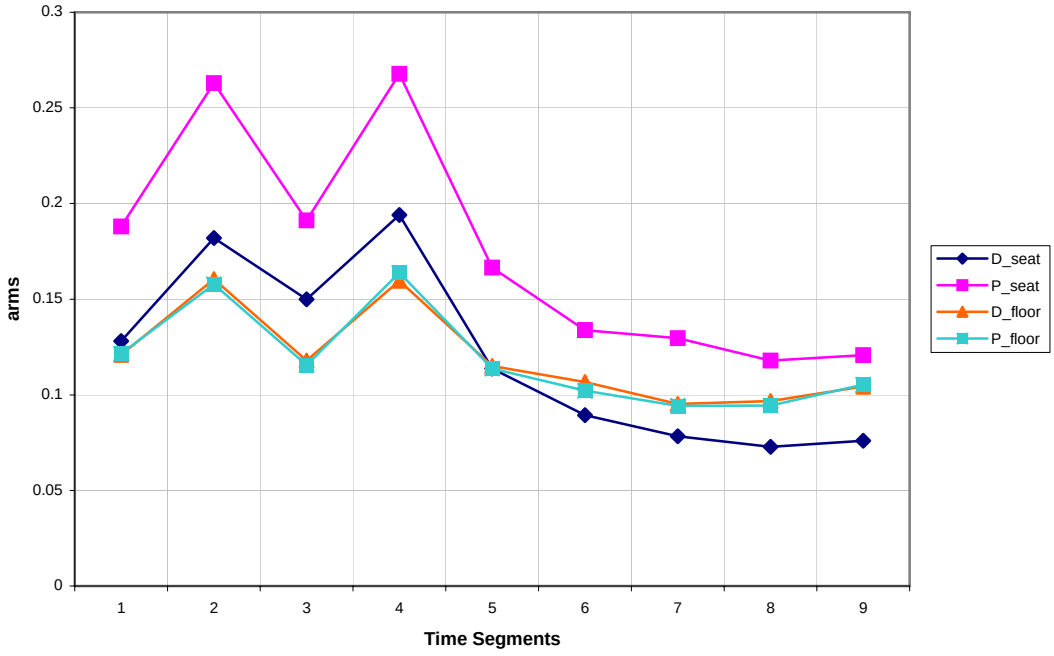


Figure 95 PT4 Driver, Passenger seat pad and floor Weighted RMS acceleration-Y axis

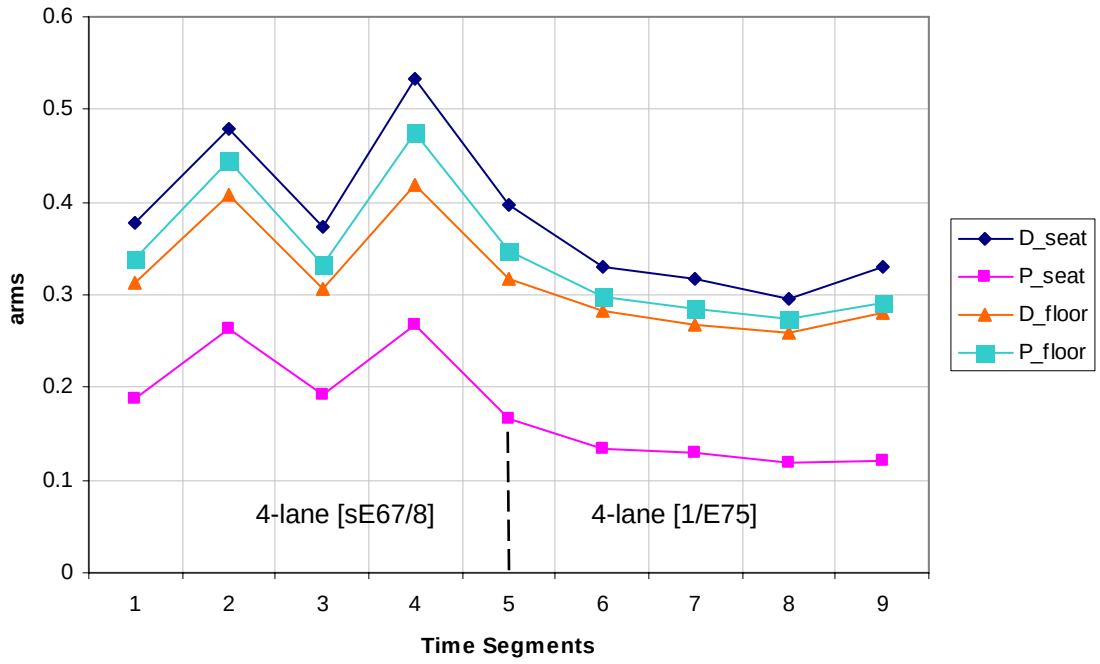


Figure 96 PT4 Driver, Passenger seat pad and floor Weighted RMS acceleration-Z axis

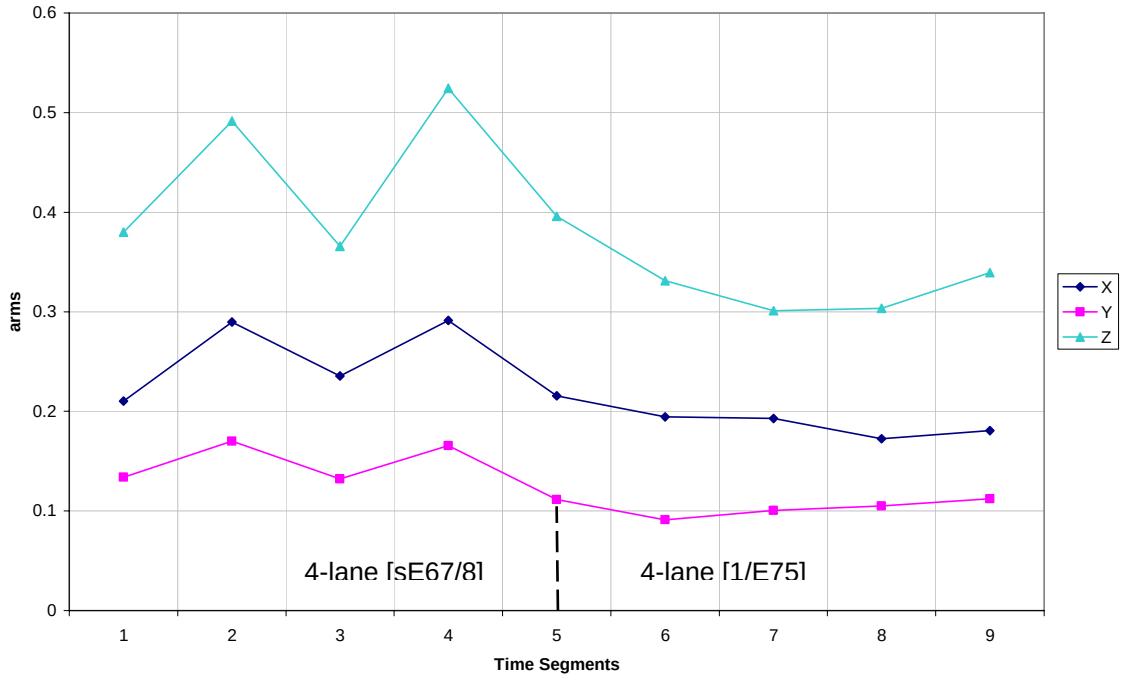


Figure 97 PT4 Passenger Seatback Weighted RMS acceleration

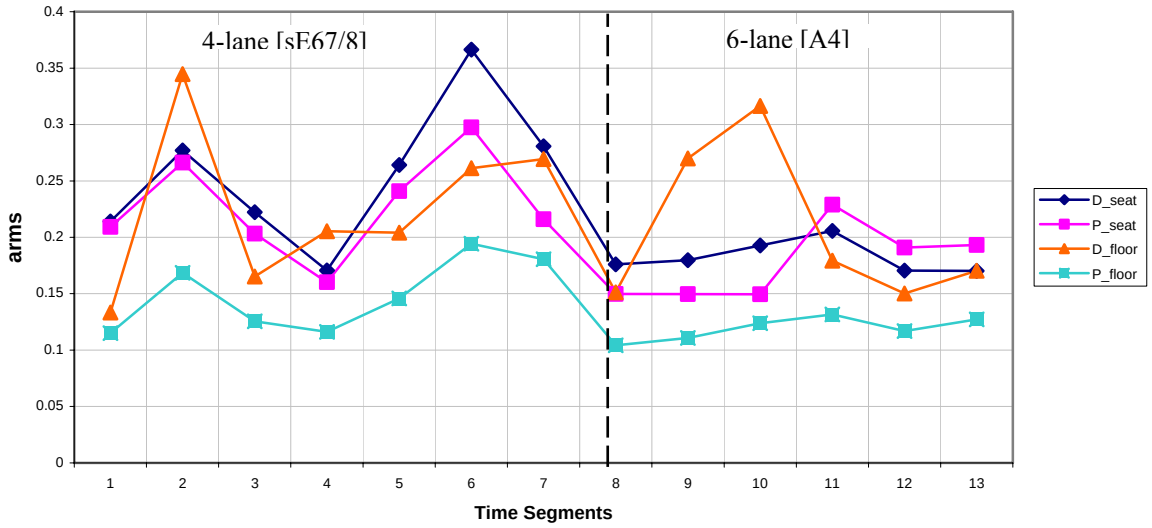


Figure 98 PT5 Driver, Passenger seat pad and floor Weighted RMS acceleration-X axis

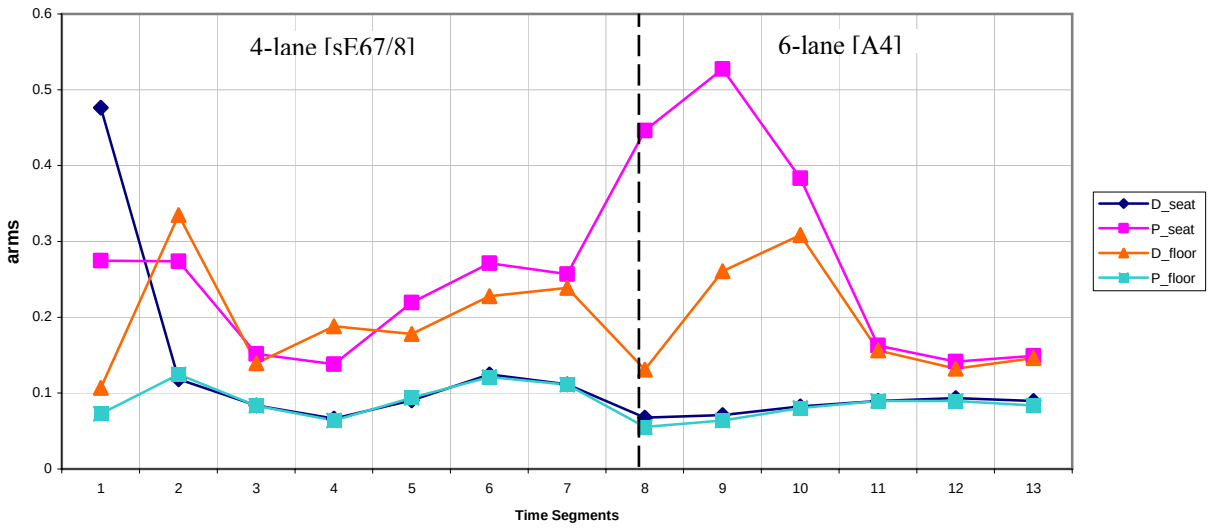


Figure 99 PT5 Driver, Passenger seat pad and floor Weighted RMS acceleration-Y axis

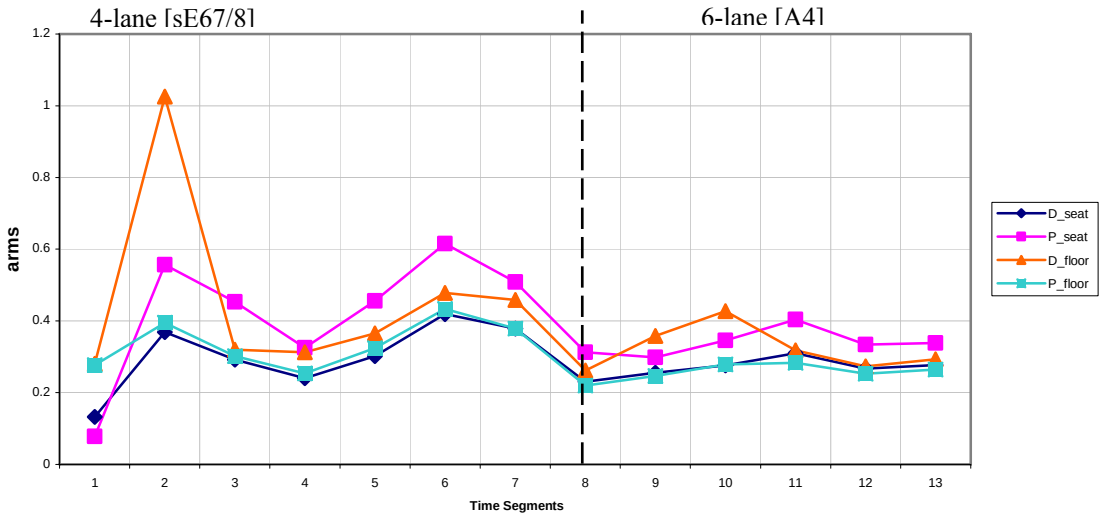


Figure 100 PT5 Driver, Passenger seat pad and floor Weighted RMS acceleration-Z axis

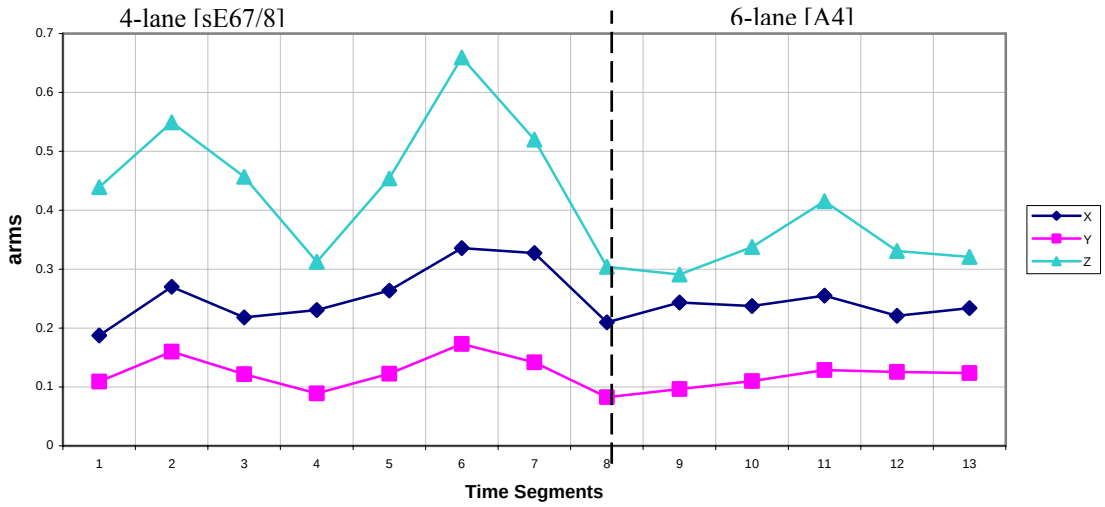


Figure 101 PT5 Driver Seatback Weighted RMS acceleration

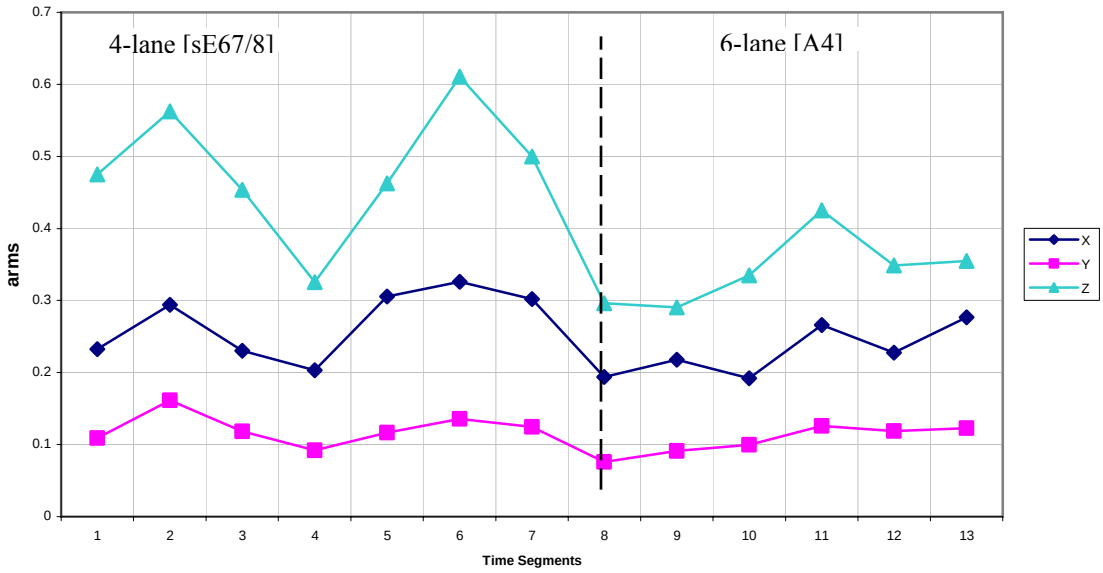


Figure 102 PT5 Passenger Seatback Weighted RMS acceleration

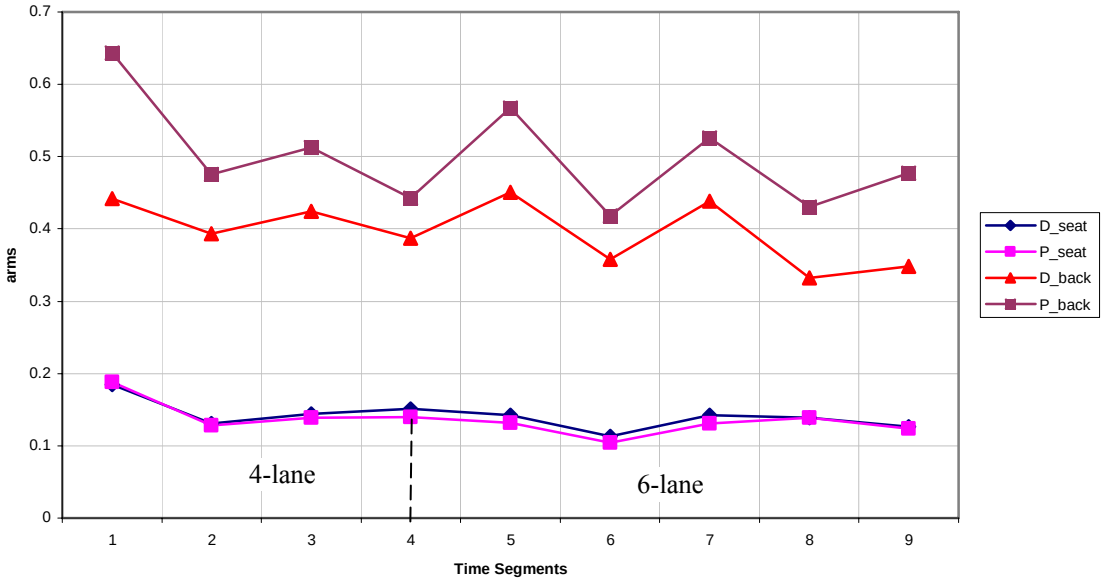


Figure 103 PT6 Driver, Passenger seat pad and seat back Weighted RMS acceleration-X axis

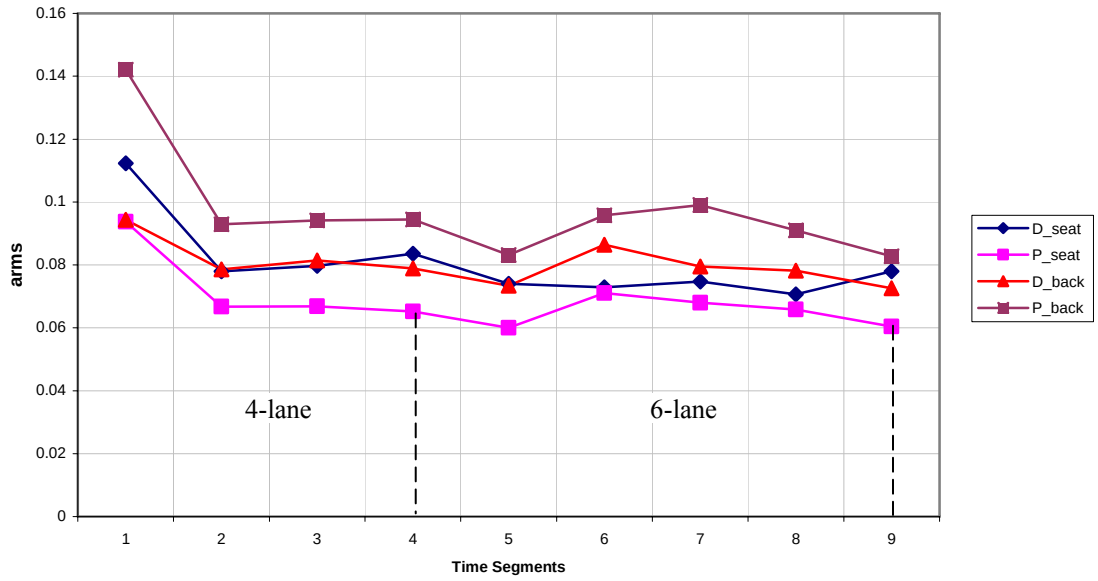


Figure 104 PT6 Driver, Passenger seat pad and seat back Weighted RMS acceleration-Y axis

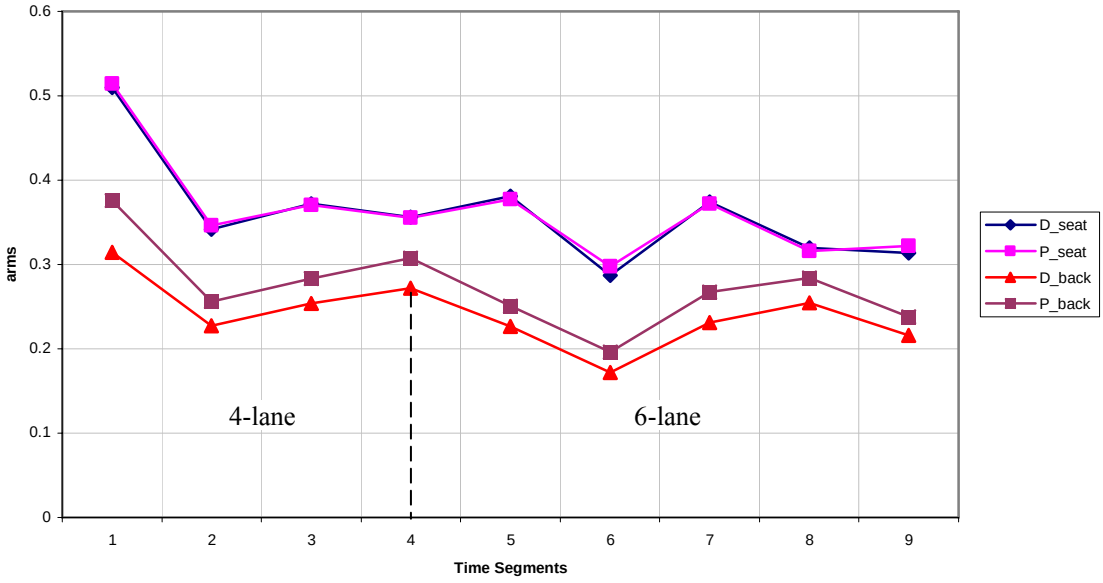


Figure 105 PT6 Driver, Passenger seat pad and seat back Weighted RMS acceleration-Z axis

Appendix-VI: Comfort plots-Poland

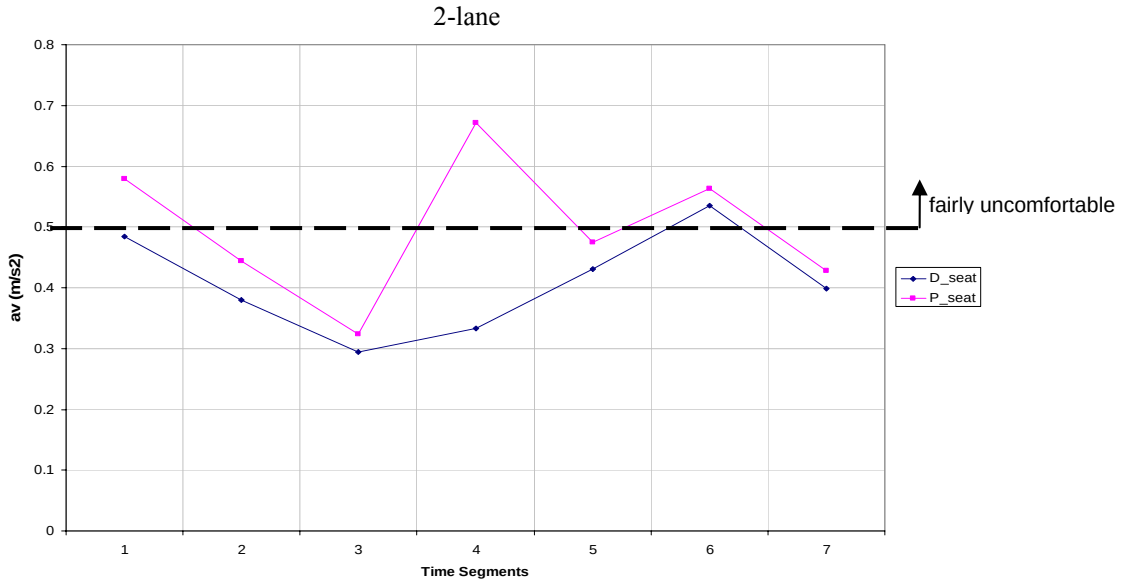


Figure 106 PT1 "Vibration Total Value" for Comfort

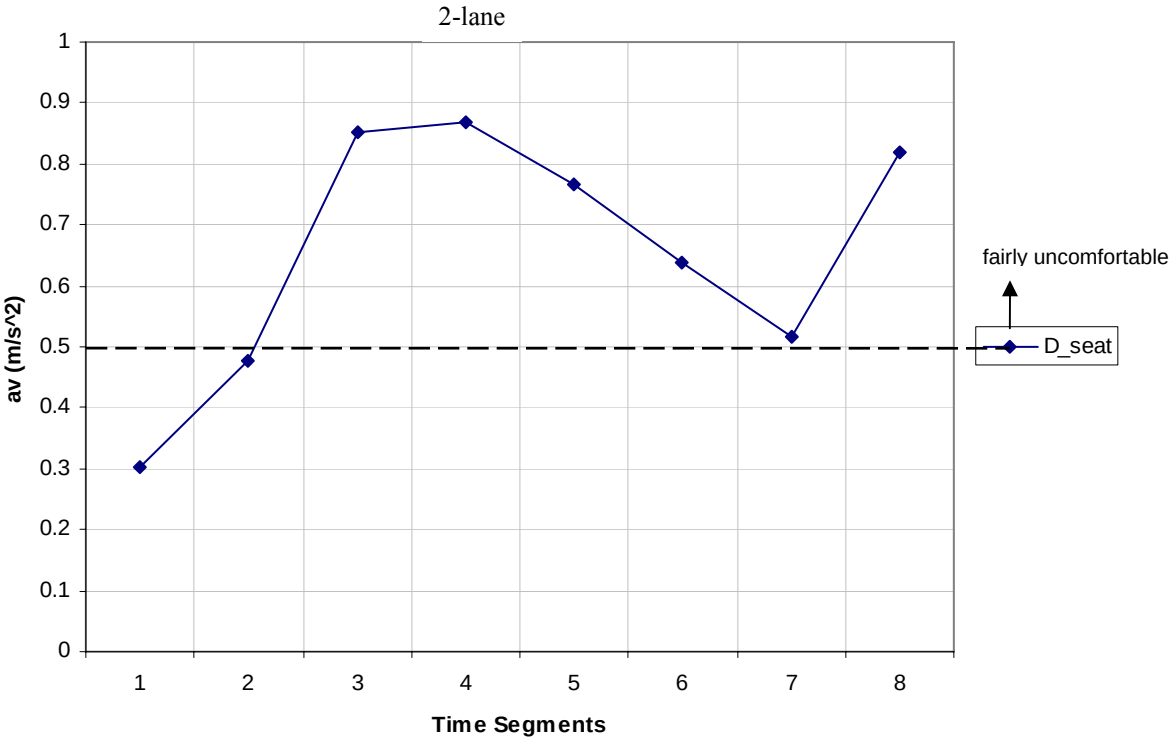


Figure 107 PT2 "Vibration Total Value" for Comfort

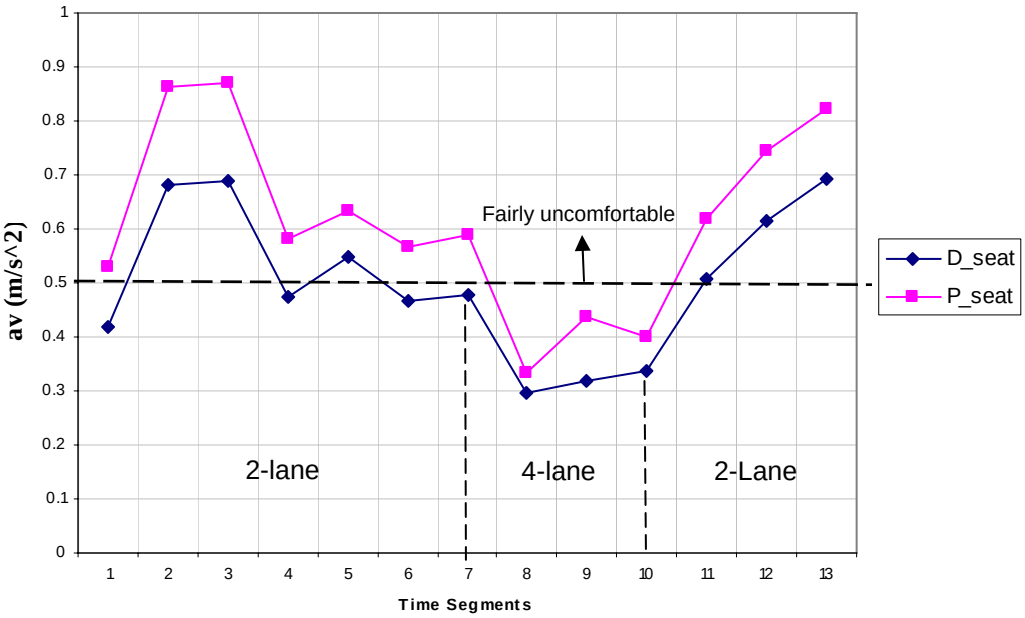


Figure 108 PT3 "Vibration Total Value" for Comfort

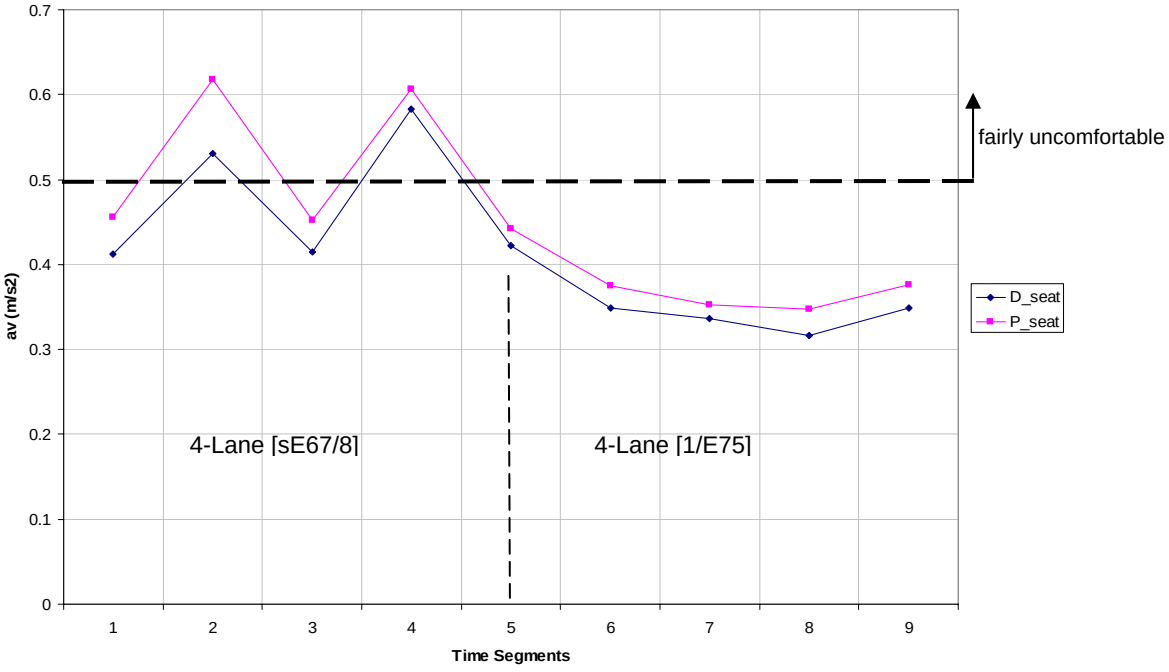


Figure 109 PT4 "Vibration Total Value" for Comfort

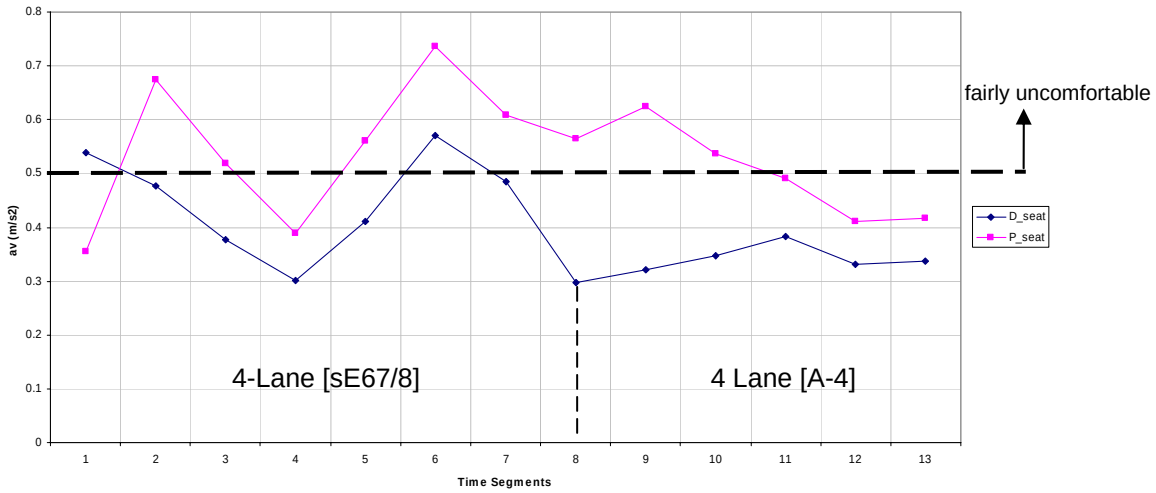


Figure 110 PT5 "Vibration Total Value" for Comfort

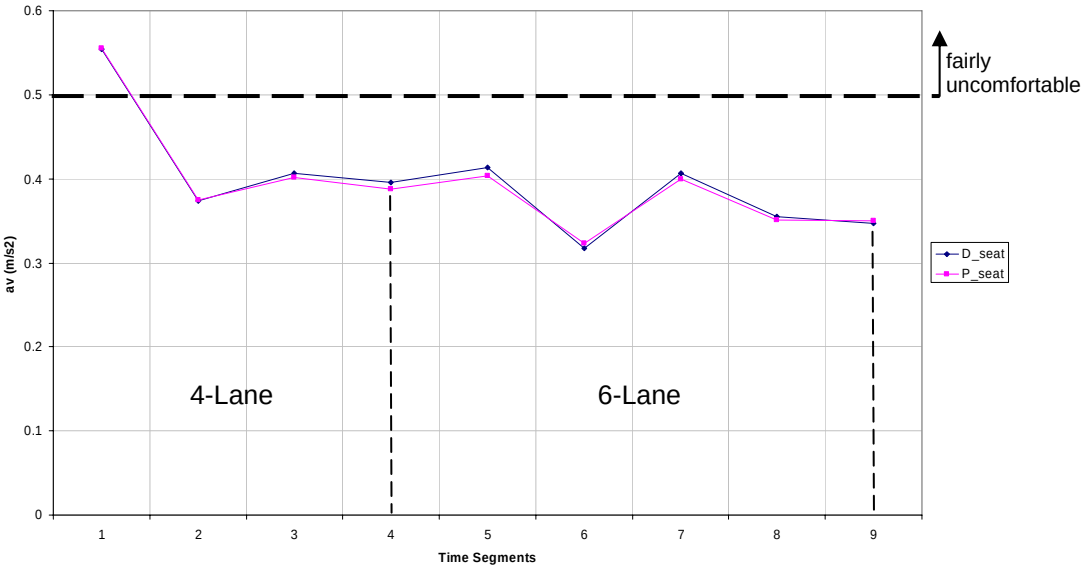


Figure 111 PT6 "Vibration Total Value" for Comfort

Appendix-VII: Selected 1/3rd octave plots-Poland

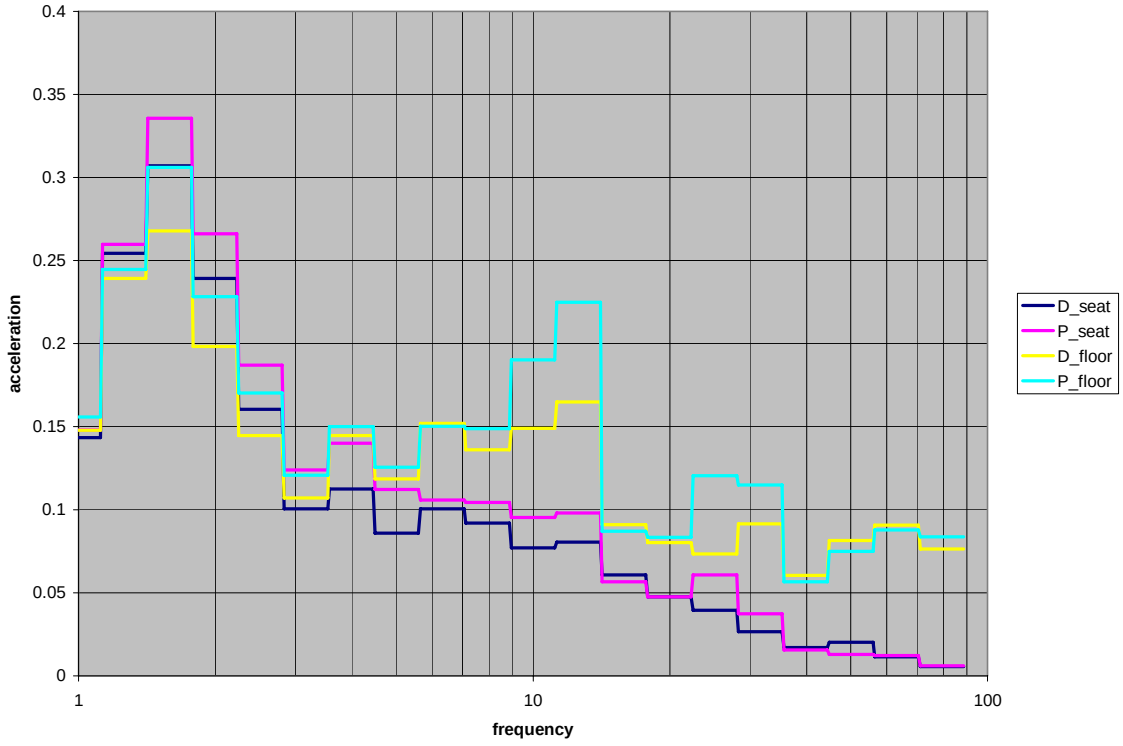


Figure 112 PT1 1/3rd octave Driver& Passenger seat pad, floor acceleration-Z axis

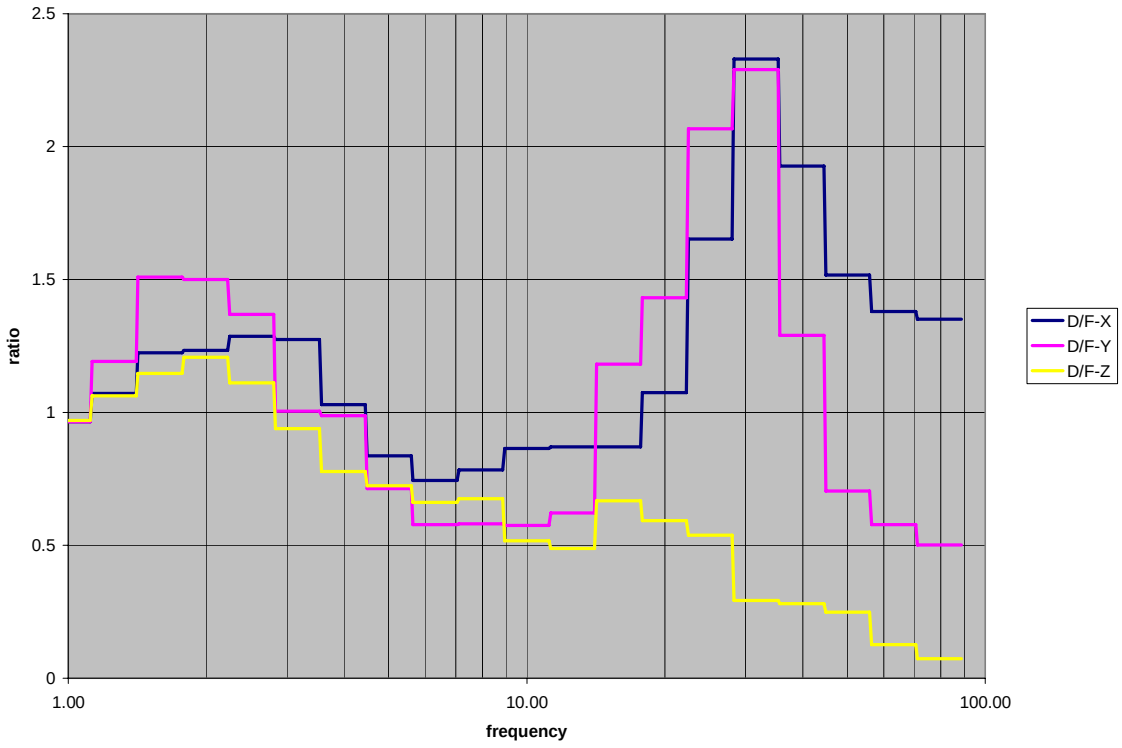


Figure 113 PT1: 1/3rd octave Driver/Floor ratio

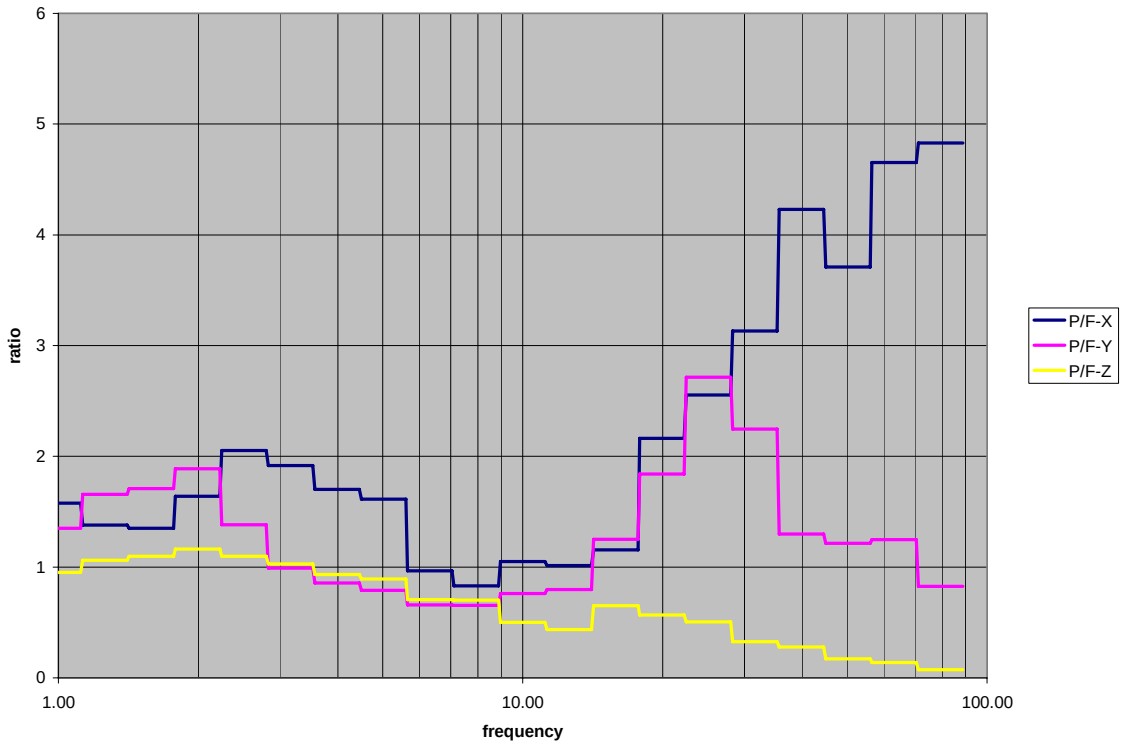


Figure 114 PT1: 1/3rd octave Passenger/Floor ratio

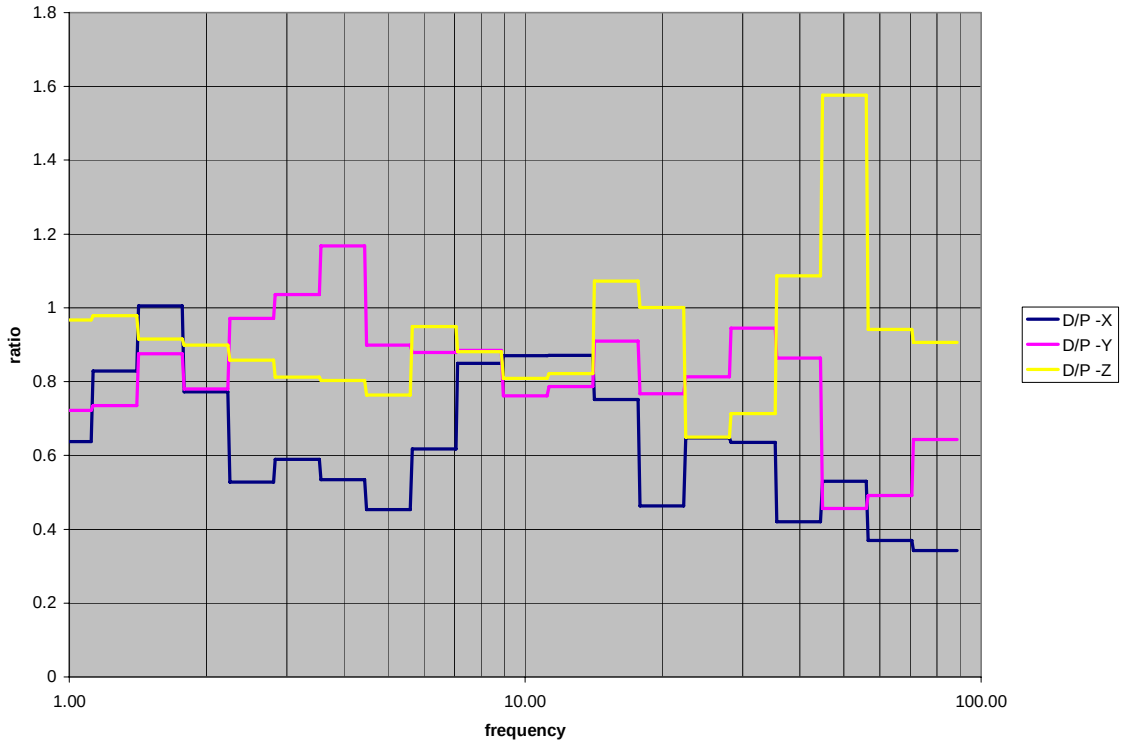


Figure 115 PT1: 1/3rd octave Driver/Passenger ratio

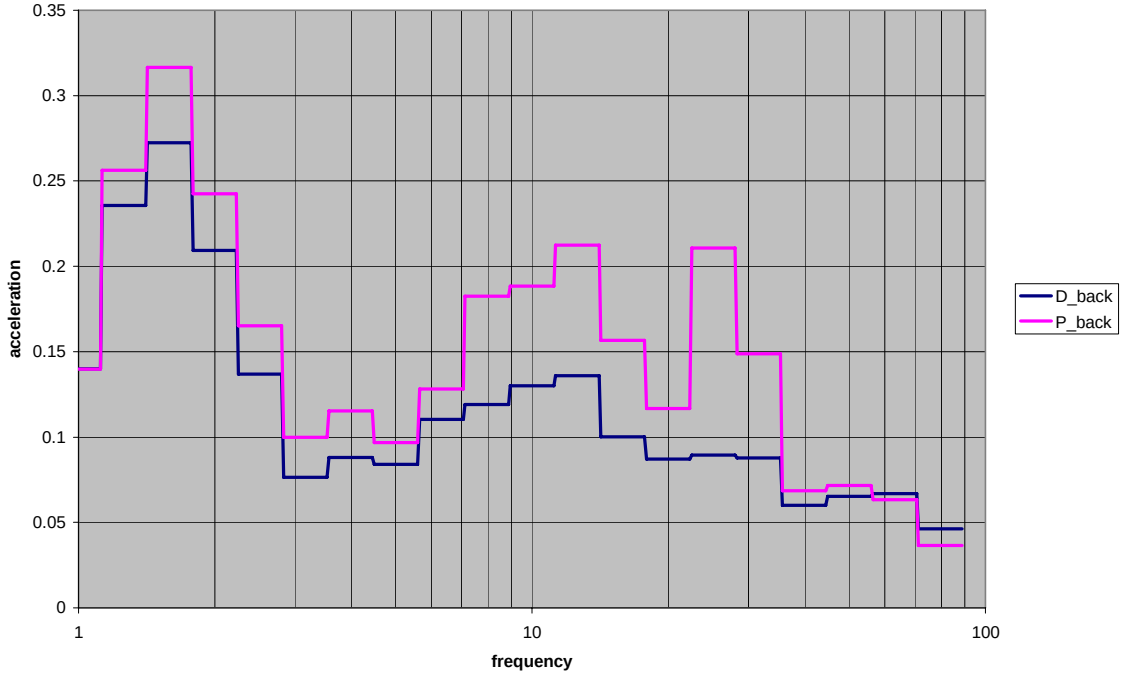


Figure 116 PT1: 1/3rd octave Driver& Passenger Seatback acceleration-Z axis

:

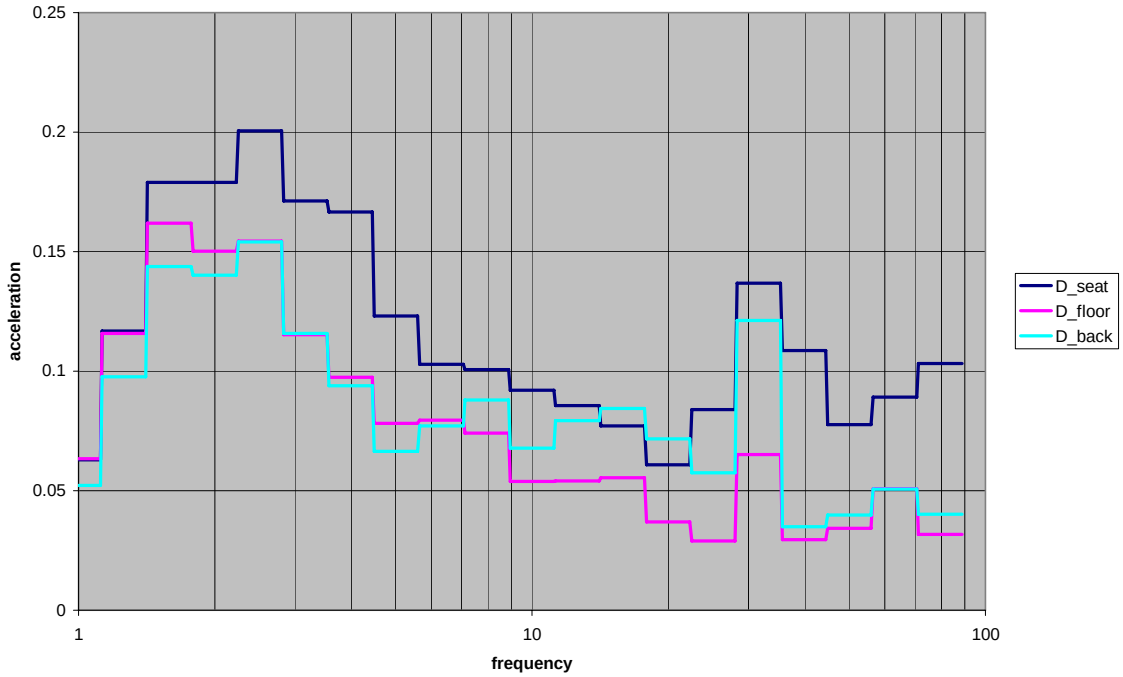


Figure 117 PT2: 1/3rd octave Driver Seat, Floor& Back acceleration-Z axis

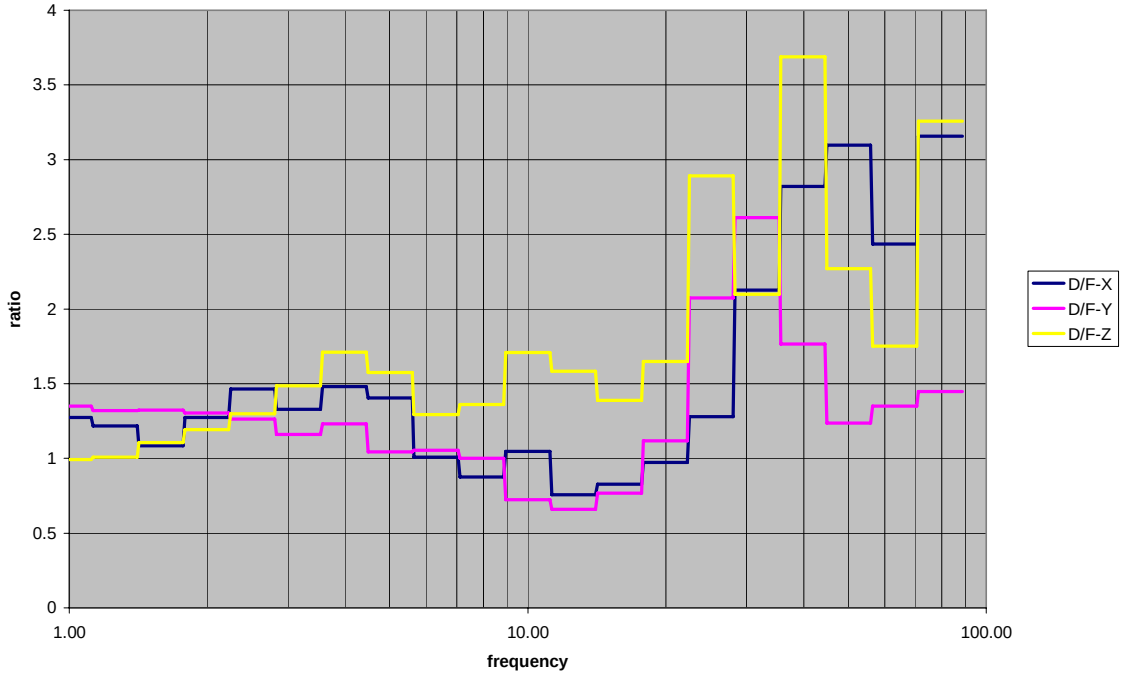


Figure 118 PT2: 1/3rd octave Driver/Floor ratio

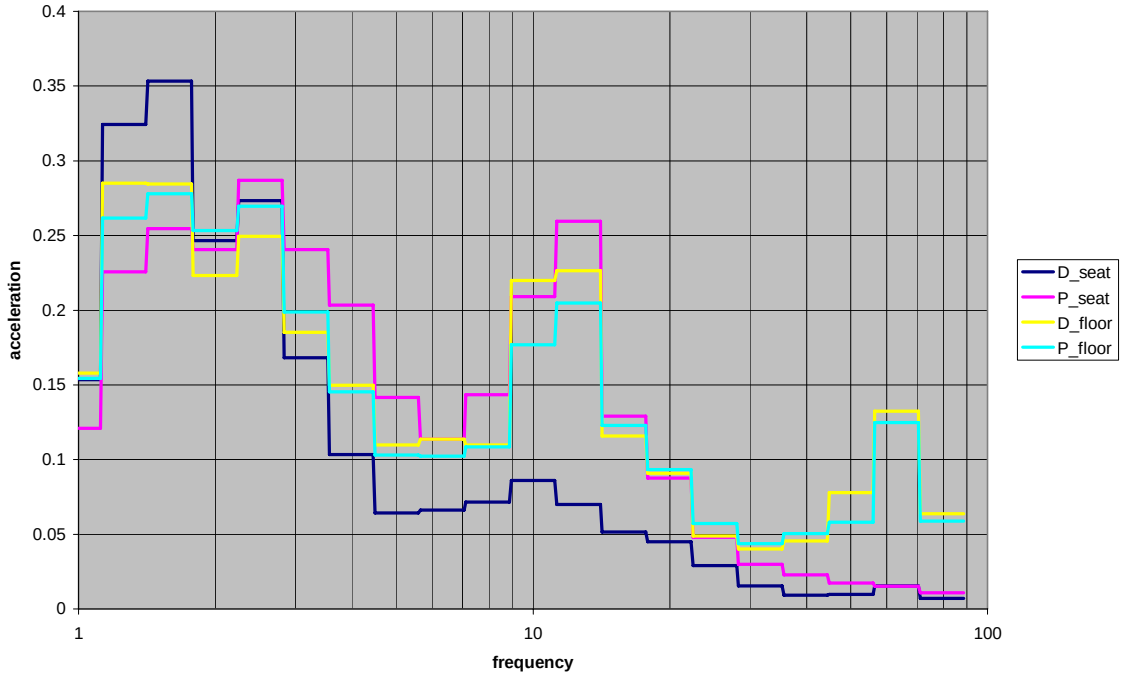


Figure 119 PT3: 1/3rd octave Driver, Passenger Seat& Floor acceleration-Z axis

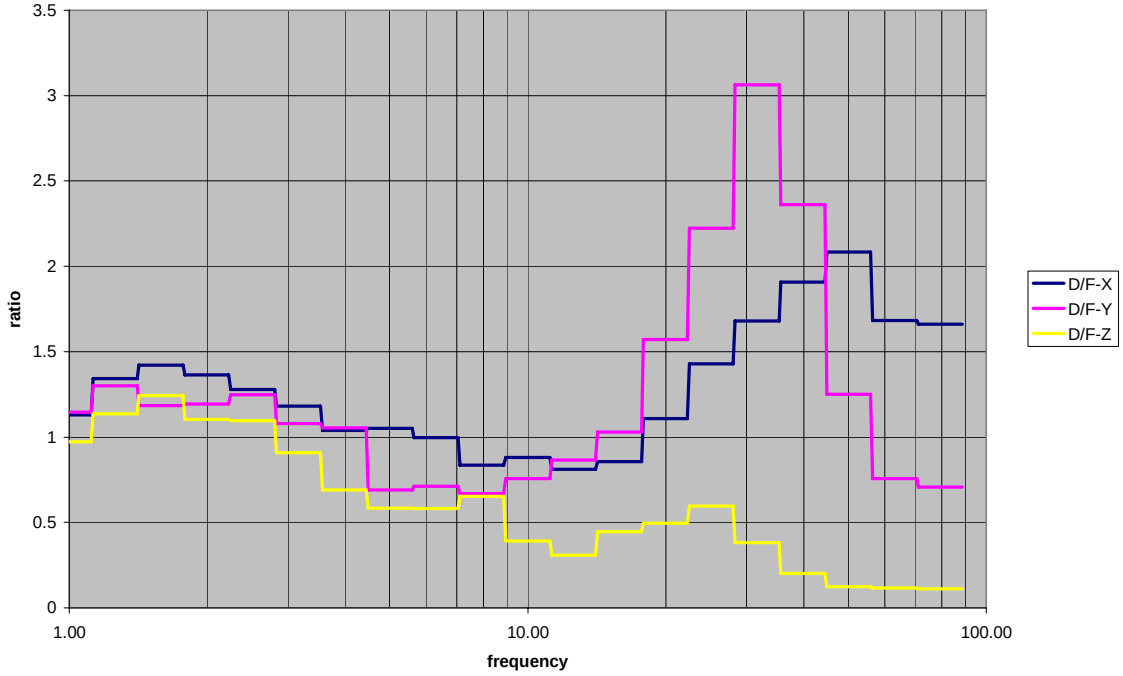


Figure 120 PT3: 1/3rd octave Driver/Floor ratio

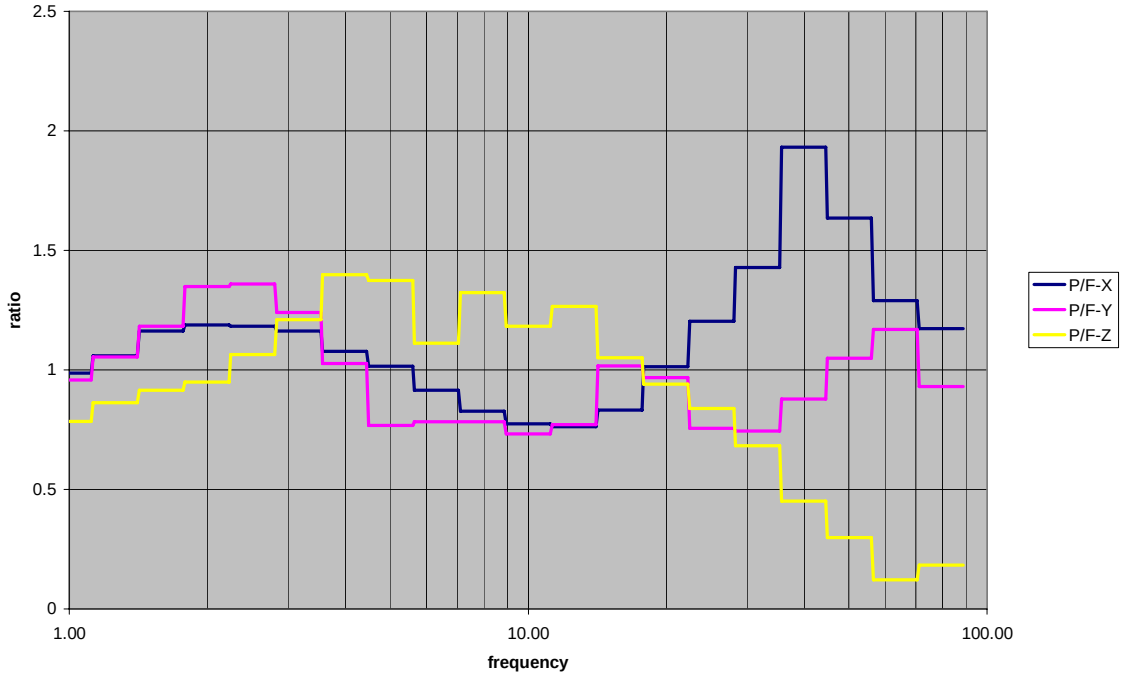


Figure 121 PT3: 1/3rd octave Passenger/Floor ratio

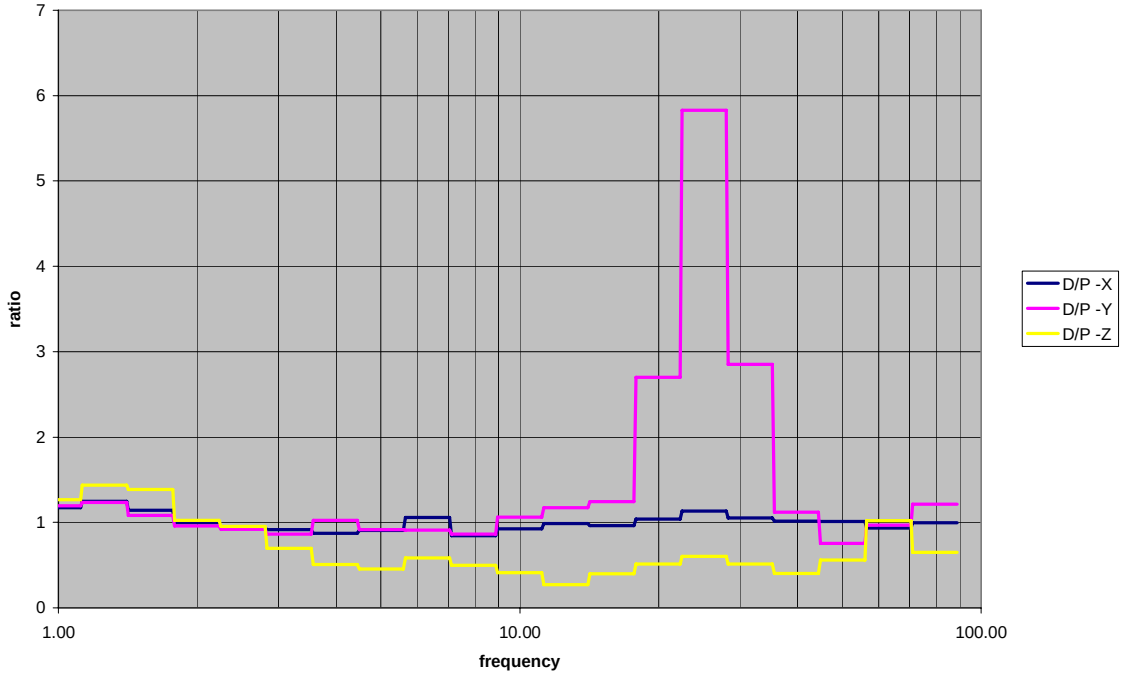


Figure 122 PT3: 1/3rd octave Driver/Passenger ratio

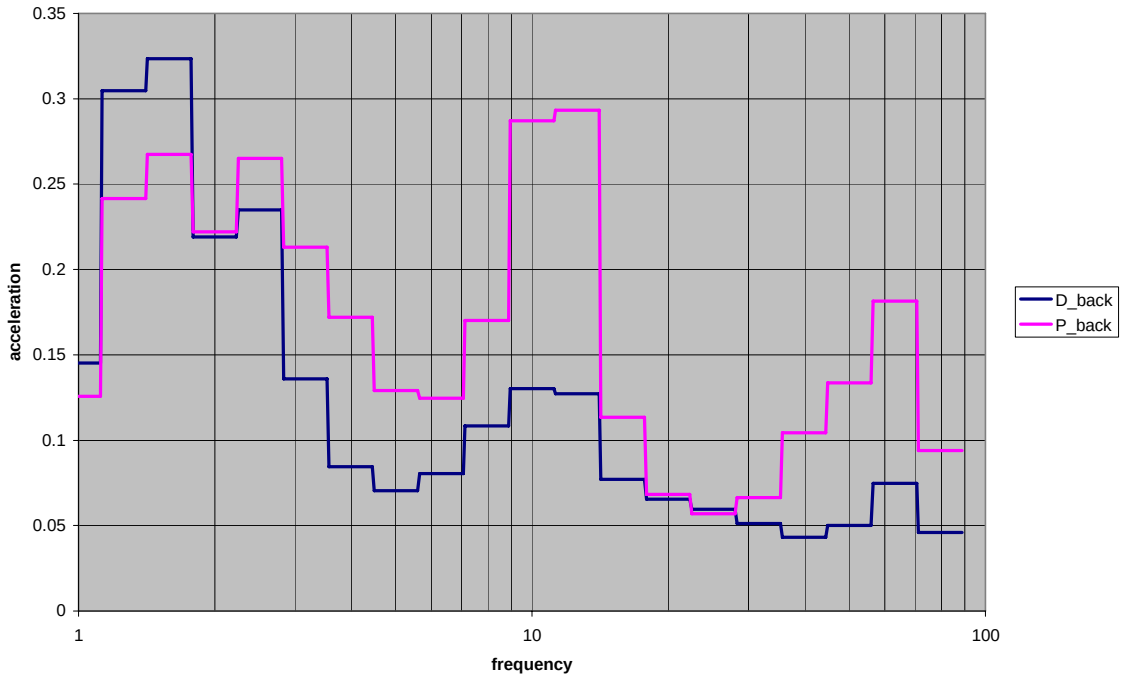


Figure 123 PT3: 1/3rd octave Driver& Passenger Seatback acceleration-Z axis

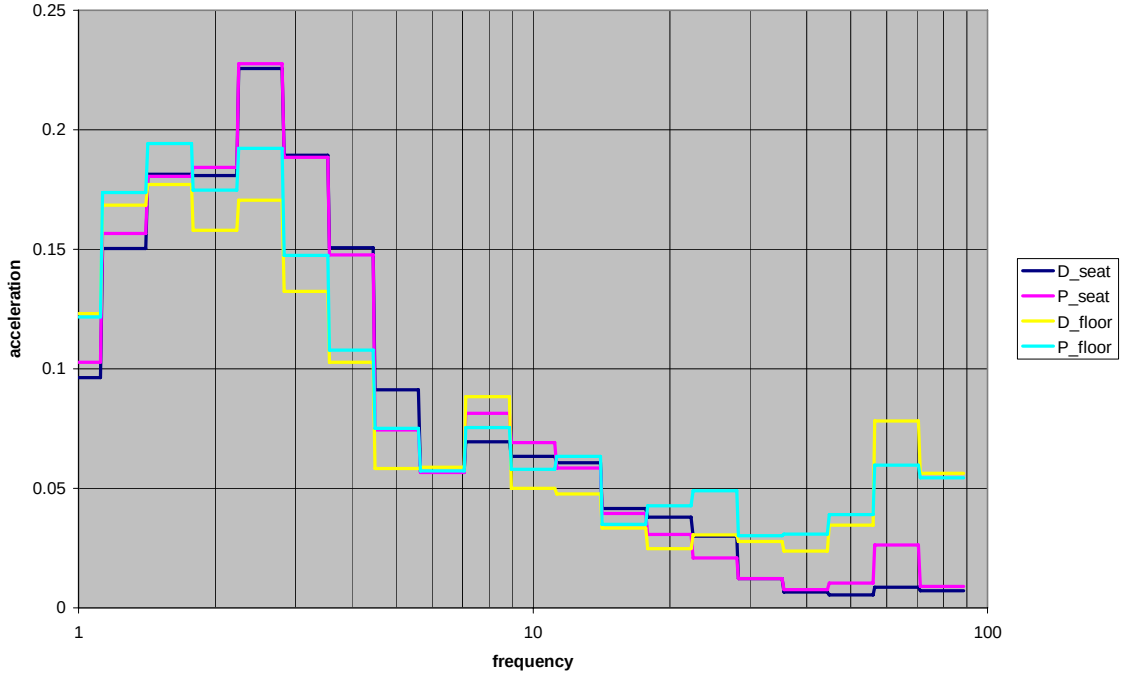


Figure 124 PT4: 1/3rd octave Driver, Passenger Seat& Floor acceleration-Z axis

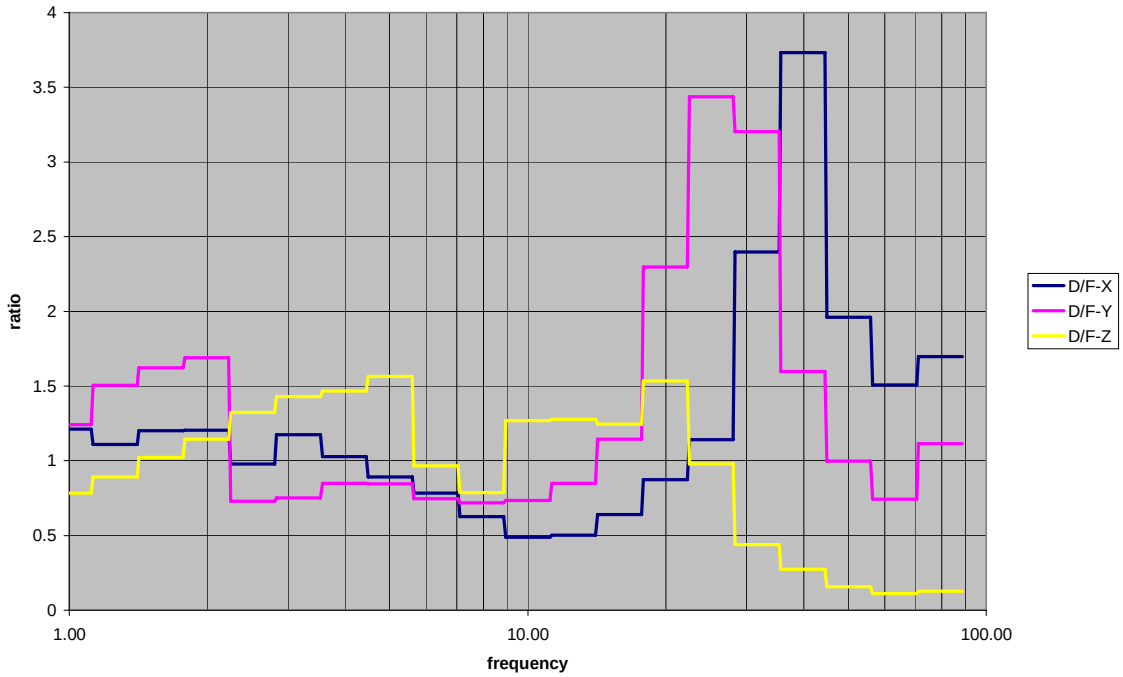


Figure 125 PT4: 1/3rd octave Driver/Floor ratio

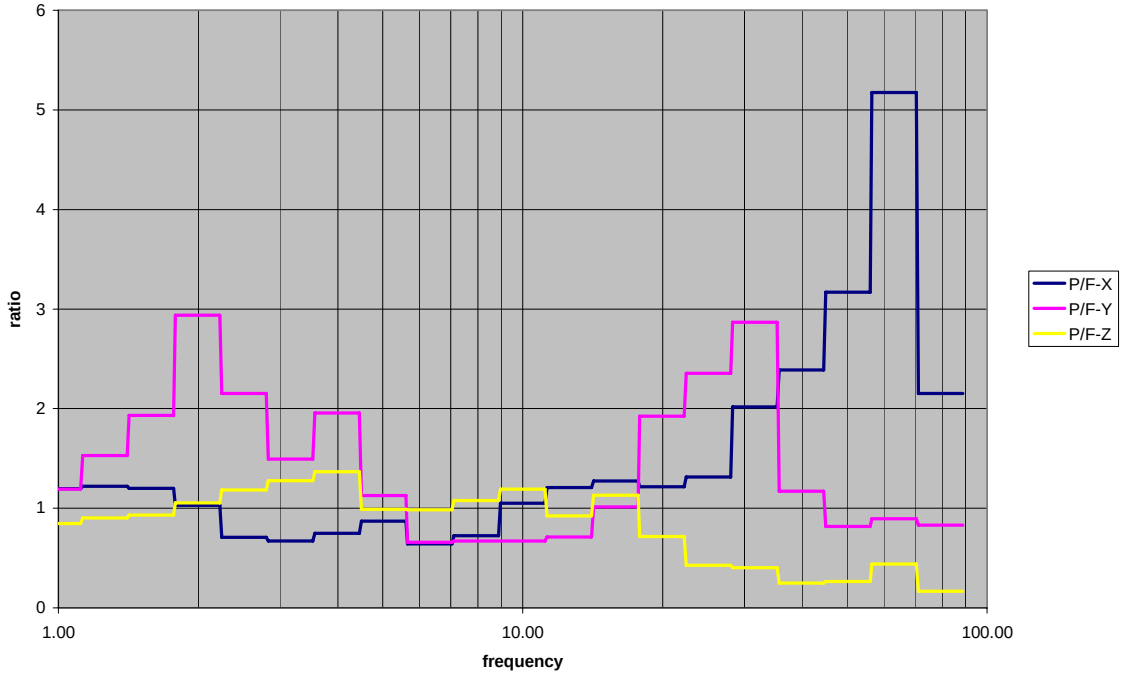


Figure 126 PT4: 1/3rd octave Passenger/Floor ratio

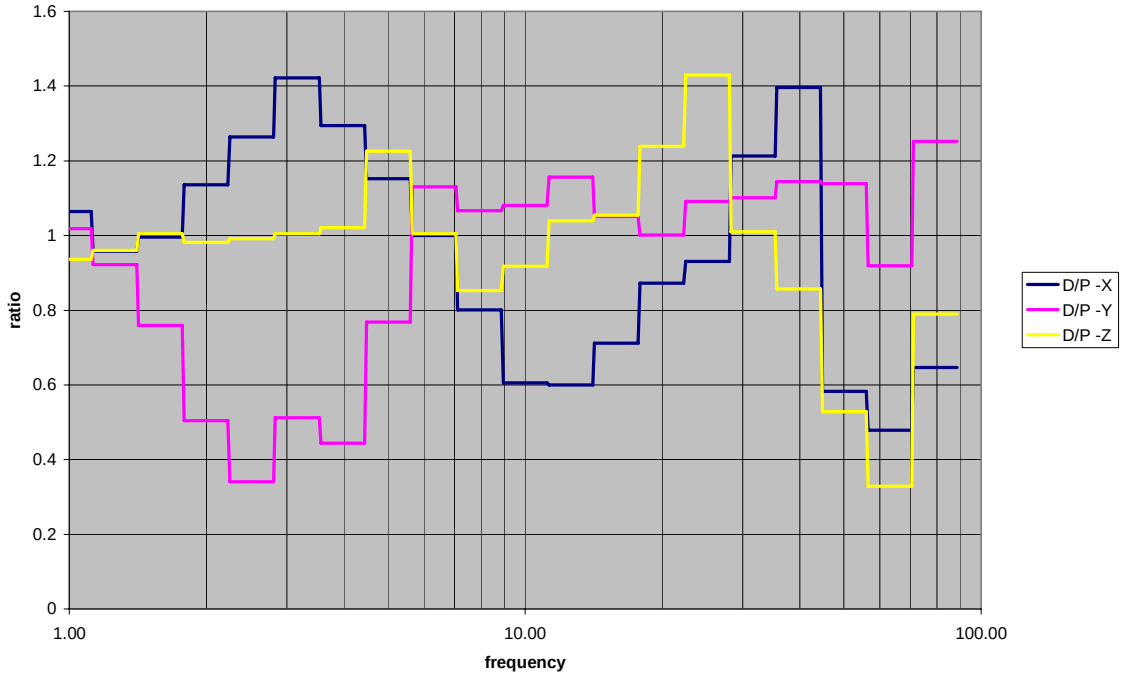


Figure 127 PT4: 1/3rd octave Driver/Passenger ratio

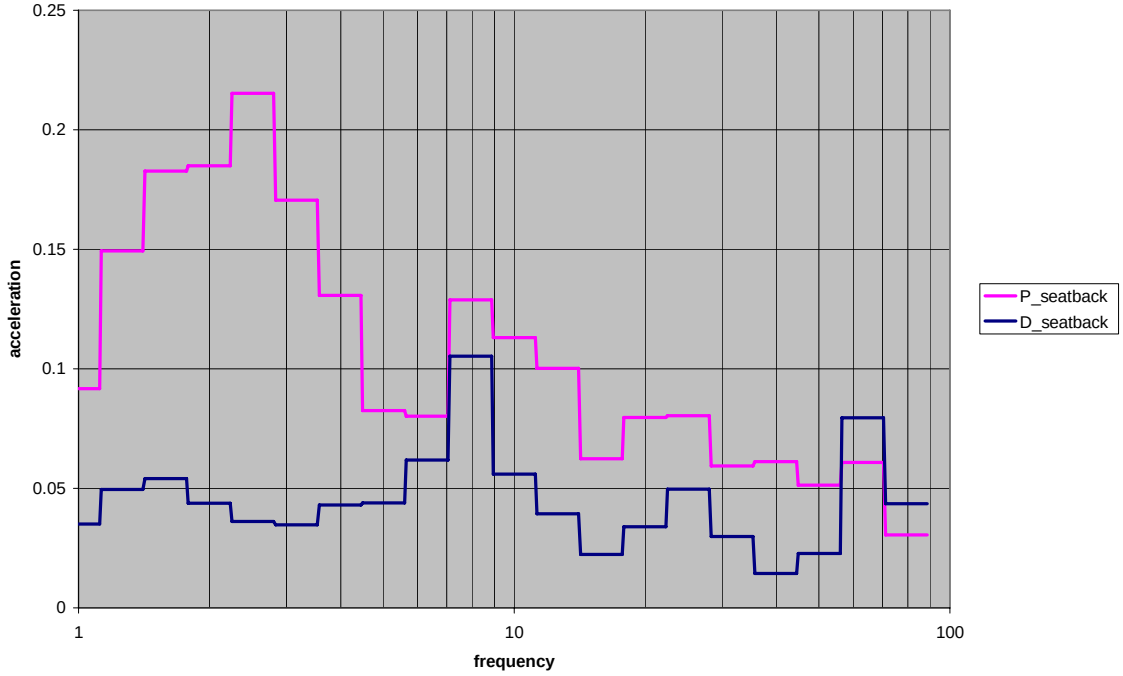


Figure 128 PT4 1/3rd octave Driver& Passenger Seatback acceleration-Z axis

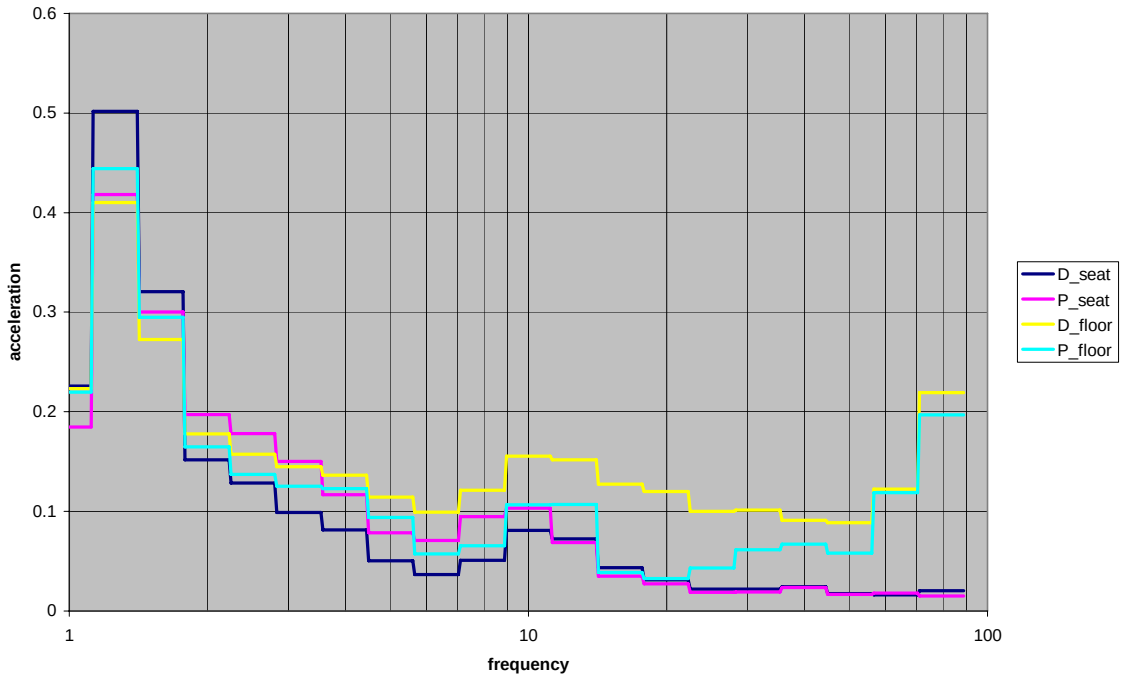


Figure 129 PT5: 1/3rd octave Driver, Passenger Seat& Floor acceleration-Z axis

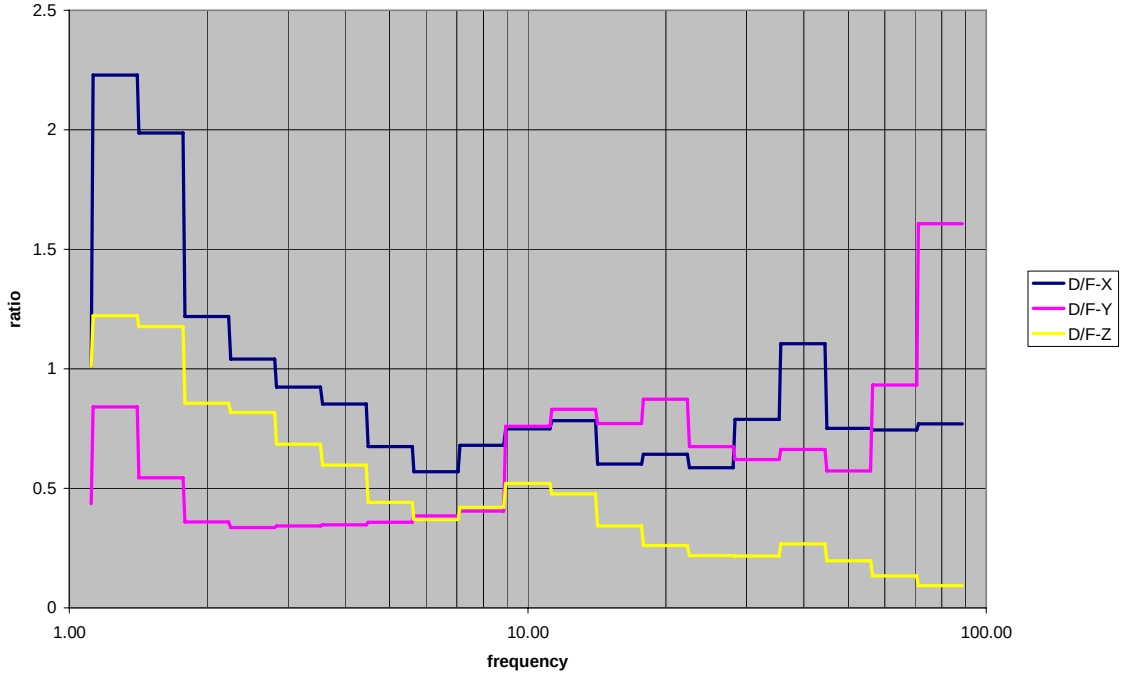


Figure 130 PT5: 1/3rd octave Driver/Floor ratio

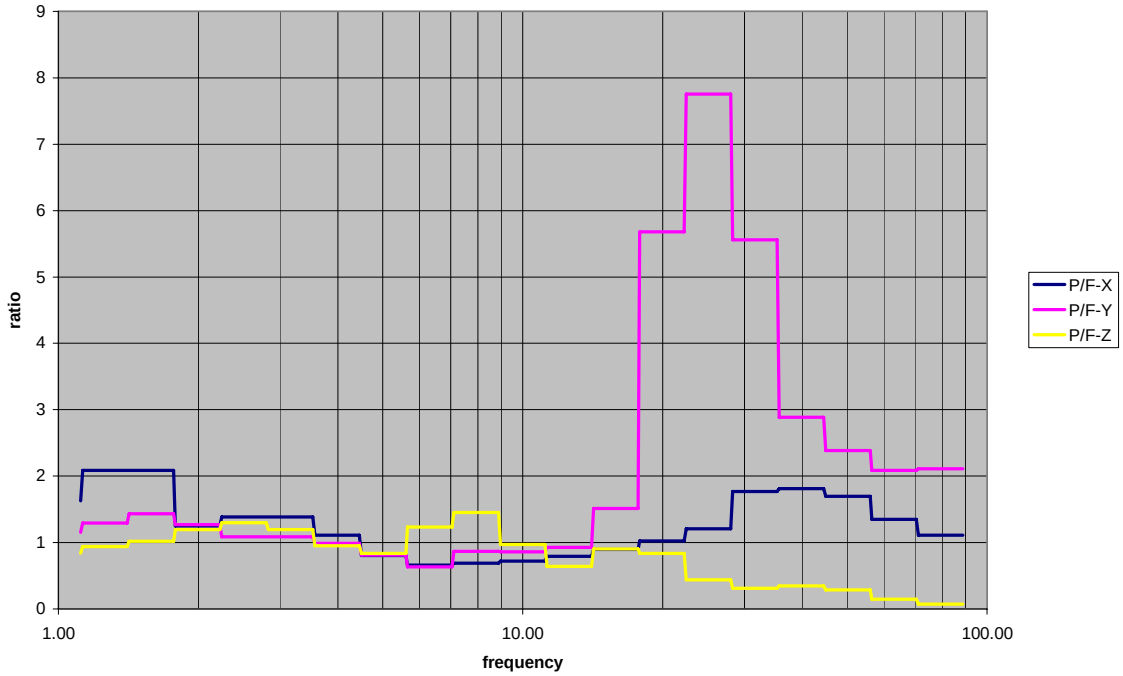


Figure 131 PT5: 1/3rd octave Passenger/Floor ratio

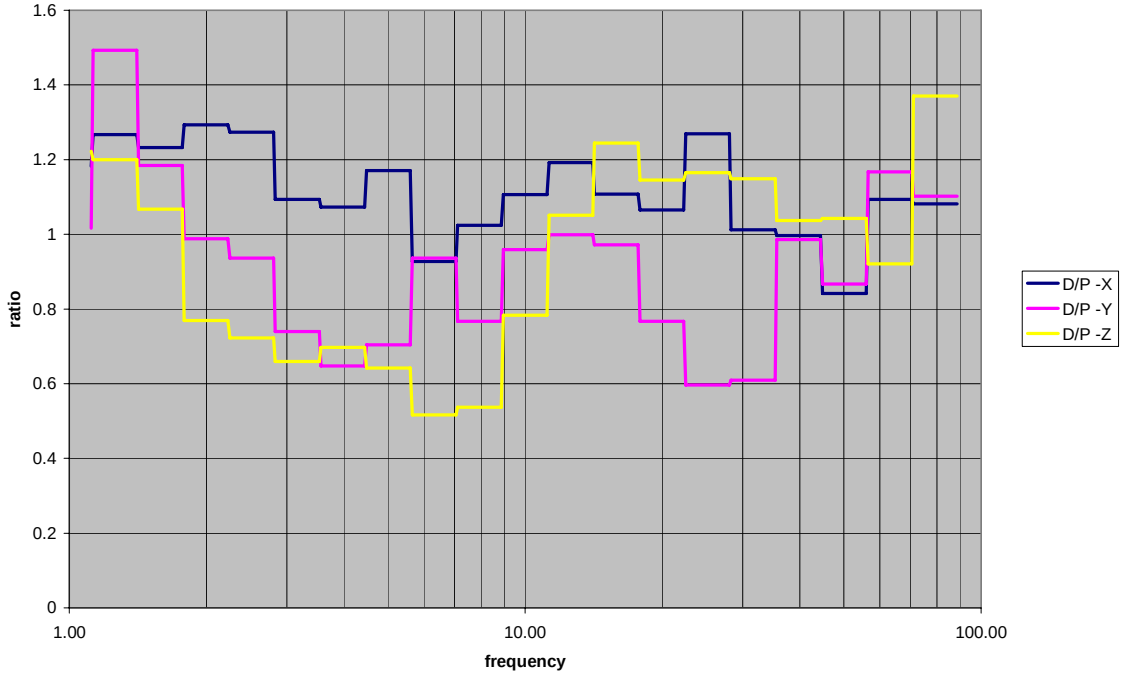


Figure 132 PT5: 1/3rd octave Driver/Passenger ratio

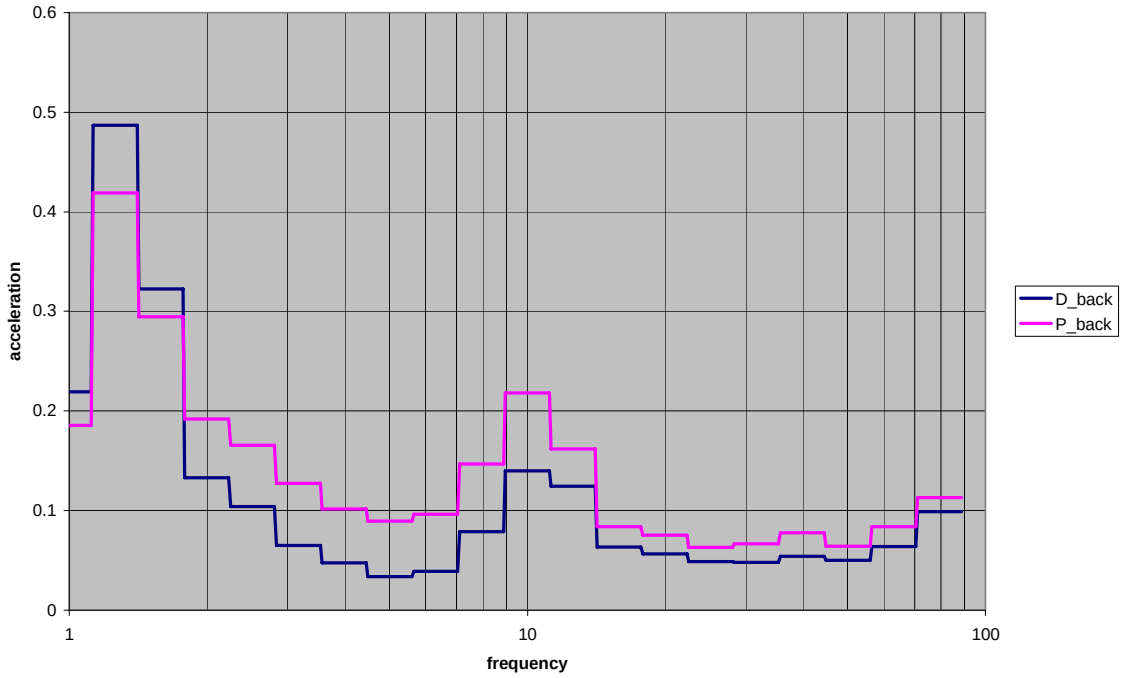


Figure 133 PT5: 1/3rd octave Driver& Passenger Seatback acceleration-Z axis

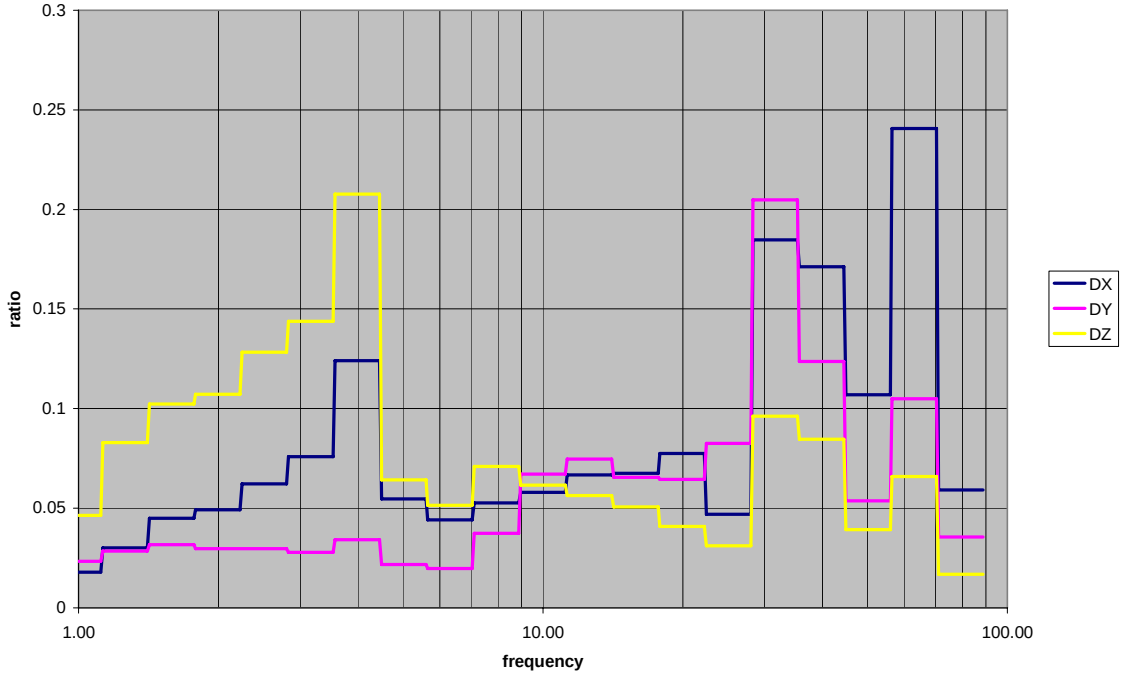


Figure 134 PT6: 1/3rd octave Driver Seat pad acceleration

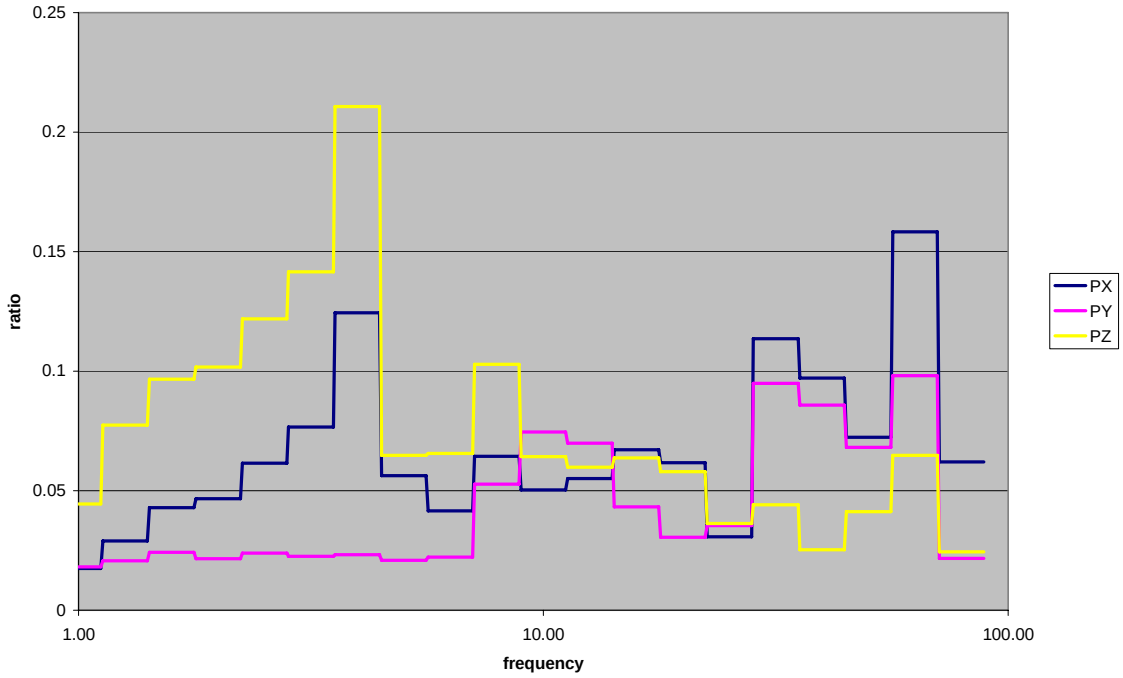


Figure 135 PT6: 1/3rd octave Passenger Seat pad acceleration

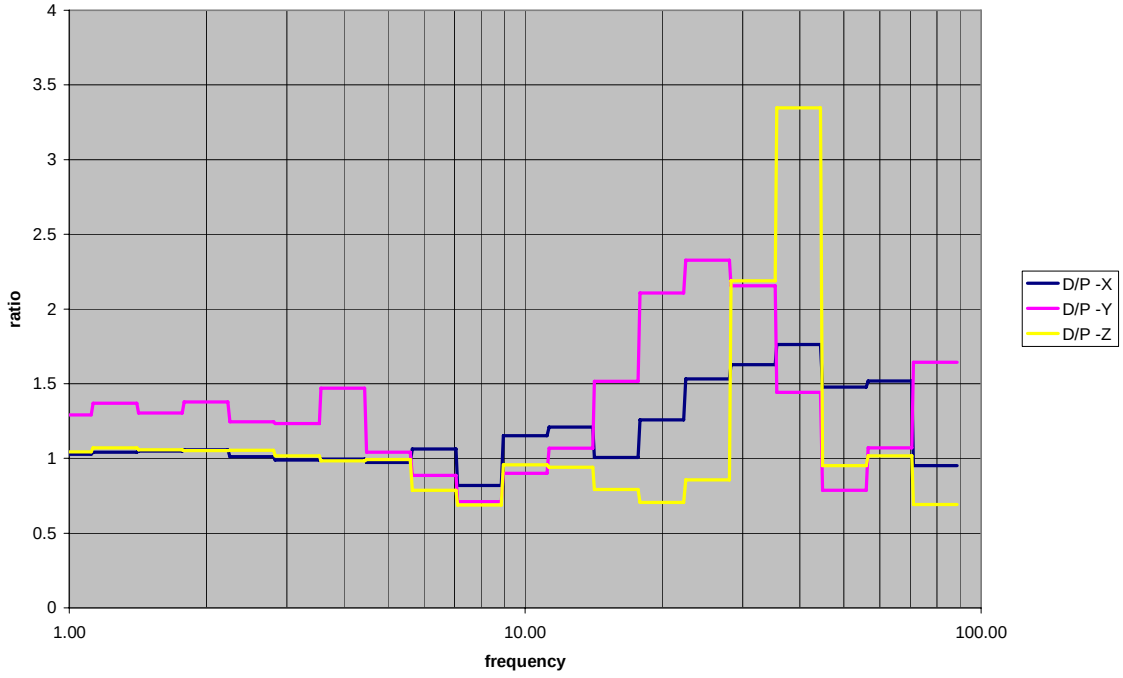


Figure 136 PT6: 1/3rd octave Driver/Passenger Seat ratio

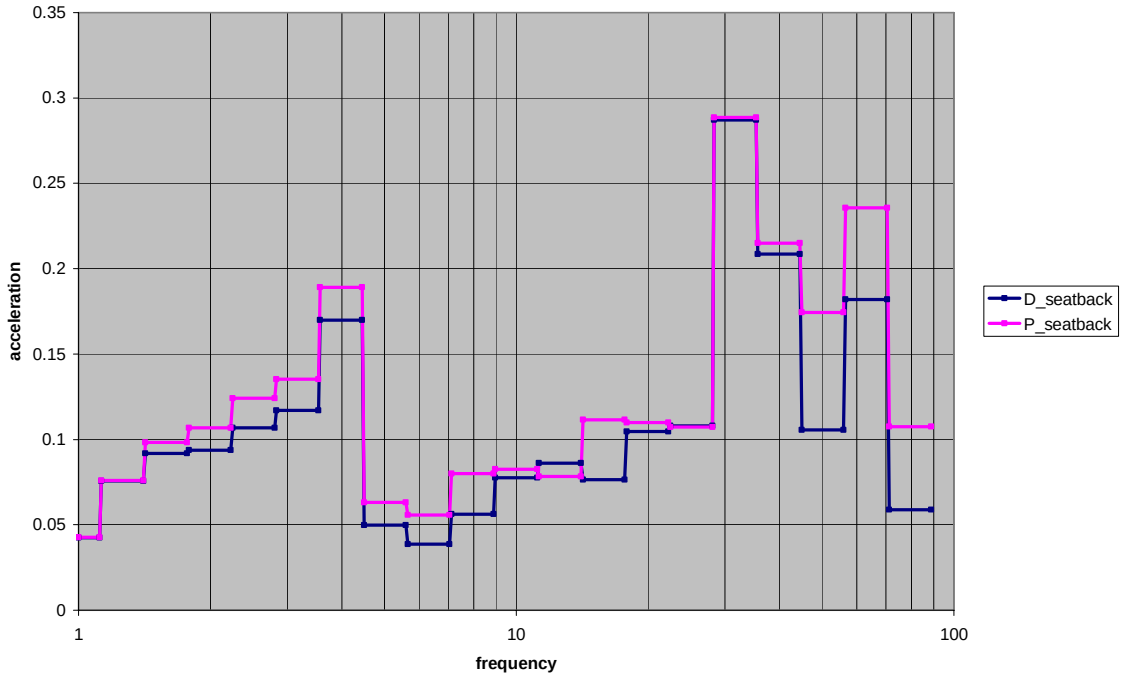


Figure 137 PT6: 1/3rd octave Driver& Passenger Seatback acceleration-Z axis

Appendix-VIII: Selected VDV plots-Poland

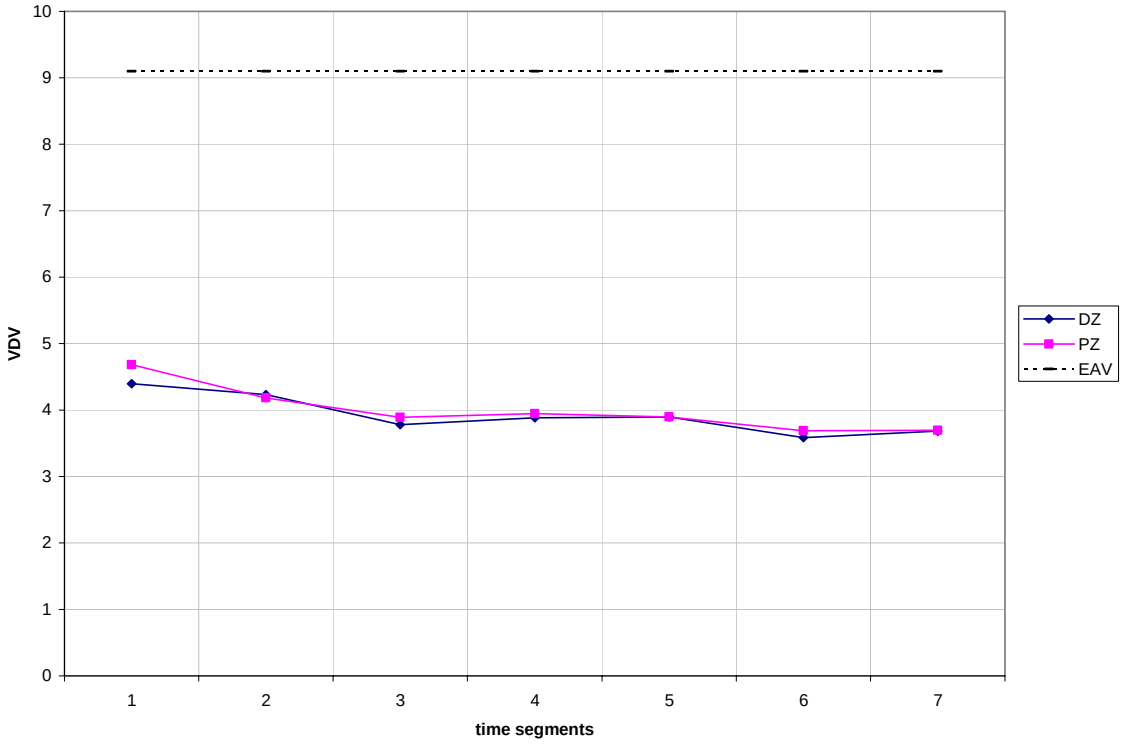


Figure 138 PT1 Driver and Passenger seat pad weighted VDV-Z axis

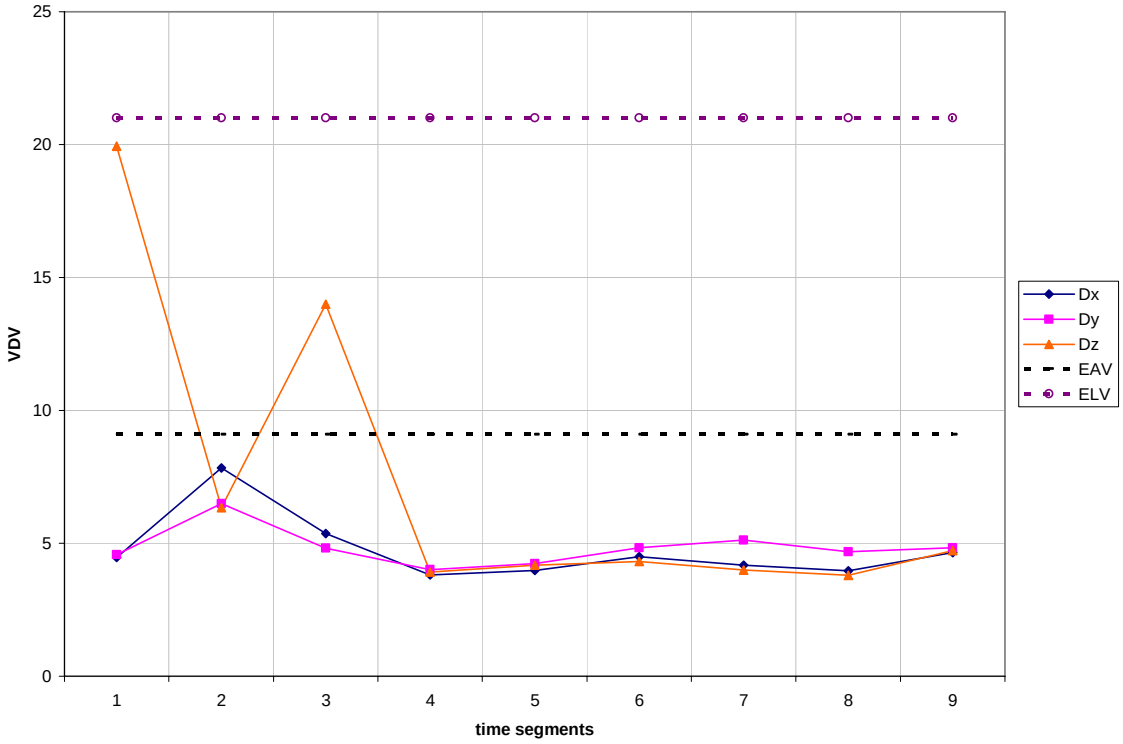


Figure 139 PT2 Driver seat pad weighted VDV-X, Y and Z axes

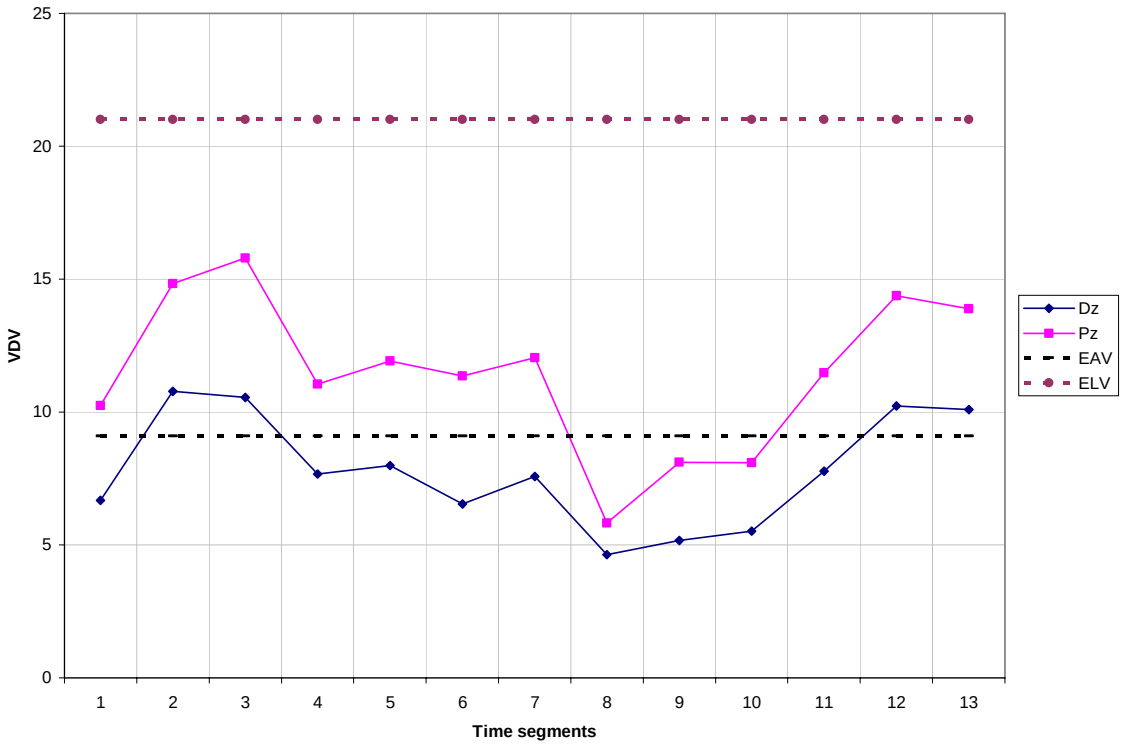


Figure 140 PT3 Driver and Passenger seat pad weighted VDV-Z axis

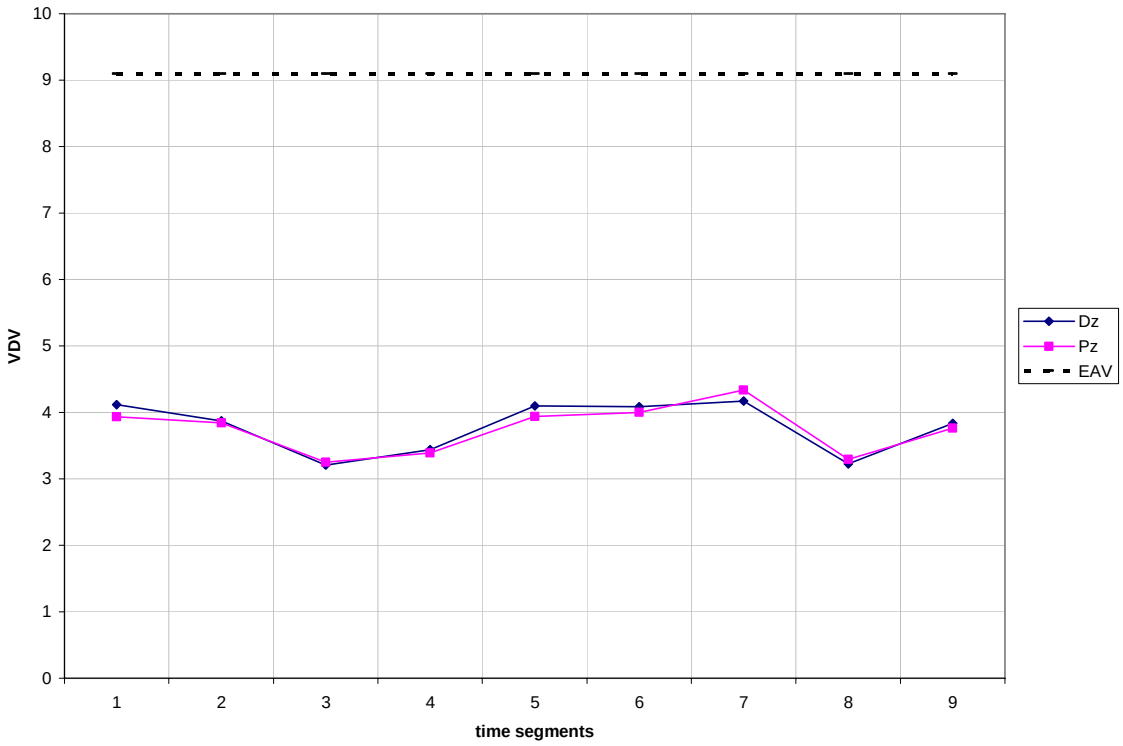


Figure 141 PT4 Driver and Passenger seat pad weighted VDV-Z axis

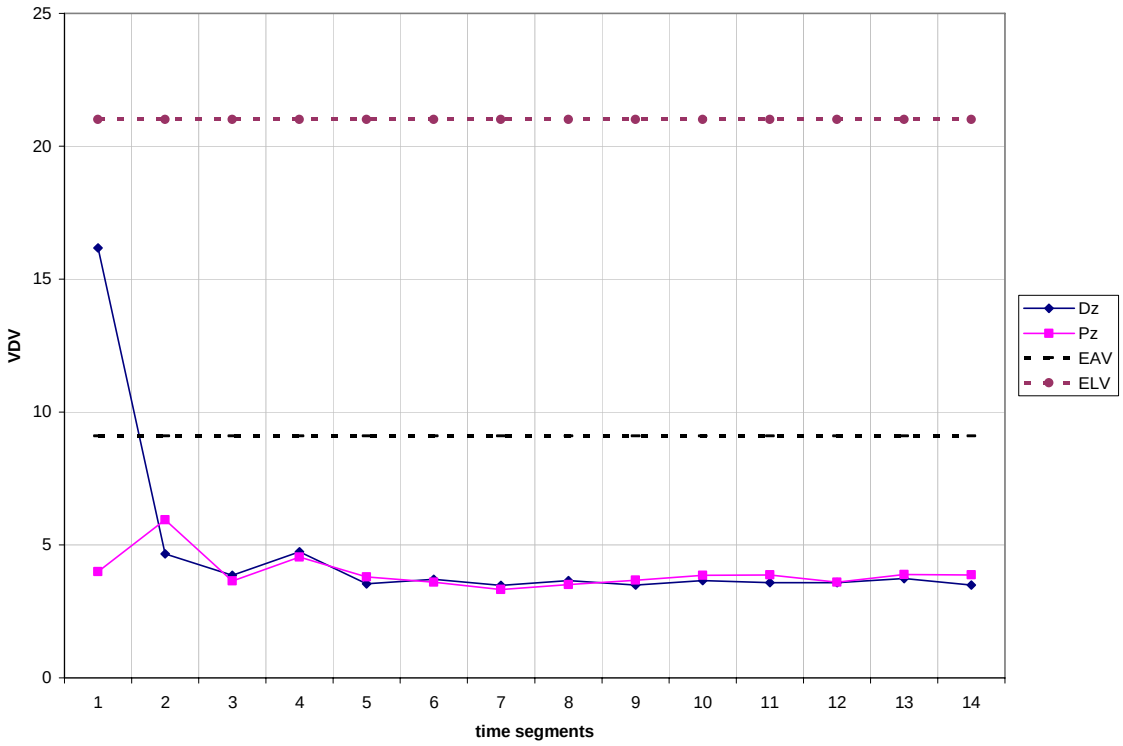


Figure 142 PT5 Driver and Passenger seat pad weighted VDV-Z axis

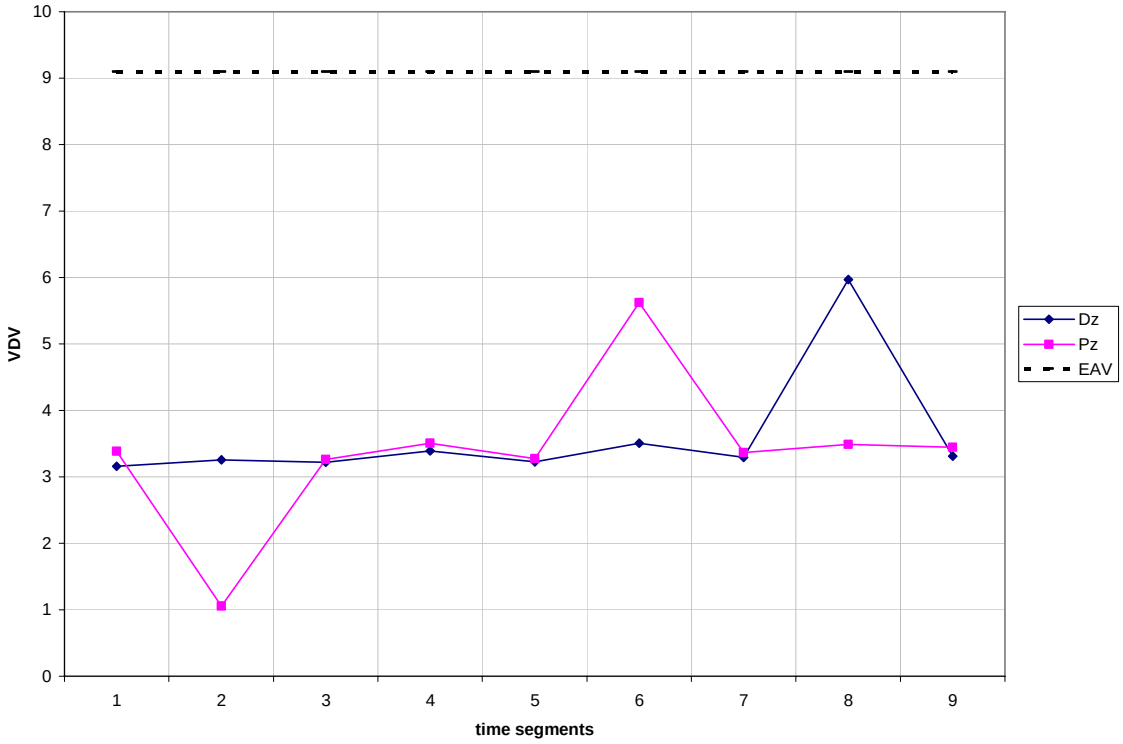


Figure 143 PT6 Driver and Passenger seat pad weighted VDV-Z axis

Appendix-IX: Selected Rotation plots-Poland

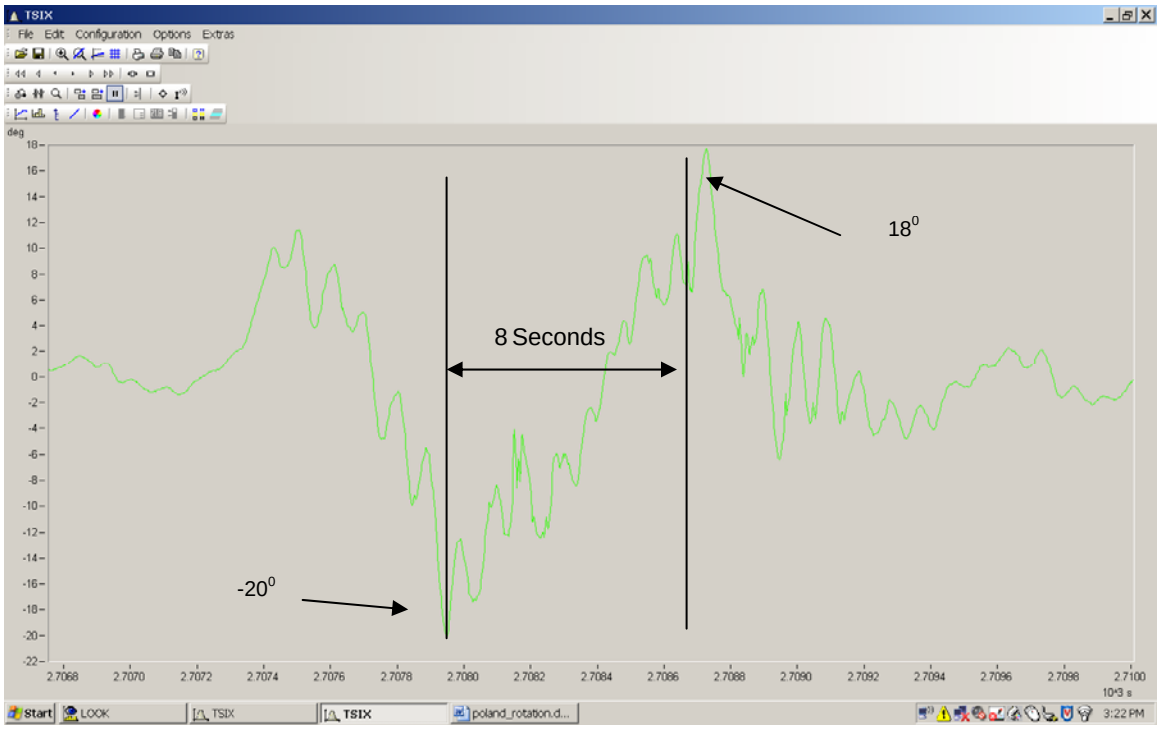


Figure 144 PT1 Cab rotation-X axis

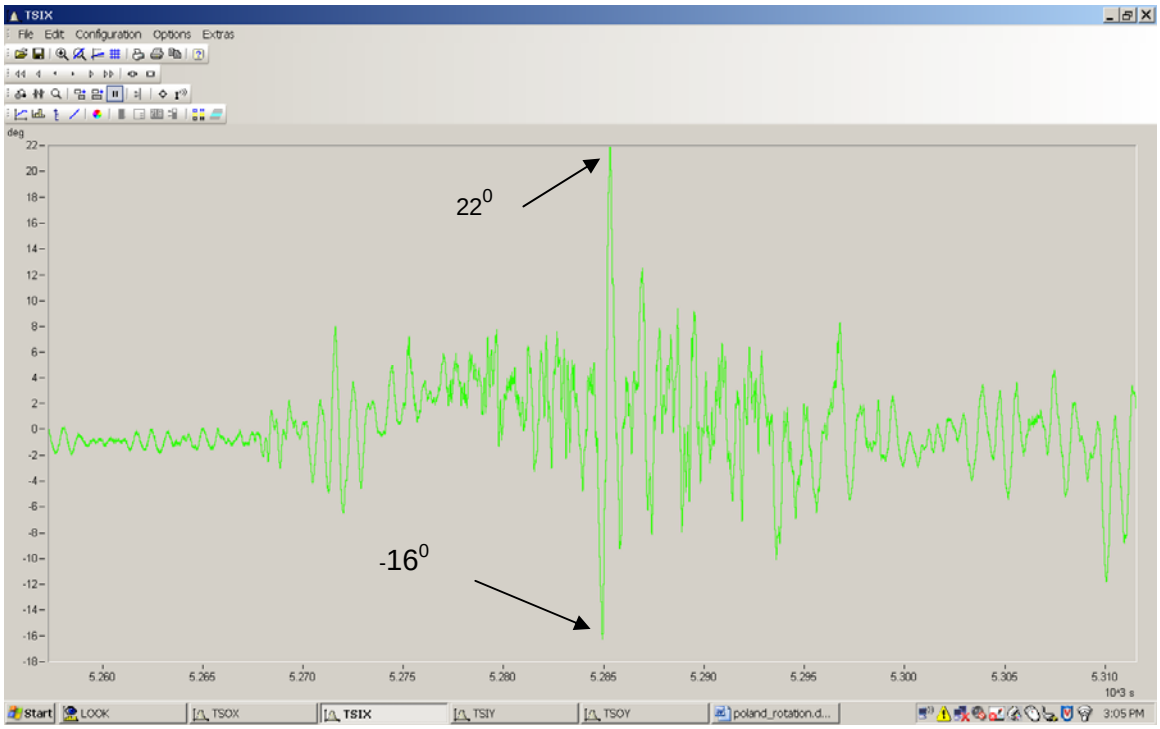


Figure 145 PT2 Cab rotation-X axis

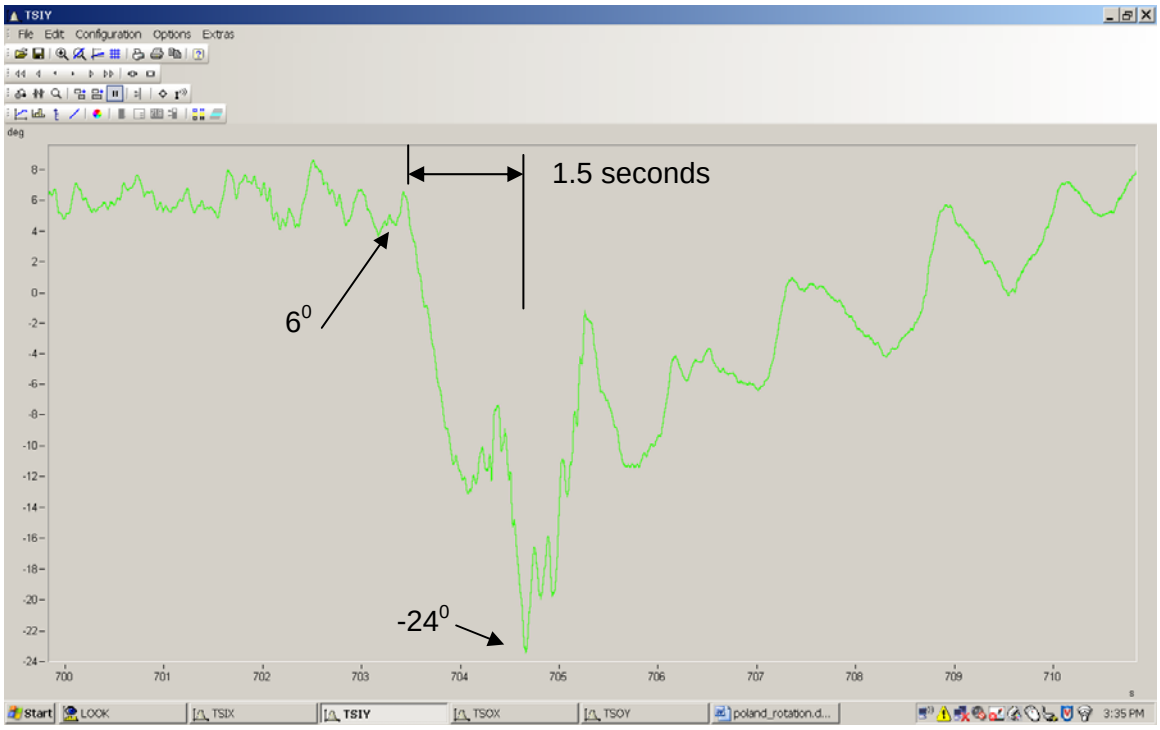


Figure 146 PT2 Cab rotation-Y axis

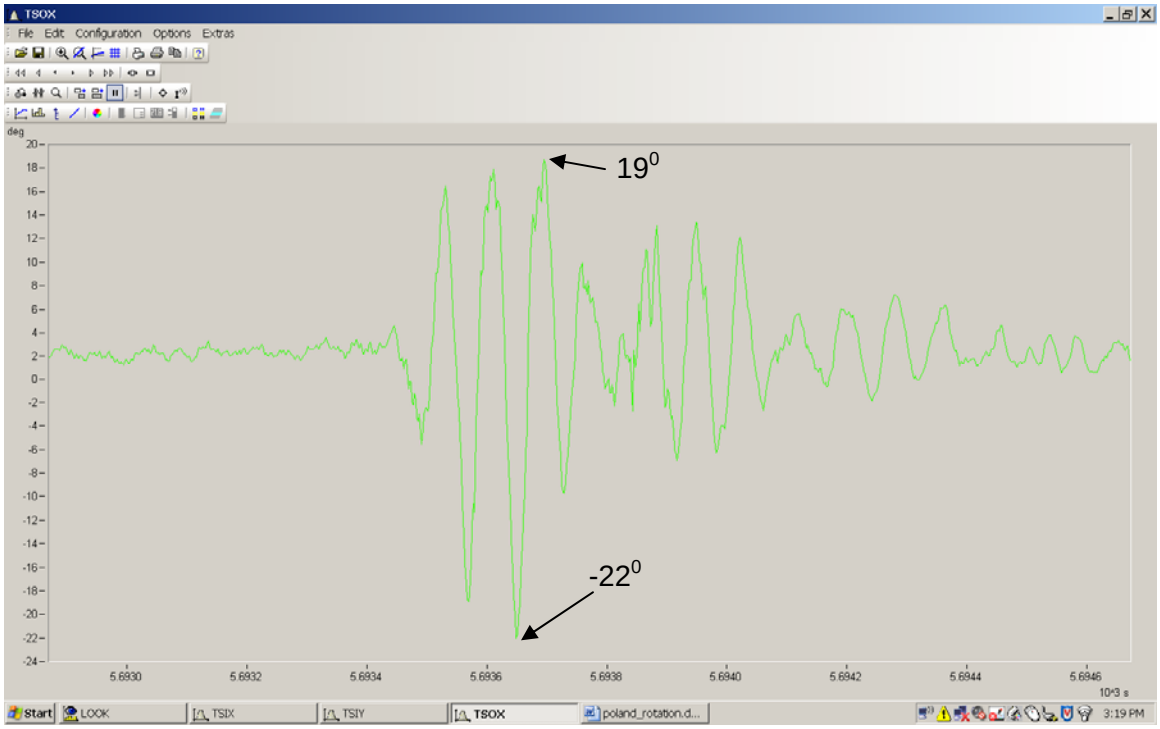


Figure 147 PT4 Cab rotation- X axis

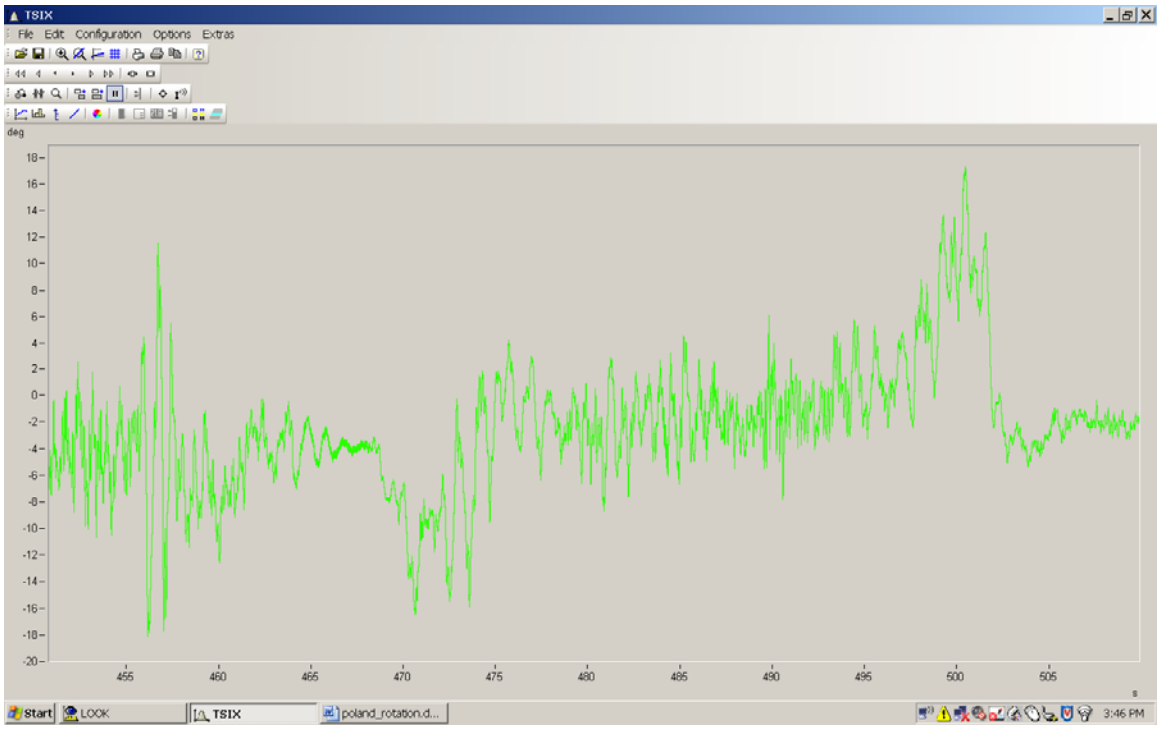


Figure 148 PT3 Cab rotation-X axis

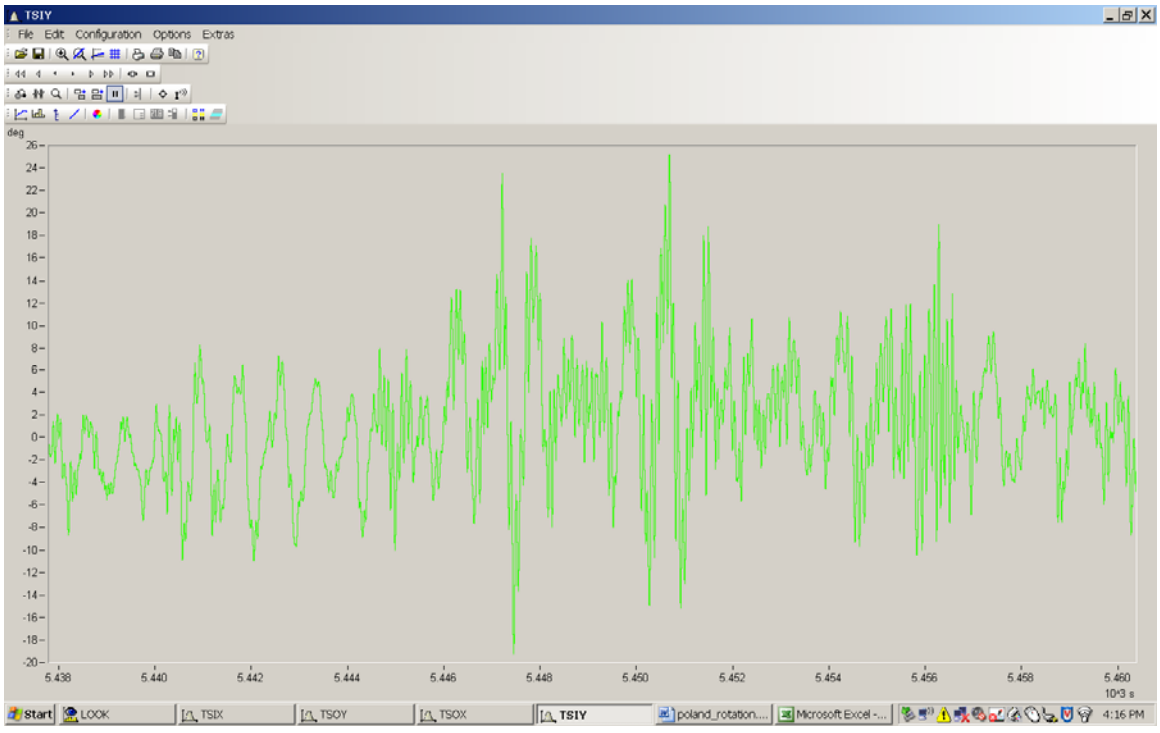


Figure 149 PT4 Cab rotation- Y axis

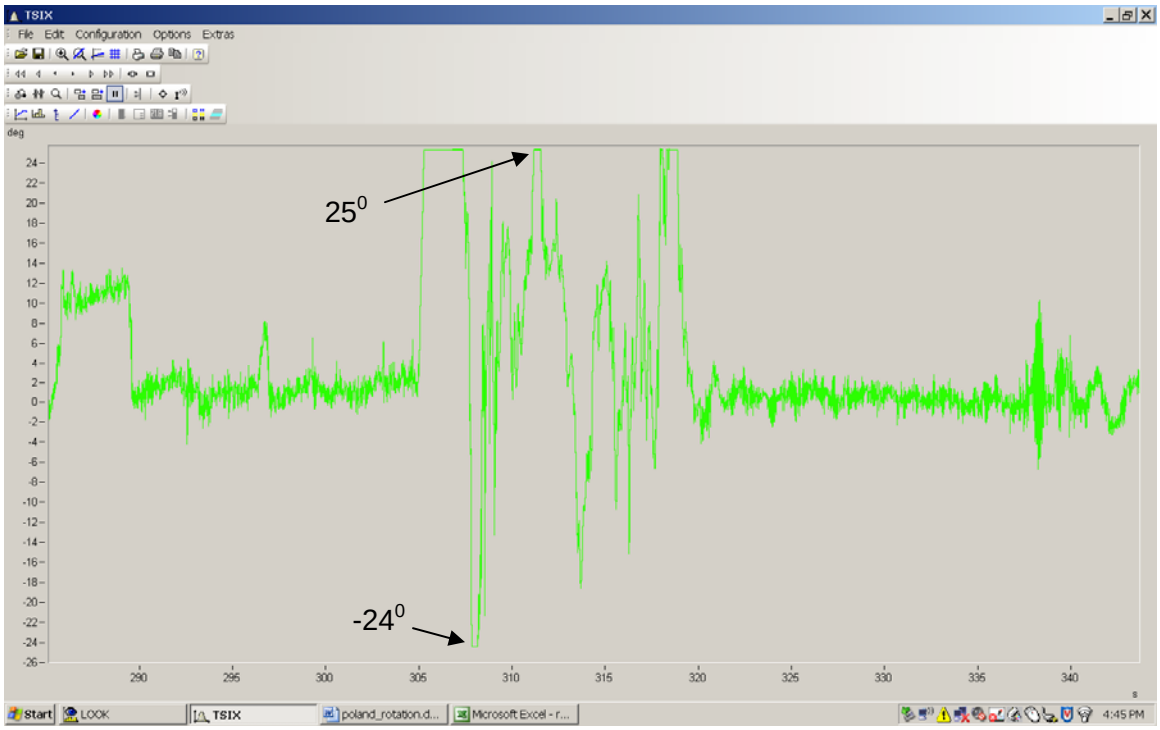


Figure 150 PT6 Cab rotation-X axis

Appendix-X: Jerk plots-Poland

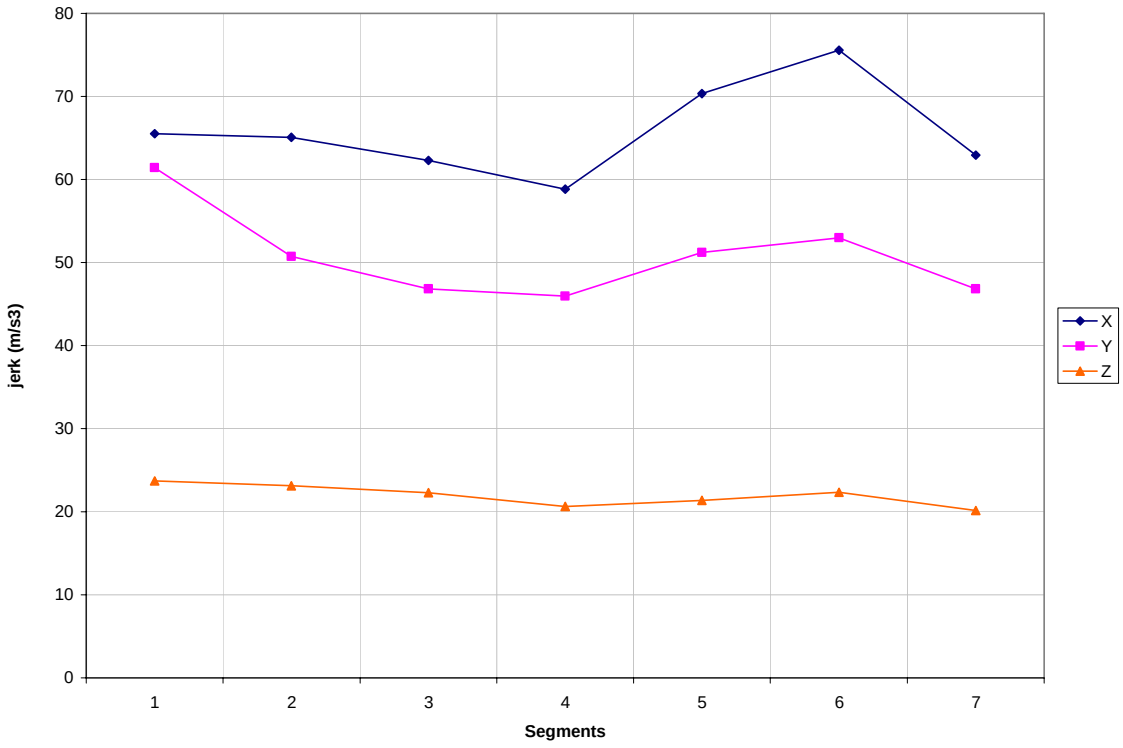


Figure 151 PT1 Driver seat RMS Jerk

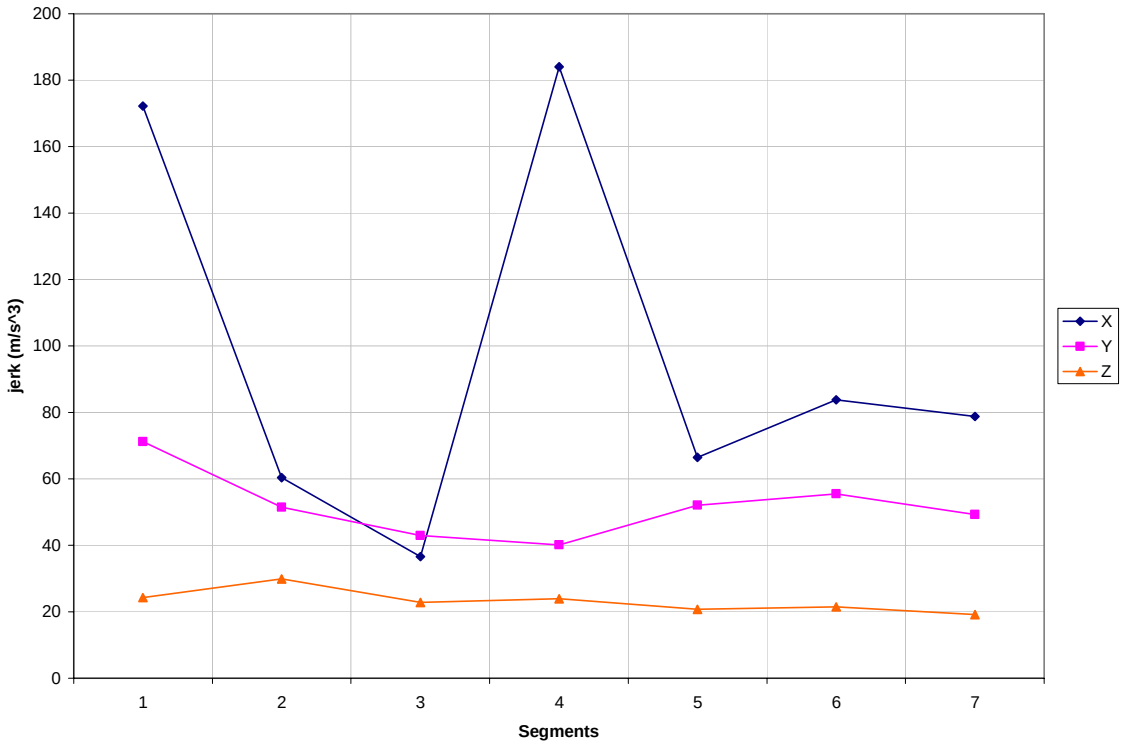


Figure 152 PT1 Passenger Seat RMS Jerk

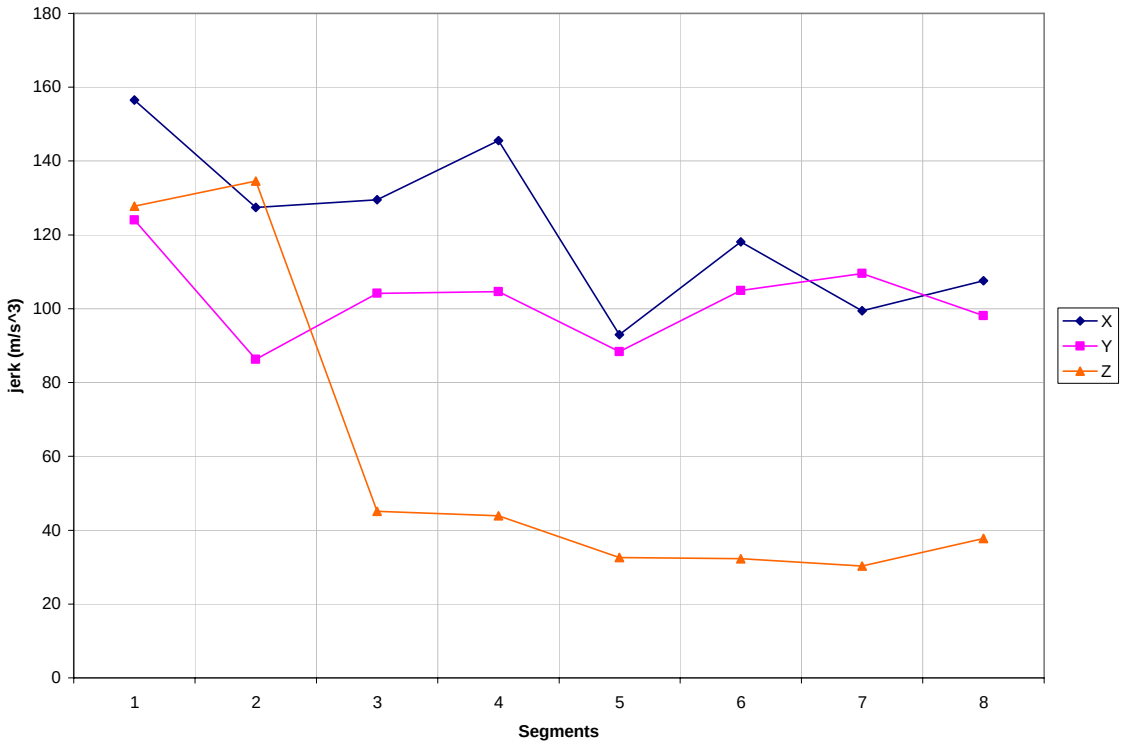


Figure 153 PT2 Driver seat RMS Jerk

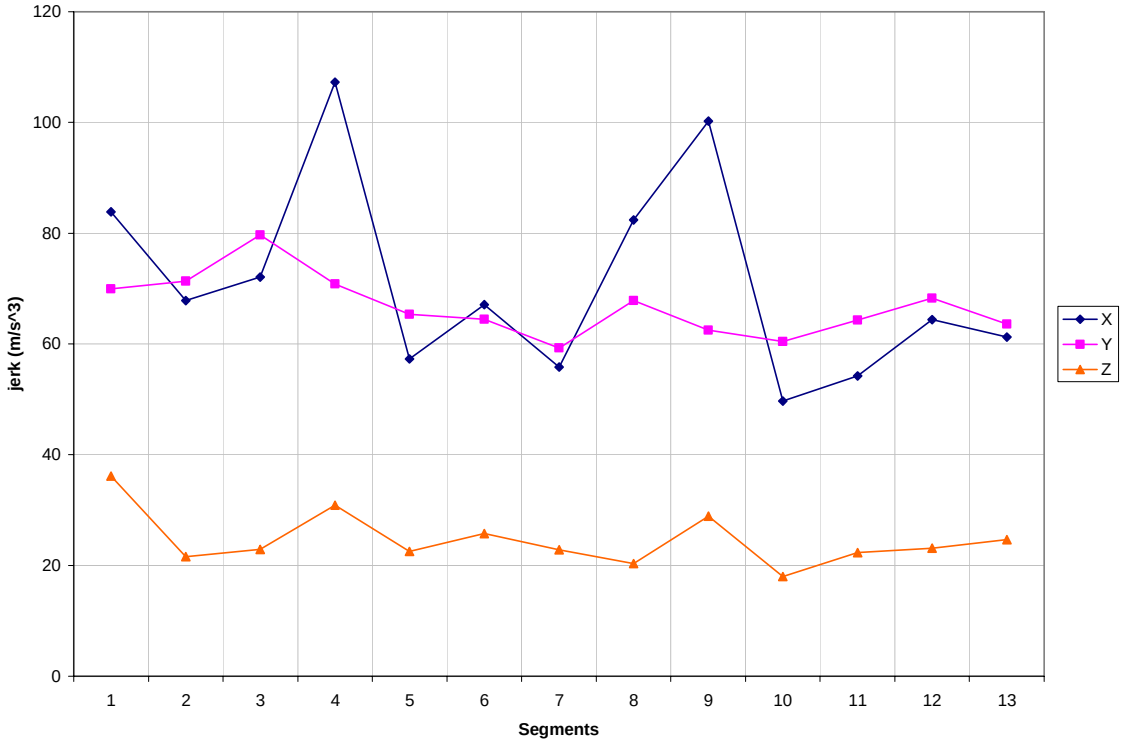


Figure 154 PT3 Driver seat RMS Jerk

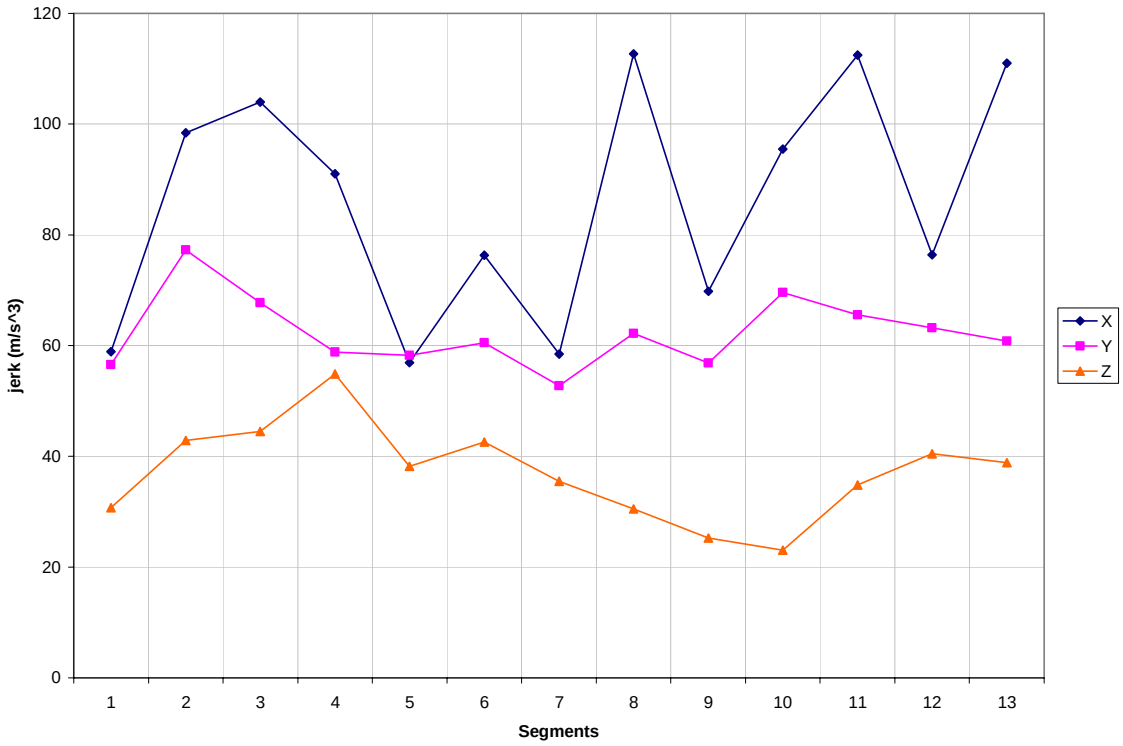


Figure 155 PT3 Passenger seat RMS Jerk

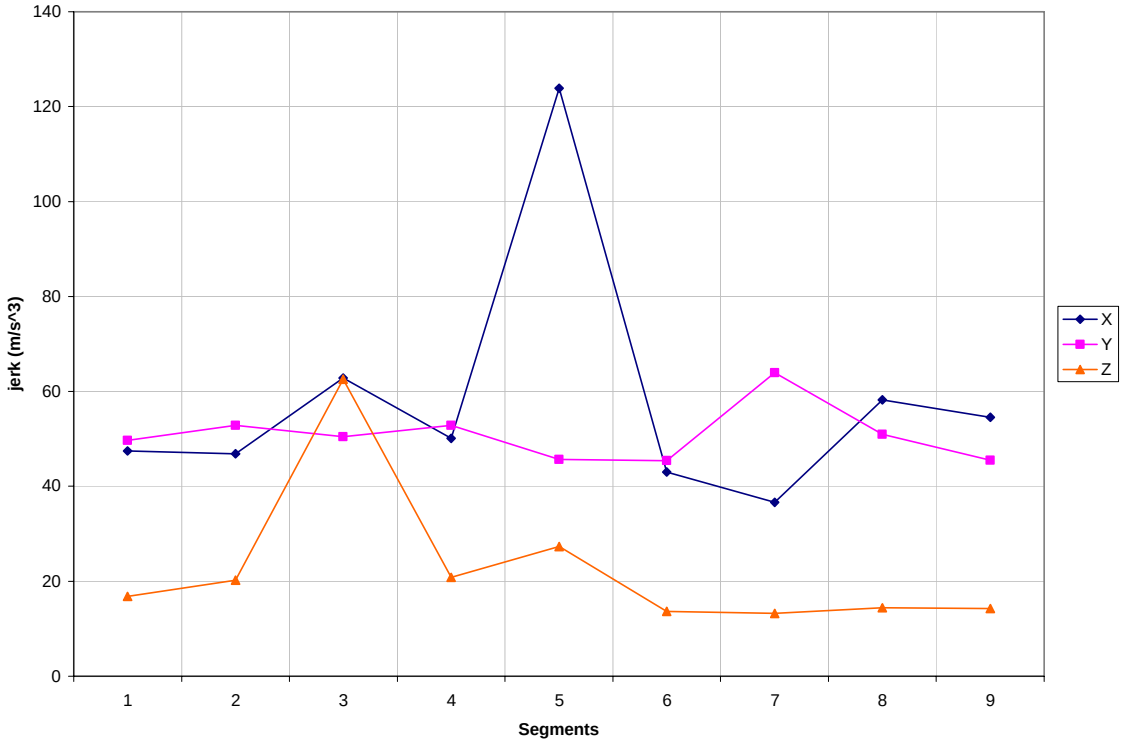


Figure 156 PT4 Driver seat RMS Jerk

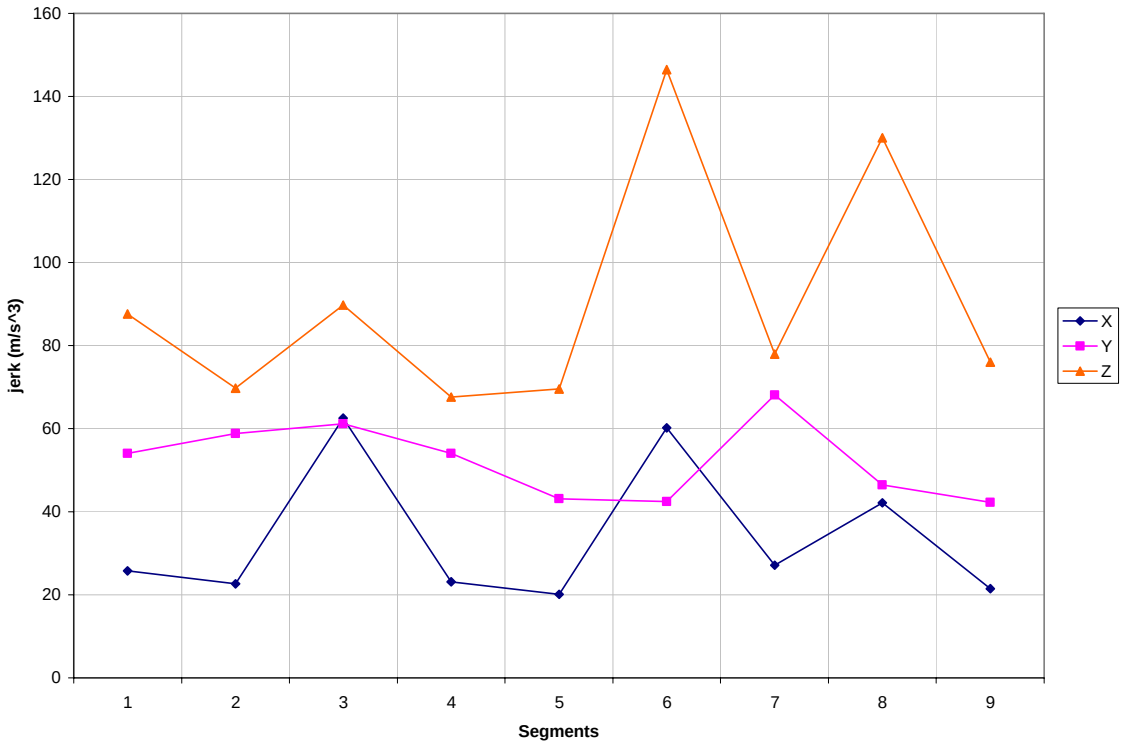


Figure 157 PT4 Passenger seat RMS Jerk

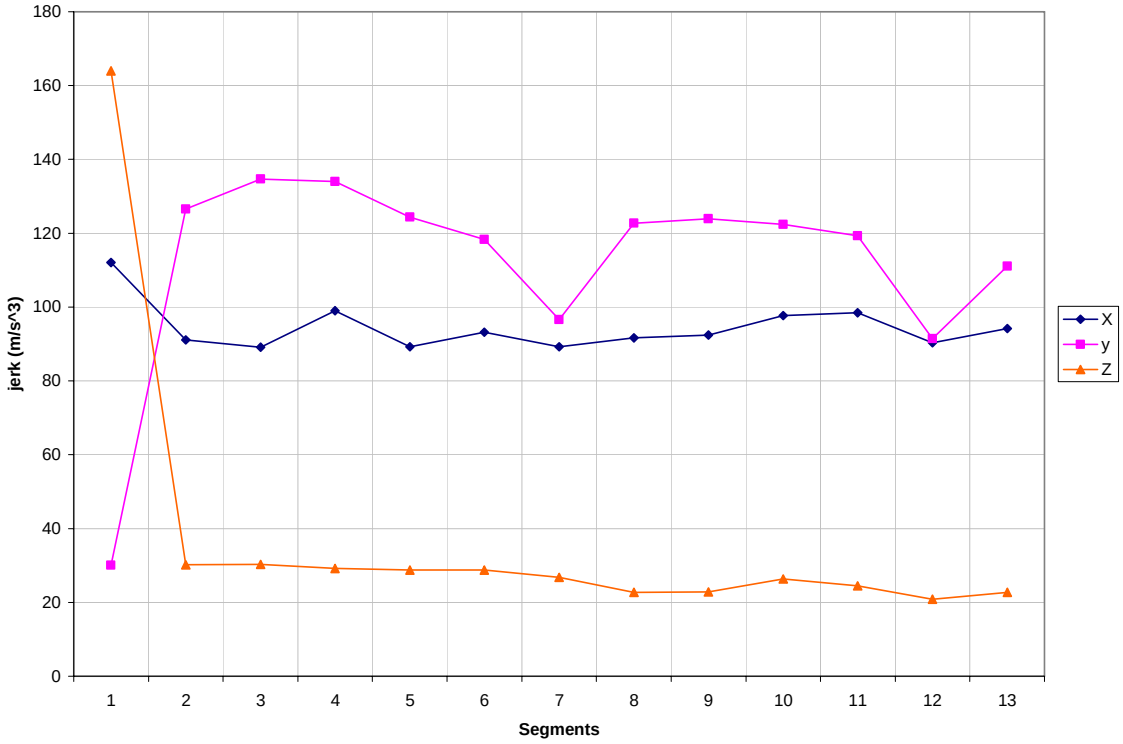


Figure 158 PT5 Driver seat RMS Jerk

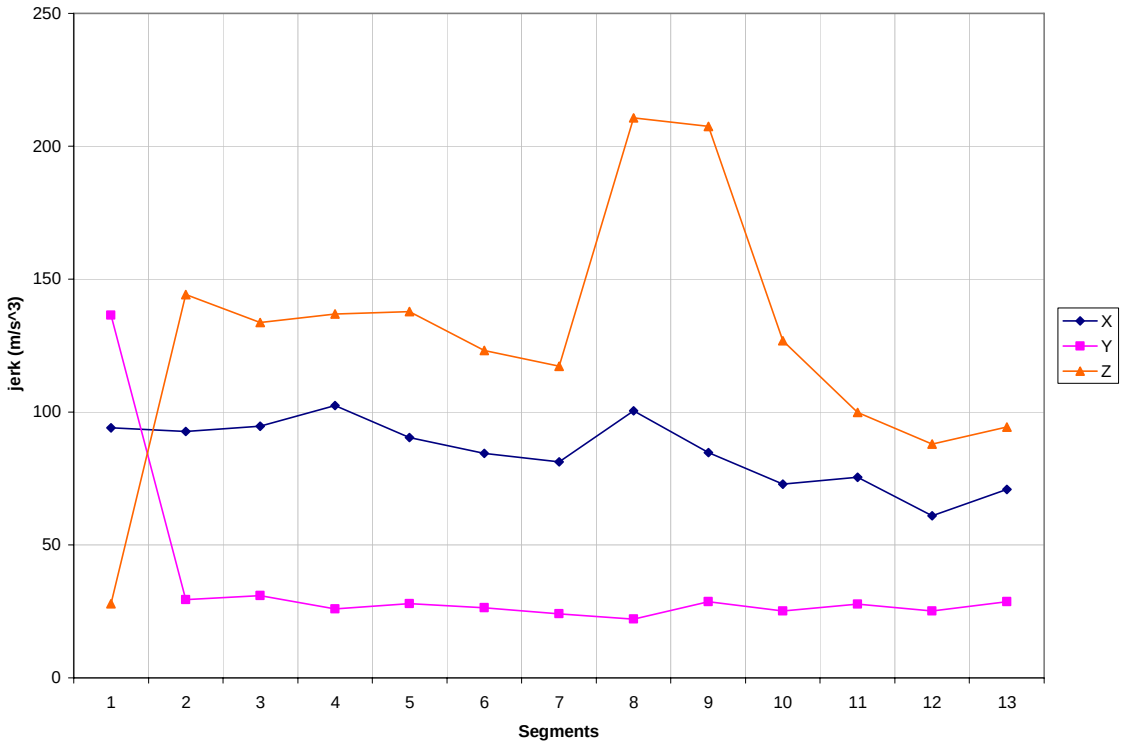


Figure 159 PT5 Passenger seat RMS Jerk

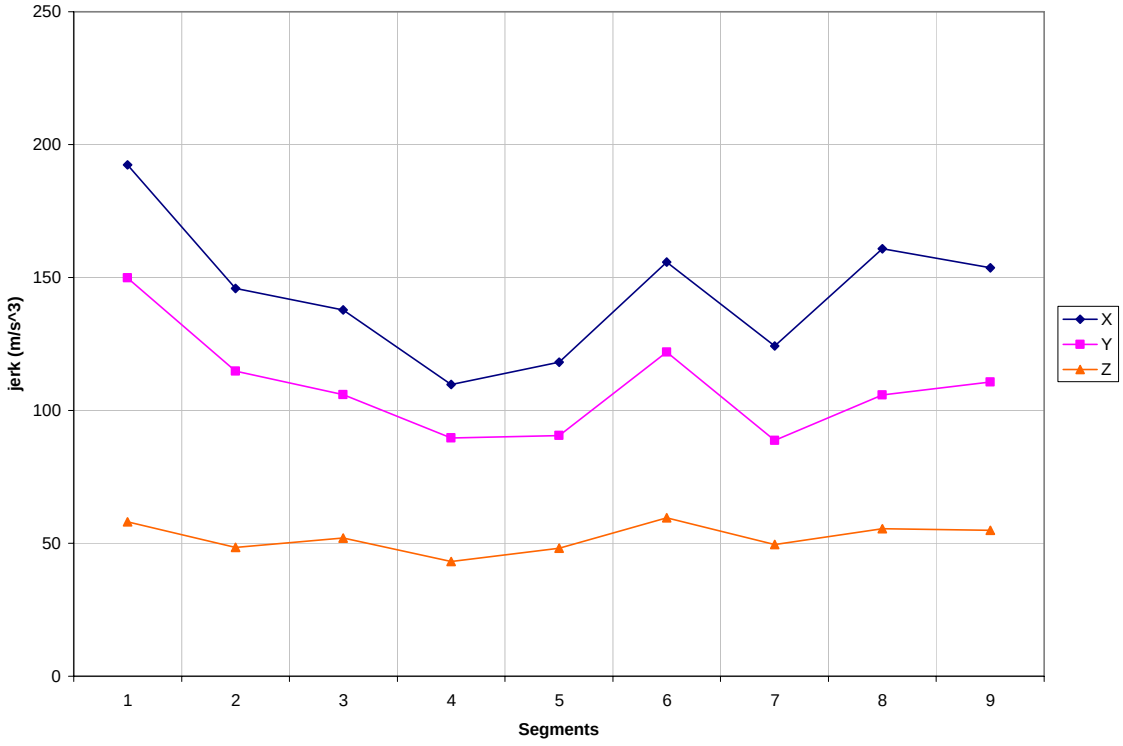


Figure 160 PT6 Driver seat RMS Jerk

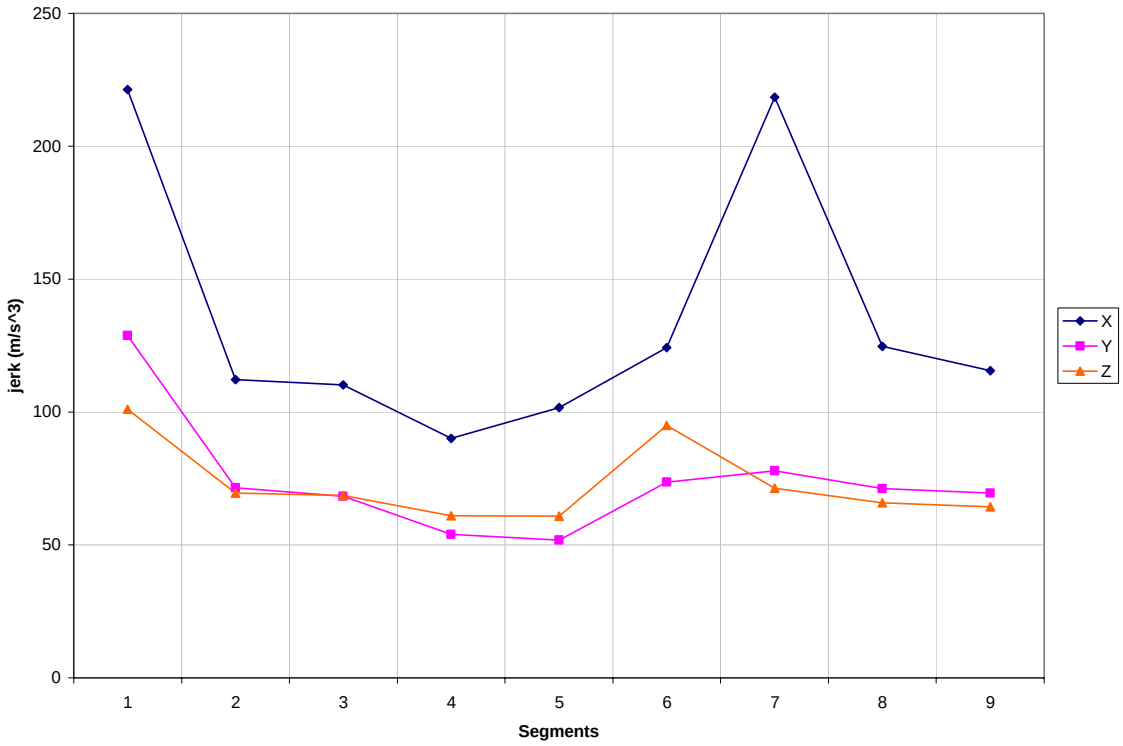


Figure 161 PT6 Passenger seat RMS Jerk

Vita

Shekhar Khanal was born in Tansen, Nepal on March 5, 1975. He got his Undergraduate degree in Mechanical Engineering from Regional Engineering College, affiliated to Burdwan University, India in 1998. He joined Tribhuvan University, Nepal as a lecturer in 1999 and continued to teach there till attending UT in Spring 2004. He graduated from UT with a Master's degree in Biomedical Engineering in 2006.