CHALMERS

# *TRUCK DRIVER USAGE OF MAIN DRIVING CONTROLS*

*Master's Thesis in Master Degree Programme, Product Development*


PAUL PRAVEEN PETER

Department of Product and Production Development
*Division of Product Development*
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2012

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**PAUL PRAVEEN PETER**

Supervisors at Volvo

Patrik Blomdahl, Ergonomics Team Leader, Volvo Trucks
Martina Söderberg, Feature Leader, Volvo Trucks

Supervisor at Chalmers

Professor Hans Johannesson, Head of Division, Product Development

Department of Product and Production Development
*Division of Product Development*
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Department of Product and Product Development
Division of Product Development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: +46 (0) 31-772 10 00

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Steering Wheel, Pedals and Gear shift lever pictures were taken from Google and they are not affiliated with Volvo Group.

# Acknowledgements

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**Paul Praveen Peter**

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# Abstract

The aim of the thesis work was to investigate and study the ergonomic issues related to the usage of the main driving controls; the steering wheel, pedals and gear shift lever in the truck. The drivers' expectations and evaluations of different features were presented in the Kano model to explore new possibilities for improvement. A methodology to search for different tools and equipment for measuring the forces from the steering wheel, pedals and the gear shifter lever was carried out. Then, one measurement technique was proposed to measure the forces from the driving controls for ergonomics testing and evaluation. The driving controls were evaluated with the Kesselring matrix to select one final driving control for detailed investigation. Pedals were selected for detailed investigation on the usage of driving controls across different truck segments.

Keywords: Steering wheel, Pedals, Gear shift lever, EuroFOT, Ergonomics, Pedal usage, driving controls

# 1. Background

The CAB division interior at Volvo Group Truck Technology (Volvo GTT) was responsible for the development of new interiors for the different Truck brands (Volvo Trucks, Renault Trucks, Mack, UD Trucks) and maintains today's production. A truck driver spends a lot of time in the driver seat. It is important that he or she can handle the truck in an optimal way.

In this thesis project, "Truck Drivers usage of main Driving Controls", the following driving controls were investigated with regards to how the drivers use the controls and how the controls could be improved.

- ⇨ Steering wheel
- ⇨ Pedals
- ⇨ Gear shift (manual / automatic)
- ⇨ Stalks

Initial studies were made about the driving controls usage in different transport segments (long-haul / distribution / construction) as well as the influences from different road conditions (smooth / rough, flat / hilly and straight / winding) and weather conditions (e.g. good friction versus slippery).

Then the force levels, strokes, feeling and feedback of the driving controls were investigated and a suitable force measuring method was proposed for the Ergonomics Division at Volvo Trucks.

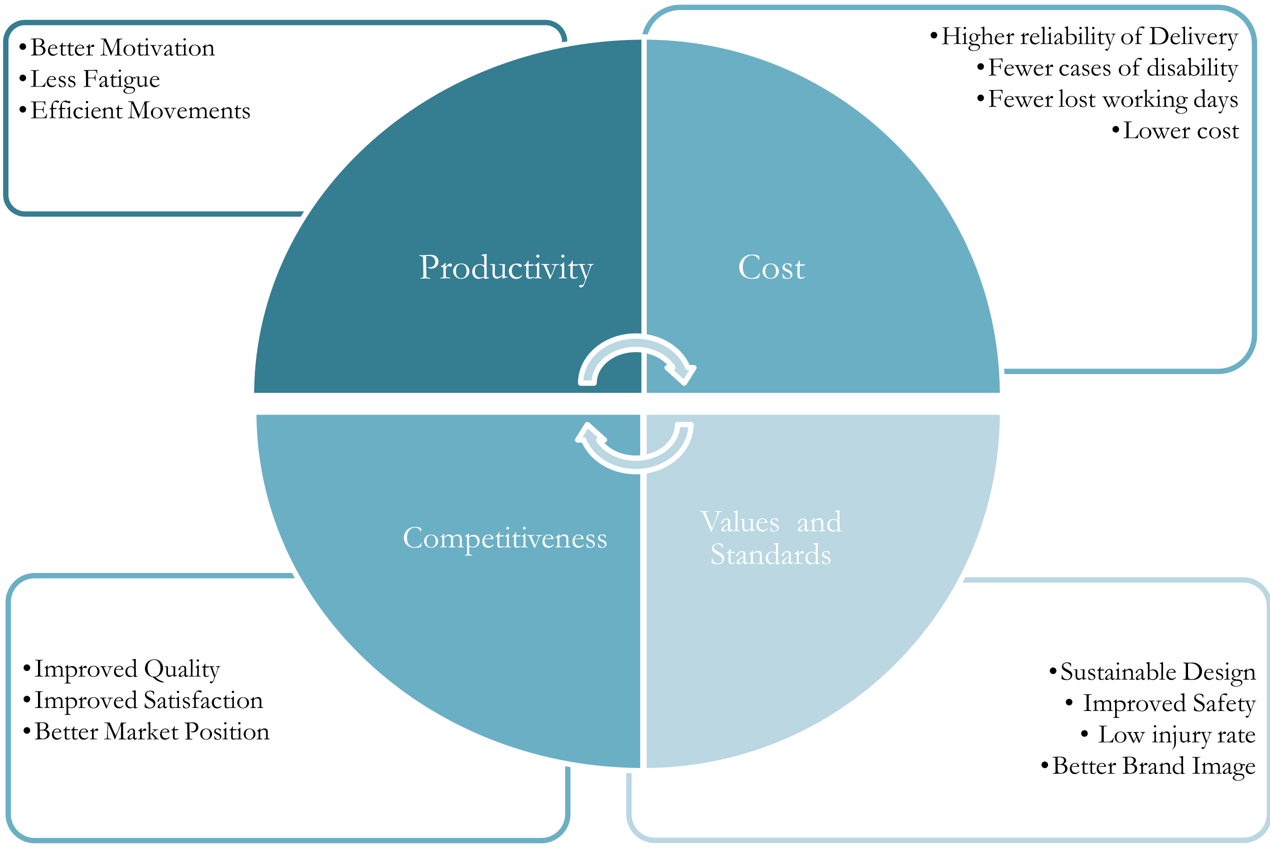
The primary target of the project was to come up with detailed information about how the controls were used, i.e. how the driver's hands and feet should be positioned in relation to the different controls. In parallel to this, proposals for how existing controls could be improved were also established.

Together with Volvo GTT, one set of controls was chosen for further investigation to establish prerequisites for a later product implementation and mean mutual gains for the truck drivers and Volvo Trucks.

## 1.1 Ergonomics

*"Ergonomics is defined as scientific discipline concerned with the understanding of the interactions among the humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human wellbeing and overall system performance" – International Ergonomics Association*

Advantages of ergonomics for Vehicle Manufacturers and Customers



## 1.2 Truck Manufacturers and Industry

Truck Manufacturers have a stake in and ownership over other truck companies to boost the sales and to share technology and expertise within their development centers. The Volvo Group consists of four truck brands, Volvo, Renault, UD trucks and Mack Trucks. The top three truck manufacturers on the global truck market were Daimler AG, the Volvo Group and Dongfeng Trucks. In Europe, other known truck brands are Scania from the Volkswagen Group, DAF from the PACCAR group and MAN SE and IVECO from the Fiat group.

The commercial vehicle market has grown, and will continuous to grow drastically. The picture below shows the market trend in the commercial vehicle (Light commercial vehicle with 6 tons and above 6 tons) market from 2006 to 2012. From a truly global perspective, the truck market is a growth oriented market with a forecast for increasing up to 33 million units by 2015 if current trends continue. (Dieter, 2011)

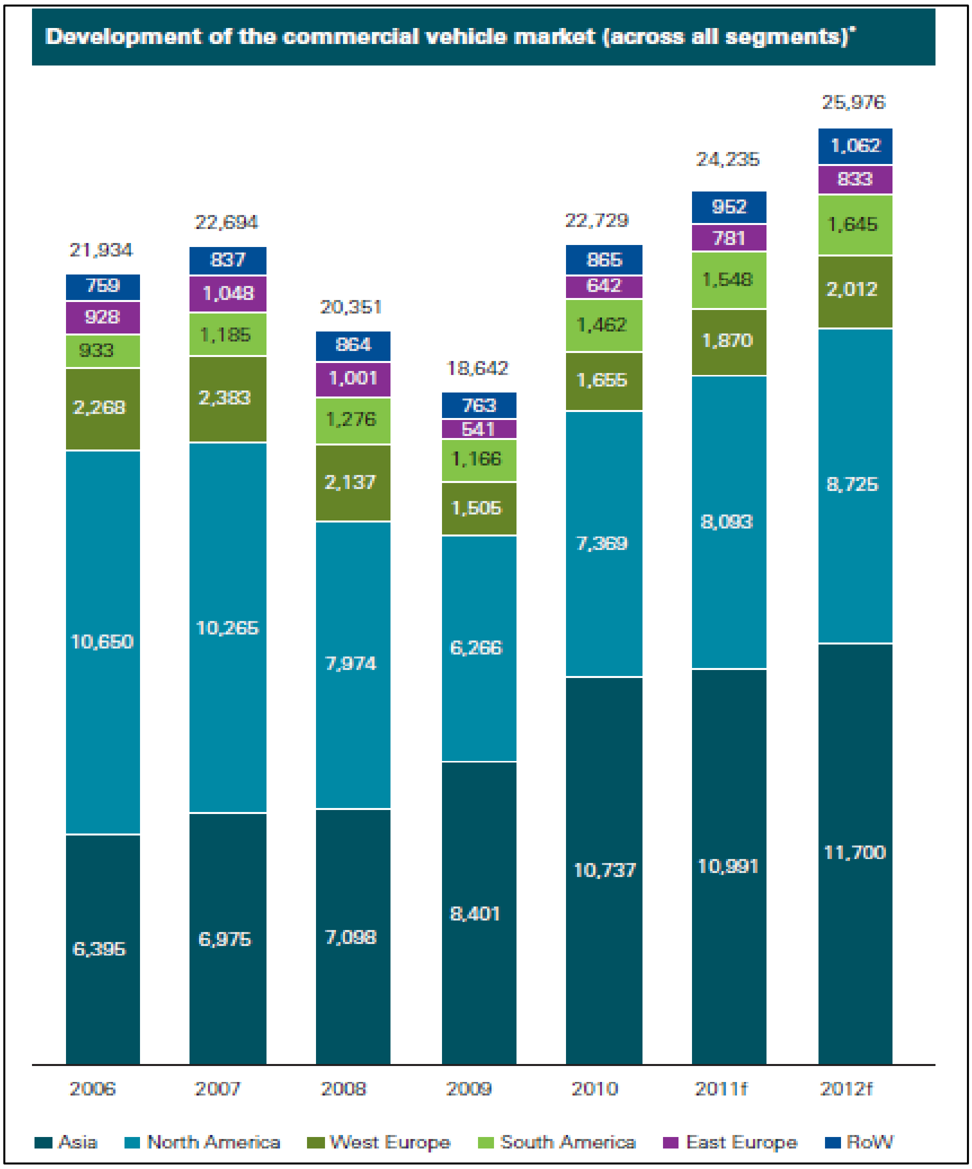


Figure 1: Development of the Commercial Vehicle Market of Trucks by region

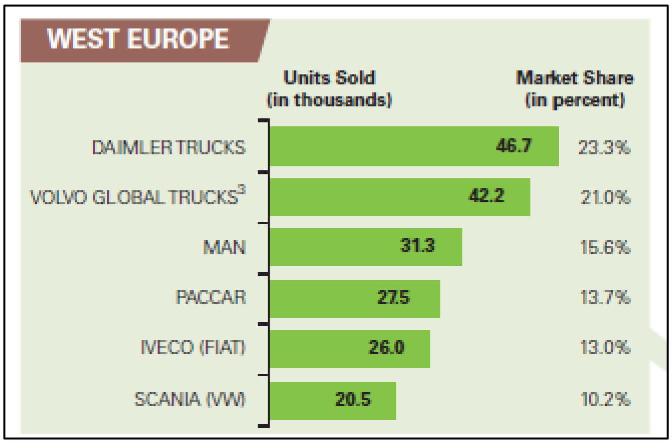



Figure 2: The market share of the truck manufacturers in Western Europe

# 1.3 Volvo Group

This thesis work was carried out at the Volvo Group Trucks Technology's headquarters in Lundby in Gothenburg. Volvo Trucks Technology, itself a company within the Volvo Group, develops solutions for the commercial truck industry for four brands across the globe. The four truck brands are Volvo Trucks, Renault Trucks, MACK trucks and UD Trucks. It also has a joint venture with Eicher India Limited as Volvo Eicher Commercial Vehicle which develops medium duty trucks for the South Asian Market. Volvo Group Trucks Technology works with Volvo Technology in advanced research programs within the transportation industry.

Volvo Group Trucks Technology was established in 2012 by combining Volvo Powertrain and Volvo Trucks Corporation. Now, Volvo Trucks Technology develops solutions for a truck as a whole and focuses on Product Development, Cab Development, Vehicle Engineering and Powertrain Development – nearly everything within the Truck.

This thesis work was carried out in the Ergonomics Division within the cab engineering department working with the ergonomic features; Driver Position, Visibility, Resting Comfort, Working Comfort and Entry & Exit.

# 1.4 Truck Segments

A truck generally is a type of vehicle used to ship goods. Commercially, trucks are used for various applications. Heavy trucks can be specified as vehicles having a total weight of around 16 tons. A loaded truck could weigh from 20 to 40 tons. The fully loaded truck may have a length of around 16 meters and weight of around 40 tons, as determined by the legal requirements in Sweden. There are heavier and longer trucks with a length of around 20 meters which are primarily referred to as road trains in Sweden. These are used for long distance transportation. Even road trains are being tested by Volvo Trucks for timber transportation applications in Sweden.

The project focuses on the trucks for different applications like long haulage, distribution and construction. The truck's container or trailer configuration differs based on the applications.

### Long-haul Trucks:

Long haulage trucks are used to transport goods regionally, nationally or even as cross-country cargo shipments. Since long haulage trucks move the goods both in the day as well at night, the drivers have to stay in the truck for few days in order to transfer the goods. The truck travels on the motorways during its mission, so emphasis is placed on driver comfort and fuel economy. For Volvo the FH series serves this application. The Volvo FH truck is available in different configurations, normally with the tractor unit and trailers attached to it.

**Figure 3 : Volvo FH –Long haulage truck**

The Long-haul truck is available in 420, 460, 500, 540, 600, 700, 750 horsepower engine configurations.

### Distribution Trucks:

The distribution trucks are used to transport goods within communities and cities and involve shorter distances with a lot of "start-stop" events. Nowadays, emissions and regulations on sustainable transport are pushing vehicle manufacturers to develop energy efficient and low emission vehicles with good energy recuperation system within the powertrain. The distribution trucks will travel for shorter distances with loading and unloading of goods. Usually, the driver will use the entry/exit doors more frequently than the long-haul truck drivers. In Volvo, FL and FE models serve the distribution segment. The distribution trucks are powered by low power engines with smaller cab.

Distribution trucks are powered by low power engines with 240 and 280 horsepower. The distribution truck drivers use the driving controls more often than the long-haul truck drivers, since the distribution trucks are often used within the city traffic limits.

Figure 4:Volve FL Distribution Truck

Figure 5: Volvo FE Distribution Truck

**Construction Trucks:**

Construction trucks are employed at mining sites and in specific geographical locations. The construction trucks are rugged with high strength and maneuverability to meet the driver's demand to move gravel and dirt on rough ground. The FMX trucks can be seen where construction equipment, like wheel loaders and excavators, are employed. These trucks can transport heavy weights and have a higher towing capability than normal trucks. The FMX is powered by a high torque capable engine specially designed for construction purposes. The FMX is a perfect off-road truck that can handle 100 tons of cargo.

The drivers usually drive the vehicle in rugged terrain so the main priority is placed on increasing driver comfort by reducing the vibrations and on increasing fuel economy. The

Volvo FMX engine is available in 380, 420, 480 and 500 horsepower configurations in I-shift, manual and Powertronic (automatic) transmissions.


Figure 6: Volvo FMX Construction Truck

## 1.5 Truck Drivers

There were around 115,000 drivers working in Sweden in 2004. However, this number was hard to pinpoint because of the number of foreign drivers who travel to and from Sweden. The truck industry is a male dominant industry with a very small percentage of female drivers. A study by Volvo says that 6% of the total 100,000 drivers are female. This percentage includes women driving the long-haulage truck as well. (PublicReport)

There are many laws regulating the driving of trucks on Swedish roads. One law is the drive and rest times. The driver is only allowed to drive for a maximum of 9 hours/day, with one break of at least 45 minutes, alternatively two breaks of 15 and 30 minutes respectively. A driver is not allowed to drive more than 4.5 hours in one run (According to EU regulations, 2006). A built-in trip computer in the truck cab automatically monitors and records the driving time. The trip computer is analyzed by the traffic police if the truck driver is stopped along the way. If the driver continues to drive one minute more than what the trip computer stipulates, the truck driver or owner of the company has to pay a fee of, at most, 10000 to 200000 SEK. (Report, 2011)

## 1.6 An Overview of the Truck Driving Controls in the Volvo FH

The driver is surrounded by the driving controls, gauges, buttons and levers in the truck cab. The main driving controls investigated in the project were the steering wheel, pedals (accelerator, brakes and clutch) and gear shift lever.

The transmission system in the FH is available in two main configurations (1) Manual gearbox and (2) Powertronic (automatic) gearbox (3) I-Shift in 12 speed gearbox.

The figure below shows the I-Shift gear lever in Volvo FH truck. I-shift combines the best characteristics of manual and automatic transmissions. I-Shift offers electronically controlled splitter and range gear shifting unlike manual transmission gear levers with I-Shift, the driver can focus on driving. It is still possible to change gears manually by simply pulling the gear lever to the manual setting and then change up or down using the button on the side of the gear knob. The truck with I-Shift system has no clutch pedal and the gear Engagement and disengagement are entirely automatic.

Figure 7: Volvo I-SHIFT Gear shift lever

Figure 8: Volvo FH Steering Wheel

The steering wheel in Volvo is equipped with a button to control the entertainment and communication system in the truck as well as to active and deactivate the cruise control features.

The steering wheel, with telescopic and tilt adjustment features, can be adjusted by manipulating a pedal operated by the left foot. However, the neck tilt function is available only in the new Volvo FH truck.

**Figure 9: Volvo FH Pedal Layout**

The accelerator and brake pedal is mounted to the right side of the steering column with two separate pedal carriers. The accelerator pedal is found in the far right position. The brake pedal is mounted between the accelerator pedal and steering column. The clutch pedal in the manual transmission truck is mounted to the left side of the steering column. The parking brake is located at the top of the instrumental panel.

The dash board or instrument panel is equipped with speedometer, tachometer and gauges in the front shelf and displays the technical information related to various systems in the truck.

**Figure 10: Volvo FH Interior Layout**

# 1.7 Ergonomic Background Studies

## 1.7.1 Anthropometry

The branch of science that relates to the measurement of the human individual is called anthropometry. Anthropometry plays an important role in driving control design and ergonomics. The anthropometric measurements can be classified into two categories.

Static Anthropometric Measurements:
The static measurements are traditional measurements obtained by the anthropologists from the human body and are comprised of length, width, height with respect to standard positions, either sitting or standing.

Function Oriented Measurements:
The functional measurements are taken with the human body at work. These measurements are mostly three-dimensional and they are expressed in three co-ordinates for workspace or body landmarks.

The functional anthropometric measurements for drivers of trucks were completely different when compared with drivers of cars. Some measurements, like total foot length and ankle height, can be used as supportive data for designing the foot controls in the truck.
(R.W.Roe, 1993)

## 1.7.2 Percentiles

The body dimensions of humans can be plotted on a graph with measurements on the horizontal x-axis increasing towards the right from the zero. The frequency of occurrences was plotted on the y-axis, increasing towards the top from the zero. A smooth curve averaging the particular height dimension will appear bell-shaped. In this case mean, median and mode do not coincide. The data from one dimension does not correlate with the other dimensions. For instance, small woman may have a small or large hip width. This information should be kept in mind when designing for an average person.

It is difficult to design for everyone. The few percent at either end of the normal curve may be so extreme that a design becomes too expensive to produce. In military standards they chose to exclude 5% at the small end and 5% at the large end. Thus, only 90% of the measured population was considered. The 5% of the value is called the 5$^{th}$ percentile and 95% of the value is called the 95$^{th}$ percentile.

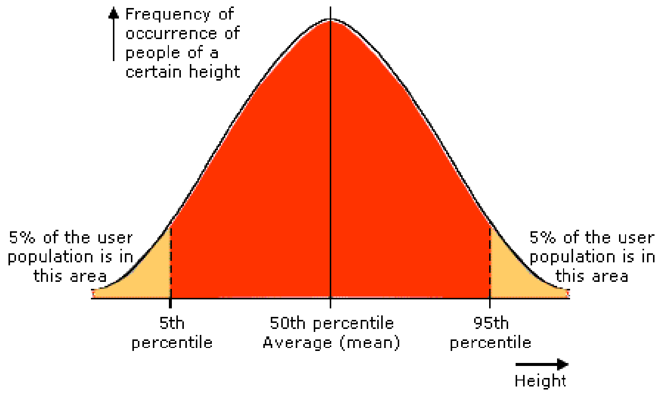



**Figure 11 Percentile in Human Population**

If we need different percentile, the standard deviation needs to be calculated.

$$SD = \sqrt{\frac{\sum(d)^2}{N}}$$

Where $\sum$= summation,
d = difference between one person's measurements and arithmetic mean of that measurement
N = Number of people measured

## 1.7.3 Human Variations

Human beings are unique and no two people are identical, not even twins. Therefore, three categories of human variability exist.

Intra-individual sizes: Sizes changes during adult life. Some changes are due to aging, others are due to movement or environmental differences from one place to another.

Inter-individual: There are big differences due to sex, ethnic and racial factors. Differences include skin, colour, body proportions and other features. The dimensions of feet and fingers differ drastically between sex and race.

Secular variability: changes occur from generation to generation for various reasons. However, the pace of change is slow; they have limited effect on human variations.
(Henry Dreyfuss, 2002)

## 1.7.4 Force Limits in using the controls

The force limits of pedals differ based on sex and foot dimensions.

Hand Controls:
Steering Wheel:
Normal force in one hand – 13 N to 22 N

Maximum force in one hand – 89 N
Maximum force in two hands – 133 N

Gear Shift Lever:
Hand Forces Push 22 N
Hand Forces Pull: 44 N
Max Force Push or Pull: 66N

Foot Controls:
Pedals:
The ball of the foot reaches the brake pedal with the force of 507N for the 5th percentile man whereas for the 5th percentile female it reaches with a force of 338N.

The resistance force from the brake pedal should be around 44.5 to 222.4 N.
The resistance force in the accelerator pedal should be around 17.8 to 44.5 N.
(Henry Dreyfuss, 2002)

## 1.8 Occupant Packaging Nomenclature

This section discusses the major technical landmark in the occupant packaging.

The functional task oriented design of foot controls is comprised of anthropometric measurements that are referenced to specific human body landmarks like BOF (Ball of Foot) and PCP (Pedal Contact Point). The reference points are normally related to the driver's foot in relation to the vehicle interior such as floor, foot controls or seat.

- Accelerator Heel Point (AHP): The lowest point at the intersection of the manikin heel and the depressed floor covering with the shoe on the default accelerator pedal position.

- Ball of Foot (BOF): A point on a straight line tangent to the bottom of the manikin shoe parallel to the y-plane 200 mm from the accelerator pedal according to the SAE standards.

- Pedal Contact Point (PCP): The point where the shoe or foot comes in contact with the pedal.

- Foot Angle: The angle measured between lower leg centreline and the barefoot flesh line, i.e. the line connecting the ball and heel of the foot. The foot angle was recommended to be around 87 degrees from an ergonomic perspective.

- Accelerator Foot Plane (AFP): A plane passing through the accelerator heel point (AHP) and the ball of foot (BOF) that is normal to the y-plane. (R.W.Roe, 1993)

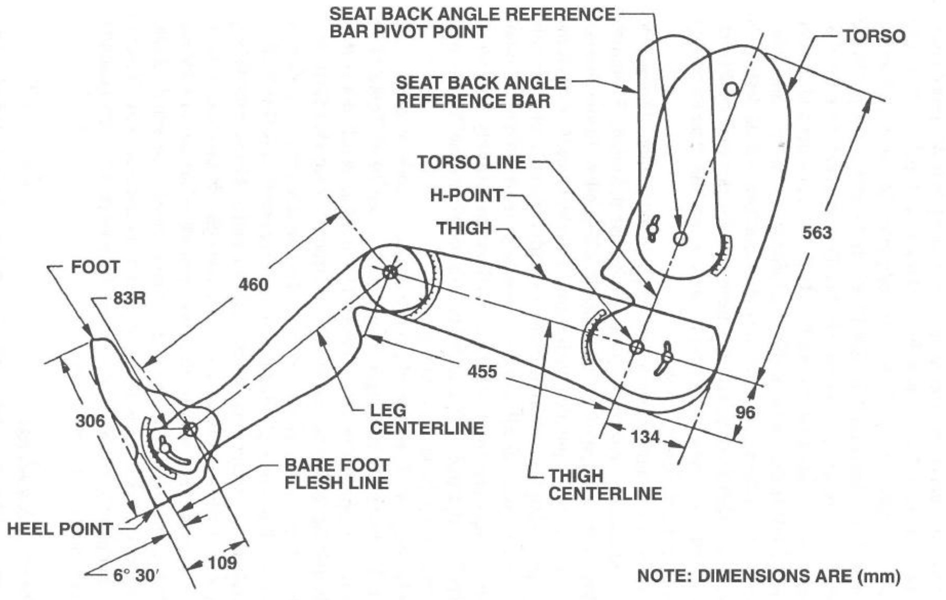



Figure 12 Two dimensional H-point machine

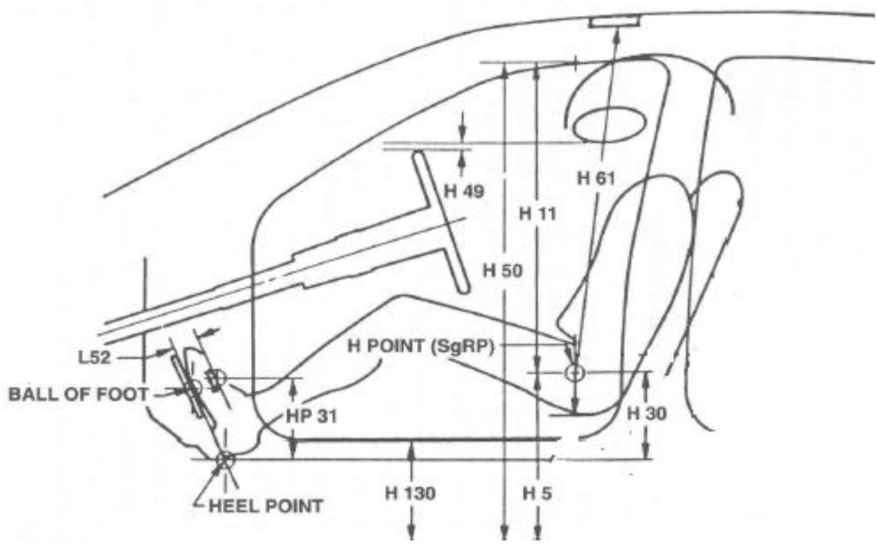



Figure 13 Dimension in SAE J1100 that define the interior space

# 2. Methods of Data Collection

The following tools were used in various phases of the project from the preliminary; and planning to the concept generation phases.

## 2.1 Questionnaires

A questionnaire is a document with questions with the specific focus on gathering the required information. It was used as a mechanism for obtaining information and opinion about the product or the system. The questionnaire can be used to investigate user needs, expectations, perspectives, priorities, preferences and satisfaction.

The questionnaire can be prepared in two ways; one with open ended questions and the other with close ended questions. The open ended question is used to gather information from the respondent in his own way or opinion. The close ended questions are designed with pre-selected answers. The respondent needs to choose the answer based on his opinion. Close ended questions are similar to a forced-answer format however, they are simpler to answer and take less time.

The questionnaires can be distributed to a large or small population based on the need for information. The questionnaire format is familiar to most respondents. The information can be collected in a structured way for analysis. Finally, the opinions are evaluated to extract the information.

The main disadvantage of the questionnaire is that the respondents may ignore or misunderstand the questions. It could be difficult to represent complex issues in the questionnaire.

## 2.2 Interviews

Interviews are an effective tool for investigating issues in an in-depth way. An Interview can disclose how individuals think and feel about the topic. Interviews can reveal the user's desires and expectations about the product. Even sensitive topic which may make some people feel uncomfortable can be discussed in the interviews. The interviewer's behavior has a great influence on the interview.

The main advantage of interviews is that it is easy to obtain information about the respondents perceptions based on his own words and there is the possibility to ask follow up questions based on the answers from the respondent's answers. In some cases, the respondent may exaggerate about some topics.

Interviews are time consuming and expensive. The interviewer's understanding of the interviewee may be colored by his own perceptions. This could be the main disadvantage of the interviews. (Ulrich & Eppinger, 2000)

## 2.3 Brainstorming

Brainstorming is one of the best idea generators that is used to generate as many ideas as possible. Brainstorming is highly effective when done in a team of people. It is the team activity that allows everyone to share their thoughts and ideas about a topic. Interesting ideas are documented as short notes for further analysis and exploration.

Brainstorming was done in several phases based on the needs of the project. It was used to promote the creative thought process within the team. The collected information was processed in an effective way.

## 2.4 Benchmarking

The benchmarking process involves "what" and "how" issues. It is a simple process tool used to achieve a thorough understanding of the competitor's solutions and how their product functions in different scenarios. The benchmarking process compares the results of two companies and their product in the same market.

In some cases, benchmarking was employed to understand the competitor's ideas behind their product. It was used to find the strength and weakness of the product in comparison to the competitor. The benchmarking should not limit the scope to its own industry, nor should benchmarking be a one-time event. (Stroud)

## 2.5 Observations

An observation based study is usually performed in a project to gather information about user, user needs or perform specific tasks. The observer can make notes and document the user action and facts for later investigation. During direct observation, the user focuses on specific tasks. The observer can also observe indirectly by viewing video material or tasks. Indirect observation might go unnoticed in a natural environment. Observations are simple, inexpensive and provide firsthand information.

The main advantage of observational research is flexibility. The researchers can change their approach or intentions as needed.  The main disadvantage is that it is limited to behavioral variables.

## 2.6 Literature Materials

The literature materials study includes background reports within Volvo and ergonomic resource materials from SAE journals and other institutions which address the issues regarding the driving controls.

Apart from them internet sources like Trucking Report, Forum and Trucking magazine and Driver Forums like kingsclubb.se; as well as automobile magazines and videos have been used as resource materials for this project.

Customer feedback from the sales and marketing department provided some insights from a marketing perspective.

# 3. Data Collection in the Project

## 3.1 Interviews at Björkäng

In order to get firsthand information during the initial study phase of the project, interviews were conducted with ten drivers at a truck stop. The questions were very general and closed ended. The drivers were asked to explain the difficulties and challenges of using the driving controls in order to give a better understanding of the areas that need improvement within the driving controls. The drivers used trucks for long haulage, tank and timber transportation applications. The questions include the driver's background information, experience in driving trucks, vehicle applications and usage of driving controls.

## 3.2 Volvo Demonstration Centre

An interview session was conducted with the driver in the Volvo Demonstration Team to get information about the features and usage of the driving controls within the Volvo Product Variants. The session also involved observation based study of driving in different variants of Volvo products, like the FH, FM, FL and FMX, which were tailor made for specific applications. The interview sessions were useful for getting to know Volvo products.

## 3.3 Scania Demo Centre

The visit to Scania Demo Centre was carried out after the visit to the Volvo Demonstration Centre in order to acquire information about the usage of controls in Scania Trucks, which is one of Volvo's competitors. The manager of sales within Scania was interviewed in order to gain knowledge about the features of the driving controls and product variants within the Scania portfolio. The session was a discussion and demonstration of the usage of driving controls.

The Scania Demo Centre visit was considered a part of the benchmarking process to get information about the competitor's products. During the visit, the usage of the driving controls in the Scania truck was reviewed. The steering wheel control was enhanced with the neck tilting adjustment for improving the comfort to the driver. The gear shift lever was replaced by a gear shift stalk in the steering column making it much easier to shift gears without much effort for the drivers. The gear shift stalk gives more room for the driver around the seat and increases the accessibility to the shelf under the bed. The observations from the visit were documented for further investigation.

## 3.4 Hällered Proving Ground

The visit at Hällered Proving Ground contained a combination of interviews as well as observation based study. The questionnaire was prepared with specific questions targeted towards the driving controls in particular to gain deeper insight into the problems and challenges the drivers encounter when driving in both normal and adverse driving conditions (e.g. using the steering wheel and brake pedal while climbing a hill during winter). The questionnaire focused on the steering wheel control, gear shift lever and pedals (accelerator & brake pedals), since Volvo has implemented I-Shift in the FH and FM series which gives the possibility to eliminate the clutch pedals. The drivers interviewed were test drivers with exceptional driving skills and good experience. The interviews were conducted at Hällered in the test circuit while driving the Volvo Trucks (FH & FM). Around 25 drivers actively participated in the session to share their experience in the usage of the driving controls.

## 3.5 Feature Specialists

At Volvo Product Development the features specialists of different driving controls systems, such as Steering System, Gear Shift System, Transmission System, Braking System, and Vehicles Dynamics actively participated in the interview sessions to share the insights on the usage of driving controls and possible improvements. The interviews, carried out with 10 feature specialists, covered the driving controls and measurement systems need to measure the forces required to operate the driving controls. The discussion involves improvements not only from the driving controls but also from the system perspective.

## 3.6 Ergonomic Feature Leaders

The final phase of the pre-study data collection was the conduction of interviews with ergonomic feature leaders within Volvo Trucks. The interviews were made while driving an FH truck near Torslanda, Gothenburg. The driving controls, steering wheel, gear shift lever and pedals were analysed individually. The comments and feedback from the feature leaders were documented.

# 4. Results of the Data Collection

The individual results from the interviews and questionnaires were documented in APPENDIX –C and APPENDIX - D

The desires and expectations of the drivers were presented in the Kano model to give a holistic approach towards the driving controls evaluation.

## 4.1 Kano Model

The requirements of the future/idealistic driving controls are that they must possess superior features to the current ones. The Kano model was used in order to evaluate the requirements and needs of the drivers from a competitive perspective.

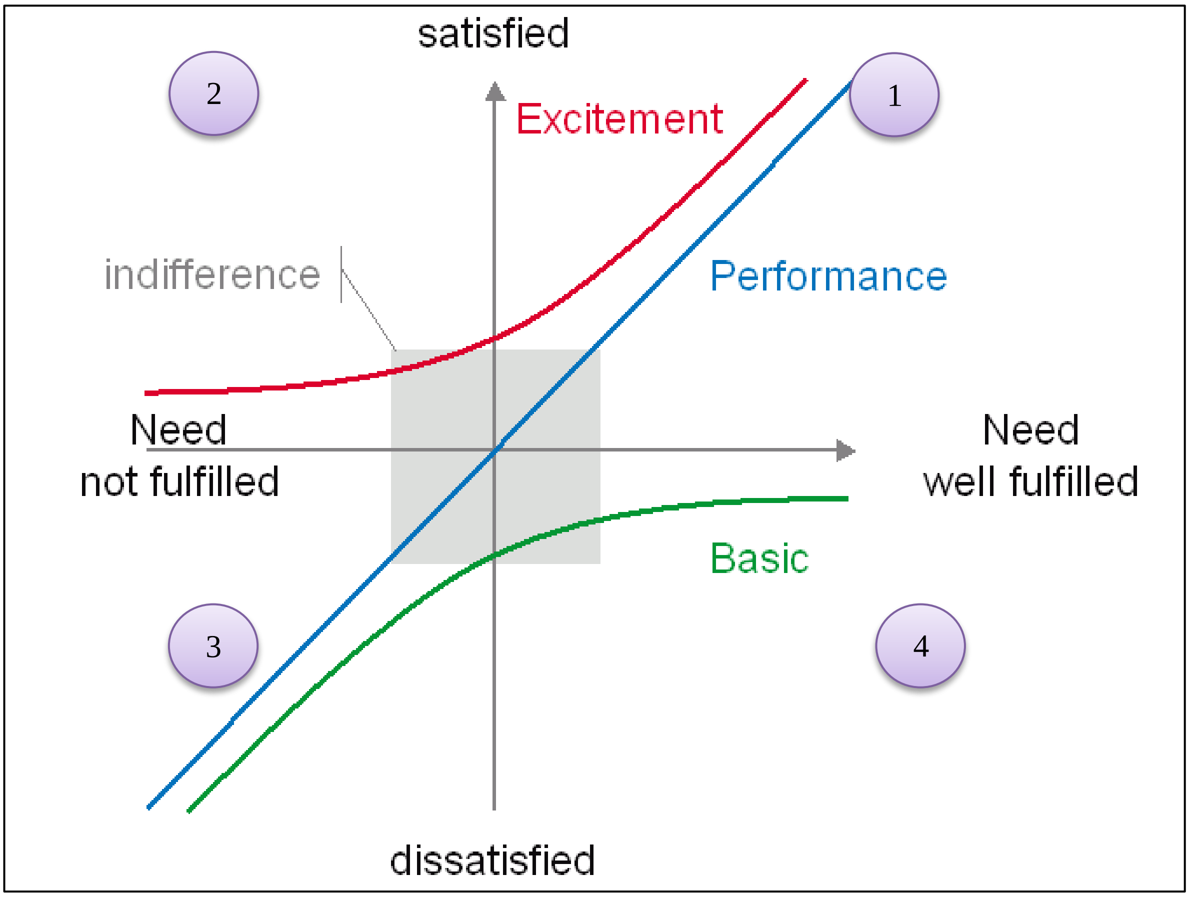



Figure 14 Kano Model

The Kano model consists of four quadrants with two lines separating them. The vertical line shows the level of satisfaction and the horizontal line shows the level of implementation or fulfilment. The first quadrant represents the performance zone and contains the features that improve the performance of the product. The second quadrant represents the excitement zone and has features that excite the customers but are not fully implemented in the product. The third quadrant represents features which are not favourable or satisfactory to user expectations and needs. These features may be an old feature that after due course of time need to be improved. The fourth quadrant represents the basic features. The product must have these features with full implementation in order to satisfy the user needs which are considered as mandatory. The features are shown as spheres in the Kano Graph.

The Kano model based study was carried out to present the features in the zones described above. The Kano model for a product shows its features arranged among the quadrants based on user opinion and expectations. The subjective evaluation of the questionnaire and comments from the drivers during the interviews or observation based studies were documented. The input from the interviews was translated to the Kano model by analysing individual responses from the each user / driver about each feature of the product. The features of the product were categorized by the number of responses from the drivers through the ratings in the subjective evaluation; also, the comments of each driver and the ratings were summed up. Based on the maximum responses and individual comments the features were translated to the respective quadrants in the Kano model.

For example, a study on the steering wheel in which; 10 truck drivers were interviewed regarding the size of the steering wheel. The steering wheel diameter comes in two configurations, 500 mm and 450 mm. If 7 drivers prefer the 450 mm steering wheel and 3 drivers the 500 mm version, then the 450 mm diameter steering wheel was considered the desired size. At the same time the comments from the drivers were also analysed - larger diameter steering wheels demand more effort and force to steer the truck while a smaller diameter steering wheel requires less effort with excellent comfort.

Some questions had mixed responses, so the individual driver's comments were examined in order to draw conclusions.

The Kano model was prepared for each driving control to show the drivers' opinions about the features in the current Volvo FH truck as well as their wants and expectations related to the future driving controls in the Volvo. The features were plotted based on the interviews with the drivers, test drivers, feature specialists and feature leaders within Volvo. Through the Kano models the user expectations and preferences were clearly revealed.

### 4.1.1 Steering Wheel Control

The Kano model regarding the steering wheel is represented below. The user needs and expectations were plotted in the Kano Graph. The steering wheel in the Volvo FH comes with two diameter sizes, (1) 500mm and (2) 450mm. The drivers feel that the 450 mm diameter steering wheel offers more comfort and lower force levels than the 500mm diameter steering wheel, because larger diameter steering wheels demand more work load and force to steer the vehicle. If the diameter of the steering wheel could be reduced to 425mm then it would be considered a "delight" to the drivers. Of course, a reduction in the steering wheel diameter requires that legal requirements be addressed before implementation. In the Kano graph the 500mm diameter steering wheel was represented as 1 in quadrant 3 and the 450mm diameter steering wheel was represented as 2 in quadrant 1 and the proposed 425mm diameter steering wheel was plotted in quadrant 1 and represented as 3. The reduced diameter steering wheel improves steering wheel usage to a greater extent by providing excellent comfort.

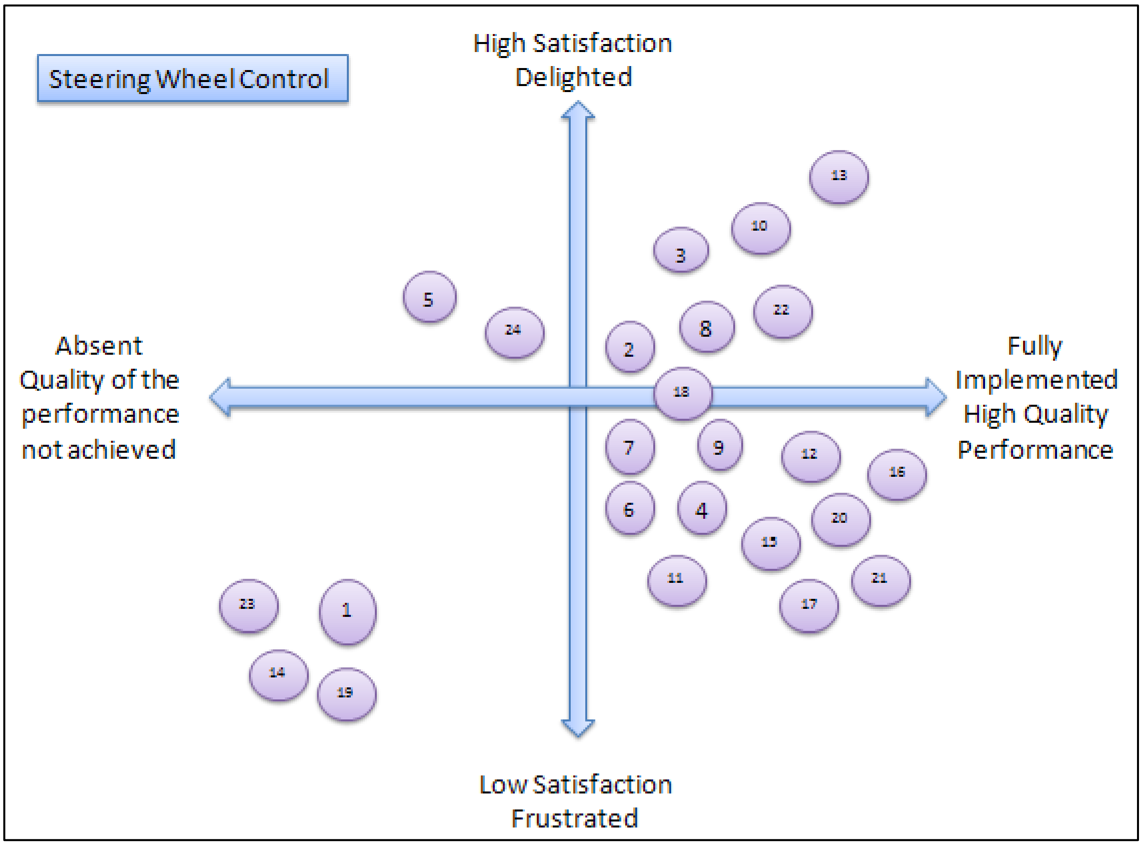



Figure 15 Kano Model for Steering Wheel

The shape of the steering wheel is round. However, feature specialists and feature leaders also considered a D-shaped steering wheel from a design perspective. During the interviews, the drivers were more comfortable with the round steering wheel when compared with the D-shaped steering wheel. Even though drivers were quite excited about the D-shaped steering wheel they were not sure about its full scale implementation. They also considered that the D-shaped steering wheel would not improve steering wheel performance even though it did offer a better view of the instrument cluster. So, the round type steering wheel was represented as 4 and plotted in quadrant 4 and because of the nature of its importance it was considered a “basic” feature. The D- shaped steering wheel was represented as 5 and plotted in quadrant 2 to emphasize its exciting nature but that it was not useful in improving the performance of steering wheel usage.

The adjustment of the steering wheel can be carried out in three different ways. Including telescopic and tilt adjustments. The driver can adjust the steering wheel based on his preferences. The neck tilting feature was not available on the old Volvo FH whereas the competitor Scania has the neck tilt function which improves driver comfort without adjusting the seat position. Today, this neck tilt feature is available in the new Volvo FH but not at the time of the studies. The telescopic movement and the tilt movement were represented as 6 and 7 and they were plotted in quadrant 4. They are basic features and are considered mandatory since without these features the users feel disappointment when using the steering wheel. The neck tilt function was represented as 7 and plotted in the 1 quadrant because it delights the customers by offering higher levels of comfort and pleasure.

The friction patterns in the steering wheel were available in a plain single pattern made of leather. However, multiple patterns with friction points made of leather could increase the comfort to a higher level in different weather conditions. The single friction pattern was represented as 9 and plotted in quadrant 4 because this feature was considered as basic. The multiple friction patterns were represented as 10 and plotted in quadrant 1 because this delights the driver and provides adequate comfort and friction.

The drivers prefer the friction material to be leather because it offers enough support in terms of grip and reliability. Based on the drivers' experience they feel materials like plastic and foam are slippery when using the steering wheel. The friction materials were represented as 14 for plastic, 15 for foam and 16 for leather. The plastic friction material was plotted in quadrant 3 because it was considered a poor feature by the drivers in various ergonomic aspects. Foam and leather were considered as basic features and they were plotted in quadrant 4.

During the observation based studies, drivers felt it difficult to adjust the steering wheel position between the driving sessions, i.e. during the entry and exit to and from the cab. A few decades back the vehicle steering wheel was rigid and non-adjustable, but now it can be adjusted easily through a tilt away function which moves the steering wheel back to its original position (with the steering wheel adjustment pedal in the Volvo FH and the Volvo FM). The drivers prefer, though, computerized functions like a customizable memory system which could reduce the work load and improve the comfort in the steering wheel usage to a greater extent by assisting the drivers in achieving a comfortable steering wheel position during entry and exit through the push of a button. The adjustment positions can be stored electronically along with the seat adjustments in a database containing the individual drivers' profiles. The customizable memory function will delight the drivers and reduce the work load. (This function was not available commercially in trucks.) The rigid steering wheel feature was represented as 11 and it was plotted in quadrant 3 because of the poor feedback from the drivers. The tilt away feature in the steering wheel was represented as 12 and plotted in quadrant 4. It was considered a basic feature. The customizable memory feature in the steering wheel adjustment position during entry and exit was represented as 13 and plotted in quadrant 1 because it delights the drivers and increases the performance factor of the steering wheel, offering comfort and reducing the work load for the drivers in the long run.

The driver normally makes 2.5 laps of the steering wheel to steer the vehicle from the left side to the right side and vice-versa. During the driving session some drivers felt comfortable with the stroke while a few drivers would prefer to reduce the strokes to less than 2 laps. If the strokes of the steering wheel were reduced in distribution trucks, then the drivers would have better control in turning the vehicle in dense city traffic situations. The steering stroke with 2.5 laps was represented as 17 and plotted in quadrant 4 which was considered as basic. Whereas, the strokes with 1.5 to 2 laps were considered as performance features and plotted in the line that separates quadrant 1 and quadrant 4.

The force levels for turning the steering wheel were similar to the force levels for the strokes. Reducing the force required to turn the steering wheel could benefit the drivers. High force levels were unacceptable and they were represented as 19 and plotted in quadrant 3 which shows their poor characteristics. Low force levels were represented as 20 and plotted in quadrant 4 which shows this feature to be a "basic" feature which cannot be compromised.

| Customer Needs | Functional Requirements | Code |
|---|---|---|
| Size | Diameter (500mm) | 1 |
| | Diameter (450mm) | 2 |
| | Diameter (425mm) | 3 |
| Shape | Round | 4 |
| | D-Type | 5 |
| Adjustment | Up and Down | 6 |
| | In and Out | 7 |
| | Neck Tilt | 8 |
| Friction Patterns | Single Pattern | 9 |
| | Multi Pattern | 10 |
| Position | Rigid | 11 |
| | Tilt Away | 12 |
| | Customizable Memory | 13 |
| Friction Pattern Material | Plastic | 14 |
| | Foam | 15 |
| | Leather | 16 |
| Strokes | Laps (2.5) | 17 |
| | Laps (1.5-2) | 18 |
| Forces | High | 19 |
| | Low | 20 |
| Stability against wind | Manual Steering | 21 |
| | Automatic Steering | 22 |
| Vibration | High | 23 |
| | Low | 24 |

**Figure 16 Key Feature table of Steering Wheel**

The stability of the vehicle when exposed to wind was an important feature because the drivers feel the feedback in the steering wheel. Manual steering could drastically increase the effort in using the steering wheel and automatic steering or an electronic stability program could reduce the effort and improve the controllability aspect of the steering wheel. Manual steering was represented as 21 and plotted in quadrant 4 because it was considered as basic. The automatic steering against wind was represented as 22 and plotted in quadrant 1 which shows it improves the performance. It also delights the drivers while driving in different weather conditions.

Over the past years the vibration from the steering wheel has been reduced in the truck. Now, the vibrations in the steering wheel were almost the same as that of a passenger car and driver comfort in regards to vibrations is extremely good. Higher vibration levels were unacceptable from the ergonomics perspective and they were represented as 23 and plotted in quadrant 3 because of their poor characteristics. Lower vibration levels were represented as 24 and plotted in quadrant 2. A trade-off should be made because maximum filtration of vibrations could eventually reduce the feedback from the steering wheel, so any improvement in reducing the vibrations should be made without compromising on the feedback from the steering wheel.

## 4.1.2 Gear Shift Lever

The Kano model shown below illustrates the features of the gear shift lever.

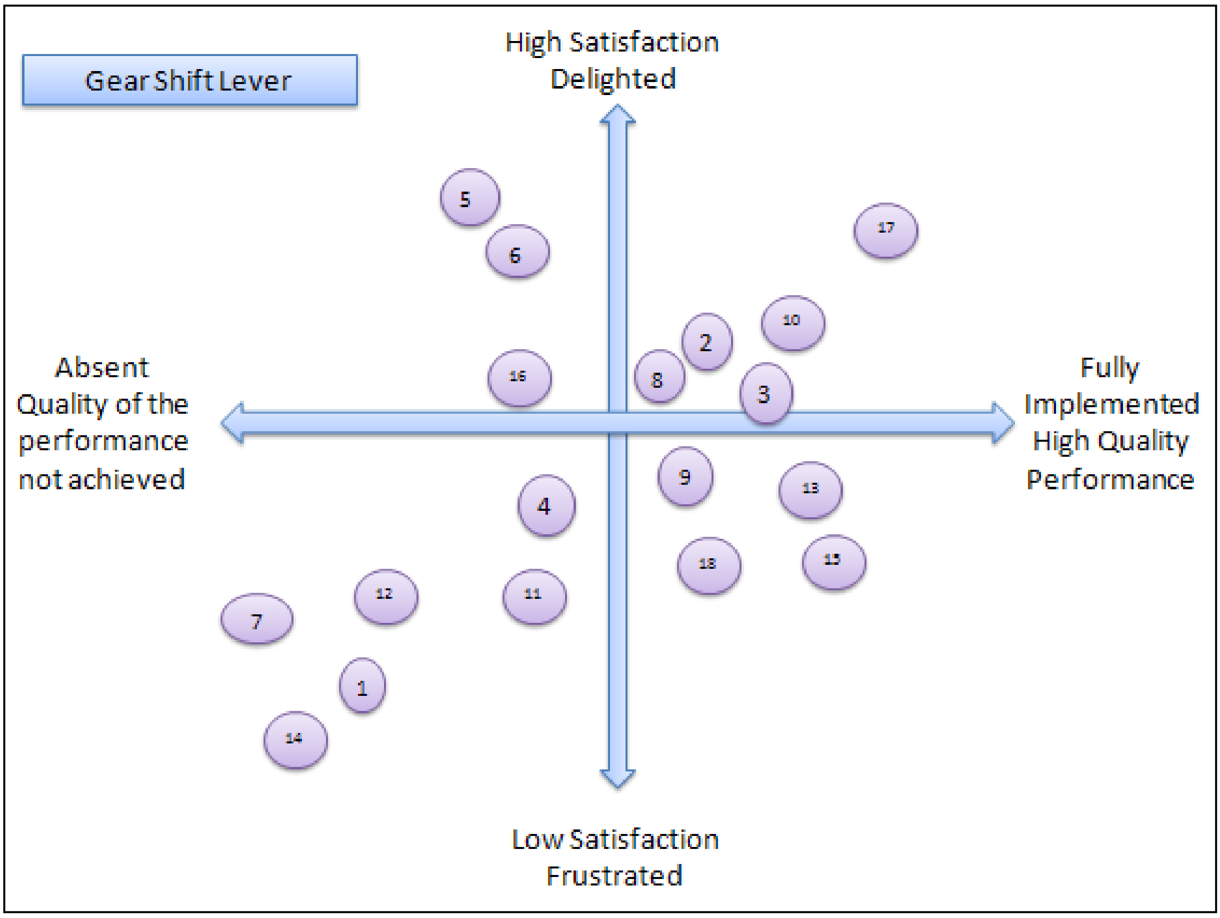



Figure 17 Kano Model of Gear shift lever

The Volvo FH comes with three different types of transmissions, (1) manual, (2) automatic and (3) I-shift. The gear shift lever is used mostly for changing gears in manual transmission trucks and in I-shift transmission trucks. In automatic transmission trucks it is only used for reverse and forward functions. In Europe, the demand for manual transmission trucks has declined in the past 5 years at the same time the I-Shift technology has replaced the manual transmission segment. However, the demand for manual transmission trucks has risen in Russia and India according to studies within the Volvo Powertrain Division.

During the interviews, the drivers considered the gear shift lever in manual transmission trucks as poor because of the high force and vibration levels, and the long stroke length. So, the gear shift lever in manual transmission trucks was represented as 1 and plotted in quadrant 3.

I-shift transmission system was considered as delight as it reduces the force levels and stroke lengths from the gear shift lever. I-shift gear shift lever was represented as 2 and plotted in quadrant 1. I-shift also improves the comfort and performance in shifting the gears for the drivers. The automatic transmission also reduces the effort and work load for the drivers in the long run. Automatic transmission gear shift levers were represented as 3 and plotted in quadrant 2.

There was speculation among the truck manufactures in positioning the gear shift lever. In Volvo, the gear shift lever is attached to the seat, in Scania it is in the steering stalks and in DAF it is near the dashboard. The gear shift lever attached to the seats were represented as 4 and plotted in quadrant 3, gear shift controls in the stalks and dashboard were represented as 5 and 6 and they were plotted in quadrant 2. However, initial studies showed that gear shift controls in the stalks would be easy to operate and require cognitive attention to shift gears and the button in the dashboard would also be an interesting area to explore.

Every driver interviewed preferred leather as a material to be used in the gear shift knob. Plastic materials were represented as 7 and plotted in quadrant 3 and leather was represented as 8 and plotted in 1. Foam was represented as 9 and plotted in quadrant 4.

| Customer Needs | Functional Requirements | Code |
|---|---|---|
| Transmission Type | Manual | 1 |
| | I-Shift | 2 |
| | Automatic | 3 |
| Position | Seat/Floor Mounted | 4 |
| | Stalks | 5 |
| | Dashboard | 6 |
| Material | Plastic | 7 |
| | Leather | 8 |
| | Foam | 9 |
| Forces | Low | 10 |
| | High | 11 |
| Strokes | Long | 12 |
| | Short | 13 |
| Vibrations | High | 14 |
| | Low | 15 |
| Feedback | Noise | 16 |
| | Display | 17 |
| | Position | 18 |

Figure 18 Feature table of Gear shift Lever

The force levels required to operate the gear shift lever were considered an important ergonomic factor. The gear shift lever requiring lower force levels was represented as 10 and plotted in quadrant 1 because it delights and improves performance when using the gear shift lever and the gear shift lever requiring higher force levels was represented as 11 and plotted in quadrant 3. Longer strokes of the gear shift lever were represented as 12 and plotted in quadrant 3. Shorter strokes of the gear shift lever were considered as basic so they are represented as 13 and plotted in quadrant 4.

The vibrations from the gear shift lever were within the acceptable range. However, maximum filtration of the vibrations could affect the feedback from the gear shift lever. Higher vibration levels from the gear shift lever were represented as 14 and plotted in quadrant 3 and lower vibration levels were represented as 15 and plotted in quadrant 4 as a basic feature.

The drivers' opinions regarding the feedback from gear shifting was in the form of (1) noise, (2) display in the instrument cluster and (3) position movement of the gear shift lever. Noise feedback was represented as 16 and plotted in quadrant 2. Display feedback in the instrument panel was represented as 17 and plotted in quadrant 1. Position of the gear shift lever was represented as 18 and plotted in quadrant 4.

### 4.1.3 Pedals

The Kano model for the pedals includes the accelerator, brake and clutch pedals. They were presented in the pictures below.

The type of pedal was a key parameter in pedal usage from an ergonomics perspective because it determines the foot position and contact points between the pedal and foot. The pedals are mounted in two different ways, suspended and floor mounted. In the Volvo FH, the accelerator and brake pedals are suspended pedals. In the DAF, the brake pedal is a floor mounted pedal and the accelerator pedal is suspended. The Kano model shown below represents the drivers' opinions regarding various aspects of the pedals.

The suspended accelerator pedal was represented as 1 and plotted in quadrant 4. It was considered a basic feature. The floor mounted accelerator pedal was represented as 2 and plotted in quadrant 3. The suspended brake pedal was represented as 21 and plotted in quadrant 4. The floor mounted brake pedal was represented as 22 and plotted in quadrant 3. The suspended clutch pedal in manual transmission trucks was represented as 41 and plotted in quadrant 4. The floor mounted clutch pedal was represented as 42 and plotted in quadrant 3. The floor mounted clutch pedal doesn't improve the performance factor of the pedal, so this feature was considered as poor by the drivers.

The drivers use their shoes/bare foot for pedal usage. Driving with shoes for accelerator, brakes and clutch operation was represented as 3 for the accelerator pedal, 23 for the brake pedal and 43 for the clutch pedal and they were plotted in quadrant 4 because these were considered "basic" features without which difficulties in pedal operation could arise. Comfort while driving barefooted was considered a delight for long haul truck drivers. Barefoot driving was represented as 4 for the accelerator, 24 for the brakes and 44 for the clutch operation. They were plotted in quadrant 3 because they satisfy user expectations and increase the performance factor of pedal usage.

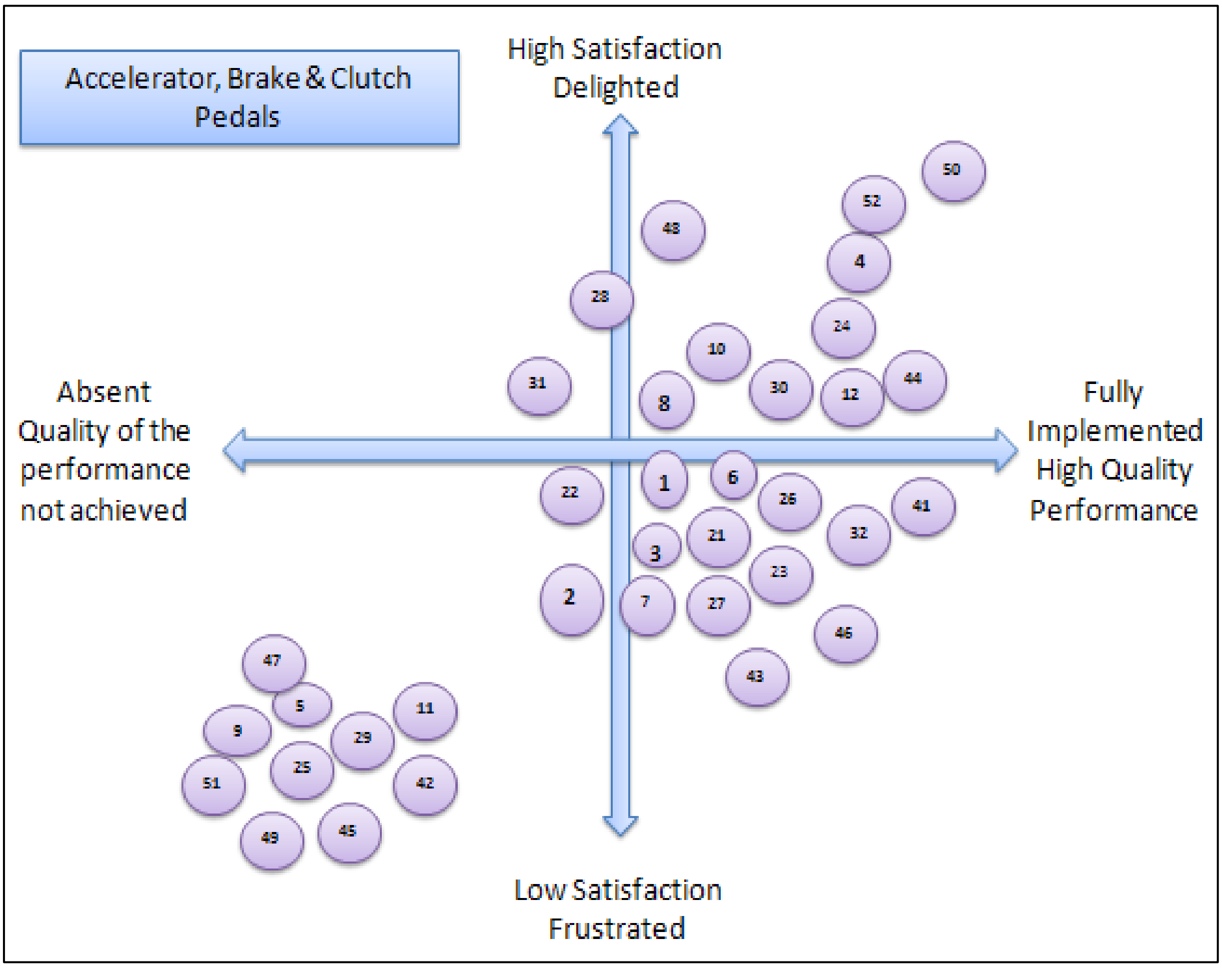



Figure 19 Kano Model for Pedals

The friction material is laid over the pedal plate to create enough friction when using the pedals. All the drivers prefer the friction material to be rubber. The drivers say the pedals feel slippery when using the plastic friction material. The plastic friction material on the accelerator, brake and clutch pedal was represented as 5, 25, and 35 and plotted in the Kano graph in quadrant 3 because of its poor reviews from the drivers. The rubber friction material on the accelerator, brake and clutch pedal was represented as 6, 26 and 36 and they were plotted in quadrant 4 which emphasizes this as a basic or mandatory feature when using the pedals as seen from the drivers' point of view

A longer pedal stroke would give sufficient control for the drivers while a shorter stroke could reduce the work load for drivers in the long run. The longer strokes were represented as 7 for the accelerator pedal, 27 for the brake pedal and 47 for the clutch pedal and they were plotted in quadrant 4. The shorter pedal strokes were represented as 8 for the accelerator pedal and plotted in quadrant 1, 28 for the brake pedal and plotted in quadrant 2 and 48 for the clutch pedal and plotted in quadrant 1. The drivers prefer longer strokes over shorter strokes for brakes.

| Customer Needs | Functional Requireme | Accelerator Pedal Code | Brake Pedal | Clutch Pedal |
|---|---|---|---|---|
| Type | Suspended | 1 | 21 | 41 |
| | Floor Mounted | 2 | 22 | 42 |
| Comfort | Shoes | 3 | 23 | 43 |
| | Barefoot | 4 | 24 | 44 |
| Friction Material | Plastic | 5 | 25 | 45 |
| | Rubber | 6 | 26 | 46 |
| Stroke | Long | 7 | 27 | 47 |
| | Short | 8 | 28 | 48 |
| Forces | High | 9 | 29 | 49 |
| | Low | 10 | 30 | 50 |
| Position | High | 11 | 31 | 51 |
| | Low | 12 | 32 | 52 |

Figure 20 Key Features table of Pedals

Higher force levels for pedal operation were unacceptable from an ergonomics perspective because they directly affect the comfort and demand more effort from the driver. Higher pedal force levels were represented as 9 for the accelerator pedal, 29 for the brake pedal and 49 for the clutch pedal.

The higher position of the pedal makes the drivers feel uncomfortable when resting their foot and it was represented as 11 for the accelerator pedal, 31 for the brake pedal and 51 for the clutch pedal. The higher position of the accelerator pedal was plotted in quadrant 3, the brake pedal in quadrant 2 and the clutch pedal in quadrant 3 based on the drivers' opinions. The lower pedal positions could improve the comfort and reduce the work load for the drivers. The lower position of the accelerator pedal was represented as 12 and plotted in quadrant 1 because it increases the performance in pedal usage. The lower position of the brake pedal was represented as 32 and plotted in quadrant 4 because it was considered a basic feature that needs to be fulfilled. The lower position of the clutch pedal was represented as 52 and plotted in quadrant 1 because it improves the performance of the product.

# 5. Measurement Technique for driving controls

The following part of the project involves finding equipment and tools to measure the force levels, as the driver perceives them, required to manipulate the driving controls. The main focus was given to finding tools which were easy to use for the ergonomics team. So, different measurement techniques were researched and presented to suit the requirements of the team.

The following lists of parameters were useful from the ergonomics perspective.

Steering Wheel: Required Force, Strokes, Torque, Number of laps to rotate the steering wheel
Gear Shift Lever: Required force and strokes to shift the gears.
Pedals: Required force and strokes to depress and release the pedal as it travels along the stroke.

## 5.1 Steering Wheel Control

The force and strokes required for using the steering wheel need to be measured in different road conditions to improve the usage of the steering wheel because the force levels differ when driving on a dry road or in snow and with a loaded or unloaded truck. To make driving more pleasurable and comfortable the force levels and number of strokes need to be measured and improved. The force levels and number of strokes required when using the steering wheel can be measured by the following measurement systems.

- Steering Effort Sensor
- Measuring Steering Wheel Adaptor
- Glove Pressure Sensor
- Pressure Mat
- Force Gauges
- Steering Robot

### 5.1.1 Steering Effort Sensor

The steering effort sensor is a telemetry system, which can be employed in trucks. It was designed to evaluate the steering torque. A small transducer that can calculate the dynamic values from standard steering wheel input was used between the steering column and steering wheel. A particular feature of the transducer is that it has the ability to feed all electrical signals from the steering wheel, so, the functionality can be adapted for airbag as well as non-airbag variants. The steering effort sensor can be easily mounted with a three point clamp assembly. The measurements from the steering effort sensor were reliable and accurate.

At Volvo's Hällered Proving Ground, the steering effort sensor was used to calculate the forces from the test vehicle in order to measure the steering input from the driver. The test vehicle was tested in different road patterns to analyse the steering behaviour. The vehicle was also tested while climbing a hill, both in normal and 5% gradient roads. The steering effort sensor can be used for ergonomic testing in measuring the steering wheel torque.

In Normal driving conditions on a straight road (unloaded truck)
Steering wheel torque: 5-10 Nm ((based on measurement test))

In sharp turns on a dry road (unloaded truck)
Steering wheel torque: 20-40 Nm (based on measurement test)

The steering effort sensor can measure:
Steering torque of around 250 Nm

Advantages:
- Easy to mount
- High Accuracy
- Minimum effects on the measurement
- A modular solution to measure forces from the steering wheel.
- Airbag compatible

Disadvantages:
- Takes time for installation.
- The steering effort sensor cannot be used for other controls.

Figure 21 Steering Effort Sensor

Figure 22 Measuring steering wheel adaptor

## 5.1.2 Measuring Steering Wheel Adaptor

The measuring steering wheel adaptor is also a telemetry system that offers continuous, non-contact torque data from a rotating steering sensor to a stationary receiver. The steering wheel adaptor system is a portable system that can be deployed both for air bag as well as non-airbag variants for measurement of steering torque and steering angle. The entire system is easy to mount and use. However, from an ergonomic perspective, the add-on steering wheel could affect the driver's natural behaviour and steering wheel usage which could affect the results.

In Normal driving conditions on a straight road (unloaded truck)
Steering wheel torque: 5-10 Nm ((based on measurement test))

In sharp turns on a dry road (unloaded truck)
Steering wheel torque: 20-40 Nm (based on measurement test)

The measurement steering adaptor can measure:
Steering torque measurements up to 600 Nm

Advantages:
- Easy installation of the equipment in the truck
- No drag from bearings or slip rings friction
- Measure steering torque and steering angle
- Digital telemetry to eliminate signal interference
- Airbag compatible models are available
- The measurement system is used within Volvo

Disadvantages:
- Expensive
- Takes time for installation
- Add-on steering wheel affects the natural steering behavior
- Cannot be used for other controls

### 5.1.3 Glove Pressure Sensor

The Glove Pressure Sensor is a multi-sensor pressure mapping system with the force acquisition system that consists of a Glove Mat and a Computer Interface. The sensors are deployed in the gloves with a customizable positioning feature and can be mounted in the double sided straps. The sensors in the gloves are covered with a Teflon coated lamination making them much more durable. The Pressure mapping system is ideally used for ergonomic applications including steering wheel analysis and vibrations. The standard configuration has around twenty-four sensors with an accuracy of ± 10%. The sensors are calibrated with the known load calibration jig. The advantage of the Glove Pressure Sensor is that it comes with a remote data logging facility which improves its usage. It can store 4000 scans in its memory when used with a 9-volt alkaline battery power during the Remote Mode. The Glove Pressure Sensor is ideal for measuring the grip forces on the steering wheel. The Glove Pressure Sensor could be an ideal solution from an ergonomic perspective for measuring the forces from the steering wheel. (Ergonomics -Glove Pressure Mapping System)

Figure 23 Glove Pressure Sensors

In Normal conditions
Pressure range in common usage less than 10 psi

Glove pressure sensor capable of measuring pressure up to 100 psi

Advantages:

- 20 or 24 sensor configuration allows for detailed measurement
- Available in 5 different Glove Sizes
- Sensor locations can be modified
- Computer interface can store the pressure data from up to 4000 scans
- Pressure range is limited to 0-100 psi

Disadvantages:

- Will measure the gripping force and not the torque from the steering wheel or gear shift lever
- Accuracy

### 5.1.4 Pressure Mats

Pressure mats are perfect pressure sensing materials for ergonomic analysis. They are three dimensional and stretchable and made with a Lycra (material). Arrays of sensors are arranged in the mats in order to sense pressure fluctuations. These sensors are extremely flexible and are available in standard and industrial mat sizes, based on customer requirements. The data acquisition system in the pressure mats captures the pressure fluctuation at various points in the mat and displays this information in a digital way. The scanning rates from the pressure mats are relatively quick. Pressure mats are widely use in research and in development of various products.

Figure 24 Pressure Mats

The smart fabric is elastic and flexible and has three elastic layers with air and vapour permeability. (Ergonomics - Pressure Mats)

In Normal conditions
Pressure range in common usage less than 10 psi.
Pressure mats can measure up to 4 psi.

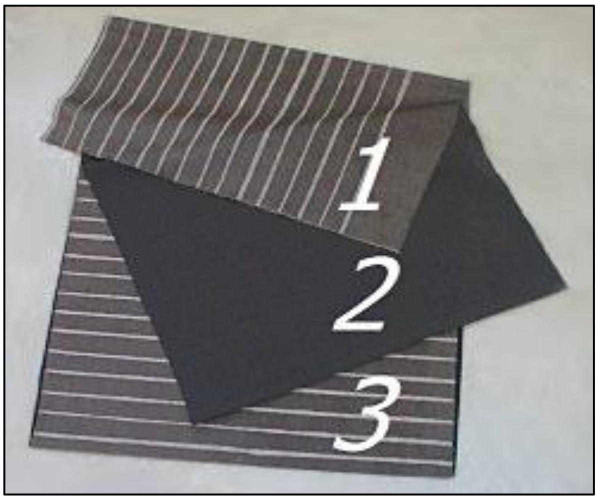



Figure 25 Pressure Mats

Advantages:

- Customized size
- 100% fabric which makes it flexible for different applications
- Pressure range 0-200 mmHg ~ 3.87 psi
- Cost effective

- Dense array of sensors as per requirements
- Minimum thickness
- Used for several applications
- Uniform pressure distribution
- Measure only the gripping force

Disadvantages:

- Does not measure the steering torque and steering angle

### 5.1.5 Force Gauges

Force gauges are used to measure the force levels in various applications. Force gauges are an economical solution for push and pull testing of up to 1500 Newton with an accuracy of ± 0.5%. The force gauges are compact, easy to hold and rugged in construction with an aluminium housing making the force gauges durable. The three push buttons allow the user to easily select the units of measurement, reset to zero and recall tensile and compressive peak loads. Force gauges are found in ergonomic toolkits as an essential testing solution. Force gauges are either operated by battery or AC power. The handles in force gauges have a good gripping feature with consistent results. The paddle attachments can be changed to flat, curved and square padded mounts to measure the forces in the musculoskeletal joints.

**Figure 26 Force gauges**

Advantages:

- Widely used force measurement tools
- Simple & rugged in construction
- Capacity to measure up to 1500 newton
- Safe operation
- No external power source
- Used within Volvo by the Ergonomic Division and the Vehicle Dynamics Testing Division

Disadvantages:

- Hard to measure forces such as the driver's perception of torque
- Cannot be used for other controls in an effective way, e.g. Gear shift lever
- Measurement error is higher than with sensors

## 5.1.6 Steering Robot

The steering robot is a special test and measuring system specifically made for the steering system. The system is designed to feed multiple inputs to be applied with high precision and accuracy to enable very high quality of precision data. The measured data were manipulated with an external data capture system with multi-channel hardware in the vehicle.

There are two variants in the steering robots system. The first configuration is called an Omni controller and the second configuration is called a mono controller. The Omni controller has been equipped to allow for multiple actuators so that it can be used for tests that require simultaneous control of steering, braking and accelerator. The mono controller is a low cost alternative to the Omni controller. The steering robot is equipped with a steering column torque sensor, gyroscopes, a transducer and GPS-motion packs with a steering wheel adaptor that needs to be mounted on the original steering wheel which can affect the natural driving behaviour.

The user interface system in the steering robot assists the user to define and run the test easily within a short period of time. The processing of the test data can be stored in the data library for future references. Some special tests, like roll stability, can also be performed with the steering robot for automotive certification and validation purposes.

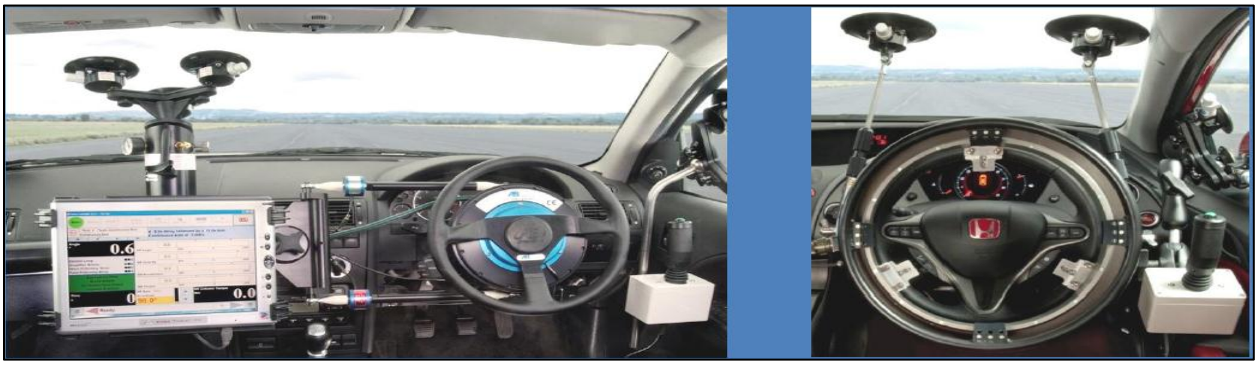


Figure 27 Steering robot

The main advantage of the steering robot is that the measurements are highly reliable. It is a proven technology adapted by almost 90% of the vehicle manufacturers. However, the limitation is that it is a relatively expensive hardware. (Steering Robot)

Advantages:

- Installation can be done in 30 minutes
- Reliable data
- High accuracy
- Widely used by automobile manufacturers

Disadvantages:

- Weight of the motor is heavy 15-19 Kg for trucks
- Expensive
- Cannot be used for other controls
- Does not measure the force levels as the drivers perceive them
- Not easy to use
- Add on steering wheel affect the results

## 5.2 Gear Shift Lever

The gear shift lever is used to shift the gears in the manual transmission truck. The forces and strokes of the gear shift lever need to be reduced for a comfortable driving experience. The following measurement system is used to measure the forces from the gear shift lever.

- Ricardo Gear Shift Quality Assessment
- Shift Knob Load Cell
- Hand Sensor Array

### 5.2.1 Ricardo Gear Shift Quality Assessment

Gear Shift Quality Assessment (GSQA) is equipment for measuring the gear shift quality in changing gears in passenger cars and trucks. The system consists of a hardware and software test system to capture the forces from the gear shift lever in manual transmission vehicles. The GSQA technique is an objective measurement technique developed by Ricardo in order to avoid the subjective measurement technique in shift quality assessment.

The gear shift lever characteristics are captured in terms of forces, position and time, then they are converted to perceived gear shift quality. Hence, the measurement technique provides precise and objective results of the gear shift quality instead of subjective results from different test drivers. The GSQA system is used to compare and benchmark the gear shift quality between different systems for further improvement.

The Gear Shift Quality Assessment is the best solution for engineers to measure the forces, strokes and position of the gear shift lever. (Bergström & Doverborn, 2009)
Under Normal conditions:
Gear shifting- the torque required to shift gears is around 100Nm
Gear Shift Quality assessment can measure torque up to 300 Nm

Advantages:

- Best solution for measuring the forces from the gear shift lever
- Most successful measurement technique among vehicle manufacturers
- Test can be carried out in 4 hours
- Highly accurate and reliable
- Gear Shift Quality Assessment system is used in the Volvo Powertrain Division

Disadvantages

- Expensive
- Takes time for installation
- Only employed in manual transmissions, not even with I-shift because the test lever is connected to the mechanical links in the gear box.

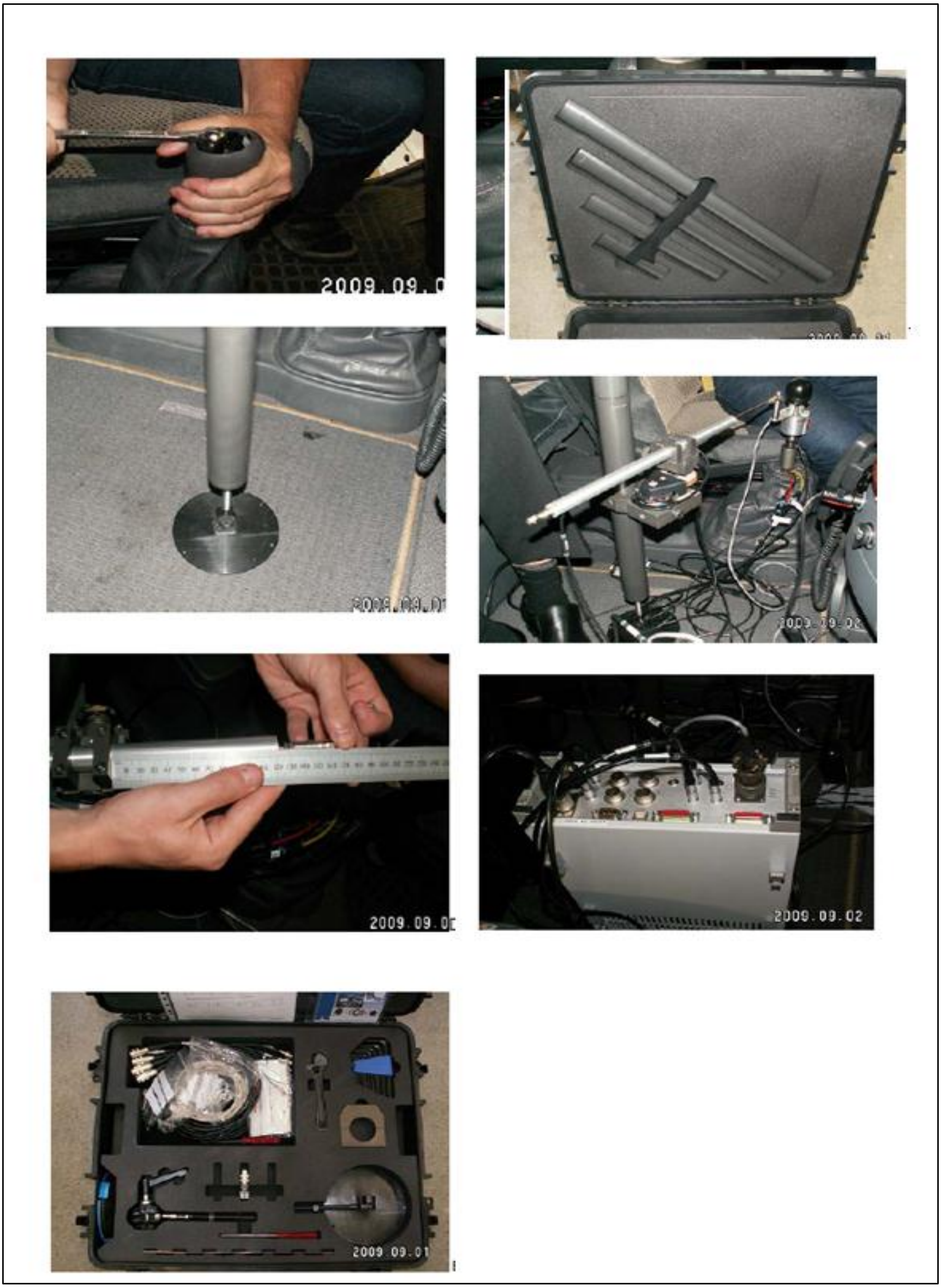



**Figure 28 Ricardo Gear Shift Quality Assessment (GSQA) installations**

## 5.2.2 Shift Knob Load Cell

The Shift Knob load sensor has a dummy gear shift knob that replaces the original gear shift knob. The dummy knob is mounted by a supporting shaft gripping adaptor. The gear shift load cell allows real time measurement of the X and Y component force level experienced by the drivers. The dynamic recording of the signals from the sensor is possible through the data acquisition system. The results can be recorded simultaneously to assist the engineers in improving the gear shift mechanisms. Shift knob load cell is used to improve the feel and feedback from the gear shift lever.

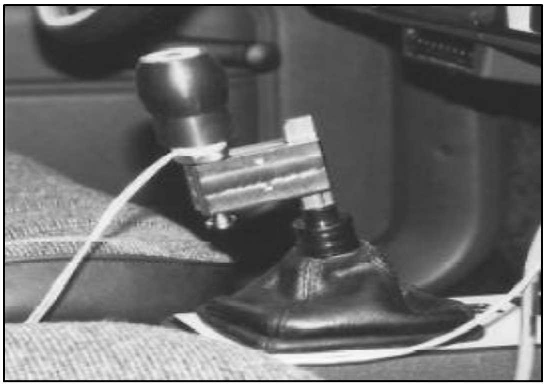


**Figure 29 Gear Shift knob load cell**

The gear shift knob load cell can handle a force capacity of up to 850N with an over-load capacity of 150% of the full scale capacity. The load cell is used at a temperature of around -53 to 120 degrees Celsius. Normally, it takes less than 100 Nm to shift gears in a truck.

The gear shift knob load cell can be used in the ergonomics division to improve the feel and feedback from the gear shift lever.

Advantages:

- Measure forces in the X and Y direction from the Gear Shift Lever
- Reliable measurement data
- Cheaper than the Ricardo gear shift quality assessment system
- The gear knob is an add-on to the original knob which affects the measurement data. However, the issue can be resolved by replacing the original knob with the test knob.

Disadvantages:

- Cannot be used for measuring forces from other controls
- Limited to manual transmission vehicles.

## 5.2.3 Hand Sensor Array

The Hand Sensor Array system is similar to pressure mats with an array of sensors in two different configurations, 8 x 8 arrays of 1 inch sensors and 24 x 24 arrays of 5/16 inch sensors, placed inside the flexible mat material. The Hand Sensor array can be used for numerous applications where you grab, grasp or apply a force to a tool or object or handle.

The Hand Sensor Array can measure the force that is exerted by each finger as an object is grasped. It is also used in seat as well as back pressure monitoring units in ergonomic seat analysis. The pressure mapping system from the hand sensor array will record the results showing each sensor's pressure data. The data gathered can be easily transferred to a spreadsheet to facilitate in depth statistical analysis. It can also be worked with the Lab view program. There is an option to use this as a telemetry system.

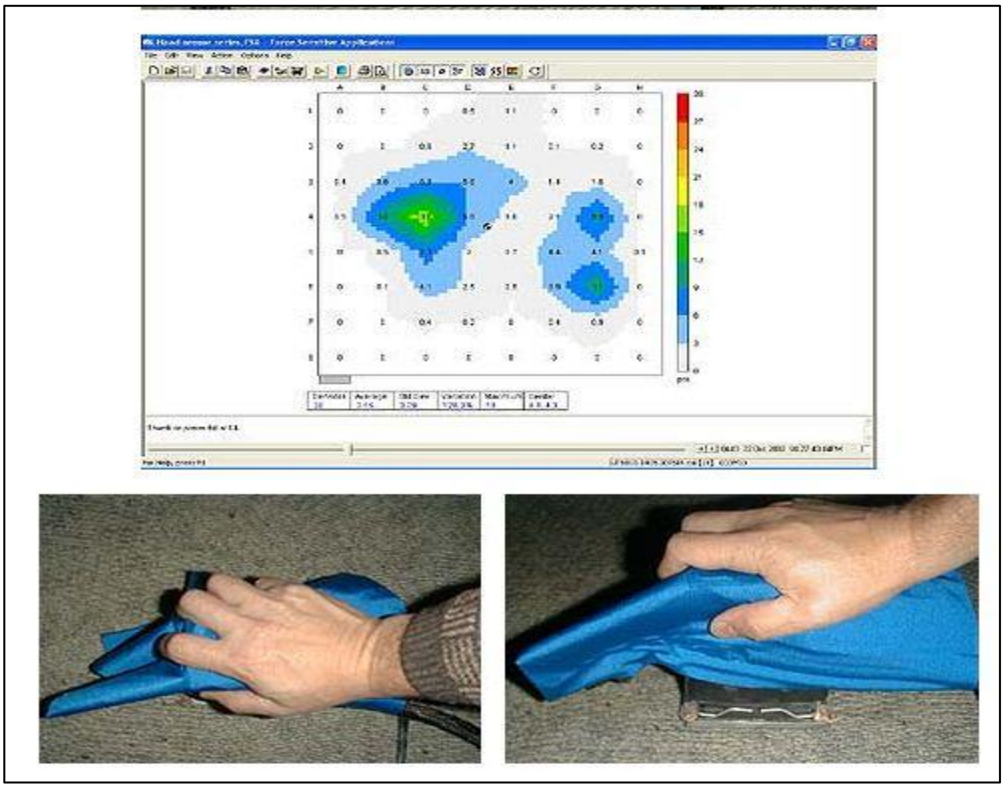


Figure 30 Hand sensor array

The picture above illustrates the pressure changes in the grid when holding the object.

**Advantages:**

- Grab/Pull/Grasp/apply force
- Available in 8x8 or 24x24 arrays of sensors with 1 inch or 5/16 inch sensors for effective calibration
- Color mapping system for each finger
- It can measure up to a pressure range of 0-30 psi

**Disadvantages:**

- Accuracy with a  10% variable
- Not all force aspects that the driver experiences are measured
- The mat itself may affect the results based on the method in which the person holds the gear shift lever.
- The Hand sensor array can be used to measure forces from the steering wheel and gear shift lever. It cannot used to measure forces from the pedals because it is designed to measure forces in grab/pull/grasp functions and the calibrated pressure range is not compatible with the pedal forces.

# 5.3 Pedals

The driver uses the pedals continuously during his driving missions both within the city limits as well as on motorways, so, the forces and strokes expended when using the pedals need to be reduced to improve comfort for the drivers. The following measurement equipment is used to measure the forces from the pedals.

- Accelerator Robot
- Brake Robot
- Pedal Force Sensor
- Pedal Force Load Cell

## 5.3.1 Accelerator & Brake Robots

The brake robot is a test and measurement system designed to apply inputs to a vehicle's brake pedal for braking characterization and handling behaviour measurement. The brake robots are employed to control the vehicle deceleration or brake pressure with the feedback controller.

The brake robot is available in two configurations, one with an on-seat configuration and another with under the seat configuration. The on-seat configuration is optimized to allow quick installation in a wide range of vehicles and it is easy to mount on the brake pedal. The under the seat configuration employs a structured arrangement with a rigid installation unit. Both these systems can be updated to driverless configurations.

The forces and strokes expended during pedal travel can be efficiently monitored and optimized with the accelerator and brake robots. The force measurement is in line with the drivers' foot input. For ergonomic analysis these robots can be effectively used to measure the forces dynamically under different road conditions and environment. There are several encoders available with the kit in order to measure the forces from brake pedals when used by customers who aggressively apply the brake pedals.


Figure 31 Brake Robot

The Accelerator robot can be installed in the truck to apply inputs to the gas pedal for vehicle speed, force and pedal travel stroke measurements. The input to the pedal is more frequently programmed to follow the driving cycle or any user profile. The accelerator robot can be used in combination with the brake robot in vehicle testing. The combination can also be upgraded to a driverless testing system.

The accelerator robot can be mounted in the driver's seat within a few minutes. There is also the possibility to mount the accelerator robot as a driverless system by mounting it under the seats. These accelerator and brake robots are highly accurate and reliable. The data acquisition software provided with the system can easily predict the results.

AR1 accelerator robot

AR1 as part of Driverless Test System (racing seat not shown)

**Figure 32 Accelerator Robot**

| | |
|---|---|
| Maximum continuous pedal force | approx. 150 N (70mm arm length)<br>approx. 110 N (95mm arm length) |
| Maximum throttle pedal travel | approx. 130mm (70mm arm length)<br>approx. 180mm (95mm arm length) |
| Maximum throttle pedal speed+ | approx. 300mm/s (95mm arm length) |

The parameters mentioned in the table above are limited to the accelerator pedal robot.

The Accelerator robot is a part of a driverless system. The maximum continuous pedal force is approximately 150 N with 70mm arm length and 110N with 95mm arm length. The maximum pedal travel will be approximately 130 mm for the 70 mm arm length and 180 mm for the 95 mm arm length versions of the robot. At 95 mm arm length the throttle pedal speed will be around 300mm/s
(AB Dynamics)

Normal force in using the pedals is around 100N
The Pedals robots can measure forces up to 150N

Advantages:

- Adjustable to enable easy installation in most vehicles
- Vehicle can be driven normally and safely with accelerator robot installed

- Can control pedal position or follow a speed profile
- Highly accurate and reliable data.
- Can be operated in autonomous and non-autonomous modes.

Disadvantages:
- Expensive
- Autonomous system affects the driver behaviour in pedal usage.
- Cannot be used for other controls
- Not easy to use

## 5.3.2 Brake Pedal Force Sensor

The pedal force sensor is used to measure the forces from the pedals. It can be mounted on the pedal through a clamp and fixture arrangement. Wire cables can also be used to tie the transducer to the pedal. The pedal force sensor consists of a transducer which converts the mechanical force into electrical signals. It can measure forces in the range from 110 to 1700 Newton.

The results of the force measurements can be interpreted using a standard digital display or with the bar graph predicting the force applied with respect to time or the brake pedal position. (Sensor Developments Inc)

Under normal conditions the pedal force is less than 200N
In adverse conditions it may reach 450N

The brake pedal force sensor can measure forces up to 1700N

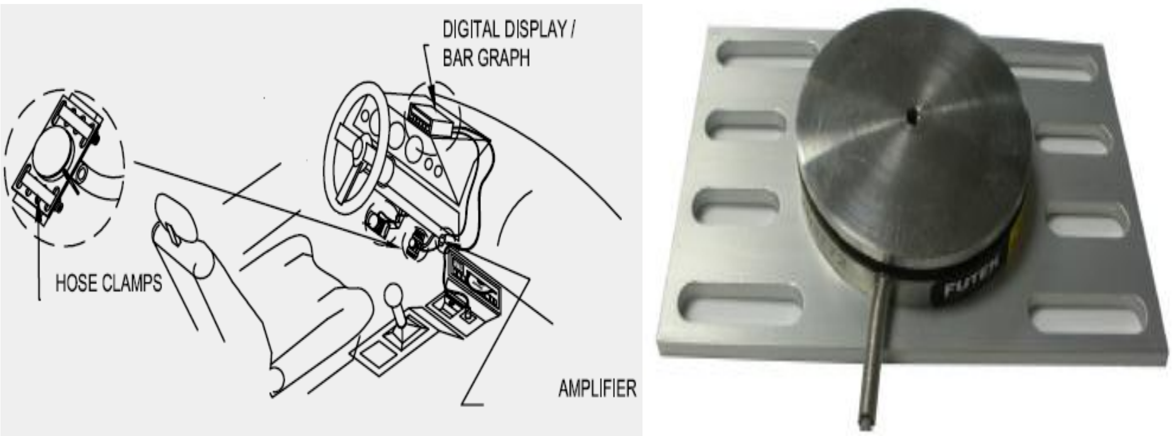



Figure 33 Brake pedal force sensor

Advantages:
- Strain Gauge based
- Lightweight
- Low profile height
- One piece construction

- Error less than 1%
- Ideal for automotive applications

Disadvantages:
- Add-on, the driver will not be in contact with the pedal which could affect the results
- Complex and time consuming installation
- Cannot be used to measure forces in other controls.

### 5.3.3 Pedal Load Cell


Figure 34 Pedal Load Cell

The pedal force load cell is used to measure the forces from the brake pedals. It can be mounted on the pedal through a clamp and fixture arrangement similar to the arrangement in the brake pedal force sensor. Wire cables can also be used to tie the load cell to the pedal. The pedal force load cell can measure forces in a range from 220 to 2200 Newton. (Interface Force Measurement, 2012)

Under Normal conditions the pedal force is less than 200 N
In adverse conditions it may reach 500 N

The brake pedal force sensor can measure forces up to 2200 N

Advantages:
- Lightweight
- Low hysteresis losses,  less than 0.05%
- Ideal for brake, clutch and gas pedals
- Mounts easily on the pedals using straps

Disadvantages:
- Add-on, the driver will not be in contact with the pedal which affects the results
- Higher thickness of the Load Cell affects the results
- Cannot be used to measure forces from other driving controls
- Complex and time consuming installation and calibration of the load cell.

## 5.4 Results from the Measurements

This section illustrates the results of the test to measure the forces from the driving controls.

### 5.4.1 Forces from the Steering Wheel using measurement steering wheel adaptor

The test to measure the steering torque and steering angle was carried out by myself at the Hällered Proving Grounds with the Vehicle Dynamics Testing Engineers in a Volvo FH Truck. The test mission consisted of three driving sessions. The measurement steering wheel adaptor unit was used to measure the steering wheel torque and steering wheel angle with respect to time during the driving sessions. The first two driving sessions were carried out on two straight roads at the testing ground. The last driving session was carried out by driving the truck through sharp 90 degree left and right hand turns in order to measure the steering torque and steering angle.

Driving Session: Test carried out on a straight road at the Hällered Proving Grounds

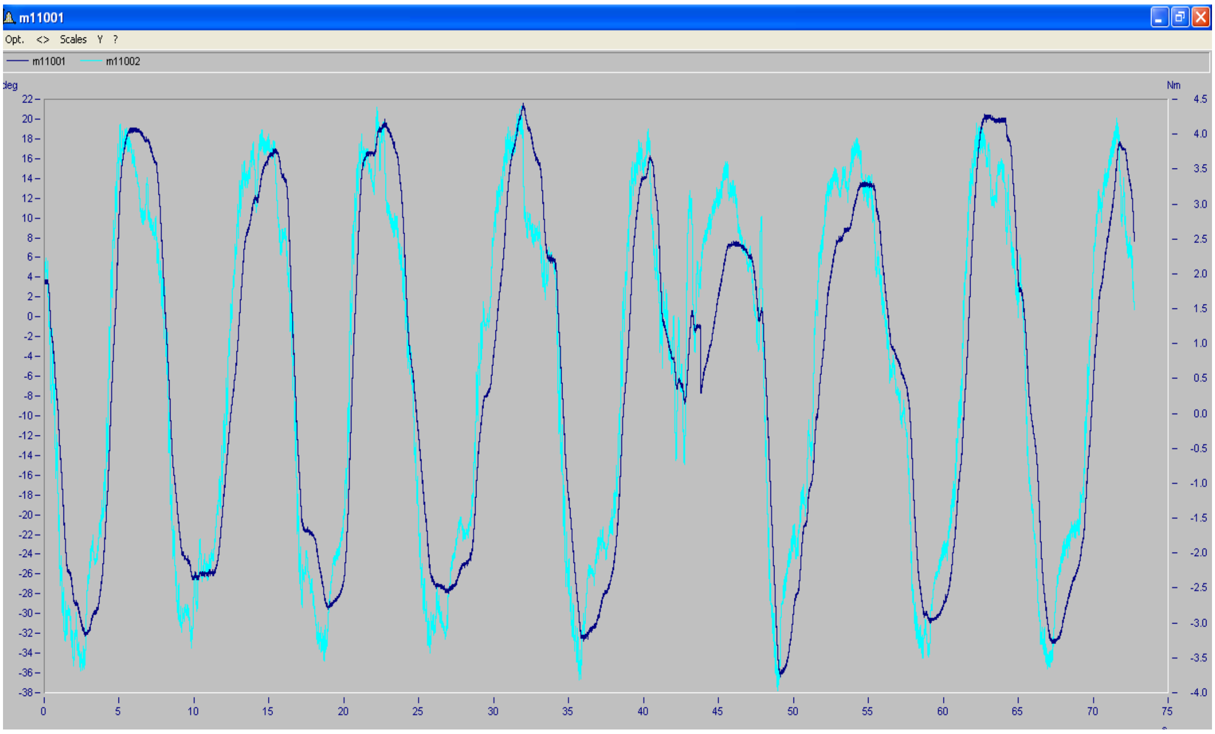



Figure 35 Steering angle & steering torque in Driving Session 1

The picture shown above (figure 26) illustrates the results of the first driving session on the straight road at the Hällered Testing Grounds. The x-axis represents the time in seconds, the y-axis scale on the left side represents the steering angle and the y-axis scale on the right side represents the steering torque. The values are plotted while driving on a straight road by steering the vehicle left and right for the given time period. During the driving session the torque reached a maximum of 4.5 Nm when turning left and 4 Nm when turning right.

Discussion

The driving sessions 1 and 2 illustrate that the measured steering torque was around 4 Nm. when the vehicle was moving on the straight road. The forces were completely dependent on the road conditions and road gradient. The forces may increase if the truck is climbing a straight hill in snow. The steering torque nearly doubled when the truck took sharp, 90 degree turns (see graph driving session 3) due to the force demands from the steering wheel, which are dependent upon the load in the truck and on the road conditions.

The measured steering torque provides the driver with feedback about the road conditions, reducing the forces to a minimum value could affect the feeling and feedback from the steering wheel. The measured steering torque does not include the gripping forces from the driver as the driver perceives them. So, this test data could be investigated further using the glove pressure sensor or pressure mats to measure the grip forces when using the steering wheel.

Conclusion:

The measurement steering adaptor could provide the steering torque and steering angle information for the ergonomics team, however, in order to measure the exact steering grip forces, the pressure mats or the glove pressure sensor should be used.

### 5.4.2 Forces from the Brake pedal using brake pedal load cell

The forces from the Brake pedal were measured by the Brake system team using the brake pedal load cell. As the driver depresses the pedal along the stroke to the maximum stroke length the force amounts to 450 N.

The trend shows the forces gradually increasing until 60 mm along stroke. After that, the forces increased drastically from 150N to 300N before the pedal reached a stroke length of 80 mm. The forces nearly doubled as the pedal moved along the stroke from 60 to 80 mm. When the pedal reached its maximum stroke length the forces amounted to 420N.

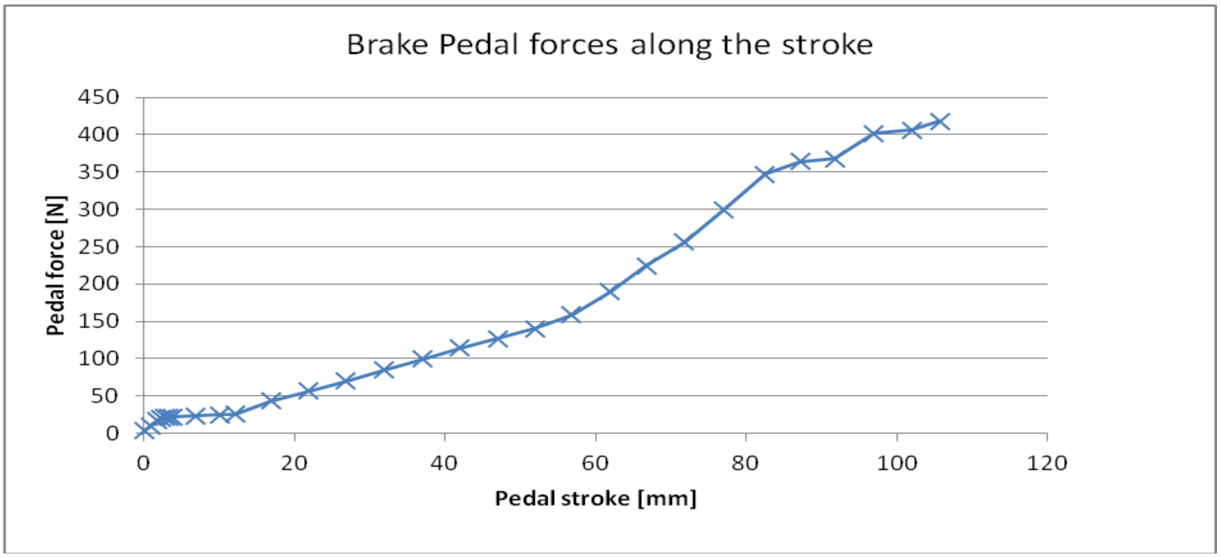



Figure 36 Brake pedal

**Discussion:**

Finally, the forces from the brake pedal amounted to 420N at the maximum pedal stroke. If we consider real time brake pedal usage, in the city or on the highway, maximum pedal stroke travel was not common. However, the forces being measured were high. This makes it difficult for the female drivers when using the brake pedal.

The measured brake pedal force could be used by the ergonomics team to analyse the forces from the brake pedal and compare the force level with competitors' trucks and make necessary modifications to improve the force level in future pedals.

**Conclusion:**

The brake pedal load cell provides the pedal force data as the pedal moves along the stroke; however, the results were not reliable from an ergonomics perspective because the load cell was a very thick piece of metal which obviously affected the results. At the same time, during the calibration the driver's foot/shoes do not have any contact with the pedal as the pedal moves along the stroke.

## 5.5 Evaluation of the measurement technique for ergonomics testing

Used with Volvo to measure the steering torque and steering angle

Ricardo GSQA system is being used to measure the forces, strokes and other attributes related to Gear shift lever

Brake pedal load cell is being used within Volvo to measure the brake pedal force as the pedal moves along the stroke

| S.No | Criteria | Steering Effort Sensor | Steering wheel Adaptor | Glove Pressure sensor | Pressure Mats | Force Gauges | Steering Robot | GSQA | Shift knob load cell | Hand sensor array | Accelerator Robot | Brake Robot | Pedal Force sensor | Pedal force Load Cell |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Supplier | SD | SD | NE | NE | Mark10 | ABD | Ricardo | SD | NE | ABD | ABD | SD | Futuk |
| 2 | Cost | | 12875 USD | 5700 USD | 2000 USD | | | | 2450 USD | 1875 USD | | | 2052 USD | |
| | **Steering Wheel:** | | | | | | | | | | | | | |
| 3 | Steering Forces | + | + | + | + | - | + | - | - | + | - | - | - | - |
| 4 | Steering Torque | + | + | + | + | - | + | - | - | + | - | - | - | - |
| | **Gear Shifter:** | | | | | | | | | | | | | |
| 5 | Shift Forces | - | - | + | + | - | - | + | + | + | - | - | - | - |
| 6 | Torque | - | - | + | + | - | - | + | + | + | - | - | - | - |
| | **Pedals:** | | | | | | | | | | | | | |
| 7 | Force | - | - | - | + | + | - | - | - | - | + | + | + | + |
| | Sum '+' | 2 | 2 | 4 | 5 | 1 | 2 | 2 | 2 | 4 | 1 | 1 | 1 | 1 |
| | Sum '-' | 3 | 3 | 1 | 0 | 4 | 3 | 3 | 3 | 1 | 4 | 4 | 4 | 4 |
| | Net Score | 2 | 2 | 4 | 5 | 1 | 2 | 2 | 2 | 4 | 1 | 1 | 1 | 1 |
| | Rank | 3 | 3 | 2 | 1 | 4 | 3 | 3 | 3 | 2 | 4 | 4 | 4 | 4 |
| | Continue | No | No | No | Yes | No | No | No | No | No | No | No | No | No |

Among different measurement techniques the pressure mats was being proposed because it can be used for multiple applications.

Pressure Mats are being selected through the selection Matrix

Figure 37 Pugh Matrix to select the best measurement technique

The evaluation of the measurement techniques was carried out by Pugh Matrix to select the best measurement technique to measure the forces from the driving controls. In the figure above criteria were established to define the most important technical parameters to be measured, from the ergonomics perspective, to improve the driving controls. The detailed table that provides information related to the cost and supplier are presented in the (APPENDIX – E)

In the steering wheel, the forces the driver perceived while driving were categorized into three types. The steering force, steering torque and the grip force when steering the vehicle. In the gear shifter, the forces the driver perceives while shifting gears were classified into shift force and shift torque to change the gears. Similarly, in the pedals the force for depressing the pedal and the force exerted at different points along the pedal stroke length need to be measured. These are the technical parameters of the driving controls that need to be measured by the ergonomics team.

The measurement systems that were investigated were listed and analysed for their capability to measure the necessary technical functions. If the measurement system can measure the technical parameters then it would be represented as 'positive' and if it does not have the capability to measure the technical function then it would be represented as 'negative'. The measurement systems were rated with positive and negative scores. Then the positive and negative scores are summed up together to find the net score. The net scores were counted and compared with other measurement systems. The ranking was made with the final scores.

In the figure, the measurement systems were rated based on their capability to measure the required technical parameters. As discussed earlier, a positive sign was used to represent the possibility to measure the forces from the technical parameters. And 'negative' sign was used to represent the measurement system's inability to measure the technical parameters. Most of the measurement systems can measure the technical parameters of either the steering wheel or gear shift lever. Among the investigated measurement systems the pressure mats have the capability to measure the forces from all the driving controls for ergonomics analysis and they were ranked '1' because of the possibility of using them in different applications as well as for being cost effective.

## Recommendation

The study of the measurement systems best suited for measuring the forces from driving controls illustrates that pressure mats were the most effective and reliable measurement technique for ergonomics testing and verification.

The pressure mats were available in customized sizes based on the applications. The sensors incorporated in the pressure mats can also be arranged as per customer requirements in order to measure the pressure in an effective way.

However, the pressure mats need to be purchased based on the customizable sizes with a density array for sensors to measure the pressure at critical points for each of the driving controls. The force can be calculated by multiplying the pressure with the area in which the pressure was assessed.

Force = pressure x area

# 6. Evaluation of Driving Controls for further Investigation

The evaluation stage of the pre-study phase of the driving controls was carried out with the Kesselring evaluation technique.

## Kesselring Matrix

### Background:

The Kesselring matrix was used to evaluate the driving controls based on the feedback from the drivers and feature leaders/specialists. The matrix consists of two main parts, the evaluation criteria and overall ratings from subjective evaluation. Each criterion in the matrix was assigned a weight factor which determined the importance of the criteria in the overall product performance. The ratings of the concept/product were taken by translating the opinion of the user/drivers concerning certain features of the product.

Finally, the weight factor of the criteria was multiplied with the overall ratings to get the weight factor rating (WV). The procedure needs to be repeated for other criteria. All the values were summed up to rank each concept. The concepts were compared with the final values of other concepts to select the best concept for further investigation or development.

$$WV = W \text{ (weighing factor)} * V \text{ (values)}$$

### Selection of Evaluation Criteria and Weight Factors:

The evaluation criteria were formulated based on the interviews with the drivers and feature specialists/leaders. The criteria were based on the ergonomics aspects and the usability factors of the driving controls.

In the questionnaire, each section had a question which required the participant to list the aspects that were important for the usage of driving control from their point of view. Among the 25 drivers interviewed around 15 drivers answer the question and their preferences regarding various aspects of the driving controls were shown.

| | | |
|---|---|---|
| Friction | Size | Friction |
| Vibrations | Laps | Robustness |
| Forces | Strokes | Material |
| Strokes | Friction Patterns | Clearance |
| Feeling | Position | Gripping Comfort |
| Shape | Easy to clean | |
| Adjustment | Sensitivity | |

In addition to the above criteria ergonomic aspects such as cognitive view and muscular skeletal parameters were added. Some criteria were refined into three main categories in order to adapt the evaluation criteria to the steering wheel, pedals and gear shift lever.

1. Design
   - ⇨ Size
   - ⇨ Shape
   - ⇨ Feeling or Feedback
   - ⇨ Sensitivity
   - ⇨ Friction
   - ⇨ Friction Material
   - ⇨ Comfort
   - ⇨ Cognitive Aspects
2. Mechanics
   - ⇨ Position
   - ⇨ Adjustment
   - ⇨ Robustness
   - ⇨ Forces
   - ⇨ Strokes
3. Muscular Impacts
   - ⇨ Musculoskeletal
   - ⇨ Causes cramped muscles

The total number of driver preferences, from an evaluation aspect, was included below (e.g.) forces were considered important by 20 drivers.

| | | | | | |
|---|---|---|---|---|---|
| Sensitivity | 4 | Size | 11 | Friction | 11 |
| Forces | 20 | Strokes | 10 | Robustness | 2 |
| Feeling | 17 | Position | 17 | | |
| Shape | 12 | Friction Material | 5 | | |
| Adjustment | 2 | Comfort | 3 | | |

So, the weight factors were assigned based on the total number of preferences. In some cases, comments during the driving session were also included. However, greater importance was given to the aspects in the table (driver preferences) above.

| **Design** | **55** | **Mechanics** | **40** |
|---|---|---|---|
| Size | 9 | Position | 12 |
| Shape | 11 | Forces | 15 |
| Feeling | 12 | Robustness | 3 |
| Sensitivity | 5 | Strokes | 10 |
| Friction | 10 | **Muscular Impacts** | **5** |
| Friction Material | 4 | Musculoskeletal | 3 |
| Comfort | 2 | Causes cramped muscles | 2 |
| Cognitive Aspects | 2 | | |

The table above shows the weight factor distributed for each of the criteria in the evaluation matrix.

The design category consists of parameters which account for 55% of the overall performance of the product. The design part was further subdivided into eight specific criterions, each aspect of the design: (1) size of the driving control contributes 9%, (2) shape contributes 11%, (3) feeling and feedback contributes 12%, (4) sensitivity 5%, (5) friction 10%, (6) friction material 4%, (7) comfort 2% and (8) cognitive aspects 2%.

The mechanical category consists of four criterion which account for 40% of product function. The criteria in the mechanical section focused on movement or adjustment of the driving controls. The position of the driving control contributes to 12%, forces for operating the driving control accounts to 15%, robustness 3% and strokes 10%. The forces, strokes and position were given much importance because of their significance towards the overall ergonomics of the driving control (see table above). The importance given to these factors was based on the comments from the drivers. High forces and longer strokes eventually reduce comfort while lower forces and shorter strokes increase comfort.

The last category focused on muscular impact which indicates the biological parameters as related to the usage of the driving control. The muscular impact section accounts to 5% of the product satisfaction. The muscular impact section was divided into two parts, musculoskeletal impacts 3% towards the overall driving control performance and cramped muscles factor 2%. These two criteria were significant in driving control usage. The evaluation criteria being discussed were interlinked with each other.

Each section and criterion have significant impact on the overall satisfaction of the usage of the driving control.

## Evaluation Process:

The weight factors were assigned through comparison, surveys and interviews with the drivers and engineers. E.g. position ratings were taken from the average sum of the ratings given by the drivers in the interview session for the position of the steering wheel. The ratings for more detailed aspects, like muscular impact, were assigned through the comments because these details were not included in the questionnaire. The information about the comments and rating can be found in APPENDIX - C and APPENDIX - D.

The detailed summary of the overall ratings of the driving controls can be found in APPENDIX - F

A weighted score was estimated by multiplying the weight factor and ratings. The final score of each control is the sum of the weight factor ratings (WV) score. This was used to compare the different concepts against each other.

$$WV = w \text{ (weighing factor) } * v \text{ (values)}$$

The evaluations of the driving controls were represented by numerical scores that give the possibility to compare the concept scores with each other. In the Kesselring matrix the steering wheel and gear shift lever had the most number of points which emphasises that the drivers were satisfied with the steering wheel and gear shift lever in comparison to the pedals. The controls were rated against the steering wheel and they were ranked. The evaluation results show that the pedals have the lowest rating which shows that pedals needs to be investigated for further improvements more than the steering wheel and gear shift lever.

## Conclusion:

Through the Kesselring matrix evaluation it was confirmed that the pedals need to be improved more than the steering wheel and gear shift lever. The result was also motivated by the Ergonomics Team.

Higher ranking indicates higher satisfaction among the drivers

| Kesselring Matrix | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S.No | Evaluation Criteria's | Weight Factor (W) | Steering Wheel | | Pedals | | | | | | Gear Shifter Lever | |
| | | | Steering Wheel | | Accelerator Pedal | | Brake Pedal | | Clutch Pedal | | Gear Shifter Lever | |
| | | | V | WV | V | WV | V | WV | V | WV | V | WV |
| | **Design** | **55** | | | | | | | | | | |
| 1 | Size | 9 | 6.82 | 61.38 | 7.7 | 69.3 | 7.54 | 67.86 | 6 | 54 | 6.7 | 60.3 |
| 2 | Shape | 11 | 6.82 | 75.02 | 7.7 | 84.7 | 7.54 | 82.94 | 6 | 66 | 6.7 | 73.7 |
| 3 | Feeling | 12 | 6.82 | 81.84 | 7.28 | 87.36 | 7.76 | 93.12 | 6.92 | 83.04 | 6.8 | 81.6 |
| 4 | Senstivity | 5 | 6.7 | 33.5 | 6.34 | 31.7 | 6.58 | 32.9 | 6.76 | 33.8 | 6.92 | 34.6 |
| 5 | Friction | 10 | 5 | 50 | 7.7 | 77 | 7.54 | 75.4 | 6 | 60 | 9 | 90 |
| 6 | Friction Material | 4 | 6.82 | 27.28 | 5 | 20 | 5 | 20 | 5 | 20 | 8 | 32 |
| 7 | Comfort | 2 | 6.46 | 12.92 | 6.94 | 13.88 | 5.66 | 11.32 | 6 | 12 | 6.52 | 13.04 |
| 8 | Cognitive Aspects | 2 | 7 | 14 | 6 | 12 | 6 | 12 | 6 | 12 | 9 | 18 |
| | **Mechanics** | **40** | | | | | | | | | | |
| 9 | Position | 12 | 8 | 96 | 7.2 | 86.4 | 6.86 | 82.32 | 5.56 | 66.72 | 6.46 | 77.52 |
| 10 | Robustness | 3 | 8 | 24 | 4 | 12 | 4 | 12 | 5 | 15 | 9 | 27 |
| 11 | Forces | 15 | 6.88 | 103.2 | 6.88 | 103.2 | 7.88 | 118.2 | 5.86 | 87.9 | 6 | 90 |
| 12 | Strokes | 10 | 7.64 | 76.4 | 7.52 | 75.2 | 7.22 | 72.2 | 7 | 70 | 6.66 | 66.6 |
| | **Muscular Impacts** | **5** | | | | | | | | | | |
| 13 | Musculoskeletal | 3 | 7 | 21 | 3 | 9 | 2 | 6 | 2 | 6 | 6 | 18 |
| 14 | Causes cramped muscles | 2 | 8 | 16 | 3 | 6 | 2 | 4 | 2 | 4 | 5 | 10 |
| Tot Wv: 100 | | **100** | | 692.54 | | 687.74 | | 690.26 | | 590.46 | | 692.36 |
| Tot Wv/Tot Wvmax | | | | 1 | | 0.993069 | | 0.996707771 | | 0.8526 | | 0.999740087 |
| Ranking | | | | 1 | | 3 | | 4 | | 5 | | 2 |

Steering Wheel

Pedals

Gear Shift Lever

Figure 38 Kesselring to evaluate the driving controls

# 7. Pedals

The pedal is a lever that is operated by foot and it is a vital part that acts as an interface between humans and vehicle. The pedal is employed for different operations like clutch operation, braking and acceleration in cars and trucks. The input is given to the pedal by the driver to perform the desired operation.

## 7.1 Type of Pedals

### 7.1.1 Suspended Pedals

The suspended pedals are also called hanging pedals. The pedal is suspended in the cab in such a way that its pedal bracket is fixed with the mechanism behind the dashboard and the pedal arm with the plate will be hanging in the air. Nowadays, most of the European trucks have suspended pedals. The truck manufacturers prefer suspended pedals because they are compact and cost effective.

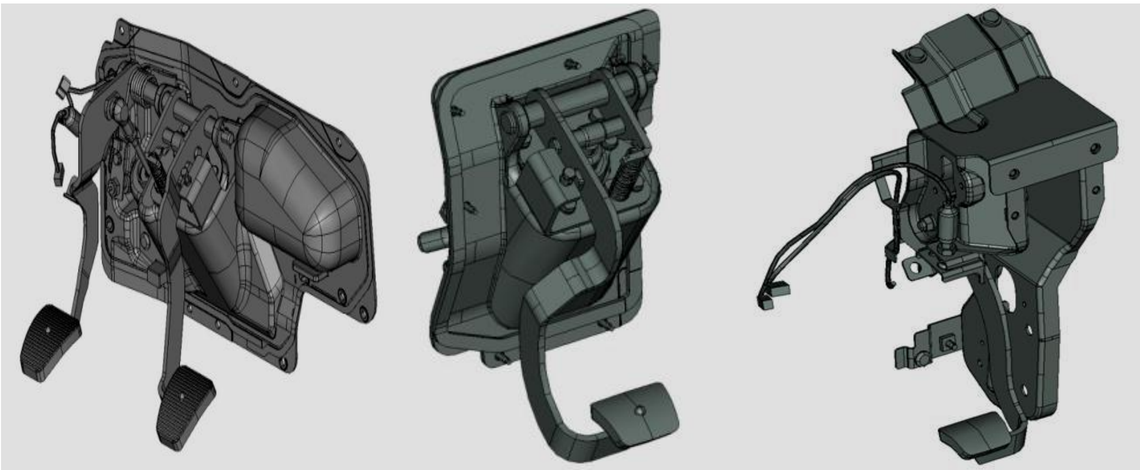


Figure 39 Suspended Pedals

### 7.1.2 Floor Mounted Pedals

The floor mounted pedals are mounted in the floor of the cabin. The subsystems supporting the pedals are accommodated below the floor. This method is widely used in buses and in Japanese trucks. There are several designs for the floor mounted pedals based on the cab size.

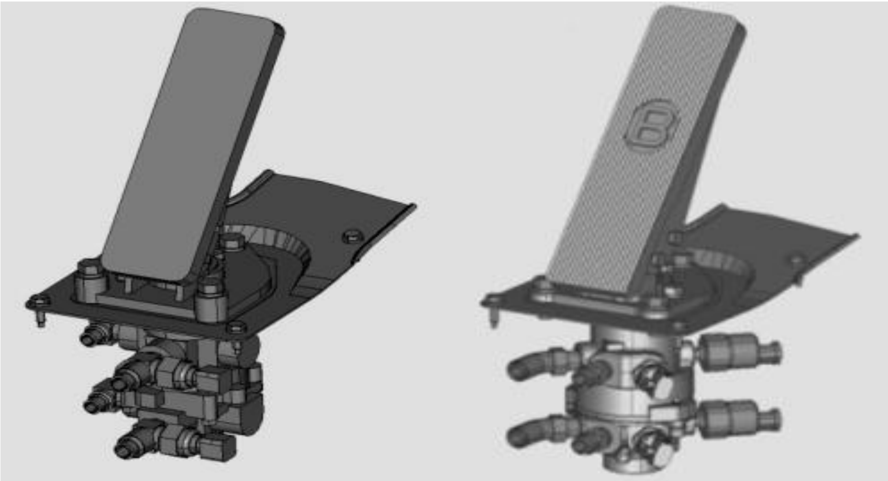


Figure 40 Floor Mounted Pedals

### 7.1.3 Combination of Floor Mounted and Suspended Pedals:

The combination method has the advantages of both the suspended and floor mounted pedals for increasing driver comfort in the vehicle. The combination pedal layout will be distinct from other configurations so that the driver can easily recognize the difference between the accelerator pedal and brake pedal.

Figure 41 combination of floor mounted and suspended pedals

### 7.1.4 Areas of Application

- Accelerator Pedal: The accelerator pedal is also known as the throttle or gas pedal. The accelerator pedal is used to control the fuel and air that is supplied to the engine to propel the vehicle. It is operated by the right foot and equipped with the fail safe design with the return spring that will automatically return to default position when it is not pressed. It is mounted close to the cab floor and engine tunnel bay/fire wall to facilitate the driver to rest his foot comfortably.

- Brake Pedal: The brake pedal is operated by the right foot and mounted close to the accelerator pedal or between the accelerator pedal and steering column / clutch pedal. It controls the vehicle speed through the braking system.

- Clutch Pedal: The clutch pedal is operated by the left foot and mounted on the left side of the leg room. It is employed to change gears in a smooth manner. Nowadays, because of automatic transmission or automated mechanical transmission, the use of the clutch pedal has been gradually reduced. In Volvo Trucks the clutch pedal has been eliminated in I-Shift transmission trucks.

# 7.2 Pedal Aspects

This chapter includes various aspects related to pedals and its usage.

## 7.2.1 Pedal Size

The pedal size is comprised of dimensions such as the length, width and thickness of the pedal. The pedal size is an important factor in establishing surface contact between the foot and the pedal.

Pedal size requirements differ based on shoe size or the size of the bare foot. It was recommended that the accelerator be at least 25 mm thick and that brake pedal be 75 mm wide. However, the length of the pedal should vary based on the shoe size. When operated with a regular shoe the length should be minimum 13 mm and maximum 65 mm. When operated with heavy boots the length should be minimum 25 mm and maximum 65 mm for enough surface area contact between the shoe and the pedal. When operated by ankle flexion in floor mounted pedals the length should be minimum 25 mm and maximum 65 mm. When the pedal is depressed by whole leg movement the length should be minimum 25 mm and maximum 180 mm. If the foot does not rest on the pedal the length should be minimum 18 mm and maximum 90mm.

Based on these recommendations, the pedal dimensions for the truck should be at least 25mm in height, 75mm in width and 65 mm in length giving the driver the advantage of being able to use the pedal with different shoe sizes.

**Dimensions of a pedal for continuous Adjustments (e.g. Accelerator or Brake)**

| | | | D, Displacement (mm) | | | | R, Resistance (N) | | | | Edge to Edge separation, S | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Height or Depth (mm) | Width (mm) | Operation with regular shoe | Operation with heavy boot | Operation by ankle flexion | Operation by whole leg movement | Foot does not rest on pedal | Foot rests on pedal | Operation by ankle flexion | Operation by whole leg movement | Random operation by one foot | Sequential operation by one foot |
| Minimum | 25 | 75 | 13 | 25 | 25 | 25 | 18 | 45 | - | 45 | 100 | 50 |
| Maximum | - | - | 65 | 65 | 65 | 180 | 90 | 90 | 45 | 800 | 150 | 100 |

Source: Ergonomics How to design for ease and efficiency – Karl Kroemer, Henrike Kroemer, Katrin Kroemer –Elbert (Page No 466)

Figure 42 Pedal Dimensions based on the type of shoe

## 7.2.2 Pedal Curvature

The curvature of the pedal can also be referred to as the shape of the pedal. A few decades back the pedals in the model T-Ford were flat and they were made of wood. Today the pedals in the truck and the passenger car are ergonomically designed to provide comfort for the driver while driving in different road conditions.

During the pedal operation, the curvature of the pedal plays an important role in establishing contact between the shoe/foot and the pedal. Flat pedals have larger surface area contact in the default position with a reduction to minimum contact as it moves along the stroke. Whereas pedals with good curvature will have minimum surface area contact which remains constant as the pedal moves along the stroke. However, optimal curvature of the pedal is dependent on how the driver operates the pedal, whether wearing a shoe or barefooted.

The curvature and position of the pedal along with the foot heel position during pedal operation are related to one another. If one of them is positioned higher or lower it could affect the comfort of the pedal operation as a whole.

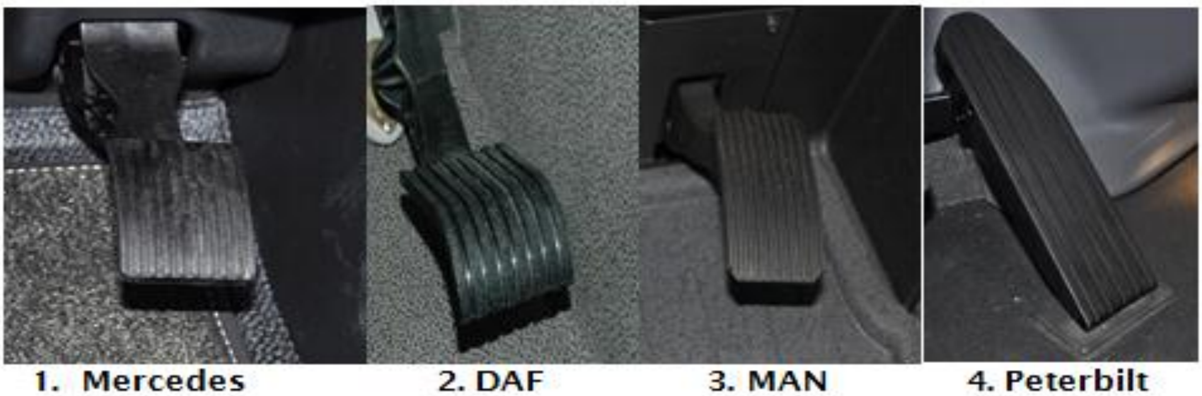



Figure 43 Pedal curvature

### 7.2.3 Movement between the pedals

The movement between the pedals is vital in pedal usage. The pedal usage differs for different applications. Long haul truck drivers use the pedals mostly within city limits. While travelling on highways they use the cruise control system. The long haul drivers usually activate the cruise control system on motor ways with specific speed limits.

Distribution truck drivers drive the truck within the city limits with frequent "starts and stops" during their missions in busy city traffic so there is frequent foot travel between the pedals.

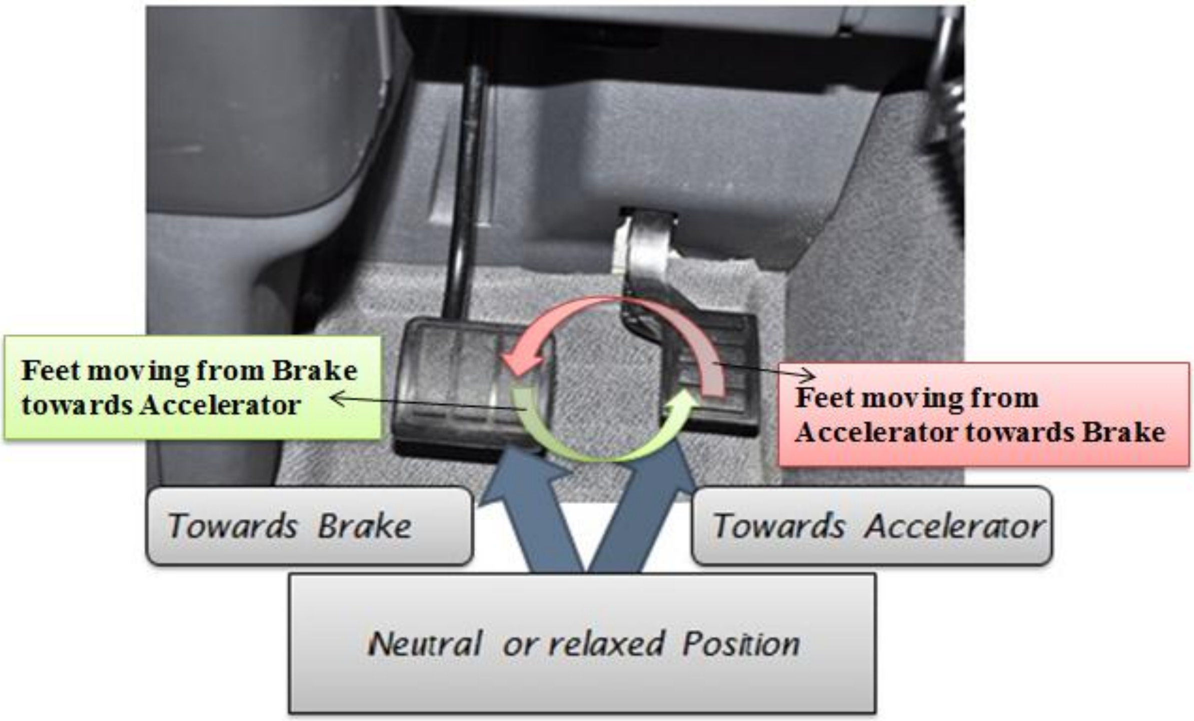



Figure 44 Movements between the Pedals

The foot movement between the pedals will be in one of the following movements

1. Neutral
2. Move Towards Accelerator
3. Move Towards Brake
4. Accelerator Engaged
5. Brake Engaged
6. Release Accelerator
7. Release Brake

The approach towards foot movement in pedal usage can be seen in the picture above. While driving, the driver moves his feet based on the above mentioned movements.

In the neutral position the driver rests his feet on the floor. There is no contact between the shoe/feet and the pedals. The neutral position is usually found before and after pedal usage.

However, it is also observed for a short interval while driving and when the adaptive cruise control mode is activated.

Figure 45 Neutral Position with shoes

Figure 46 Neutral Position with barefoot

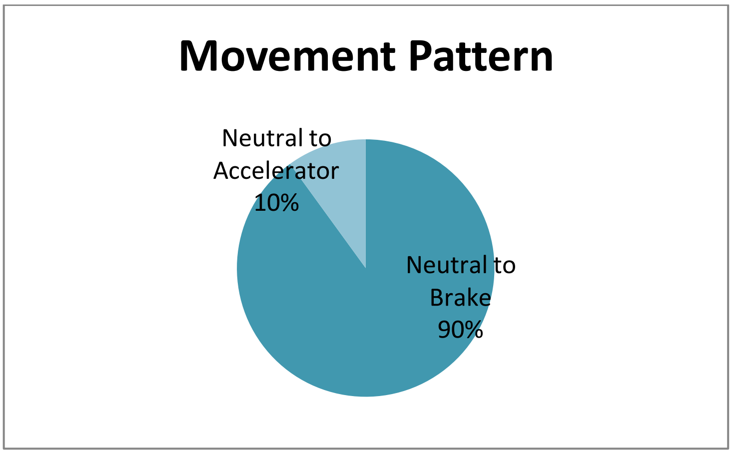



Figure 47 Movement Pattern

The figure above illustrates that nearly 90% of the drivers move from the neutral position towards the brake when accelerating the truck in dense traffic situation and 10% of the drivers use the accelerator directly for accelerating the vehicle. The data was based on the pedal usage observation studies.

The drivers move their foot from accelerator to brake when driving the truck in fly-overs within the city. The feet movement from accelerator to brake and brake to accelerator was observed in driving the truck in harbor or loading and unloading terminals.

### 7.2.4 Fitts Law

The study of the relationship between average amounts of time taken to perform an operation between two test parameters. The test parameters are the target width and target separation.

$$MT = a + b \left[\log_2\left[\frac{2A}{W}\right]\right]$$

MT - Movement time
A & b - Constants
$\left[\log_2\left[\frac{2A}{W}\right]\right]$ - Index of difficulty

An implication of the Fitts law is called Speed Accuracy Trade-off. It suggests that since the rate of information processing is constant in the driver's mind, movement patterns between the pedals can be characterized by two cases, either with high speed or with high accuracy; however both are not possible.

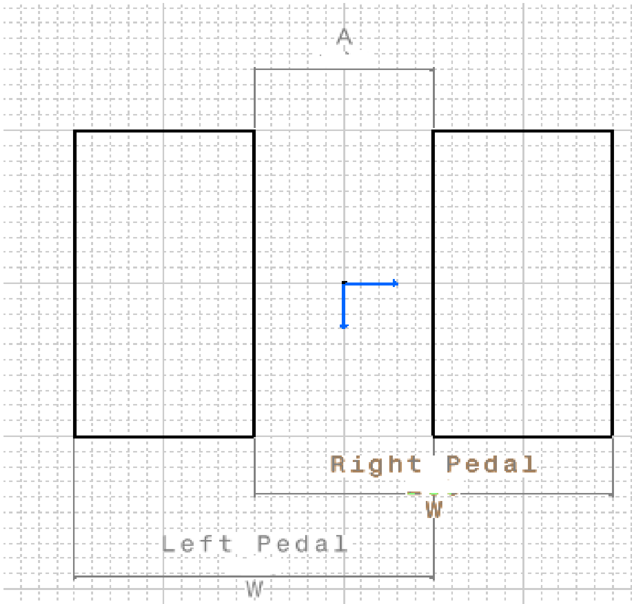
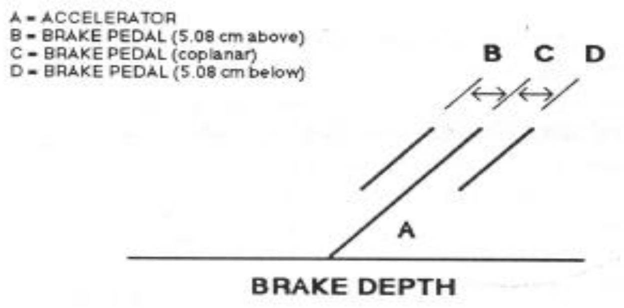


Figure 48 Distance between pedals

The expression $\log_2$ (N), where N is the number of equally like stimulus-response alternatives, is a measure of the information to resolve the uncertainty in N alternatives. The component $\log_2$ (N) is found in many information based theories such as Hick's law.

So, the term $\log_2$ (2A/W) was considered to be associated with the nervous system being a processor of information. The movements between the feet on the pedals were made complex by adjusting the distance between the pedals or by adjusting the pedal plane. As a result of this action the amount of information that has to be processed will be increased. Since the amount of information that can be processed per unit time is fixed, the need to complete all the necessary processing leads to longer movement times.

Over the years many investigations were carried out regarding the generality and the applicability of Fitts' Law. It was found to work well in an impressive range of applications from children to adults to disabled individuals, for movements in air and space, and for movements so small as to require a magnifying glass to view.



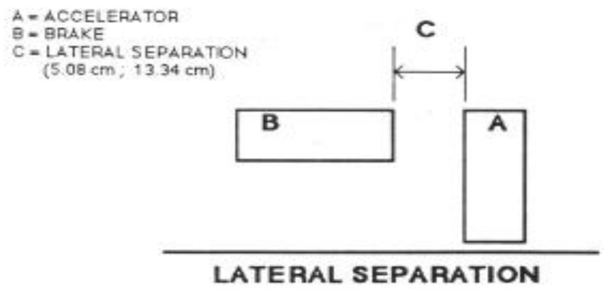




**Figure 49 Pedal position optimization between the accelerator and brake pedals**

An optimization study based on the movement time on the brake pedal location was carried out in 1986. The purpose of the study was to reduce the travel time between the pedals thereby increasing efficiency.

In the picture above three brake pedal depth and separation configurations were taken between the accelerator pedal and brake pedal. They were tested with different drivers in order to figure out the best possible design for reducing the movement time between the pedals.

The reduced lateral separation distance between the brake and accelerator pedals eventually reduces the movement time. However, the effect was not statistically significant. In another case, the brake pedal depth was also reduced to the accelerator pedal depth which produced results which were statistically significant in reducing the movement time for male and female drivers.

| Brake Depth | Lateral Separation Brake /Accelerator | Gender | Mean Travel Time (s) | Standard Deviation |
|---|---|---|---|---|
| **Above** | Near | Male | 0.171 | 0.036 |
| | | Female | 0.260 | 0.016 |
| | Far | Male | 0.190 | 0.036 |
| | | Female | 0.254 | 0.074 |
| **Co Planar** | Near | Male | 0.153 | 0.034 |
| | | Female | 0.188 | 0.049 |
| | Far | Male | 0.157 | 0.047 |
| | | Female | 0.190 | 0.047 |
| **Below** | Near | Male | 0.155 | 0.051 |

| | | | |
|---|---|---|---|
| | Female | 0.151 | 0.050 |
| Far | Male | 0.144 | 0.034 |
| | Female | 0.153 | 0.020 |
| | | | |

However, some human factors studies showed that the movement time between the pedals was dangerous in the co-planar arrangement due to the higher possibility of pedal misapplication errors. In order to avoid the pedal misapplications, the brake pedal needs to be mounted higher than the accelerator pedal.

### 7.2.5 Friction

Friction material is laid over the pedal plate to provide sufficient grip for the driver's shoe or bare foot. Rubber is the preferred material among drivers because optimal friction can be achieved with rubber in comparison to plastic. The drivers felt the pedals with plastic friction material to be slippery, which may lead to pedal misapplication such as slipping off to the floor or depressing the pedal unintentionally.

The friction patterns were designed similar to the thread patterns in tires. The patterns were standard within the automotive industry with lines in the x-direction or the y-direction or with a combination of x-y direction lines, and in some cases with rubber dots.

The following friction patterns were taken from pedals in trucks and passenger cars.

1. Volvo Accelerator Pedal 2. MAN 3. Flight liner 4. Ken worth
5. BMW Brake Pedal 6. Go Kart 7. Audi Brake Pedal

**Figure 50 Pedal friction Patterns**

### 7.2.6 Reachability

The reachability factor is defined as the relationship between seat adjustment position and pedal position. Nowadays, all trucks have adjustable seats unlike 30 years back where they had fixed, wooden seats. The reachability factor will be different for each driver based on their anthropometric data and comfortable seat positioning. Due to technological advancements customizable workspaces were proposed by researchers within ergonomics. The reachability could be improved by implementing the adjustable seat position with adjustable pedals which eventually improves the overall comfort for drivers with different anthropometric sizes.

### 7.2.7 Strokes and Sensitivity

The stroke length of the accelerator pedal and sensitivity of the accelerator pedal were related to each other. In Volvo trucks, the accelerator pedal works on a "Shift by Wire" concept and the brake pedal works by a mechanical arrangement of mechanisms between the pneumatic cylinders and pedal box.

Stroke length is inversely proportional to sensitivity.

The stroke length can be reduced by increasing the sensitivity or sensitivity can be reduced by increasing the stroke length. So, both stroke length and sensitivity are vital in pedal usage. Through the shift by wire method the forces were reduced and sensitivity was increased. The sensitivity of the accelerator pedal can easily be fined tuned.

In the brake pedal, the sensitivity cannot be fine-tuned in the pedal. The stroke length or the sensitivity can be tuned only in the hose or the cylinder in the pneumatic system. A shorter stroke length with increased sensitivity would be beneficial from an ergonomic perspective because it would reduce the work load for the drivers in the long run.

# 8. EuroFOT –European Field Operative Test

## 8.1 Background

EuroFOT is a European Union funded research project which relates to its seventh frame work programme on the "European Road Safety Action Programme 2011-2020" to reduce accidents and fatalities on European roads.

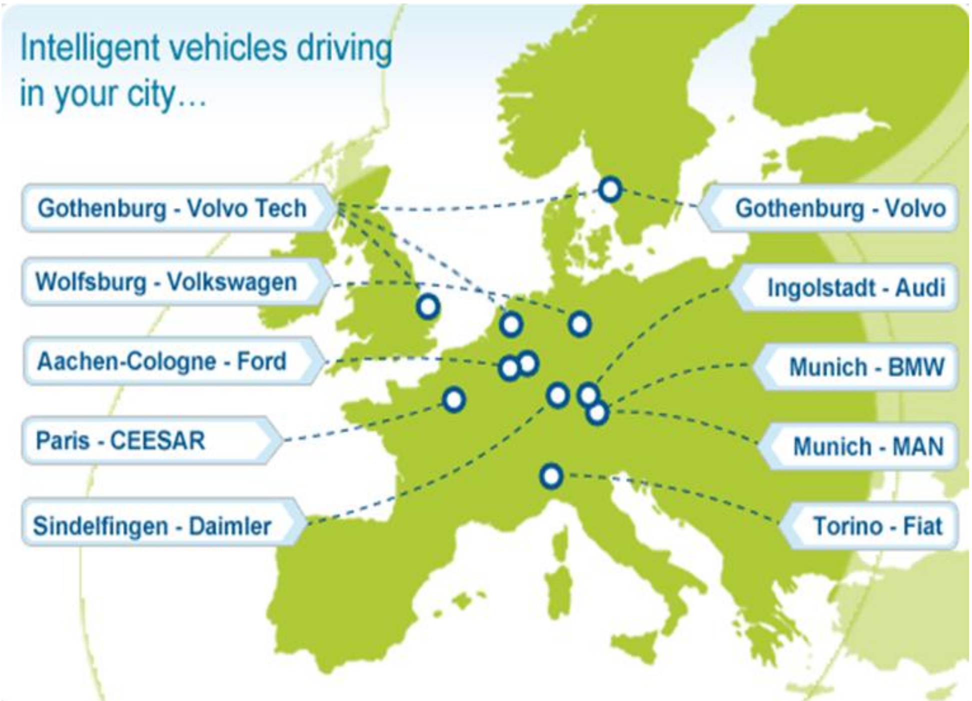



Figure 51 EuroFOT Project Partners

The EuroFOT project encourages top vehicle manufacturers like Volvo to get engaged in the project to improve the safety of the vehicles and make them smarter and fuel efficient. The EuroFOT project of the Volvo group has been carried out at Volvo Technology. The field operative test involves around 50 Volvo FH trucks equipped with advanced driver assistance systems and cameras to monitor driver behavior and the usage of controls in a natural environment on European roads. The EuroFOT data has been shared by the vehicle manufacturers as well as by the transport department of the governments and accounts for around 70 terabytes of data obtained from 1000 drivers across Europe. The Volvo FH trucks were mostly driven on roads in the United Kingdom and the Netherlands.

During the project, the EuroFOT data was used to analyze how the driver responds to different incidents to gain knowledge of traffic safety and human behavior in using the pedals. The trucks were used on highways, motorways, city roads and in rural traffic in normal weather conditions as well as in rain and snow. This explicit data gives us a range of information about the usage of controls by the drivers. The footage and videos were confidential and shared only with the EuroFOT project members.

# 8.2 Process

The EuroFOT material is a huge collection of data. It was impossible to go through all the trip videos. So, the videos were filtered through a set of parameters to reduce the video material.

The input was given as criteria in the form of commands in the MySQL workbench. The command list and dialogue windows can be found in (APPENDIX-I). Based on the input, software will search for events and Trip_id based on the information in the MySQL database which is connected to EuroFOT trip files. Once the system recognizes the events it will list the events based on the trip and driver id. The data can be saved in a excel sheet which can be accessed through mat-lab through a special FOTware tool to view the videos for analyzing the usage of driving controls.

**EuroFOT Data working Methodology**

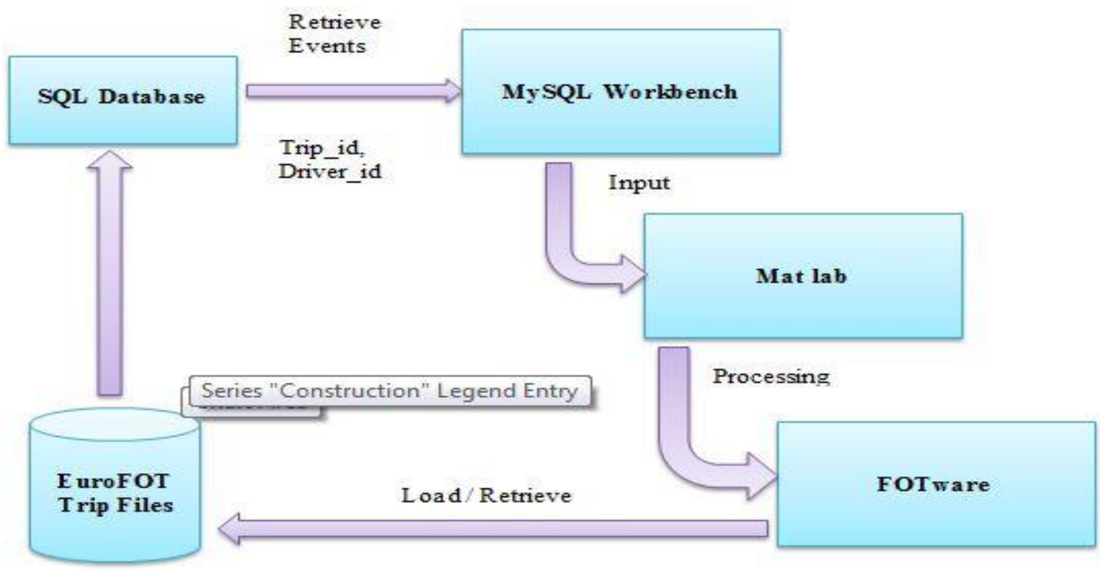



Figure 52 EuroFOT Data Working Process

The videos can be viewed in four windows with four different views (figure 50)
1) Road conditions
2) Driver using the steering wheel
3) Pedal usage
4) Rear view of the vehicle

Figure 53 EuroFOT Video Camera views

## 8.3 Investigation

During the investigation of the usage of the driving controls the video material of 13 drivers were analysed for two days. The analysis was based on type of road, foot positioning, foot movement between the pedals, and driver foot behaviour in different traffic situations. The drivers were using the Volvo FH long-haul truck in cities and on rural roads and motorways. The investigation also involves comparing driver pedal usage between city driving and highway driving with and without shoes, i.e. barefoot with socks.

Since the main objective of the EuroFOT material is to analyse the pedal usage the videos were selected from driving trips with accelerator cruise control in OFF mode and speeds of more than 70 Kmph for highway driving and less than 70 Kmph for city driving. The detailed command list can be found in APPENDIX-I. The parameters for highway driving and city driving were differentiated in the investigation through the following parameters in the command list from the EuroFOT material.

Can be found in (APPENDIX-I)

mGetCountry_MAP,
mSpeedkmph_MAP
mLongitude_GPS
mLatitude_GPS
mAltitude_GPS

## 8.4 Results

The video material of 13 drivers from the EuroFOT project was investigated. The results are based on this analysis.

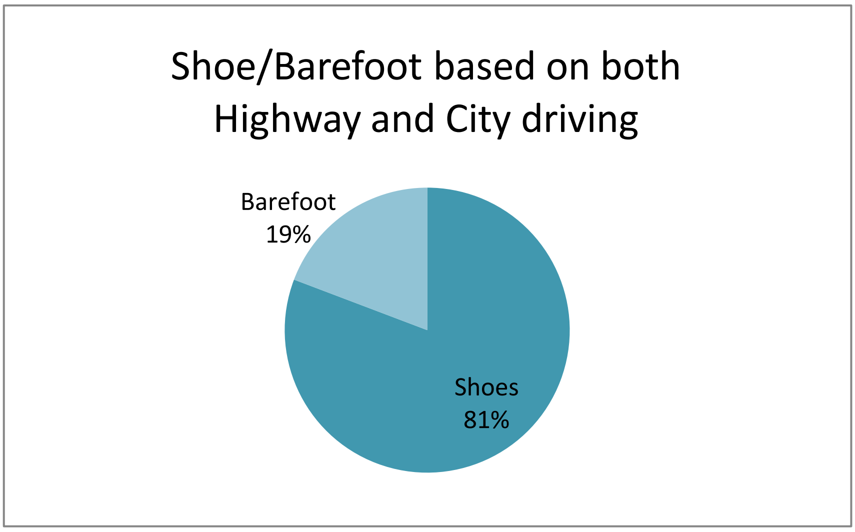



Figure 54

The analysis of the EuroFOT data for the project was useful in gaining knowledge about driver foot position and pedal usage in real traffic situations in city as well as on motorways.

Figure 55 from the investigation of the EuroFOT material shows data from city driving and highway driving combined. Around 81 percent of the drivers were driving with shoes and 19 percent were driving barefooted with socks.

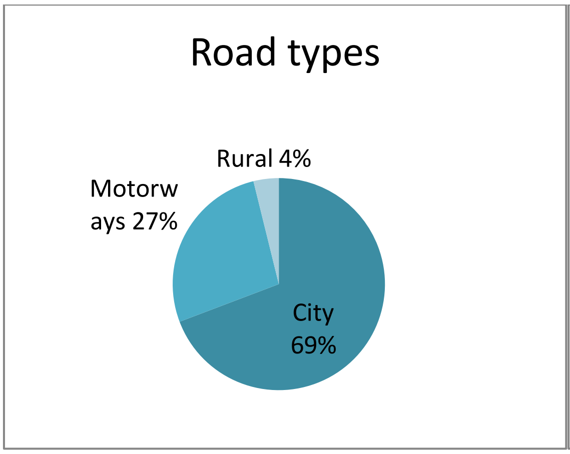



Figure 55

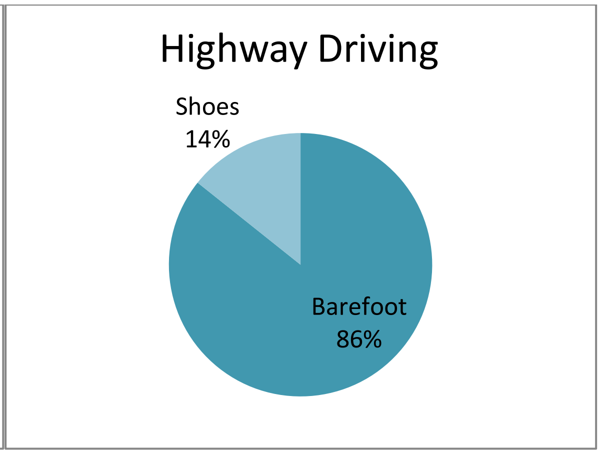



Figure 56

If we consider the highway driving, 86 percent of the drivers were driving barefooted and 14 percent were driving with shoes. The drivers were using the trucks on different types of roads, 69 percent of the drivers drive in cities followed by 27 percent on motorways or highways and 4 percent on rural roads.

## 8.5 Observations

In highway driving, the drivers drive barefooted with socks instead of with shoes for driving trucks for acceleration when the vehicle speed is around 60 Kmph and if the vehicle speed exceeds 70 Kmph the drivers activate the active cruise control function. Once the cruise control is activated the driver rests his feet near the seat supports or the steering column. If the speed is less than 70 Kmph the driver will rest his foot against the engine tunnel bay for comfort while accelerating the vehicle. As the driver depresses the accelerator pedal the heel point is lifted up from the floor due to the position of the accelerator pedal. However, this needs to be confirmed because in the EuroFOT project the camera was mounted in the dashboard allowing only for a top view of the pedals.

In city driving, the movement of feet between the pedals from accelerator to brake and vice-versa was frequent. The drivers with larger feet length move their feet between the pedals by keeping the heel point as centre. The estimated time for feet movement between the pedals was 0.60 sec from accelerator to brake pedal and vice versa. The estimate movement time was based on Fitts law.

When driving with shoes, the contact point between the pedal and foot is the ball of foot. This conclusion is based on video material and needs confirmation through detailed study. If the size of the brake pedal is very wide it makes the drivers' pedal travel very difficult if they are using a big boot or winter shoes. There exists a possibility that the feet could get struck between the pedals

In barefoot driving, the contact point for acceleration may be the ball of the foot or the toes. However, the contact points were dependent on the anthropometric data of the drivers. Toe operation in barefoot driving could be difficult for shorter drivers because of the higher position of the accelerator pedal in respect to the heel point position. Barefoot pedal usage could also be difficult for drivers when driving in city traffic because the brake pedal operation requires the entire foot to be moved since the position of the brake pedal plane is higher than the accelerator pedal plane.

## 8.6 Proposals

The size of the brake pedal could be reduced or the distance between the accelerator and brake pedal need to be increased to avoid the driver's boot getting struck between the pedals in city traffic.

City driving demands continuous movement of foot between the pedals. So, the brake pedal plane and the accelerator pedal plane should be at the same position for comfortable foot movement.

The position of both the accelerator and brake pedal should be lowered for comfortable accelerator pedal operation using toes in barefoot driving thereby eliminating the lifting of heel for pedal stroke.

## 8.7 Limitations

1. The EuroFOT project employs one camera for pedal usage. So, it is very difficult to interpret the foot angles from the material.
2. The pedal contact point and accelerator heel point cannot be observed through the EuroFOT material.
3. The EuroFOT material does have any information regarding the drivers' anthropometric data for ergonomics studies.
4. The higher level of confidentiality makes it difficult to access and share the material during the studies.

# 9. Pedal usage observations

## 9.1 Background

The pedal usage observations were carried out as a part of the project to investigate pedal usage of 11 drivers in the Volvo FH truck. The main objective of the observations was to observe the pedal contact point between the shoes or bare foot and the pedal, the accelerator heel point position, foot angles and movement of the foot between the pedals. The studies involve foot angle measurements and subjective evaluation of pedal usage with shoes and while barefooted.

The pedal usage when driving with shoes or while barefooted was completely different from each other. Normally the pedals are designed for driving with shoes and it has been assumed by ergonomists that the contact point between the pedal and the accelerator heel point position is at about 75 percent of the shoe length. Hence, in the pedal usage observations the contact point and the relation between the pedal contact point and accelerator heel point need to be investigated. Another motivation for these observations was to investigate the comfort level in using the pedals with shoes or while barefooted because the long-haul truck segment drivers prefer barefoot for pedal operation over shoes.

## 9.2 Fixture Design

Fixtures were designed for the pedal usage observations for the mounting of cameras to record the videos during the driving sessions. The fixtures were design and manufactured at the workshop at Volvo in Lundby. The fixtures for holding the cameras were mounted in the cab. Both fixtures were employed to hold camera 1 and camera 2 for recording the observations.

| Fixture | Controls | Location in the Cabin |
|---|---|---|
| Fixture 1 | Heel point position | Passenger Door |
| Fixture 2 | Accelerator and Brake Pedals | Dashboard near steering column |

The manufacturing drawings of the fixtures can found in the APPENDIX-T.

## 9.3 Process

Figure 58 shows the different steps involved in pedal usage observations.

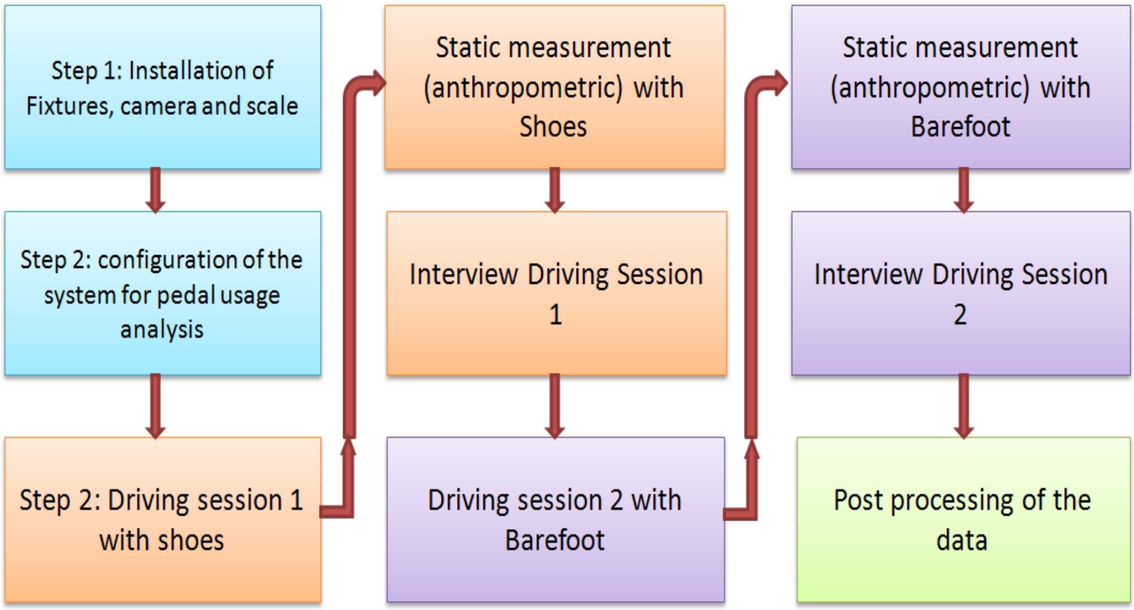



Figure 57 Process Flow of Pedal usage observations

The pedal usage observations were carried out in a Volvo FH truck with 11 drivers participating in the session and with a ratio of 9 (male): 2 (female). The Pedal Usage Observation Study involves 3 cameras for capturing pedal usage along with 2 computers for recording the videos directly from the cameras (live recording). The drivers were given the route map which was comprised of both urban traffic as well as rural roads.

## STEP 1: Installation

The first step in the pedal usage observation was the installation of fixtures in the cab for the mounting of the cameras. The first camera was mounted on a fixture near the door to capture the Accelerator Heel Point (AHP) and Ankle Angle Movements as the vehicle travels during the session. The second camera was mounted on the instrumental panel to monitor foot movement between the pedals as well as the x–axis orientation of the feet with the pedal. The third camera was mounted on the engine tunnel wall near the accelerator pedal to view the pedal contact point between the shoe and the pedal.

A paper measurement scale with markings was attached to the floor mat to find the approximate AHP location in relation to the pedal contact point on the pedal. Then landmarks like the heel point location when using the accelerator pedal and brake pedal were also studied in different driving situations. Another scale was attached to the shoe and bare foot to view the exact contact between the shoes or bare foot and the pedal.

Camera 1

Figure 58

Camera 2

Figure 59

Camera 3

Figure 60

Illumination Lamp

Figure 61

Figure 62 Neutral position with shoe

Figure 62 Neutral position with shoe

The computer software for capturing the videos from the cameras was configured for the driving sessions and the drivers were instructed about foot position while using the pedal so that their feet would not block the camera view. This could be a source of error in the observation method.

Figure 64 Overall camera set-up

## STEP 2: Driving session with shoes

The second step in pedal usage observation was the driving session with shoes. The measurement scale was attached to the shoes of the drivers. The measurement scale was made visible to camera 3 so that the exact Pedal Contact Point (PCP) between the shoe and pedal could be measured. Then the cameras were activated to record the driving session. The drivers were asked to drive the truck along the route. After the driving session was over the cameras were deactivated.

The photographs taken during the driving session with shoes can be found below.

The photographs from figure 62 were used to evaluate the foot position on the pedal from the video material. Through these data the ankle angle range can be calculated.

Figure 65 Accelerator Pedal use with shoe from the Pedal Usage Observation study

A questionnaire was prepared to extract the driver's opinion in driving with shoes in different truck applications. The questionnaire can be found in APPENDIX-L. Opinions were drawn from the drivers using shoes about the pedal size, curvature and friction patterns and how these affect foot position and pedal usage within different truck segments such as long haul, distribution and construction. The drivers also discussed issues and possible improvements in the lateral separation distances between the pedals and pedal position. All the comments and opinions from the drivers were documented.

## STEP 3: Driving session with barefoot

The third step in pedal usage observations was the barefooted driving session. The measurement scale was attached to the driver's bare foot. This task was challenging and care was given when attaching the scale to the barefoot because the foot profile of the drivers was varied. The scale '0' was placed near the toes so that the exact contact point for estimating the exact Pedal Contact Point (PCP) in the bare foot was visible on Camera 3.

The cameras were activated to record the barefoot driving session.

Figure 66 Accelerator Pedal use with barefoot from the Pedal usage observations

The photographs above were taken from the video material that was captured during the barefooted driving session.

The questionnaire was prepared to extract the drivers' opinions in barefoot driving to differentiate the experience the drivers felt between the shoes and the bare foot. The questionnaire can be found in APPENDIX-M. Opinions were drawn from the barefooted drivers regarding pedal size, curvature and friction patterns and how they affect foot position and pedal usage among different truck segments. While driving on the road the drivers also discussed the issues and possible improvements of the lateral distances between the pedals, pedal position and pedal plane position when compared with driving with shoes.

## STEP 4: Post processing of the video material

The cameras were deactivated and the videos were saved in the folder for each driver. The file formats differ between the cameras so the files were compressed by using video converter software and they were standardized to AVI format. The photographs were also examined to extract the right critical parameters of interest.

In order to analyse the video from three cameras simultaneously a GUI needs to be developed for effective dynamic study analysis. So, by using SIMULINK and Image

Acquisition Tool Box, a model similar to FOTware in EuroFOT was developed to play the videos in three different viewers with the click of the button. The post processing was a time consuming task due to the approximately 200 gigabytes of data.

## Processing the Video Material

The video material from the pedal usage observations could be viewed through a VLC player or through the Simulink model using the Gaussian pyramid. To explore the usage of the pedals the Gaussian pyramid block set was used to improve the texture of the video material and simultaneously process the data in three windows.

Camera 1's output was used for measuring the ankle angles by making snap shots of the video frames in the video material and measuring the angles physically. The Camera 2 output was used to get insight into the movement between the pedals and accelerator heel point (AHP) position. Camera 3 was used to view the exact contact point between the pedals and shoe or bare foot.

Limitations:

1. Time consuming for synchronizing the videos of three inputs at the same time.
2. The playback was relatively slow in viewing the videos because of the low resolution computer graphics capability in retrieving the three inputs into one window.

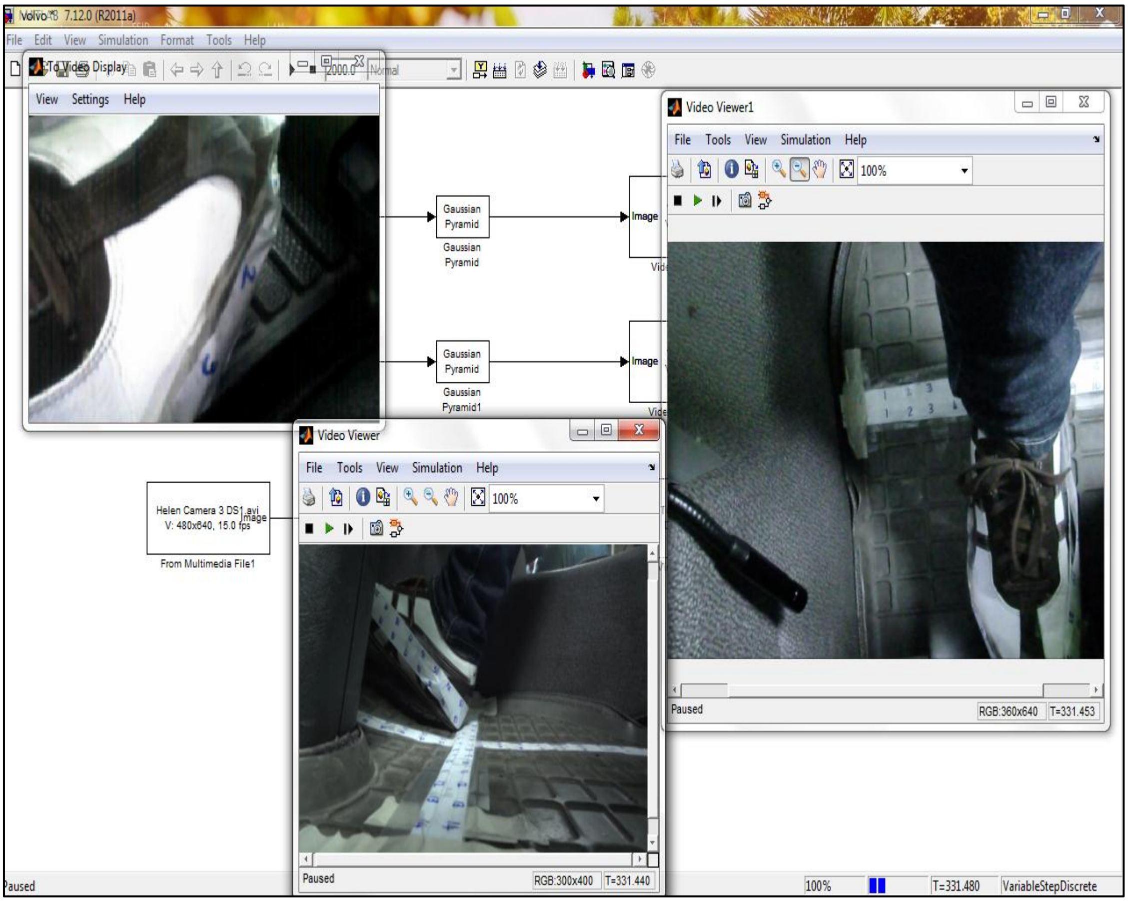



Figure 67 Simulink Model

## 9.4 Limitations of the Method:

1. There is a possible source of error in the observation method. The natural driving behaviour of the drivers was affected when the drivers were instructed to keep their feet slightly away from the edges of the accelerator pedal in order to be able to view the contact point between the pedal and shoe/barefoot.
2. There was a source of error when positioning the measurement scale for shoes and bare feet because the foot-shoe profile was different among the drivers and the measurements may have been affected.
3. The video output of Camera 3 was not stable because of the low resolution hardware.
4. Positional accuracy and precision errors were common among the measurement scale with a tolerance of +/- 0.2 Inch because the measurement scale attached to the driver's foot or shoe was in Inches.
5. Camera observation error was due to vibrations in the cab during the driving session. This may affect the pedal contact position relative to the accelerator heel point (AHP).
6. The mounting units and camera position of the observation method around the legroom of the cab affects the natural driving behaviour and seat position. This may be a source of error.
7. The ankle angles were measured from Camera 1 where the photos were taken from the video material as photo frames which contain errors due to the translation process.
8. Foot angle measurements always have a degree of error due to angle variation along the pedal usage during the driving sessions.
9. The pedal contact points observed from Camera 3 definitely have measurement error because measurements were taken from the videos and not measured or observed physically.
10. Apart from the previously listed errors there will always be some miscellaneous errors due to environment, light illumination around the legroom, etc.

# 10. Results from Pedal usage observations

The results from the pedal usage observations were derived from two different methods, (1) objective measurements and (2) subjective evaluation from the driving session. The objective measurement results will be presented first followed by the subjective evaluation.

## 10.1 Objective Measurements

The objective measurements were made through physical measurements of the length of the foot/shoe and stature height of the driver. The contact point measurements were manipulated from the video materials of Camera 3 which provides the details from the measurement scale attached to the shoe and bare foot. Foot angles were manipulated through the video output of Camera 1.

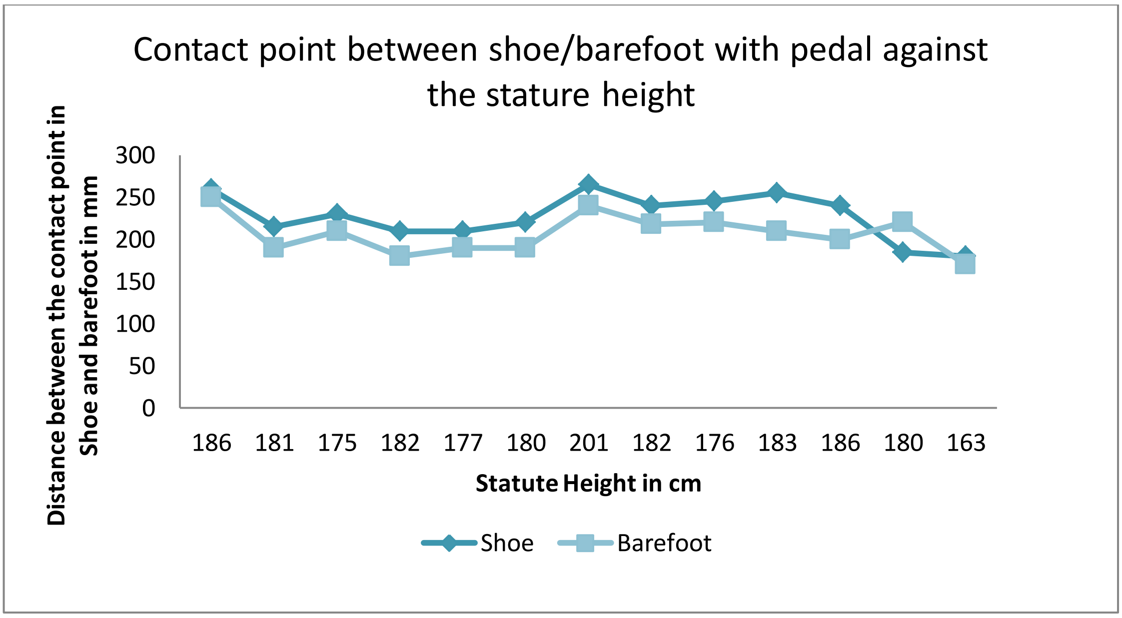



Figure 68

Figure 68 above illustrates the contact points of shoe and bare foot from the accelerator heel point position (AHP). The contact point of the shoe was higher than the barefoot because of the position of the pedal and the length of the foot. In the 12th driver's case, the shoe profile of the driver made the contact point of the shoe appear much lower than that of the barefoot. It was, however, a rare scenario.

The figure also shows data from a shorter driver with 165 cm statue height. The contact points between shoe/bare foot and pedal were very close when compared with the average stature height of other drivers. The same trend was also observed in tall drivers with a statue height of 201 cm and 186 cm. The driving session was carried out with only 13 drivers making this hard to predict. At the same time there was also the possibility of measurement errors because the drivers were instructed to keep their feet slightly away from the edge of the pedal.

When driving with shoes, the average distance from the accelerator heel point (AHP) is 227.30 mm and the standard deviation is 25.97 mm.
When driving barefooted, the average distance from the accelerator heel point (AHP) is 206.769 mm and the standard deviation is 23.14 mm

The distance variation range between the pedal and shoe/bare foot has been between 23 mm and 25 mm. The results were reliable with regard to variation. There may be some tolerance in variation of up to 4 cm due to measuring faults or errors from various sources. The contact points between the pedal and shoe/foot also depend on the driver's anthropometric dimensions and foot positioning.

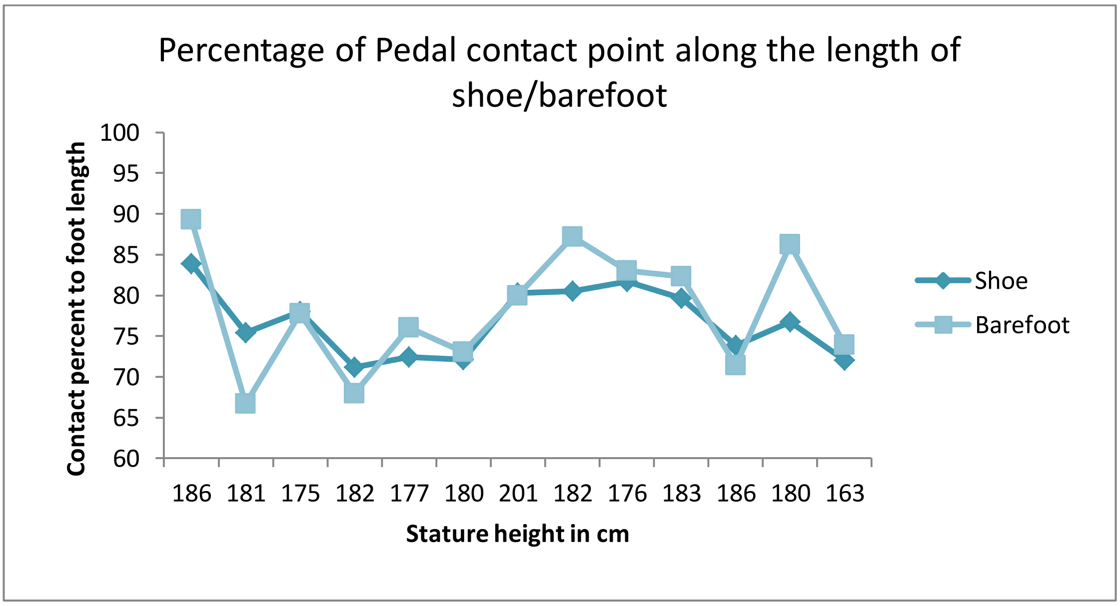



Figure 69

Figure 69 above shows the percentage of pedal contact point along the length of the shoe and bare foot. When driving with shoes, the average pedal contact point is 76% of the shoe length from the accelerator heel point (AHP) and the standard deviation is 4.23%. When driving barefooted, the pedal contact point is 78% of the foot length from the accelerator heel point (AHP) and the standard deviation is 7.34%.

The figure shows that the average percentage of pedal contact with shoes had minimum variation when compared with the percentage of pedal contact with the bare foot. In order to be more precise, the contact percentage with shoes was around 4% whereas the contact point percentage with bare feet was around 7%. The percentage of contact point with shoes was completely dependent on the size, profile and type of the shoe in combination with the drivers' foot position. The percentage of contact point with bare feet was dependent on the foot size, foot position and position of the pedal. Even though the results were reliable there was high probability of measurement errors/faults from various sources during the observations.

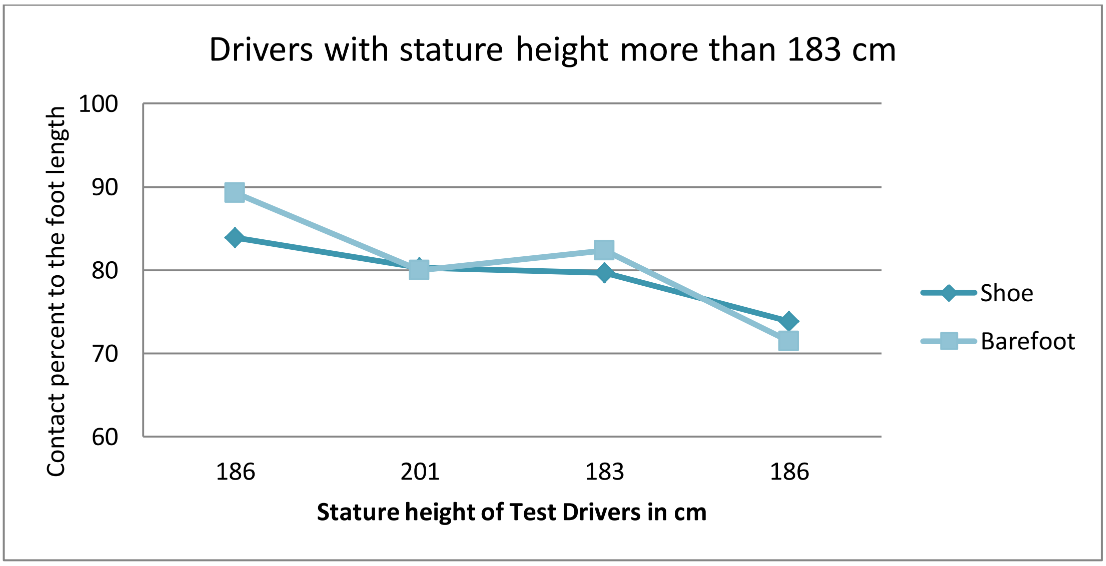



Figure 70

Figure 70 above shows the percentage of the pedal contact point along the length of shoe/bare foot with a drivers' stature height of over 183 cm.

When driving with shoes, the average pedal contact point is 79.42% of the shoe length from the accelerator heel point (AHP) and the standard deviation is 4.15%.
When driving barefooted the average pedal contact point is 80.76% of foot length from the accelerator heel point (AHP) and the standard deviation is 7.36%

The variation in the percentage of pedal contact with shoes is over 4% and the percentage of pedal contact with bare feet is around 7%. The difference in variation was similar to the variation in percentage found in the percentage of pedal contact with all the drivers. However, the average contact point percentage among tall drivers reached 80%, this was a significant observation in regards to tall drivers and shows that if the percentage of pedal contact with shoe/foot length reaches around 80% we can conclude, to some extent, that the driver uses his toes for pedal operation rather than the ball of the foot.

The figure shows that for most tall drivers with a stature height over 200 cm the contact point of both the shoe and the bare foot were at the same point or had a minimum of clearance between the points in shoe and the bare foot as compared with the average contact points of other drivers with a stature height of less than 183 cm. Still, this conclusion was based on observations made during the driving session. In order to draw a final conclusion, however, the analysis needs to be further investigated for drivers with a size of 190 cm to 200 cm.

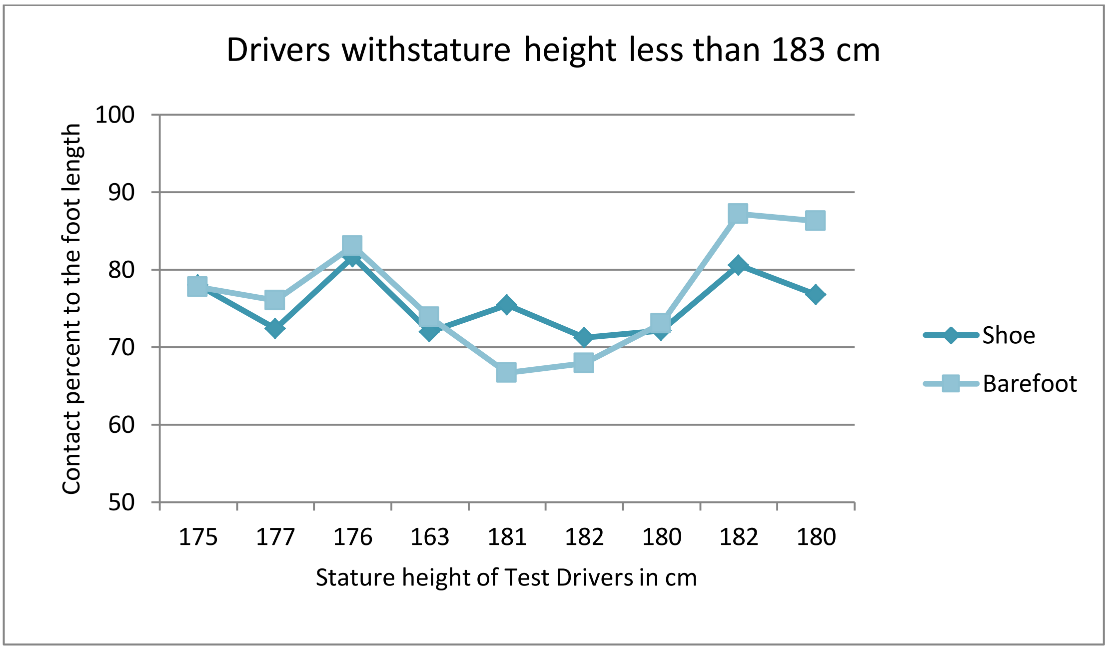



Figure 71

Figure 71 above shows the percentage of pedal contact point along the length of the foot and shoe with a drivers' stature height of less than 183 cm.

When driving with shoes, the average pedal contact point is 75.56% of the shoe length from the accelerator heel point (AHP) and the standard deviation is 3.91%.
When driving barefooted, the average pedal contact point is 76.86% of the foot length from the accelerator heel point (AHP) and the standard deviation is 7.43%

The standard deviation of the contact point percentage when wearing shoes, was around 4% and that of the bare foot was over 7%, which was similar to the percentage of pedal contact point with respect to shoe and foot length for taller drivers and the average contact point of all the drivers. The average percentage of pedal contact was similar to the percentage the ergonomics team initially assumed for the percentage of pedal contact point with shoes. In addition to that, of the driver population that participated in the driving session, the contact point percentage for bare feet was around 77% of the foot length.

One short driver, just over 163 cm, had the same percentage for the contact point with both shoes and bare foot. This conclusion was based on observing the driver population during the driving sessions. The contact point percentage was dependent on the anthropometric dimensions of the short drivers and the foot position in using the pedals. In some cases it was assumed that short drivers have difficulty in reaching the pedals from a comfortable seat position. This may also affect the results in addition to the measurement method observation errors from various sources.

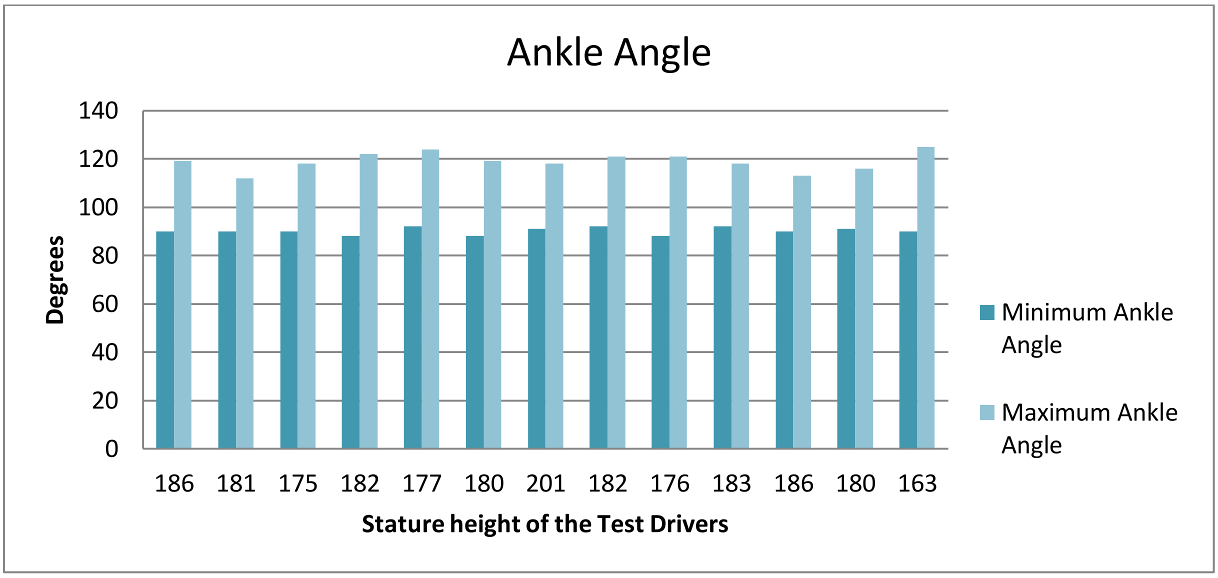



Figure 72

Figure 72 above shows the degrees of ankle angle when using the accelerator pedal. The average minimum ankle angle is around 90.15 degrees with a standard deviation of 1.46 degrees. The average maximum ankle angle during pedal operation is around 118.92 with a standard deviation of 3.81 degrees.

The variation with the minimum ankle angle was around 2 degrees and the maximum ankle angle was around 4 degrees. The measurement data was dependent on the drivers' foot position when using the pedals. The measurements may also have possible errors due to incorrect observation, camera position, and translation of the picture frames from the video material. In order to conclude the accuracy of the foot angles the observations need to be carried out with different driver sizes to make the results more reliable.

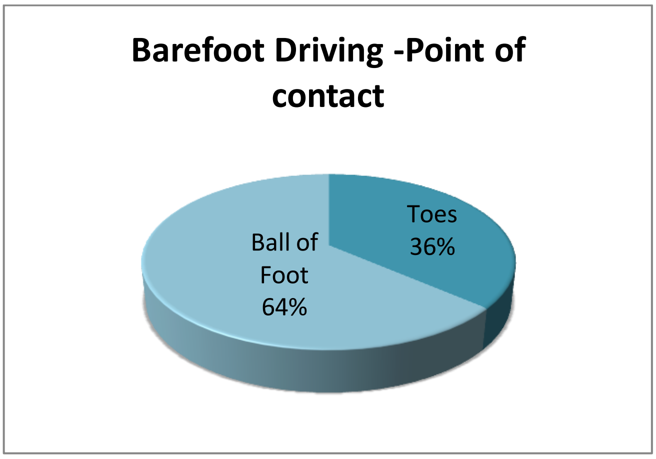



Figure 73

The pie chart above shows that in barefoot driving 64% of the drivers use the ball of foot (BOF) and 36% of the drivers use their toes for the accelerator pedal. The data provided above was not reliable because it was based on the data from the pedal contact percentage with respect to the foot length of the participating driver population. It can be made reliable by repeating the observation method with more drivers of different sizes and with an extra miniature camera near the pedal to observe the contact points precisely.

## 10.2 Subjective Evaluation

The subjective evaluation was carried out through questionnaires and interviews with the drivers during the driving session. The responses from the drivers about different aspects regarding the pedal usage in the driving sessions were evaluated.

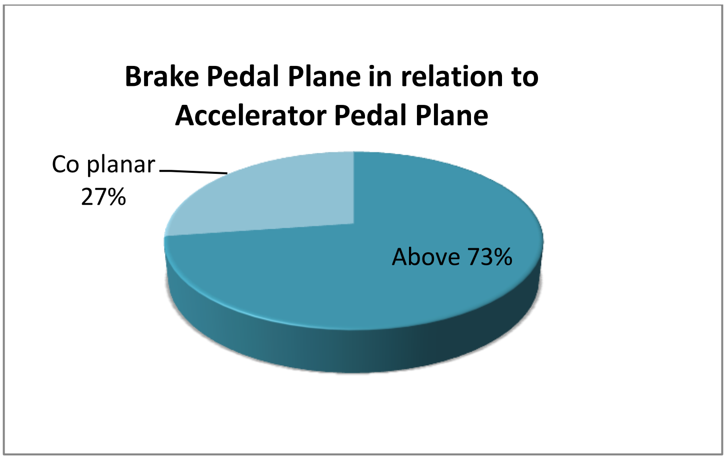



Figure 74

The pie chart illustrates that 73% of the drivers, because they were comfortable with the pedal plane in the truck, prefer that the brake pedal plane position be higher than that of the accelerator pedal plane. Twenty seven percent of the drivers prefer both the accelerator and brake pedal to be in a co-planar arrangement because this allows easy movement of the feet between the pedals in dense traffic situations.

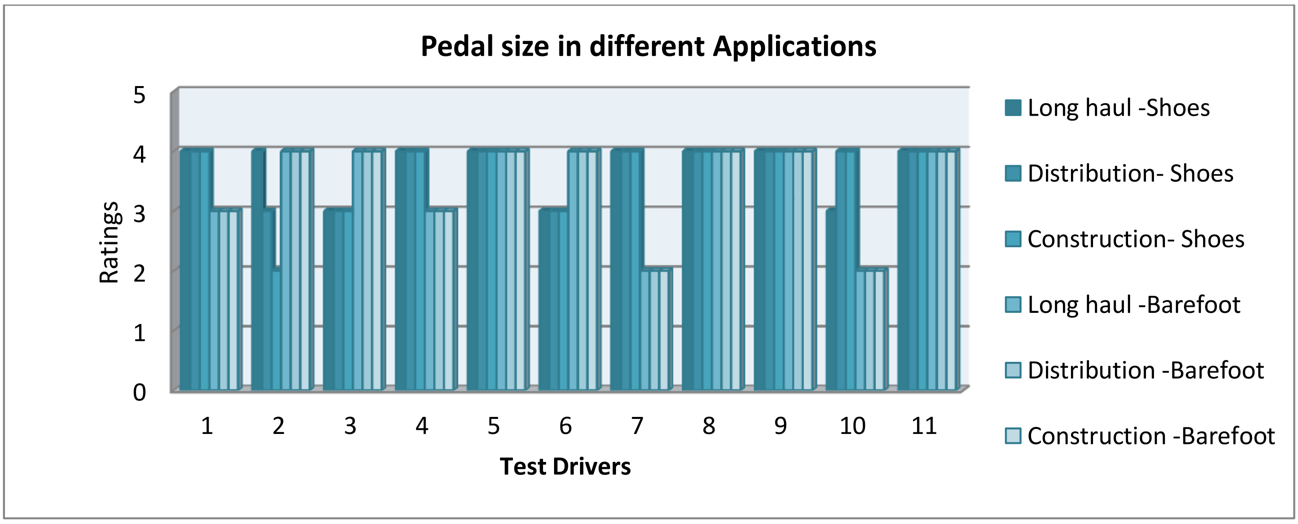



Figure 75

The graph depicts the opinion of the drivers driving with shoes and barefoot across different truck segments. The drivers were comfortable with the pedal size when driving with shoes in long haul, distribution and construction applications whereas driving barefooted seems difficult for the drivers because the brake pedal size seems to be too big and the surface area contact between the accelerator pedal and foot is too small.

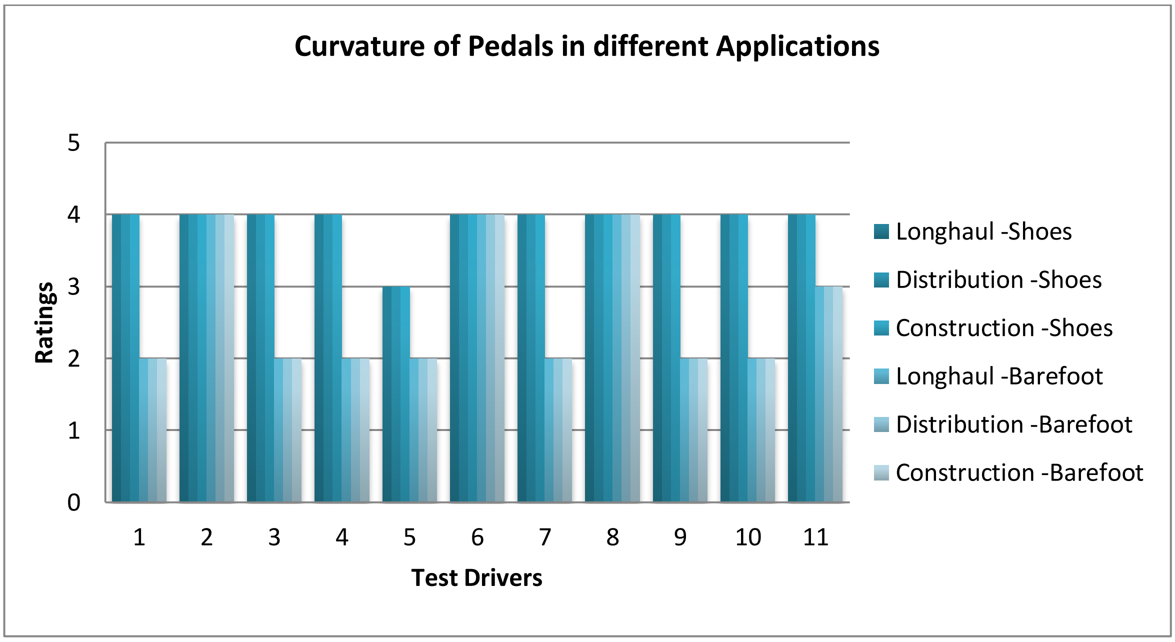



Figure 76

The graph depicts the opinion of the drivers driving with shoes and barefooted across different truck segments. The curvature of the accelerator pedal does not affect the driver when driving with shoes. Most of the drivers were satisfied with the curvature of the pedal when driving with shoes. The same drivers were completely dissatisfied with the curvature of the pedals in barefoot driving. The poor ratings were due to the curvature of the accelerator pedal. The pedal was too rigid, with sharp corners and minimum contact area. As the pedal moves along the stroke it seems difficult for the drivers' foot to reach maximum stroke length because of sharp edges.

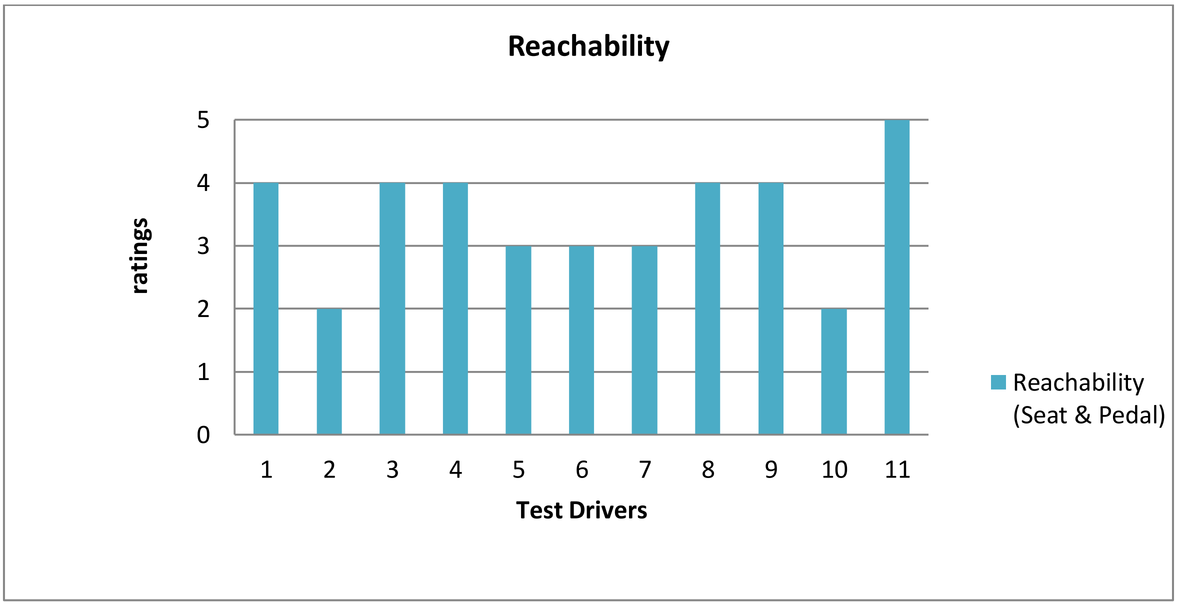



Figure 77

The trend shows most of the drivers were comfortable with the reachability factor between the seat and pedal. The lower ratings were given by one short driver and one tall driver. The short driver was not comfortable with the reachability factor between the seats and the pedals in barefoot driving. A similar situation arose for the one tall driver also. The driver was not comfortable with the seat position in relation to the pedals because of his long legs.

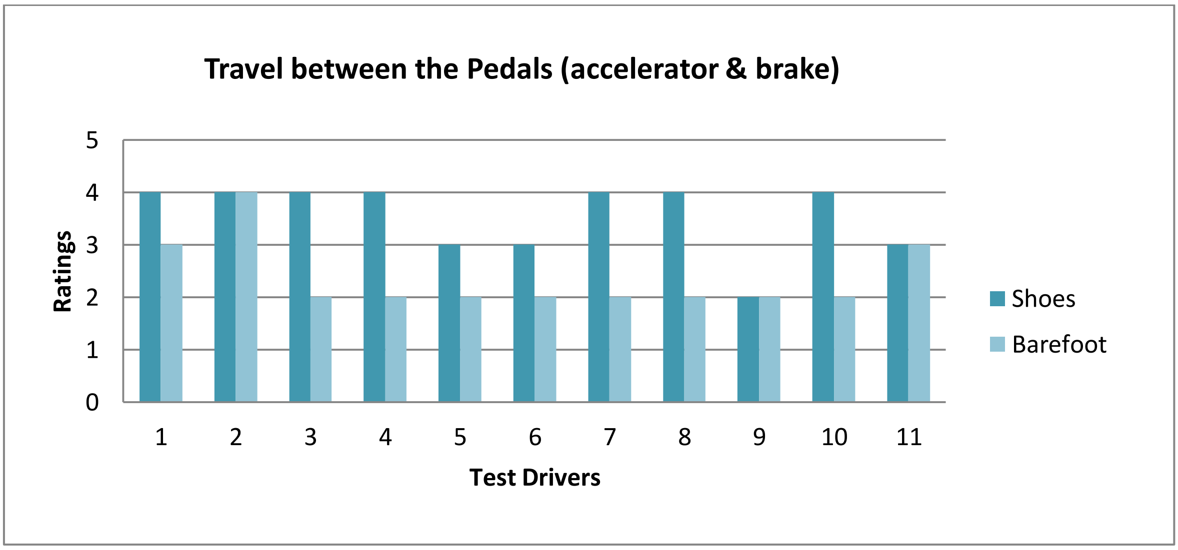



Figure 78

The trend shows the drivers were comfortable with the distance between the pedals while driving with shoes. Two drivers found the distance between the pedals difficult while driving with big boots. The drivers in barefoot driving were not comfortable with the distance between the pedals because of the position and difficulty in moving the foot between the pedals.

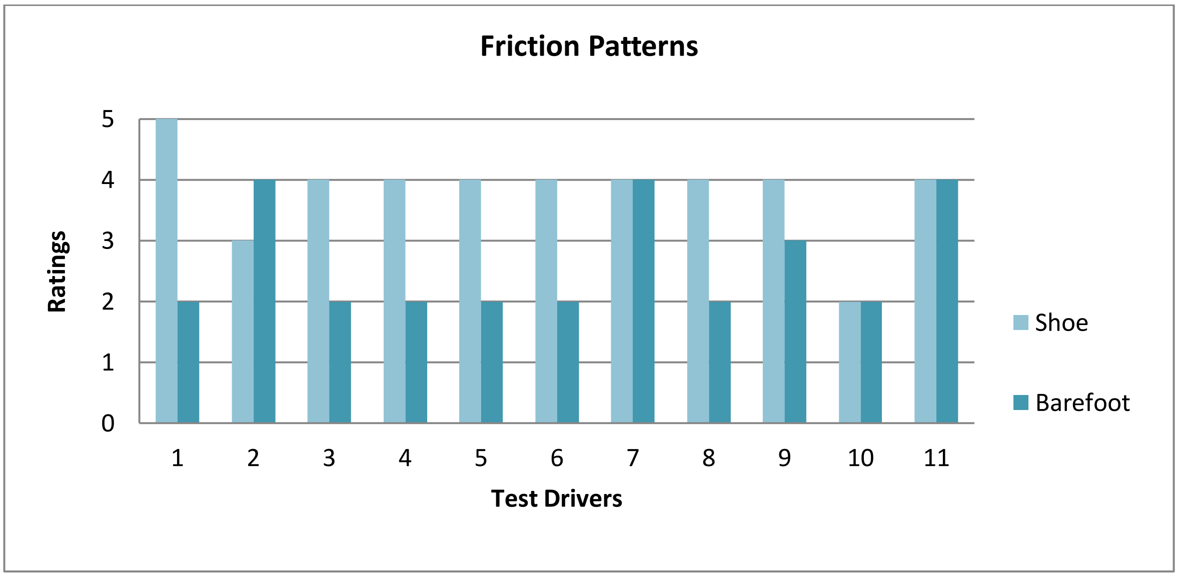



Figure 79

The trend shows the friction patterns were good for driving with shoes. One driver felt the friction patterns were slippery during the driving session. The drivers were not satisfied with the friction patterns when driving barefooted because the sharp edges in the friction pattern hurt the drivers' feet as the pedal moved along the stroke. These issues resulted in poor ratings for the friction pattern.

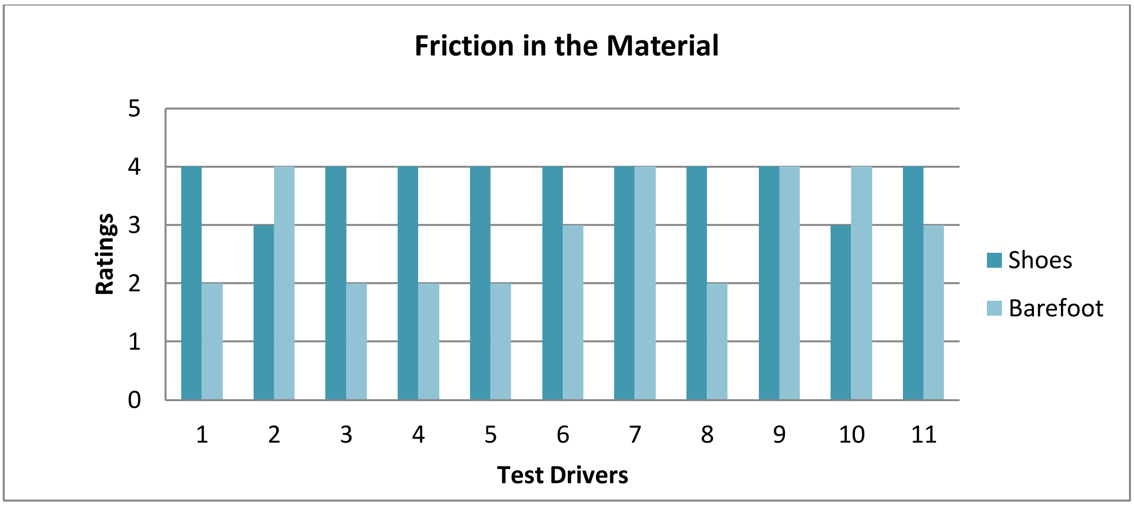



Figure 80

The trend shows the friction between the shoes and the pedals were good according to the drivers' opinion. However, the friction between the barefoot and pedal was poor because of the slippery nature of the plastic material on the accelerator pedal.

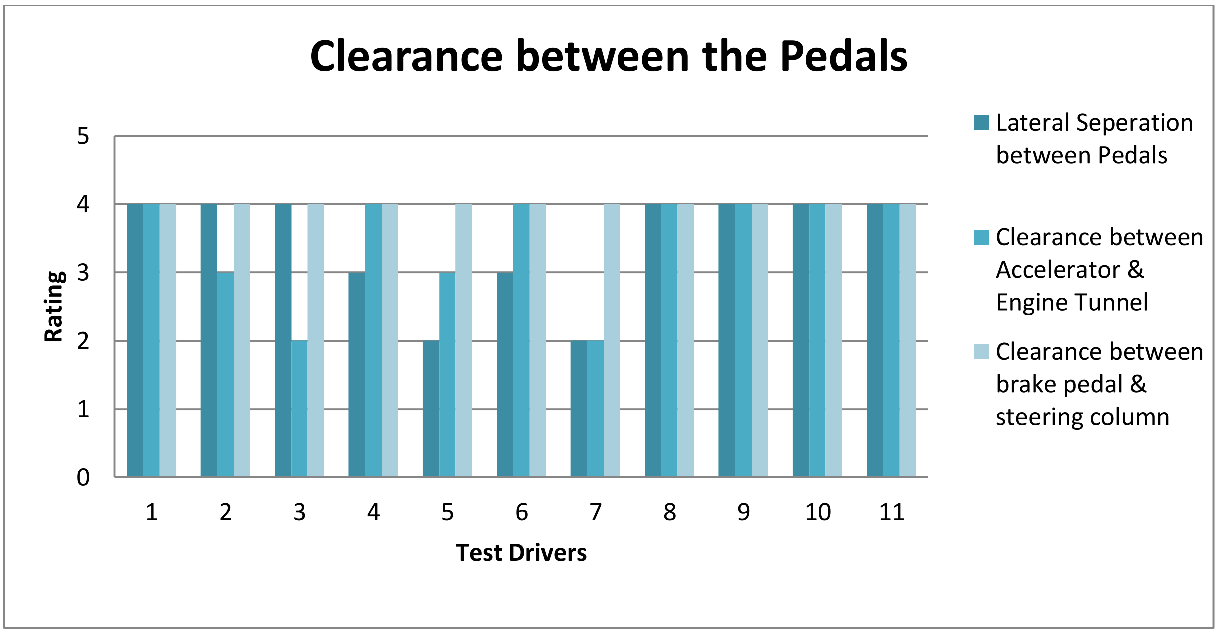



Figure 81

The graph depicts the drivers' opinions about the clearance distance between the pedals and their surroundings. The trend shows the drivers were comfortable with the distance between the pedals. Some drivers found it difficult to use the pedals when driving with boots or big shoes. Most of the drivers were comfortable with the distance between the accelerator pedal and engine tunnel. A few drivers prefer the distance be increased to avoid tight clearance when resting the foot against the engine tunnel wall when using the accelerator pedals. All the drivers were comfortable with the distance between the brake pedal and the steering column.

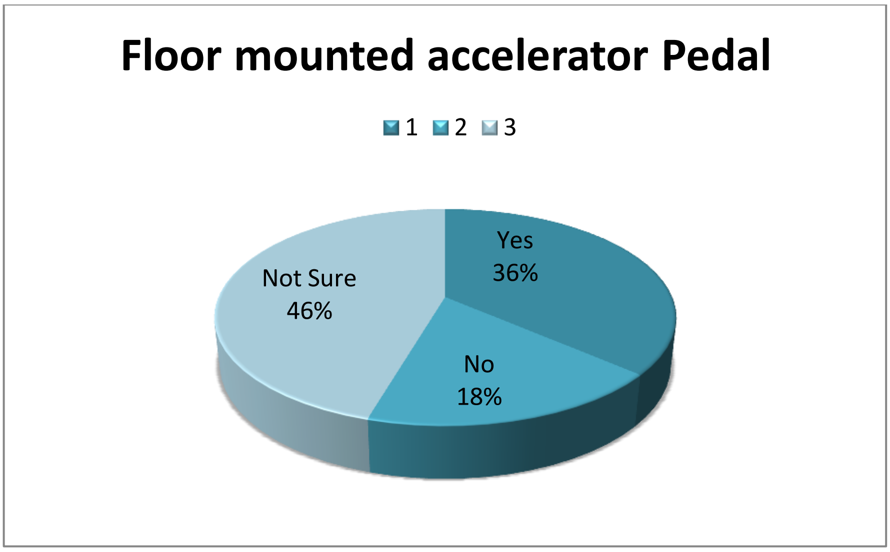



Figure 82

The graph shows the drivers' preference for floor mounted pedals for the accelerator pedal. Around 36% of the drivers prefer floor mounted pedals over suspended pedals and 18% of the drivers prefer the suspended pedals. The rest of the 46% majority of the drivers were not sure because they had no experience in driving vehicles with floor mounted pedals.

**Overall ratings from the subjective evaluation of the pedals during the driving session**

**1) Driving Session 1 with Shoes**

| S.No | Questions | Average Scores (5-rating scale) |
|---|---|---|
| 1 | Opinion on the size of the Pedal | |
| | Longhaul application | 3.72 |
| | Distribution application | 3.72 |
| | Construction application | 3.63 |
| 2 | Opinion on the curvature of the Pedal | |
| | Longhaul application | 3.9 |
| | Distribution application | 3.9 |
| | Construction application | 3.9 |
| 3 | Opinion on the friction patterns in the Pedal | |
| | Longhaul application | 3.81 |
| | Distribution application | 3.81 |
| | Construction application | 3.81 |
| 4 | Opinion on the friction from the gripper in the Pedal | |
| | Longhaul application | 3.81 |
| | Distribution application | 3.81 |
| | Construction application | 3.8 |
| 5 | Opinion on the lateral separation distance between the pedals | |
| | Longhaul application | 3.45 |
| | Distribution application | 3.45 |
| | Construction application | 3.45 |
| 6 | Opinion on the distance between the engine bay and accelerator pedal | |
| | Longhaul application | 3.45 |
| | Distribution application | 3.45 |
| | Construction application | 3.45 |
| 7 | Opinion on the distance between the steering column and brake pedal | |
| | Longhaul application | 4 |
| | Distribution application | 4 |
| | Construction application | 4 |
| 8 | What is your opinion on the reachability between the pedals and seat | 3.45 |
| 9 | What is your opinion on the foot angles when using the brake pedal as it moves along the stroke | 3.63 |
| 10 | What is your opinion on the foot angles when using the | 3.54 |

| | | |
|---|---|---|
| | accelerator pedal as it moves along the stroke | |
| **11** | What is your opinion on the easiness of travelling between the pedals with shoes | 3.54 |

The table above shows the average ratings given by the drivers during the subjective evaluation of the pedals while driving with shoes. Detailed information of the individual ratings of the drivers can be found in APPENDIX – Q.

### 2) Driving Session 2 with Barefoot

| S.No | Questions | Average Scores (5-rating scale) |
|---|---|---|
| **1** | Opinion on the size of the pedal | |
| | Longhaul application | 3.45 |
| | Distribution application | 3.45 |
| | Construction application | 3.45 |
| **2** | Opinion on the curvature of the Pedal | |
| | Longhaul application | 2.63 |
| | Distribution application | 2.63 |
| | Construction application | 2.63 |
| **3** | What is your opinion on the friction patterns in the accelerator pedal | 2.63 |
| **4** | What is your opinion on the friction from the material | 2.9 |
| **5** | What is your opinion on the foot angles when using the brake pedal as it moves along the stroke | 2.72 |
| **6** | What is your opinion on the foot angles when using the accelerator pedal as it moves along the stroke | 2.72 |
| **7** | What is your opinion on the easiness of travelling between the pedals | 2.63 |

The table above shows the average ratings given by the drivers during the subjective evaluation of the pedals while driving barefooted. Detailed information of the individual ratings of the drivers can be found in APPENDIX – Q.

# 11. Discussion of the results

The pedal usage observations gave interesting results from the objective measurements through the video material and subjective evaluation through the interviews with the drivers from the driving sessions.

The conclusions of the results were presented based on the pedal usage observation studies.

### Observation Method:

The observation method used in pedal usage studies was not reliable because the drivers were asked to position their feet slightly away from the edges of the accelerator pedal in order to give a better view of the contact point on the accelerator pedal. This could affect the results and was a source of error. At the same time the natural driving behavior of the drivers was affected. Another challenge during the studies was the attachment of the paper measurement scale to the shoe and bare foot which could affect the measurements manipulated from the video material.

The anthropometric dimension of the individual drivers and size and profile of the driver's shoe or feet had a great impact on the objective measurements. For example, if we take the objective measurements from a driver using the pedal with formal leather shoes and then repeat the same method with the same driver driving with sandals or winter shoes the measured contact points and foot angle between the driving sessions will differ.

Other factors like shoe/barefoot profile and foot position also affect the results. During the objective measurements the data acquired from Camera 3 was of low quality. This could be improved by using a wide-angle compact miniature USB camera which could be accommodated inside the leg room of the truck so that the observation method could be more accurate and reliable.

### Pedal Contact Points:

Initially, it was assumed that the pedal contact point would be around 75% along the foot length. This was verified (see figure 69) through the observations of the driver population during the driving sessions. The pedal contact point exists at 76% along the foot length in driving with shoes and 78% when driving barefooted.

The pedal contact point also differs based on the stature height of the drivers. The observation studies reveal that for tall drivers with a stature height over 185 cm their pedal contact point is at around 80% of their foot or shoe length. The same observation was also encountered with one short driver with stature height of around 160 cm whose pedal contact points with shoe and bare foot had a minimum distance between them. (See figure 70 and figure 71)

The standard deviation of the pedal contact percentage with shoes was around 4% and with bare feet was around 7%. The variation was estimated to be around 4-7% based on the objective measurements from the driving session. The results were not reliable because of the measurement error or faults from the observation method. At the same time the results could be evaluated by repeating the observation method with different driver sizes.

During the barefoot driving session 64% of the drivers used the ball of the foot for acceleration and 34% used the toes. The observations show that the drivers feel much more comfortable and relaxed when accelerating with the toes than when accelerating with the ball of the foot. The ankle angle in the default position of the accelerator pedal is around 90 degrees and when the driver reaches the maximum stroke it reaches around 118 degrees.

### Pedal Size:

The drivers were comfortable with the size of the accelerator pedal, see figure 75, for all the truck segments when driving with shoes and barefooted. However, drivers prefer the width of the brake pedal to be reduced because if the brake pedal is too wide it interrupts the pedal operation when driving with boots or winter shoes.

In barefoot driving the drivers feel that the accelerator pedal is narrow with minimum surface area contact and that the brake pedal is too wide. Drivers with big feet have difficulty with the size of the accelerator because the length of the pedal is very small compared with the depth.

In distribution trucks, as the driver has to continuously move between the pedals, the current pedal layout has a high possibility of either pedal misapplication or of the foot getting struck between the pedals when driving with boots or winter shoes. The drivers also felt the pedal size of the competitor trucks were not preferred.

### Pedal Curvature:

During the driving session with shoes, 10 out of 11 drivers were comfortable with the curvature of the pedal and rated it as very good. (See figure 76). Around 7 drivers, which accounts for more than 50% of the drivers interviewed in the driving session, felt uncomfortable with the curvature of the pedal when driving barefooted and rated it as fair because the sharp corners on the accelerator pedal make it difficult for the drivers as the pedal moves along the stroke. The sharp edge hurts their feet. The issue is very serious when the driver moves his foot between pedals in panic situations or dense city traffic. The drivers also prefer the radius of curvature to be increased in the accelerator pedal for barefoot driving to avoid the flat and sharp corners of the pedal. At the same time, the curvature of the pedal should have some soft material for improving the comfort with barefoot driving.

### Reachability:

The reachability factor between the pedals and the seat were rated as good by 9 out of 11 drivers. (See figure 77) However, tall drivers preferred their seat to be moved backwards which makes them feel comfortable and gives them enough space around their feet while driving. Important to note is that the driver's seat cannot be moved beyond the limit because of the bed behind the seat. A similar situation arises for shorter drivers who have the same problem, especially in barefoot driving, reaching the pedals from their comfortable seat position. The issue was predominant in shorter female and male drivers during the driving session. The reachability factor also affects the drivers' heel resting on the floor from the comfortable seat position. One driver feels the reachability parameter of Scania is better than Volvo's for tall persons as it gives adequate space around the driver's seat to reach the pedals.

### Position and the movement between the Pedals:

The drivers feel uncomfortable with the position of the pedals. The observation studies show that the main concern was with pedal usage in barefoot driving because the position of both accelerator and brake pedals were higher than the allowed limits. The shorter drivers feel especially uncomfortable with the pedal usage because the default ankle angle is quite tight and as the driver presses the accelerator pedal to the maximum the heel point is lifted up instead of resting on the floor. (See figure 82) The movement between the pedals could be made comfortable if movement could be accomplished by rotating the foot instead of lifting it. (See figure 83)

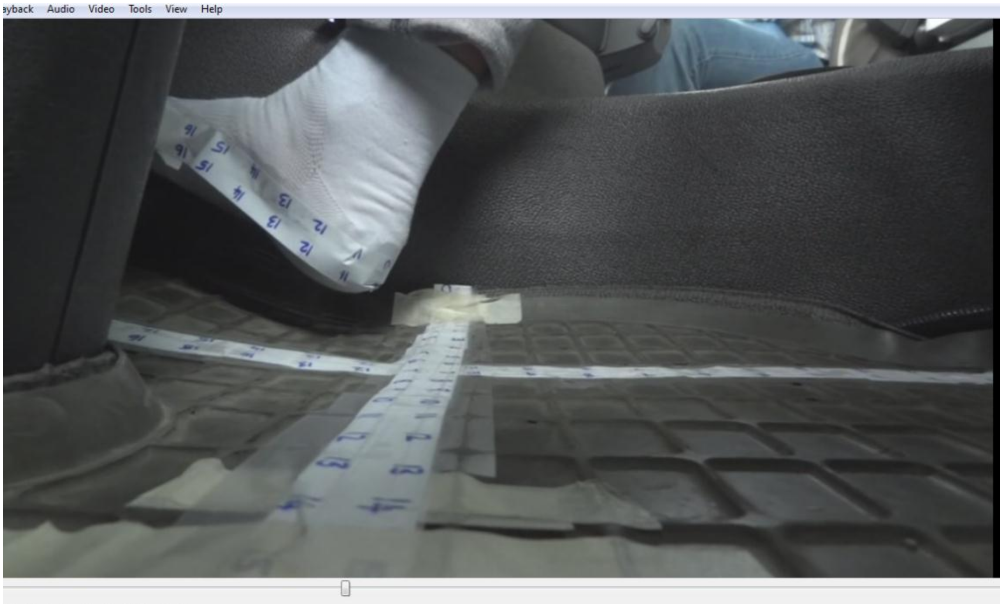



Figure 83

### Position of the brake Pedal in relation to the accelerator Pedal:

The subjective evaluation shows that 73% of the drivers were comfortable with the brake pedal plane positioned higher than the accelerator pedal plane because suspended pedals allow comfortable pedal usage and also eliminate pedal misapplication errors and 27% of the drivers prefer both the pedals in coplanar arrangement. The co-planar arrangement allows for easy travel of foot between the pedals in city traffic and the straight position of seated drivers in distribution trucks makes the co-planar arrangement more comfortable. However, the drivers should be aware of which pedal they are pressing to avoid the pedal misapplication errors. (See figure 74)

### Clearance distance between Pedals:

The drivers rated the clearance distance between the brake pedal and the steering column as very good during the driving session. (See figure 81)

Among the 11 drivers, 7 drivers have rated the clearance distance between the accelerator pedal and the engine tunnel as very good, 2 drivers have rated it as good and 2 drivers as fair. The observations and interviews reveal that most long haul truck drivers prefer to rest their feet against the engine tunnel during acceleration. It is possible to have a small strip or support on the engine tunnel on which to rest the feet for comfortable acceleration for long haul drivers. While, other drivers would prefer that the clearance distance between the accelerator pedal and engine tunnel be increased to create adequate space around the pedals. (See figure 81)

The drivers' opinions about the lateral separation distance between the pedals were mixed with 7 drivers out of 11 rating it as very good, drivers rating it as good and 2 drivers rated it as fair. The reason for dissatisfaction was related to the brake pedal width because the drivers prefer enough space between the pedals for ease movement of the feet when driving with big boots or winter shoes. Tight space interrupts free movement of feet between the pedals. (See figure 81)

# 12. Recommendations

The recommendation section consists of possible improvements that will increase the overall comfort for the drivers based on the observations from the EuroFOT and Pedal Usage Observations. The section is comprised of four major types of driving.

**Recommendation for improvement while driving with Shoes:**

- The pedal contact point for the pedals was around 76% with shoes. The contact point could be used for the European driver population. However, further studies, could enable deeper understanding of the foot position with different driver sizes, especially with short Asian drivers, both male and female.
- The contact point in the pedal is also related to the stature height. Tall drivers have a contact point of 79% of the shoe length from the AHP while average and short drivers have a contact point at 75% of the shoe length from the AHP. Further investigations are needed to measure the percentage of contact point for female drivers. (See figure 68 and Figure 69)
- The drivers prefer a floor mounted accelerator pedal for distribution applications because it offers enough comfort in moving the feet between the pedals. At the same time the floor mounted pedals offer good support when driving on bumpy roads.
- The position of both the accelerator and brake pedals needs to be lowered based on the interviews during the driving session. Lowered pedal position could eliminate the lifting up of the heal point during the pedal operation. Shorter drivers, especially, have difficulty in using the pedals because of their positions.
- The radius of curvature of the accelerator pedal needs to be increased for a more comfortable foot angle between the foot and the pedal as the pedal moves along the stroke. (See APPENDIX – D)
- The friction on the accelerator pedal is too low for some drivers because of the plastic friction material. The friction material needs to be replaced with rubber for better friction and comfort in different weather conditions. The drivers also prefer a softer friction material. (See APPENDIX –D)
- The feeling and feedback from the accelerator pedal need to be improved. One driver commented that the feedback from the accelerator pedal is low due to intense filtration of vibrations from the pedal.
- The friction patterns and relation between the friction pattern and grip forces has to be investigated to draw conclusions.
- The relation between the pedals and seats has to be defined for different driver sizes, for tall as well as short drivers. The recommendation was based on the comments from drivers. (See Figure 77 and APPENDIX D –Accelerator pedal)
- The lateral separation between the pedals has to be increased to accommodate the shoes of the driver (big boots or winter shoes) (See figure 81) because the width of the brake pedal could possibly lead to pedal misapplication errors or to the shoes getting stuck between the pedals. Sufficient space between the pedals improves the comfort and easy movement of the feet between the pedals.
- The clearance distance between the accelerator pedal and engine tunnel has to be increased based on driver opinion from the subjective evaluation. (See figure 81)

Further investigations are needed to draw conclusions on the distance between the accelerator pedal and engine tunnel.

- The brake pedal width has to be reduced to increase the space between the pedals.
- Around 73% of the drivers prefer the brake pedal to be positioned higher than the accelerator pedal whereas 27% of the drivers prefer both the accelerator and brake pedal to be in the co-planar arrangement. The co-planar arrangement would improve foot movement in distribution trucks.
- The forces from the brake pedal are high because the pneumatic system demands high forces from the drivers with the longer strokes. The forces from the brake pedal can be decreased through an electronic backup system in future brake pedals instead of a pneumatic system directly connected to the brake pedal. The system will resemble the "Shift-by-wire" method in accelerator pedals.
- Normally, in a transport company, the drivers will drive different trucks. For example a Volvo FH or a Volvo FM. The force levels from the pedal are not same. Drivers would feel comfortable if the force levels were the same across the Volvo brand. This would improve the comfort and give better control when using the pedals.
- The drivers also prefer the brake retardation and pressure level to be consistent within an allowable range. A few drivers had a problem with the brake pressure level. The pressure level was too high in a loaded truck when compared with an unloaded truck. Improving the brake pedal pressure and force characteristics could improve driver comfort when using the pedals. (See APPENDIX –D)

## Recommendations for improvement in driving with Barefoot:

- The size of the accelerator pedal needs to be increased. Because the surface area contact between the pedal and foot is minimal.
- The radius of curvature of the accelerator pedal needs to be increased to offer better support to the feet because the drivers felt it was flat and driving barefooted hurts their foot as the pedal moves along the stroke. See figure 76 for the ratings on the pedal curvature for the barefoot as well as the diving session observations. The edges of the accelerator pedal need to be rounded.
- The contact point of the drivers' foot in barefoot driving was 78% of the foot length from the accelerator heel point (AHP). Here the contact point depends on the stature height. Tall drivers over 190 cm have the pedal contact point at 80% of the shoe length from the AHP compared with average and short drivers whose contact point is at 76% of the shoe length from the AHP. The difference in the contact point between tall and short drivers is over 4%. So, from this it was observed that stature height and foot position were important factors in using the pedals. (See figure 68 and figure 69).
- Further investigation of the contact point could be carried out with short drivers, both male and female, for a detailed conclusion for barefoot driving.
- The position of the both the accelerator and brake pedals needs to be lowered based on the interviews in the driving session. (See APPENDIX-D)
- The corners of the accelerator pedal need to be rounded off and sharp edges needs to be made curved because of the impact on the foot as the pedal moves down the stroke. (See figure 75 and figure 76 for the ratings on barefoot and APPENDIX-D)
- The friction material on the accelerator pedal should be rubber because the drivers feel that the current plastic accelerator pedal is slippery when driving barefooted. The

drivers also prefer softer material for barefoot driving. (See figure 80 for the rating on the friction material in the pedals)

- Some drivers felt that the sharp edge in the friction patterns hurt their feet while driving at lower speeds. At higher speeds the issue disappears as the pedal moves along the stroke. This issue could be resolved by having a pivot joint in the pedal which acts like an adjustable flap making pedal operation comfortable.
- Detailed study should be carried out in the selection of the friction patterns to verify how the friction pattern could affect the foot positioning in barefoot driving.
- From the drivers' perspective for long haul applications the brake pedal plane should be slightly above the accelerator pedal plane. Around 73% of the drivers prefer the brake pedal plane to be higher than the accelerator pedal to avoid pedal misapplication errors.
- Based on the observation based studies, the movement between the pedals will be more comfortable for the drivers if the foot could move rotationally between the pedals with the heel point resting on the floor instead of being lifted up. (See Figure 83 & APPENDIX –D)
- Detailed studies should be made to investigate and measure the pressure distribution between the foot and the pedal while driving barefoot on different types of roads, especially muddy terrains or bumpy roads.
- Ergonomics team should investigate the movement time between the pedals on the basis of Fitts law to optimize the position and usage of pedals in barefoot driving.
- The drivers driving on bumpy roads experience vibrations in the cab. During these situations the pedal operation of suspended pedals could be challenging, however, floor mounting could be used for accelerator pedal.
- Floor mounted accelerator pedals offer excellent support for the feet during continuous pedal operation. Nowadays, many luxury passenger car manufacturers use a floor mounted accelerator because of its ergonomic design and usage.
- The position of both the pedals needs to be lowered.
- The drivers prefer the force level among different Volvo trucks to be standard. For example the force levels within different Volvo FH trucks were not same. This affects the drivers because they use different trucks during their career with the transport company. Each truck demands different force levels.
- The brake pedal shape and size was good from the drivers' opinion when compared with the accelerator pedal.

## Recommendations for driving Long-haul Trucks:

- The best possible arrangement for a long haul truck is the suspended accelerator pedal and brake pedal. Some drivers, especially long haul drivers who use the accelerator pedal continuously, prefer a floor mounted accelerator pedal because it offers excellent support for the feet.
- The curvature of the pedal needs to be altered for barefoot driving in order to increase comfort. Because barefoot driving is more common in long-haulage trucks than in other segments the curvature could assist comfortable pedal usage for those who drive long distances.
- The clearance distance between the brake and the accelerator pedal should be increased for long-haul trucks because the movements of the feet between the pedals

is much fewer when compared with those in drivers of distribution trucks. Enough leg room would increases comfort while driving on motorways.

- The clearance distance between the accelerator pedal and the engine tunnel should be increased for some drivers. This aspects needs to be investigated for further development.
- The plastic friction material on the pedals needs to be replaced with rubber because the drivers feel the accelerator pedals to be slippery when the plastic material is used.
- Adjustable pedals could increase the comfort and reachability of the shorter and taller drivers for long-haul operation. In long haul truck operation, taller and shorter drivers prefer their seat to move backwards for the most comfortable posture while driving the truck. (See figure 78) Adjustable pedals could facilitate in the customized comfort for pedal application. This aspect needs to be further investigated and evaluated in the truck during different driving sessions.

### Recommendations for Distribution Trucks:

- A floor mounted pedal could be an interesting pedal concept for distribution trucks because the drivers move their feet frequently between the pedals. The floor mounted pedal would support the feet, allow for natural foot movement between pedals and provide more comfort than suspended pedals. However, most of the drivers in the driving session do not have experience with floor mounted pedals. (See figure 79) Around 36% of the drivers prefer a floor mounted accelerator pedal and 46% of the drivers want to try a floor mounted accelerator pedal. The drivers use the trucks in different weather conditions. The floor mounted pedal offers comfort with winter shoes, boot and normal shoes. The floor mounted pedal needs to be investigated further.
- The floor mounted pedal also assists the foot movement for distribution truck drivers when driving on rural roads for distribution applications.
- The accelerator and brake pedals could be mounted in a co-planar arrangement for distribution trucks since the driver's feet move often between the pedals due to city traffic and their missions. Floor mounted accelerator pedals offer good support for the feet with comfortable pedal operation along with the suspended brake pedal.
- Most of the distribution truck drivers continuously move the foot between the pedals. The movement time between the pedals needs to be studied through Fitts law in real-time city traffic situations.

# 13. Future studies in Driving Controls

The thesis work can be continued by the ergonomics division for future developments and improvements in the driving controls.

Further investigation could be done with the floor mounted accelerator pedal in the truck to investigate and compare the contact points and positions in relationship to the suspended pedals. See the recommendations section because floor mounted pedals have become a standard in the luxury passenger car segment because of increased comfort and support. It could be interesting to evaluate the floor mounted pedal while driving with shoes and barefoot to explore the difference between the pedals in terms of Accelerator Heel Point Position (AHP). The foot position in the x-direction in the accelerator pedal and asymmetrical accelerator pedal also needs to be investigated with the simulator environment.

While investigating the floor mounted pedals, detailed studies should be done to precisely measure ankle angle in both the floor mounted and suspended pedals. The ankle angles also need to be measured separately for both the brake and accelerator pedals for comparison and subjective evaluation.

Investigation should be made with different truck drivers in Volvo FM and UD to compare the pedal usage within the brands. UD is equipped with the floor mounted pedal with the suspended mechanical support. During the investigation pressure mats could be used for measuring the forces from the suspended pedals and floor mounted pedals. The pedal arrangement in Left Hand Drive (LHD) and Right Hand Drive (RHD) also needs to be studied.

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# APPENDIX - A

| S.No | | | | | | | | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Driving Experience | 12 | 24 | | 6 | 40 | | 10 | | 10 | | |
| | **Name of the Drivers** | | | | | | | | | | | |
| | **Test Persons** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| | **Trucks** | Scania R420 | Scania R560 | Scania R500 | Volvo FH 16 | Volvo FH | Volvo FH | Volvo FH | Volvo FH | Scania R440 | Scania R124G | **Comments** |
| S.No | **Questions** | Score | | | | | | | | | | |
| | **Steering Wheel Usage** | | | | | | | | | | | |
| 1 | What is your opinion about the Steering Wheel Adjustment? | 4 | 4 | 4 | 5 | 3 | 5 | 3 | 3 | 5 | | |
| 2 | Ehat is your opinion about the force excerted by steering in different road conditions? | 3 | 3 | 4 | 2 | 5 | 5 | 5 | 4 | 5 | | |
| | | | | | | | | | | | | |
| | **Stalks** | | | | | | | | | | | |
| | | | | | | | | | | | | |
| 3 | What is your opinion about the gear stalks and switches? | 5 | 4 | 3 | 5 | 4 | 5 | 4 | 4 | 5 | | |
| 4 | What is your opinion of the stalks? | 1 | 4 | 4 | 5 | 2 | 4 | 5 | 4 | 5 | | |
| | | | | | | | | | | | | |
| | **Pedals** | | | | | | | | | | | |
| 5 | What is your opinion about position (location) of the pedals? | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 5 | | |
| 6 | Which type of Accelerator pedal do you prefer? | H | H | H | H | H | H | H | H | H | | |
| 7 | Which type of Brake or Clutch pedal do you prefer? | H | H | H | H | H | H | H | H | H | | |
| 8 | What is your opinion about the forces from the pedal? | 4 | 4 | 5 | 4 | 3 | 5 | 4 | 3 | 4 | | |
| 9 | What is your opinion about pressing the pedals for long distances in long haul trucks? | 1 | 4 | 5 | 1 | 3 | 5 | 4 | 3 | 4 | | |
| | | | | | | | | | | | | |
| | **Gear Shifter** | | | | | | | | | | | |
| 10 | What is your opinion about location/position of the gear shifter? | S | S | S | S | S | S | S | S | S | | |
| 11 | What is your opinion about the forces needed for changing gears? | 5 | 4 | 2 | 4 | 5 | 5 | 4 | 2 | 4 | | |
| 12 | What is your opinion about the range and split switches in gear knob? | 4 | 4 | 5 | 4 | 5 | 5 | 4 | 4 | 4 | | |
| 13 | What is your opinion about changing from lower gear to higher gear? | 4 | 5 | 4 | 3 | 5 | 5 | 2 | 4 | 5 | | Time lag in downshifting from 6th to 1st ----> 7th Driver |
| 14 | What is your opinion about changing from higher gear to lower gear? | 5 | 4 | 4 | 2 | 5 | 5 | 2 | 2 | 4 | | Time lag in downshifting from 6th to 1st ----> 7th Driver |
| 15 | Do you prefer high forces from the controls? | Y | N | N | N | N | Y | N | N | Y | | |

# APPENDIX - B

**Data Collection**

**Background Details**

**Driver**

**Name :**

**Age (years) : Height (cm) :**

**Experience as truck driver: (Number of years)**

**Experience as truck driver: (distance per year)**

**How long have you driven this truck : (years)**

**Which Year the Truck was bought?**

**Which Truck (make, model) :**

**Have you driven other trucks, in that case which? (Make, Model):**

**Vehicle Condition: □Very Old □Old □Good □New**

**Truck Application: □ Long Haul □ Distribution □ Construction □ Several**

**Road Conditions:**

**□Smooth □ Rough □ Flat □ Hill □Straight □ Winding □ Bumpy □ Sand Roads □ Gravel Roads**

**Weather Conditions : □ Dry □ Wet □ Slippery**
**Outside Temperature :**

Steering wheel

1) What is your general opinion about how easy it is to use the steering wheel in this truck?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………………………

2) What aspects do you think are important when using the steering wheel?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

3) What is your opinion about the size, shape, material and position of the steering wheel?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

4) What is your opinion about the forces while using the steering wheel?

a) In Bumpy Road Conditions (Low speeds)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

b) In Bumpy Road Conditions (High Speeds)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

c) In Windy Road Conditions (Low Speeds)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

d) In Windy Road Conditions (High Speeds)

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………

5) What is your opinion about how much you need to ROTATE the STEERING WHEEL in different driving conditions?

a) Slow Speeds

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

b) In Higher Speeds

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………

6) What is your opinion about the feeling and feedback you get from the steering wheel while driving in different conditions

a) Low Speeds?

□Poor □Fair □Good □Very Good □Excellent

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

b) High Speeds?

□Poor □Fair □Good □Very Good □Excellent

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

c) Bumpy Roads?

□Poor □Fair □Good □Very Good □Excellent

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……………………………………………………………………………………………
……………………………………………………………………………………………

d) High Friction

□Poor □Fair □Good □Very Good □Excellent

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

e) Low Friction

□Poor □Fair □Good □Very Good □Excellent

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………

f) Windy Conditions

□Poor □Fair □Good □Very Good □Excellent

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……………………………………………………………………………………………
……………………………………………………………………………………………

7) What is your opinion about the stability of the steering wheel? (Force required to return to straight forward position, contact with the road, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

8) What is your opinion about gripping comfort when using the steering wheel in different driving conditions? (Longer time-periods of long-haulage, distribution in dense city traffic, construction work on bumpy roads, low speed manoeuvring)

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

9) What is your opinion about vibrations from the steering wheel? (at high speeds, at low speeds, in bumpy conditions, at stand-still)

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………

10) What is your opinion about using the steering wheel in different driving conditions?

a) long-haulage for longer time periods

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

b) Distribution in dense city traffic

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………

c) Bumpy construction driving

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………
d) Low speed manoeuvring

□Poor □Fair □Good □Very Good □Excellent

Why?
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……………………………………………………………………………………………
……………………………………………………………………………………………

11) What is your opinion about the input you can receive about the road conditions via the steering wheel? (high / low friction, driving over a pot-hole, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?
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……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

12) Are there other aspects about using the steering wheel that we should have asked about?

□ Yes □ No

If yes, list them below:
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……………………………………………………………………………………………

Pedals (accelerator, brake, clutch)

13) What is your opinion about how easy it is to use the pedals in this truck?

□Poor □Fair □Good □Very Good □Excellent

Why?
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

14) What is your opinion about the force levels when using these pedals?

□Poor □Fair □Good □Very Good □Excellent

Why?
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

15) What is your opinion about the strokes needed for using the pedals?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………………
…………………………………………………………………………………………………

16) What is your opinion about the available foot clearance for using the pedals (accelerator, brake, clutch) against the steering column?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
…………………………………………………………………………………………………

17) What are the aspects do you think are most important when using the pedals?

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Accelerator Pedal

18) Accelerator Pedal: What is your opinion about the size, shape and friction of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
…………………………………………………………………………………………………

19) Accelerator Pedal: What is your opinion about the position of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
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20) Accelerator Pedal: What is your opinion about the **STROKE** of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………

21) Accelerator Pedal: What is your opinion about the **FORCES** for using the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
…………………………………………………………………………………………………

22) Accelerator Pedal: What is your opinion about the feeling within the pedal? (Response from the vehicle based on your action)

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

23) Accelerator Pedal: What is your opinion about how comfortable the pedal is against your shoe / foot?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

24) Accelerator Pedal: What is your opinion about using the pedals in conditions where the cab moves or vibrates? (Bumpy or shaky conditions)

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

25) Accelerator Pedal: What is your opinion about using the pedals in different driving conditions? (Long distances, active driving in dense traffic, low speed manoeuvring)

□Poor □Fair □Good □Very Good □Excellent

Why?

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26) Accelerator Pedal: What is your opinion about the quality of the information you receive from the pedal regarding different road conditions? (Low / high friction, pot-holes, stones / sand / snow in the way, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?

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Are there any other aspects about using the accelerator pedal that we should have asked about?

□ Yes □ No

If yes, list them here:

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Brake Pedal

27) Brake Pedal: What is your opinion about the size, shape and friction of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

28) Brake Pedal: What is your opinion about the position of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

29) Brake Pedal: What is your opinion about the **STROKE** of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

30) Brake Pedal: What is your opinion about the **FORCES** for using the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

31) Brake Pedal: What is your opinion about the feeling within the pedal? (Response from the vehicle based on your action)

□Poor □Fair □Good □Very Good □Excellent

Why?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

32) Brake Pedal: What is your opinion about how comfortable the pedal is against your shoe / foot?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

33) Brake Pedal: What is your opinion about using the pedals in conditions where the cab moves or vibrates? (Bumpy or shaky conditions)

□Poor □Fair □Good □Very Good □Excellent

Why?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

34) Brake Pedal: What is your opinion about using the pedals in different driving conditions? (Long distances, active driving in dense traffic, low speed manoeuvring)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

35) Brake Pedal: What is your opinion about the quality of information you receive from the pedal about different road conditions? (Low / high friction, pot-holes, stones / sand / snow in the way, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?
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36) Are there other aspects about using the pedals that we should have asked about?

□ Yes □ No

If yes, list them here:
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Clutch Pedal

37) Clutch Pedal: What is your opinion about the size, shape and friction of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

38) Clutch Pedal: What is your opinion about position of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

39) Clutch Pedal: What is your opinion about the **STROKE** of the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

40) Clutch Pedal: What is your opinion about the **FORCES** for using the pedal?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

41) Clutch Pedal: What is your opinion about the feeling within the pedal? (Response from the vehicle based on your action)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

42) Clutch Pedal: What is your opinion about how comfortable the pedal is against your shoe / foot?

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

43) Clutch Pedal: What is your opinion about using the pedals in conditions where the cab moves or vibrates? (Bumpy or shaky conditions)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

44) Clutch Pedal: What is your opinion about using the pedals in different driving conditions? (Long distances, active driving in dense traffic, low speed manoeuvring)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

45) Clutch Pedal: What is your opinion about the quality of information you get from the pedal about different road conditions? (Low / high friction, pot-holes, stones / sand / snow in the way, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

46) Are there other aspects about using the pedals that we should have asked about?

□ Yes □ No

If yes, list them here:

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…………………………………………………………………………………………
…………………………………………………………………………………………
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Gear lever (manual or automatic)

47) What is your opinion about using the gear lever in this truck?

□Poor □Fair □Good □Very Good □Excellent

Why?

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…………………………………………………………………………………………
…………………………………………………………………………………………

48) What aspects do you think are most important when using a gear lever?

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…………………………………………………………………………………………

49) What is your opinion about the force levels when using the gear lever? (Forwards / backwards as well as sideways, to engage different gears, in different driving conditions, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

50) What is your opinion about the comfort of the gear lever? (Size, Shape and material)

□Poor □Fair □Good □Very Good □Excellent

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

51) What is your opinion about how easy it is to use the gear lever?

□Poor □Fair □Good □Very Good □Excellent

Why?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

52) What is your opinion about the position of the gear lever?

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

53) What is your opinion about the comfort of the gear knob? (amount of roundness against the palm when holding the gear knob)

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

54) What is your opinion about the strokes of the gear lever?

A) Forwards

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

B) Backwards

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

C) Sideways

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………

55) What is your opinion about how easy it is to understand from the gear lever which gear is activated? (see or feel)

□Poor □Fair □Good □Very Good □Excellent

Why?

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……………………………………………………………………………………………
……………………………………………………………………………………………

56) What is your opinion about vibrations you might feel via the gear lever? (from road conditions, from engine, at speed / at stand-still, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

57) What is your opinion about the feedback you get via the gear lever? (What gear you are in, that a gear is properly engaged, where you are in the gear shift pattern, etc.)

□Poor □Fair □Good □Very Good □Excellent

Why?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

58) What is your opinion about how quickly the drive-line changes gear after selecting a new gear with the gear lever?

□Poor □Fair □Good □Very Good □Excellent

Why?
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…………………………………………………………………………………………………
…………………………………………………………………………………………………

59) Are there specific road conditions when gear-shifting is more difficult? (More time-critical, harder, etc.)

□ Yes □ No

If yes, list these:
…………………………………………………………………………………………………
…………………………………………………………………………………………………
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…………………………………………………………………………………………………
………………………………………………………………………………………………

60) Do you find any difficulty in up shifting? (Changing from lower gear to higher gear)

□ Yes □ No

If yes, list these:
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………………

61) Do you find any difficulty in down-shifting? (Changing from a higher gear to a lower gear)

□ Yes □ No

If yes, list these:
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

62) Are there specific weather conditions when gear-shifting is more difficult? (Windy, slippery, warm / cold, etc.)

□ Yes □ No

If yes, list these:

……………………………………………………………………………………………
……………………………………………………………………………………………
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……………………………………………………………………………………………
………………………………………………………………………………………

63) Are there other aspects about using the gear lever that we should have asked about?

□ Yes □ No

If yes, list them here:

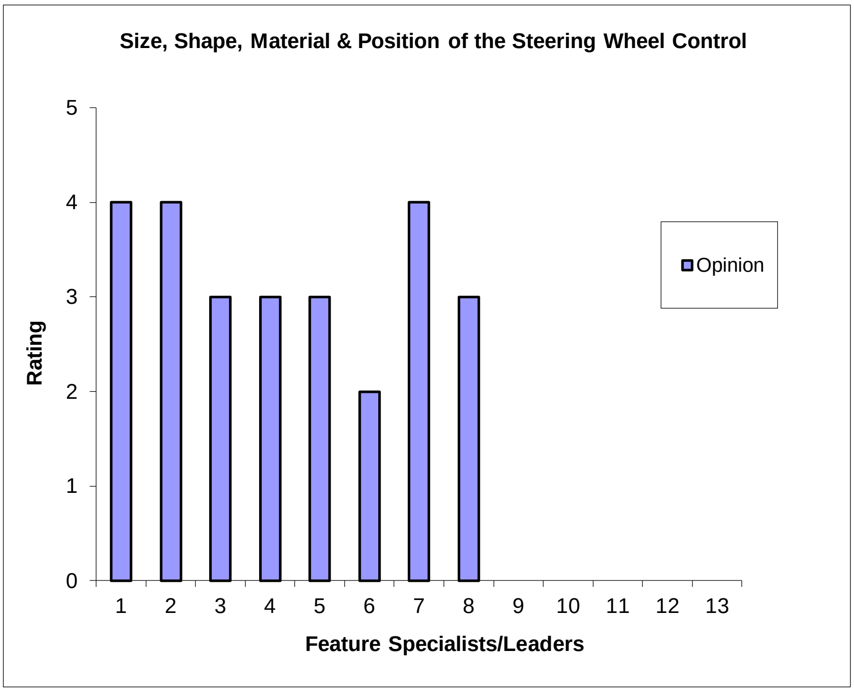
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………

# APPENDIX - C

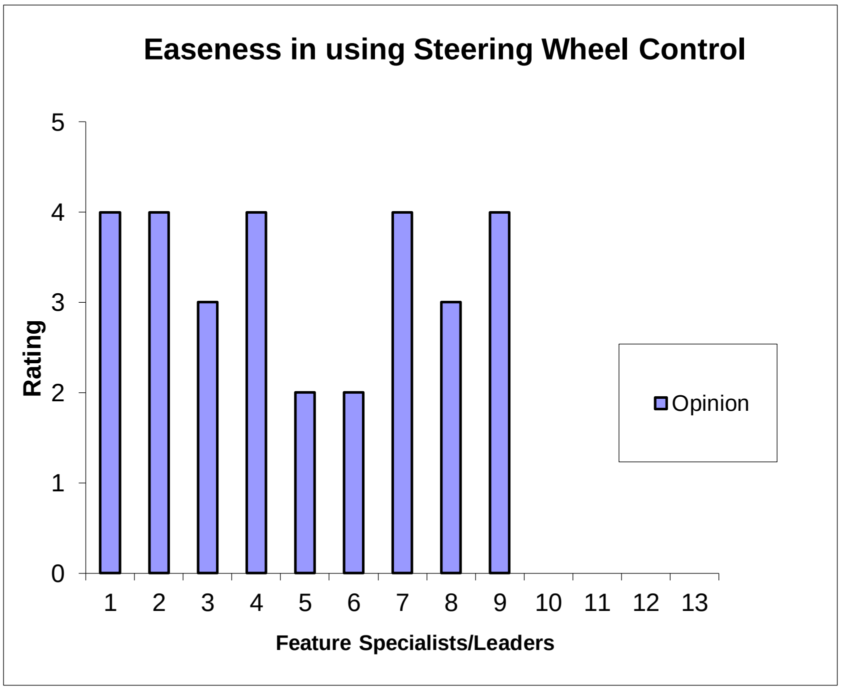
Results of Data Collection Phase

The results from the interviews with Feature Specialists & Feature Leaders

1) Size, Shape, Material & Position of the steering Wheel

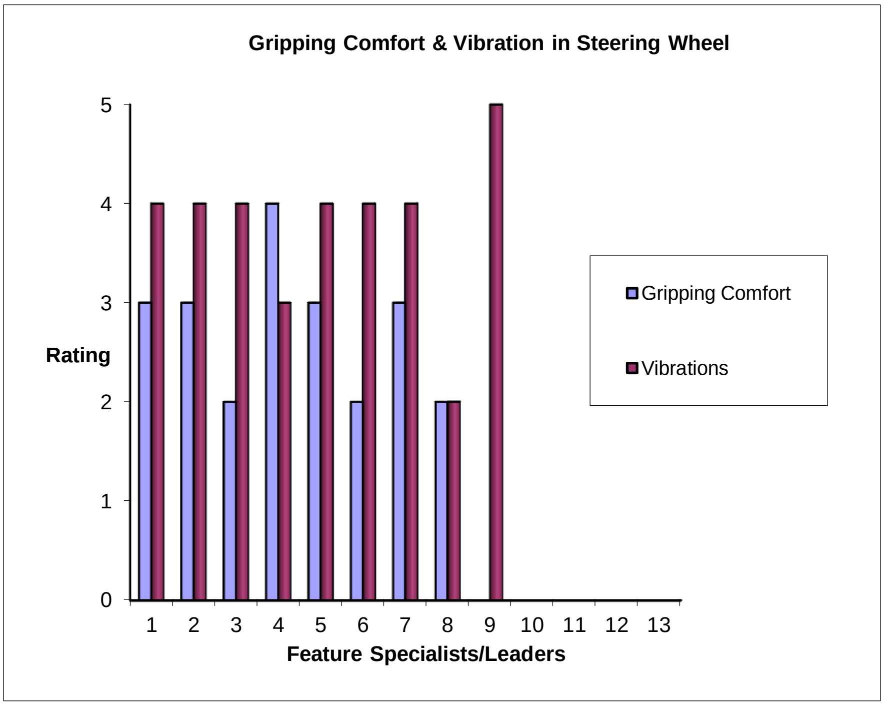



2) Easiness in using steering wheel control

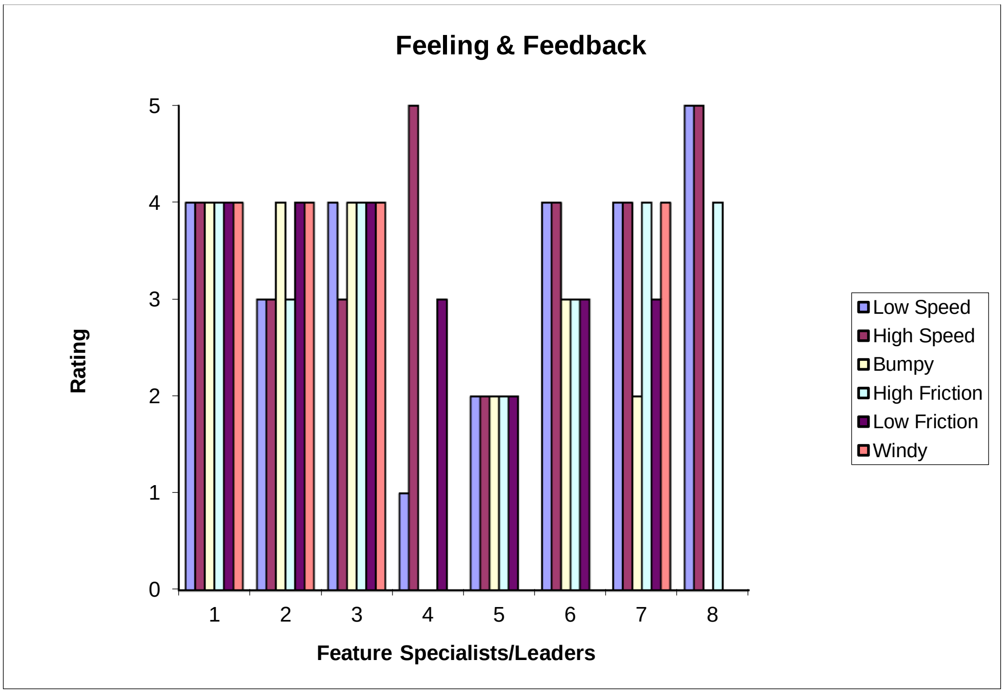


3) Rotation of the steering wheel

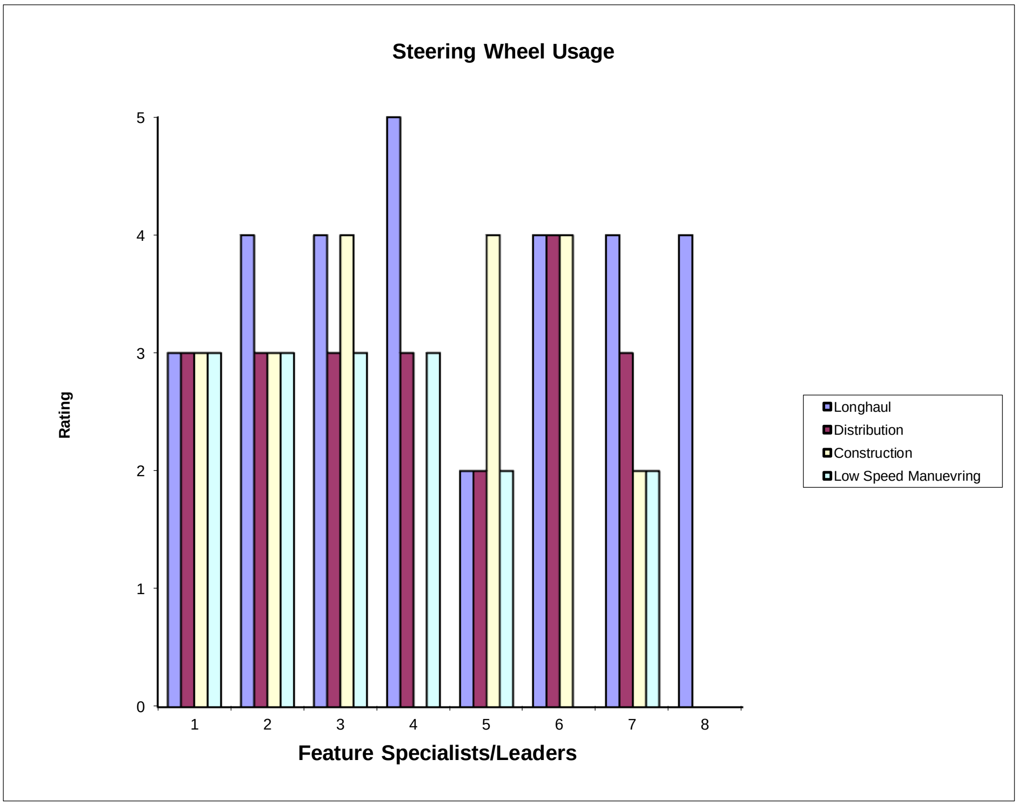

4) Gripping comfort and vibrations from the steering wheel



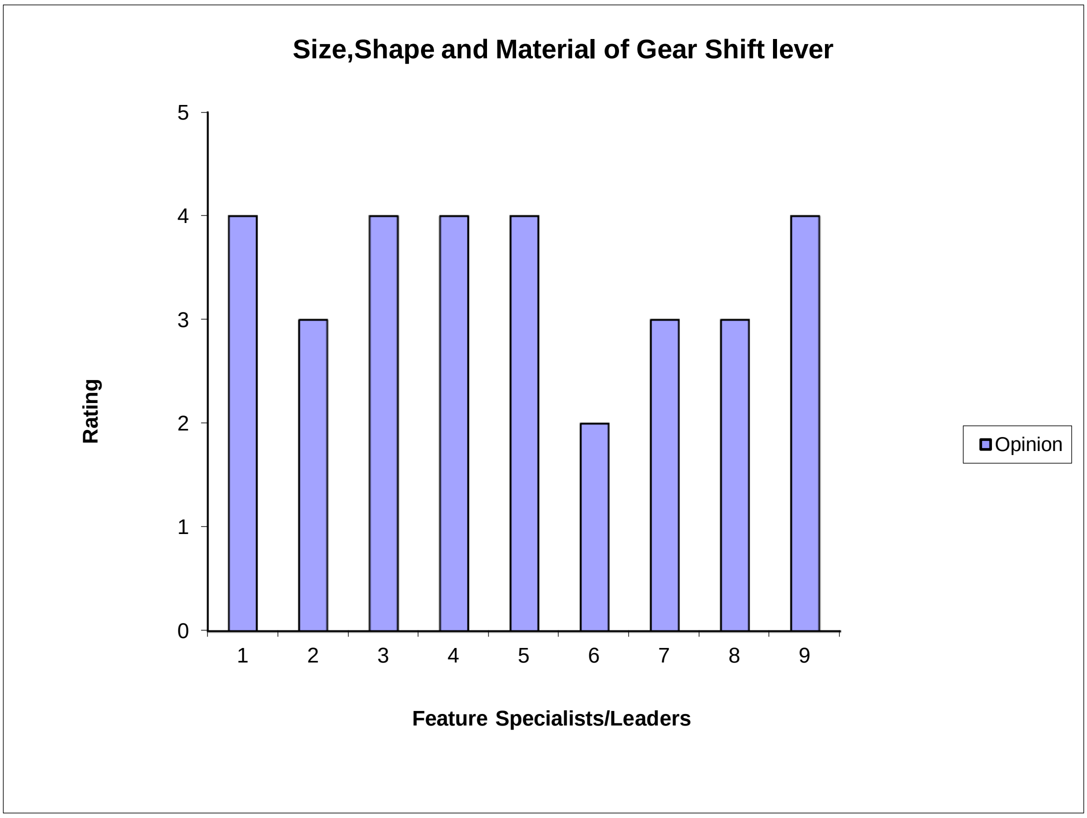
5) Feeling and feedback from steering wheel usage



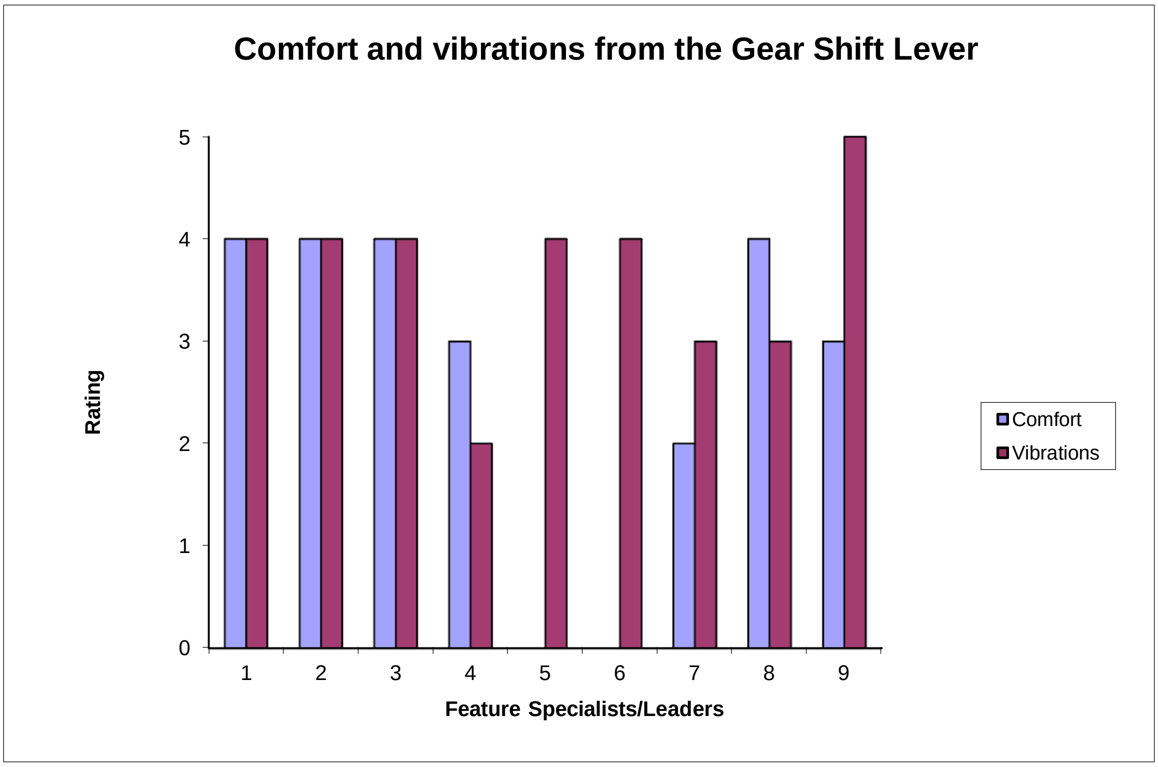

6) Stering wheel usage in different vehicle applications



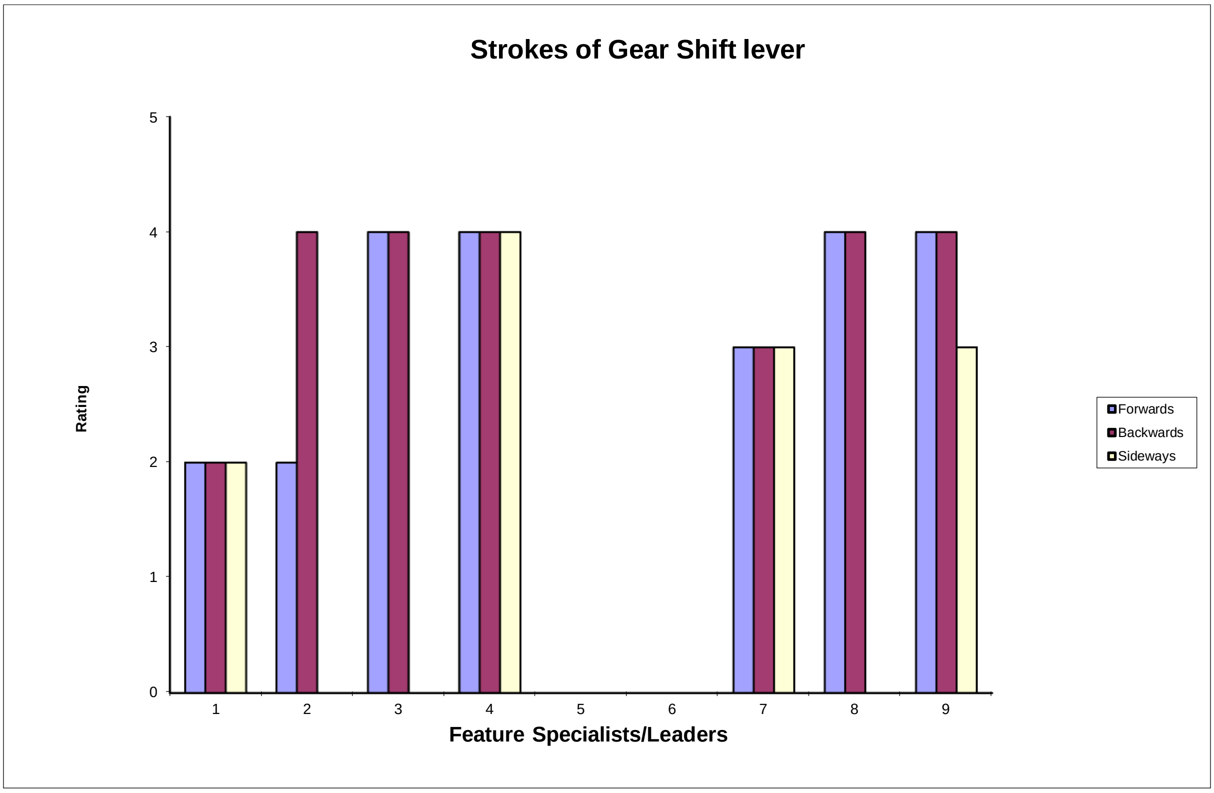
7) Shape , Size and Material of Gear Shift Lever



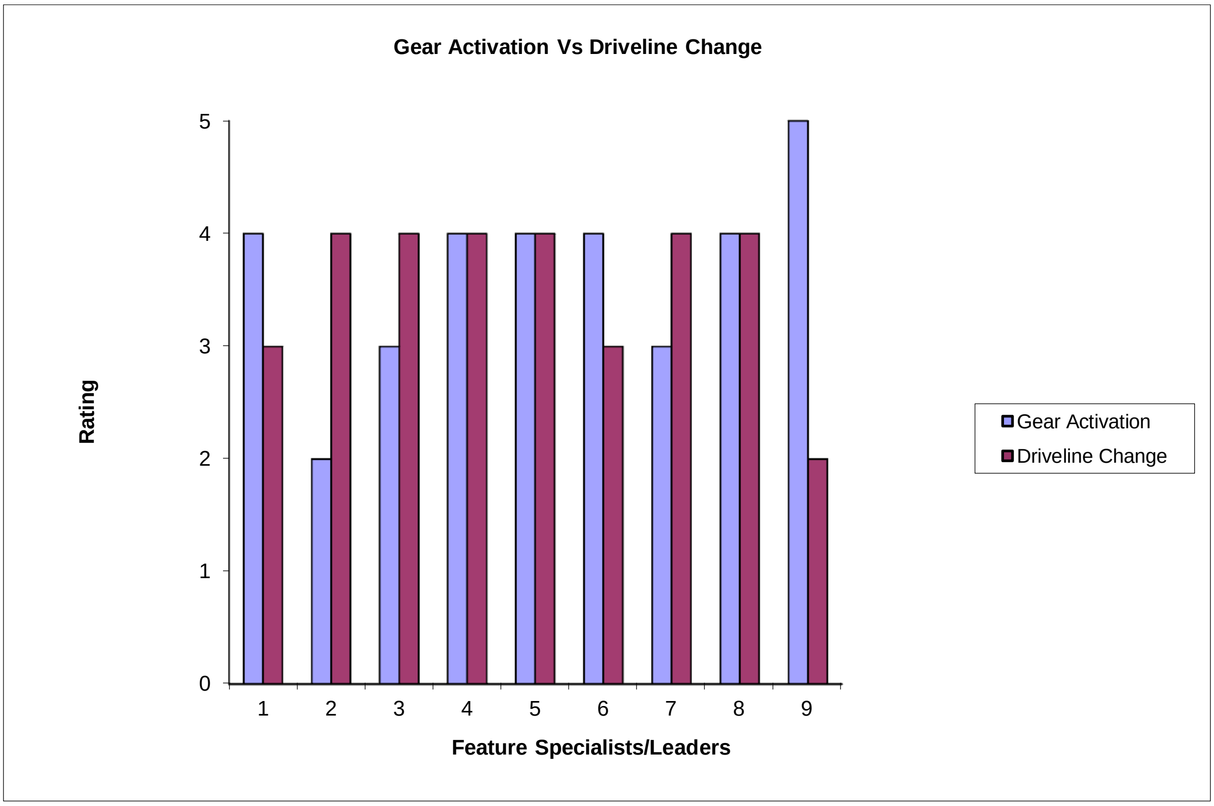

8) Comfort and vibrationsfrom the gear shift lever



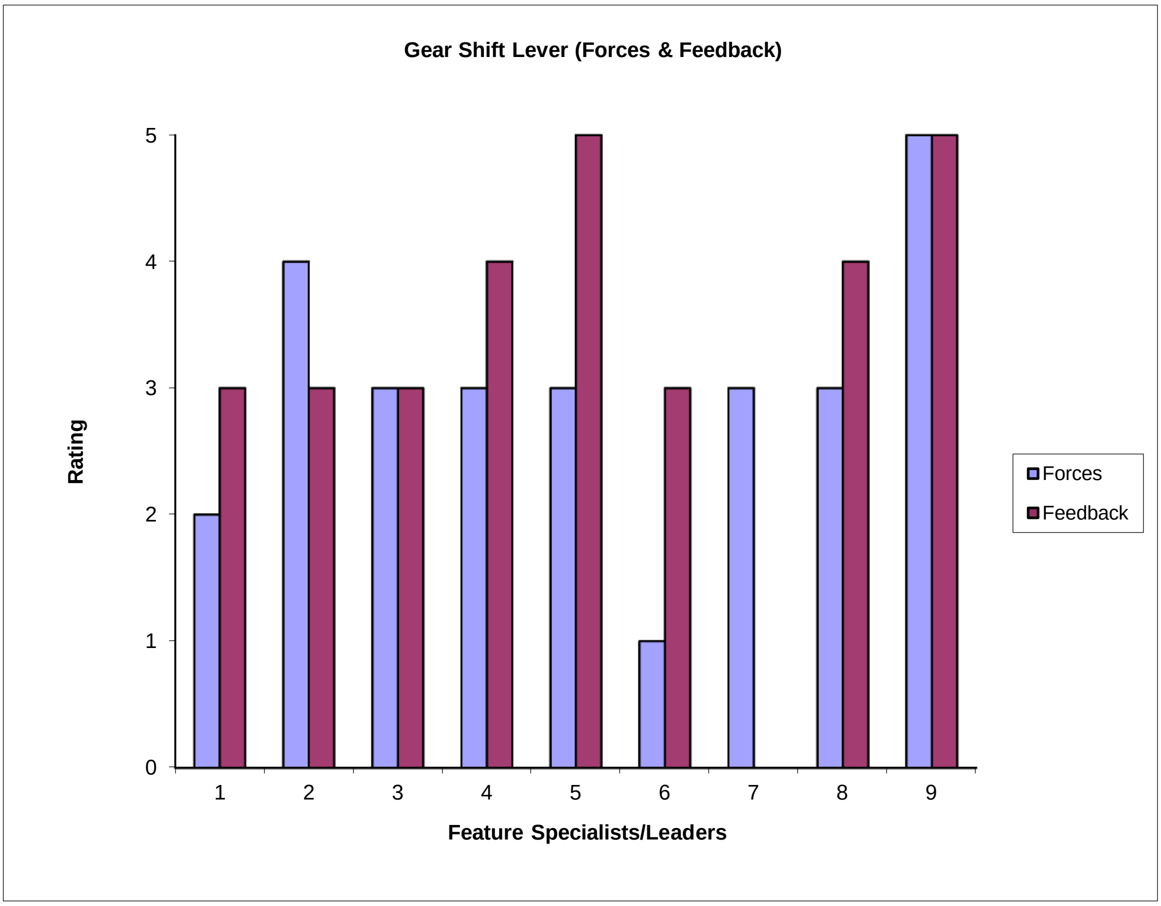
9) Strokes of the Gear Shift Lever



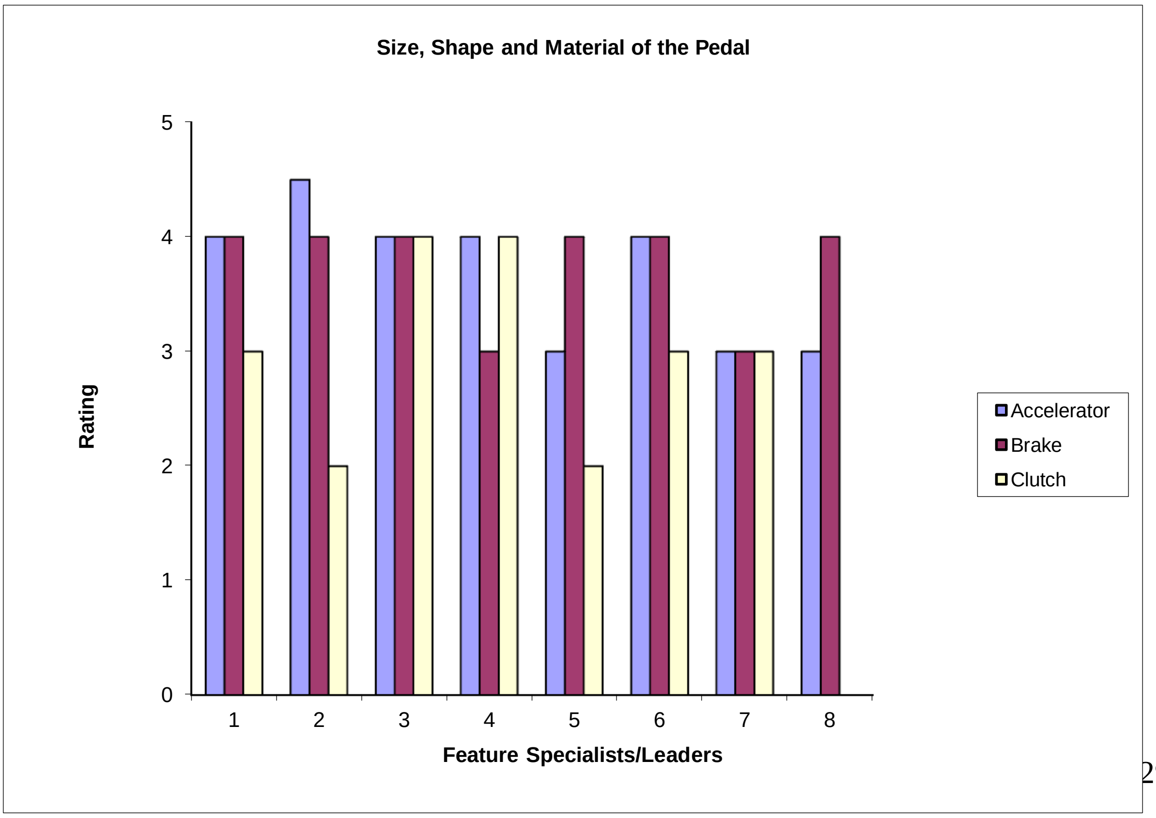

10) Driver line change and Gear Activation



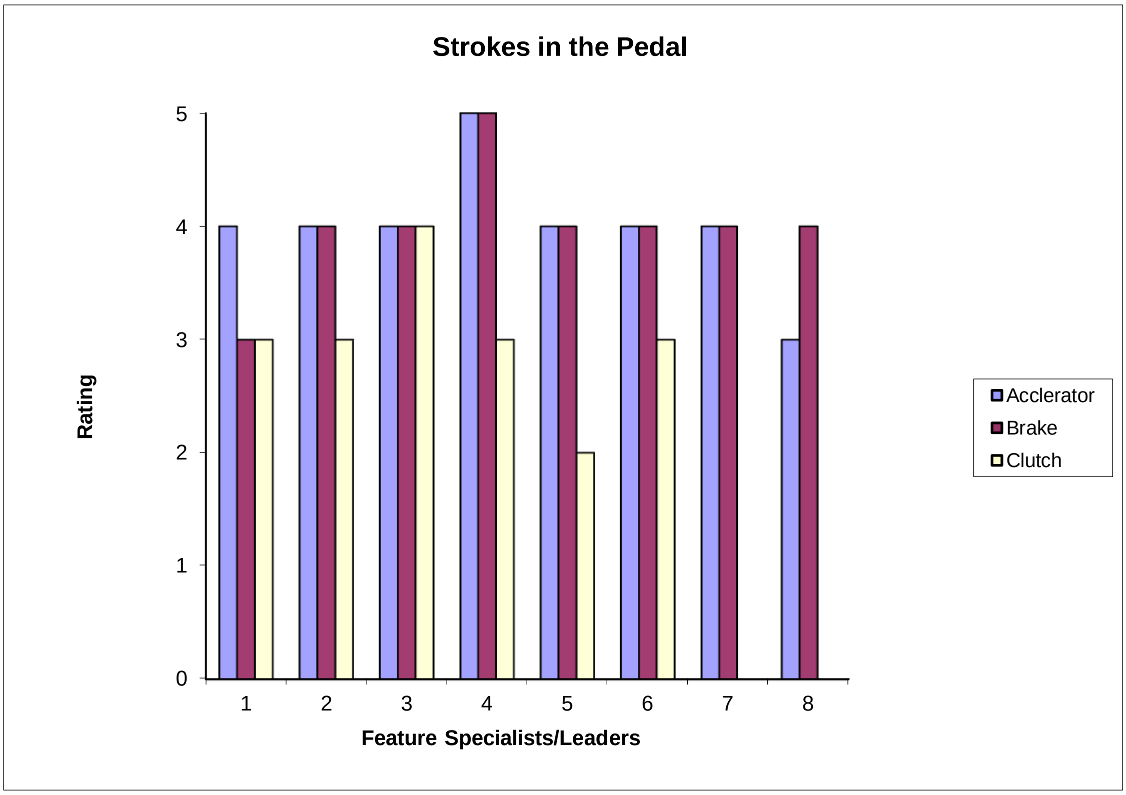
11) Forces and feedback from the Gear Shift Lever



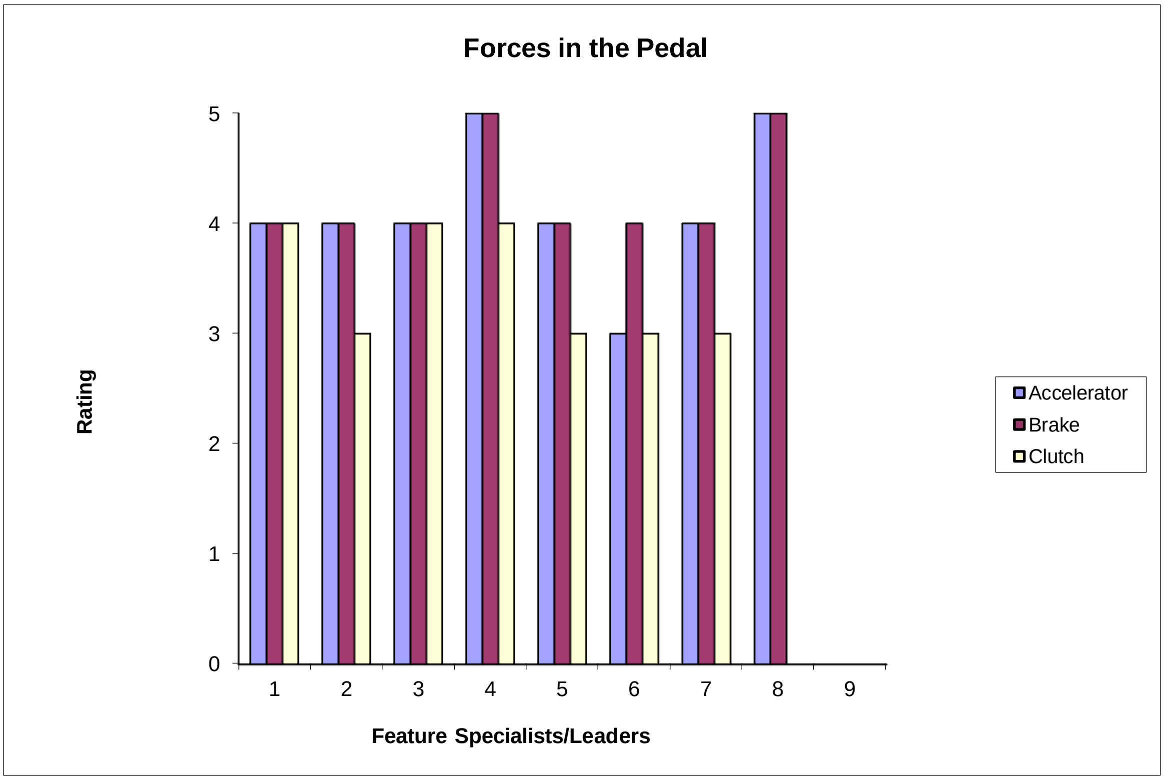

12) Size, Shape and Material of the Pedal

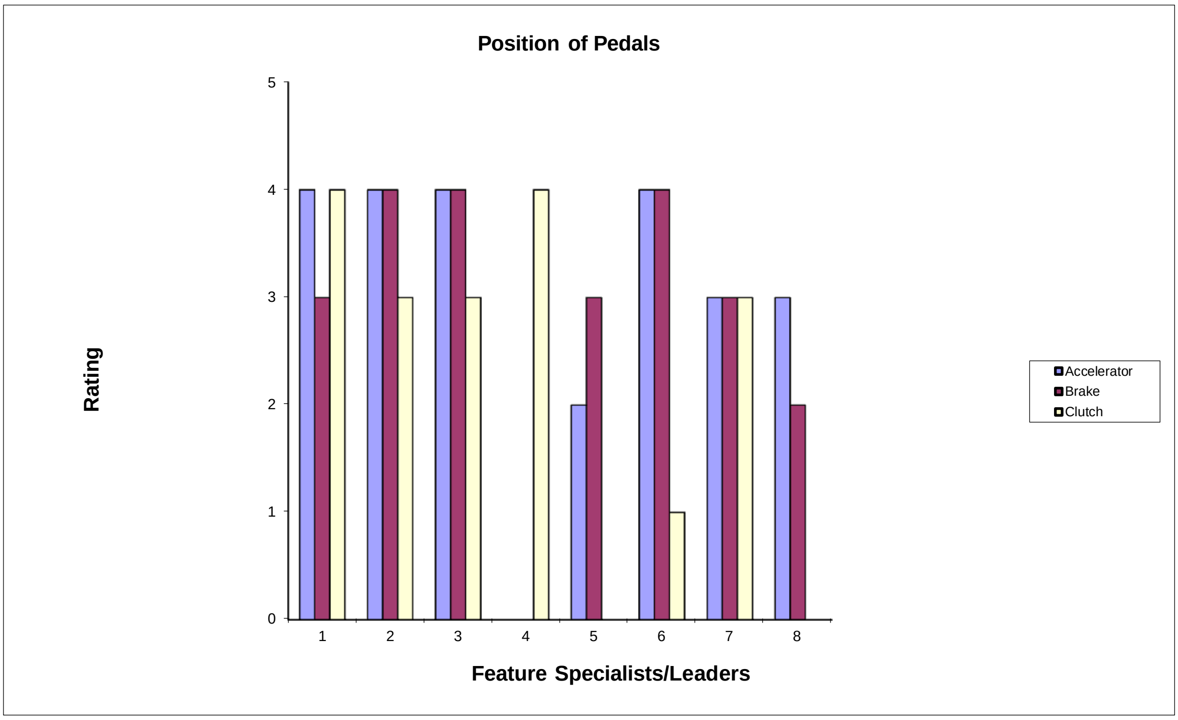


13) Strokes in the Pedals

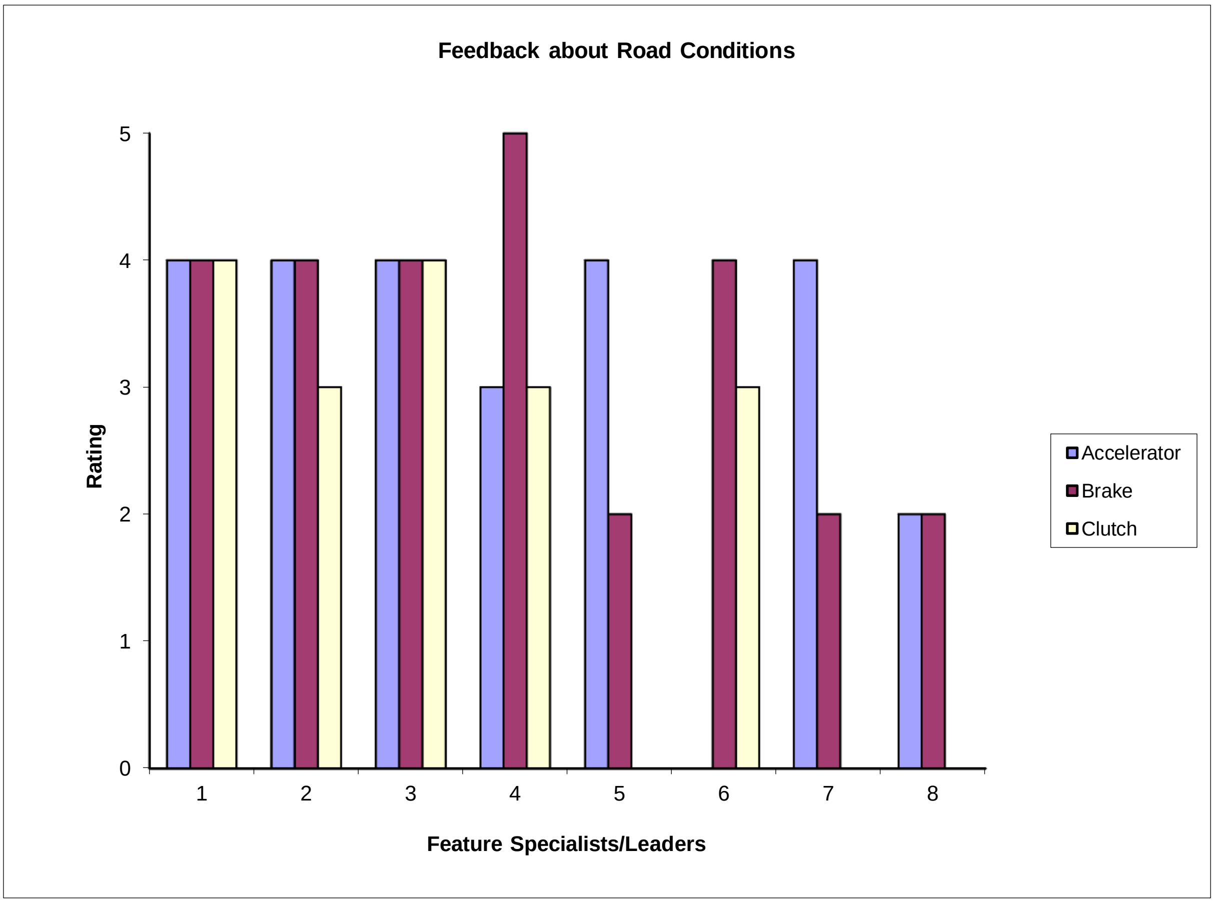



14) Forces in the Pedal

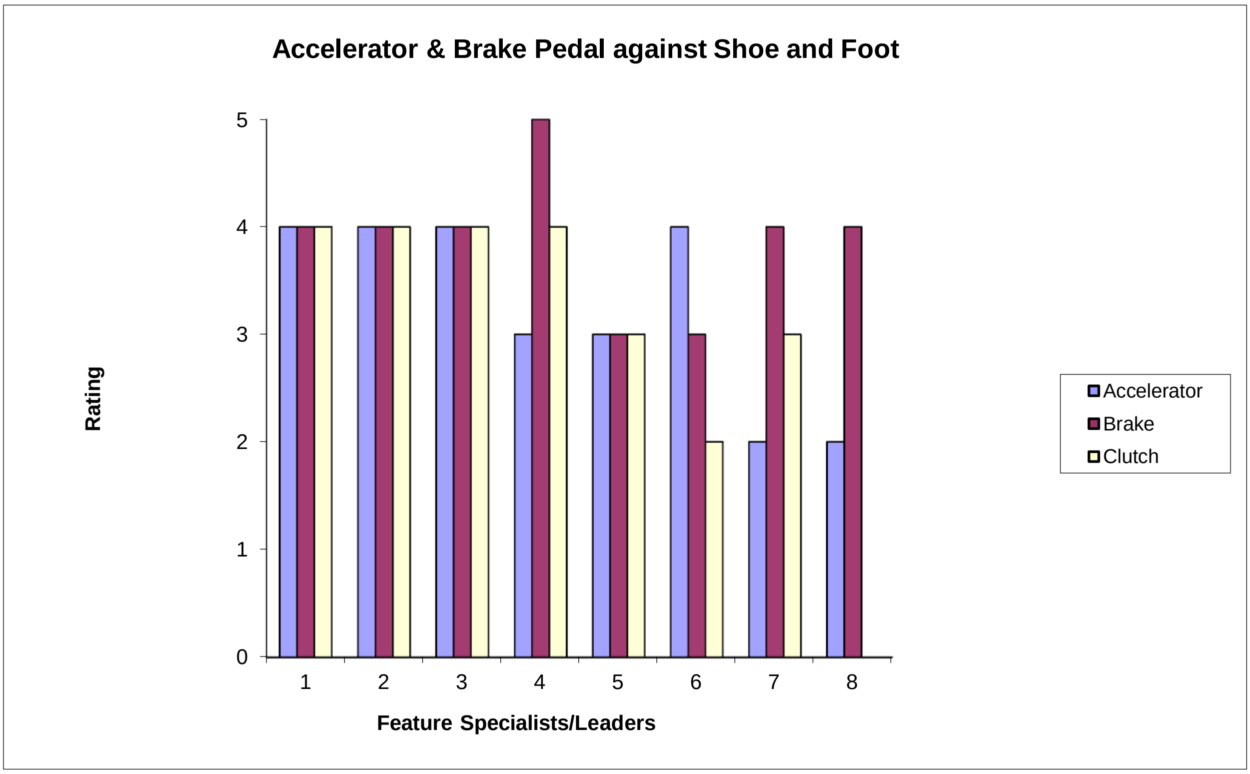





16) Feedback about road conditions

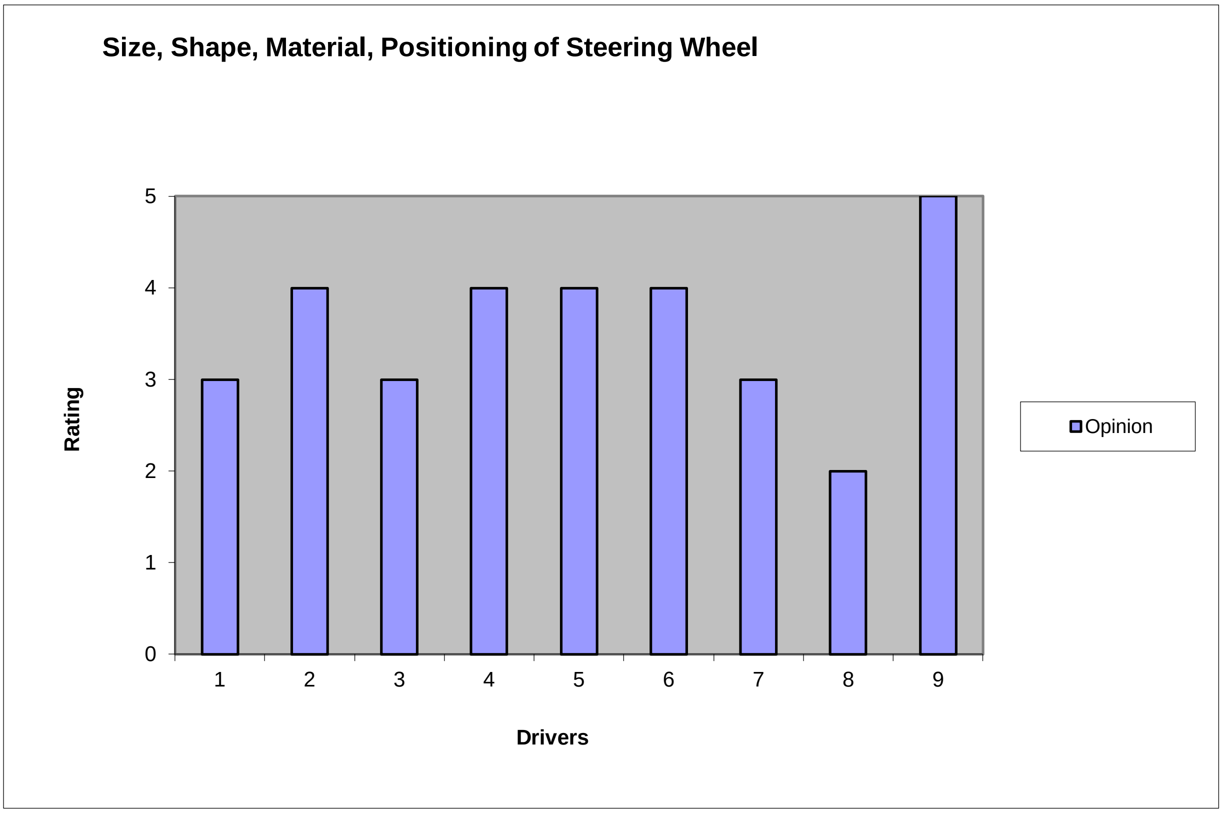


17) Overall opinion about the Pedals against shoe & barefoot

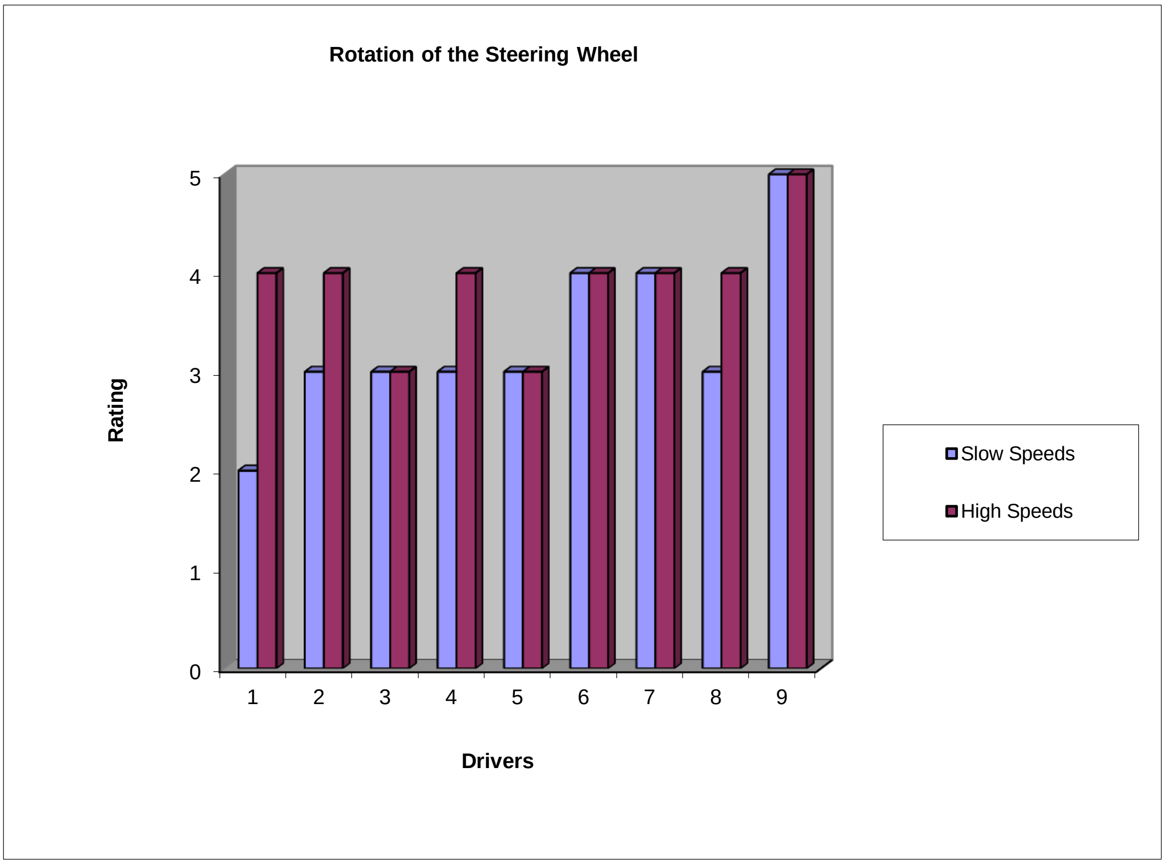



The results from the interviews with Test Technicians & Truck Drivers

1) Size, Shape, Material and Position of the Steering Wheel

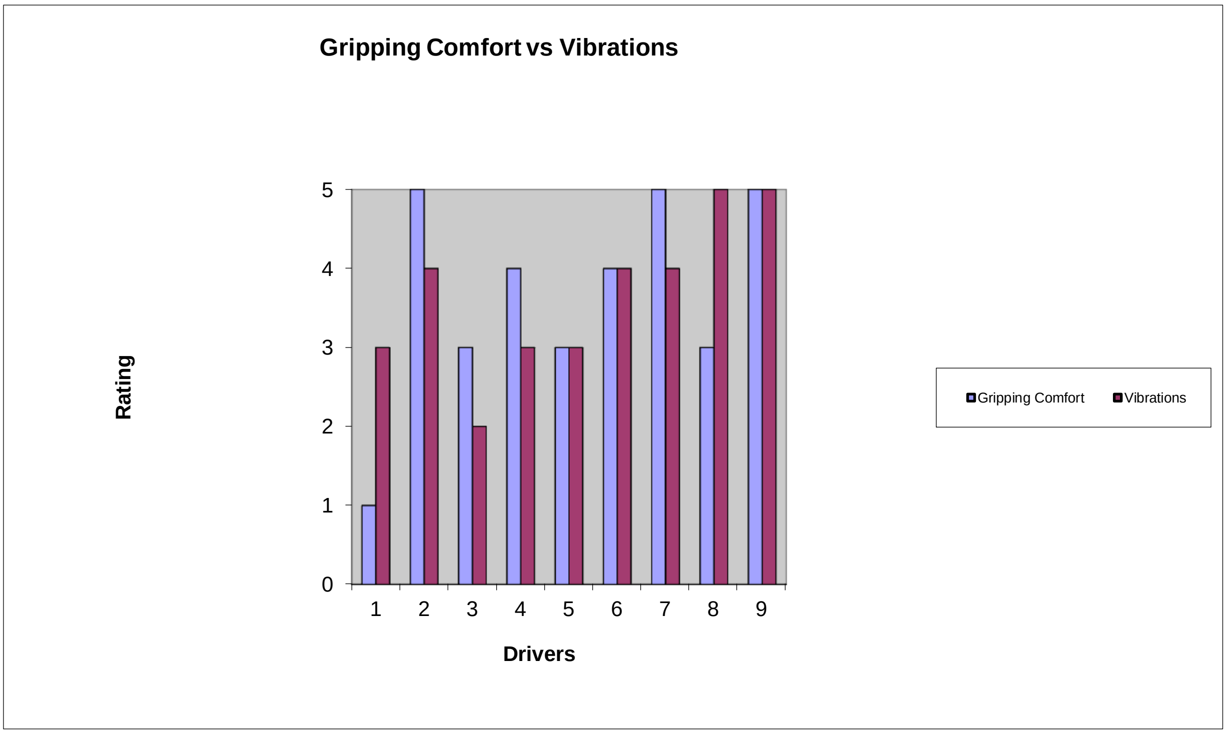


3) Rotation of the steering wheel control

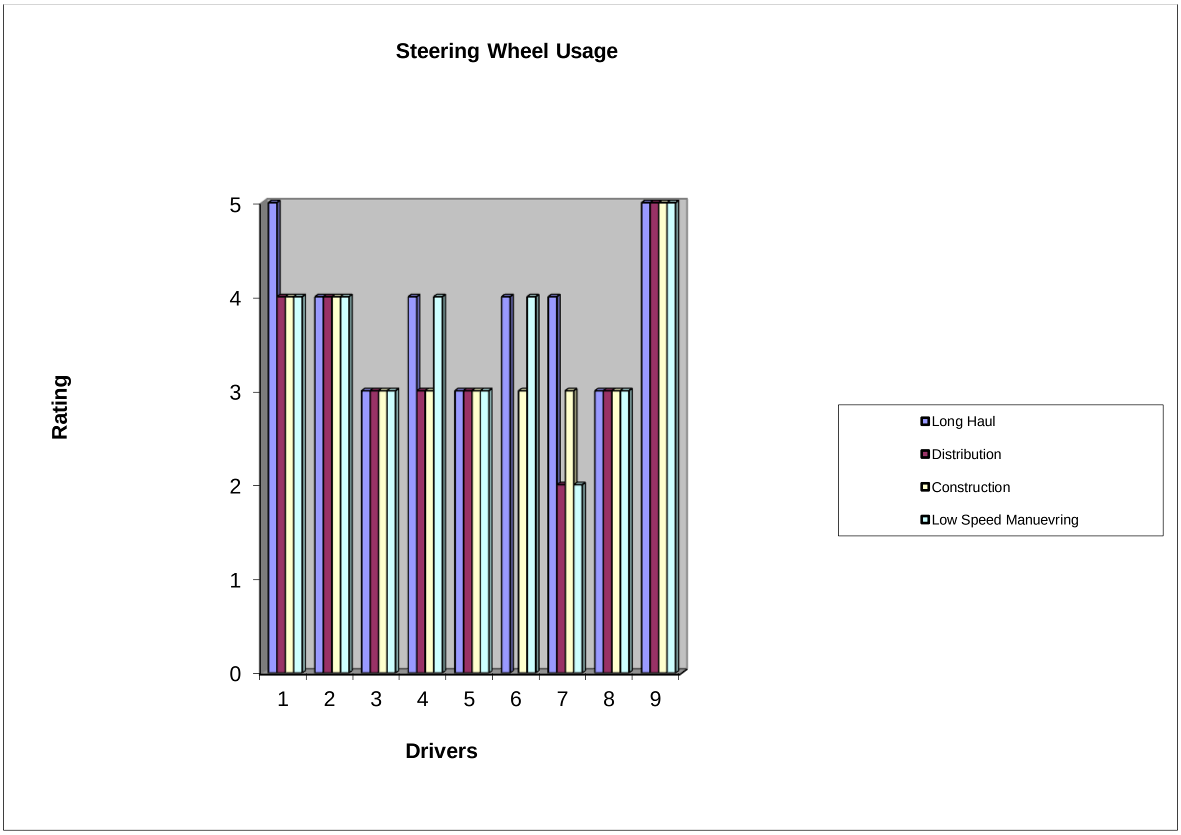



4) Feeling & Feedback from the steering wheel control at different speeds

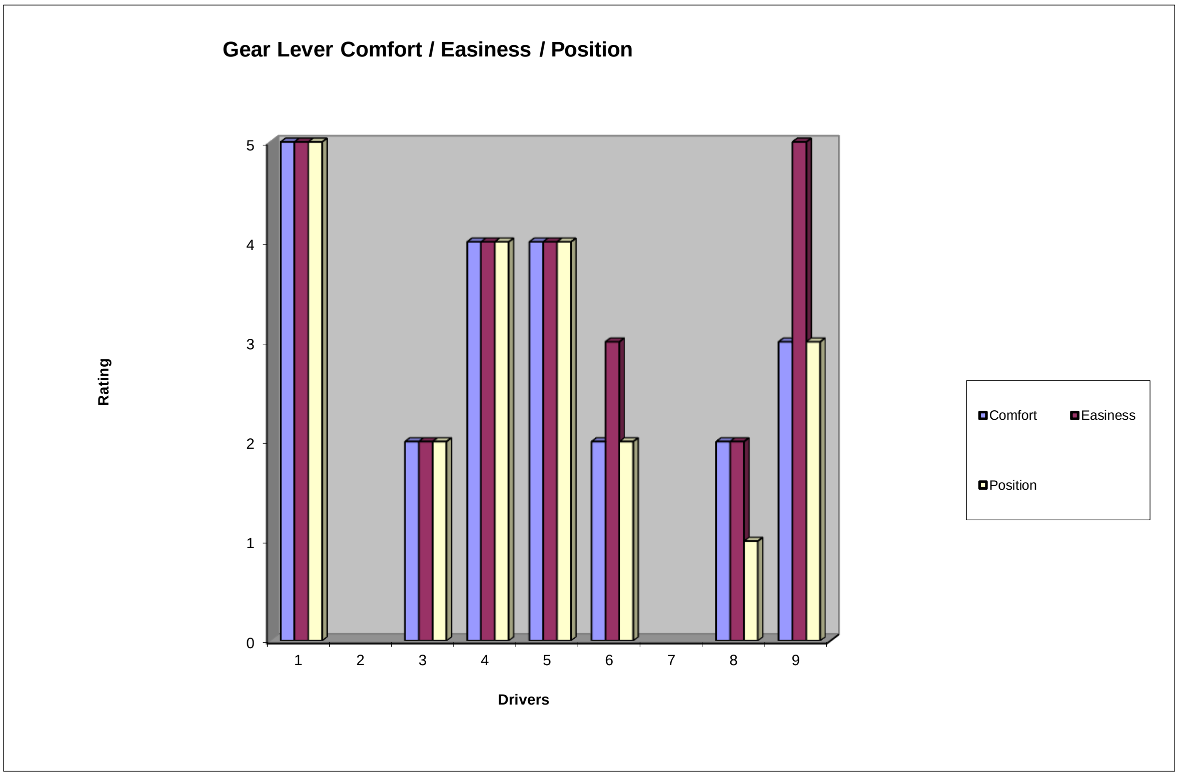
5) Gripping comfort and vibrations from the steering wheel



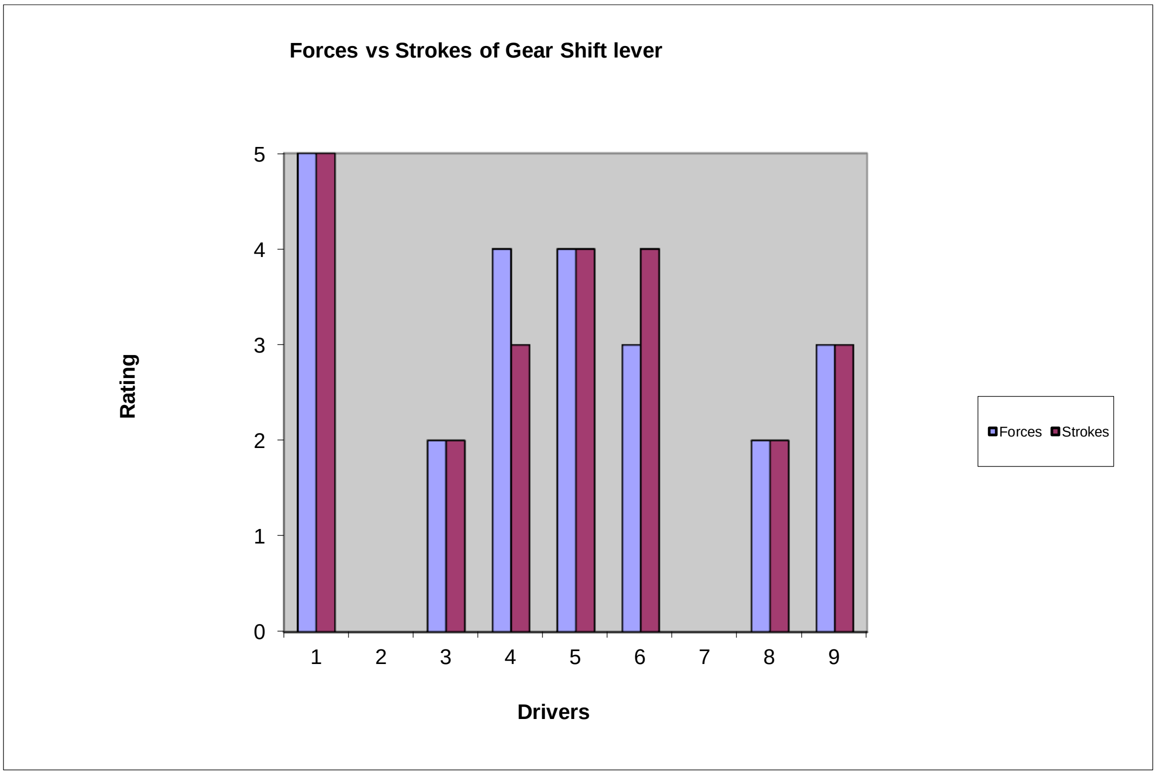

6) Steering wheel usage in different vehicle applications



7) Comfort, Easiness and Position of the Gear Shift Lever

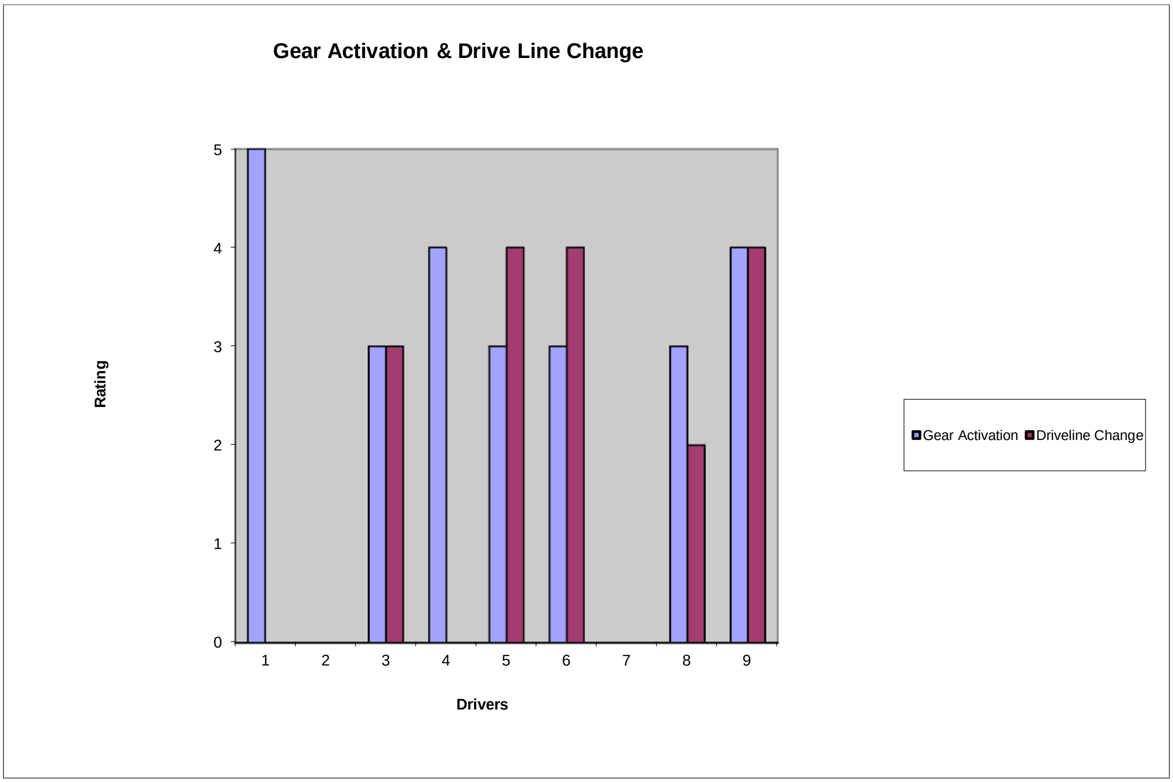



8) Forces and Strokes of the Gear Shift Lever

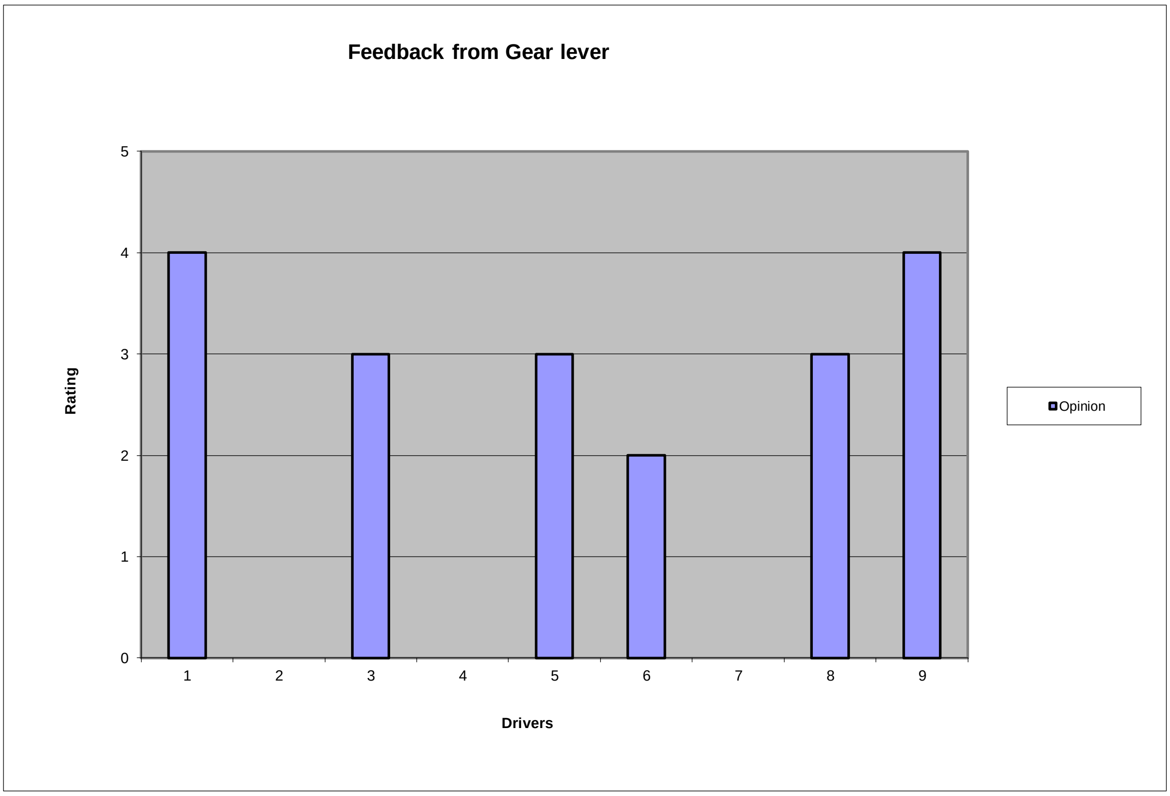


9) Gripping comfort and vibrations from the gear shift lever

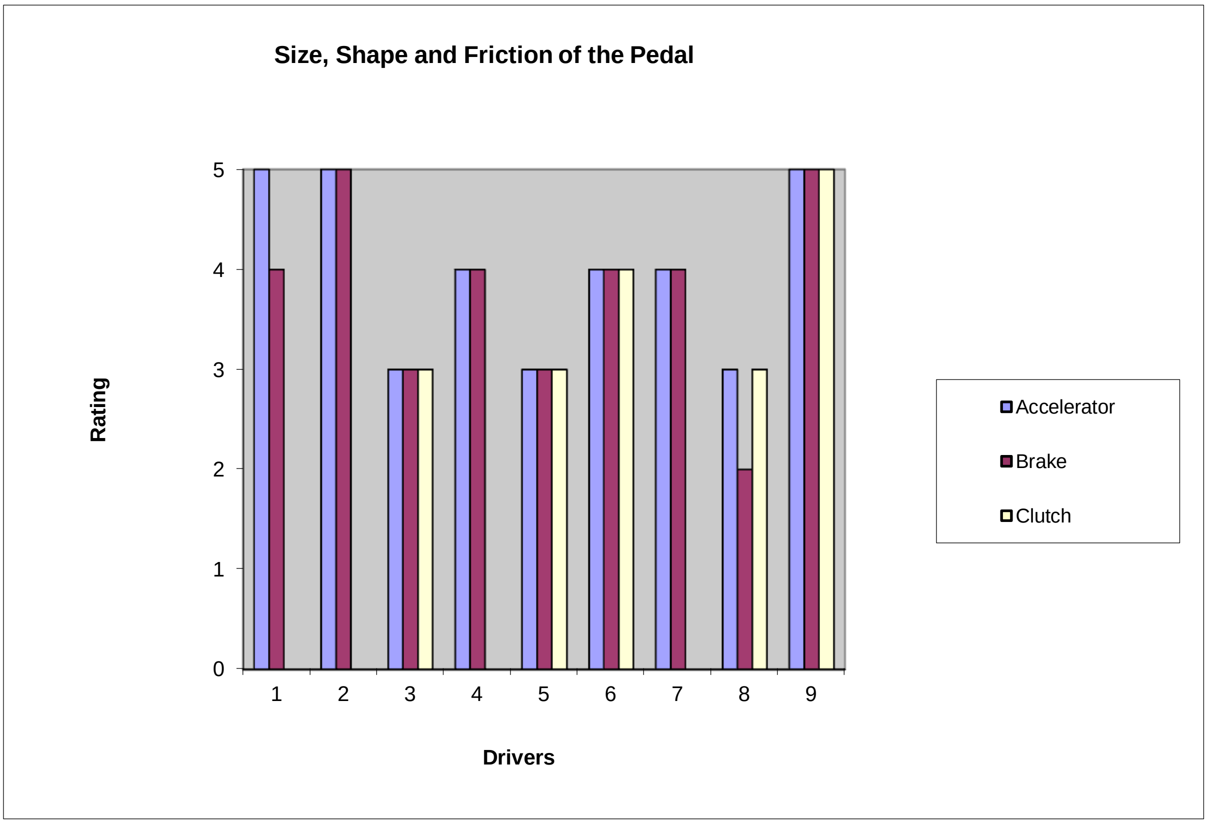

10) Gear activation and drive line change in the gear shift Lever



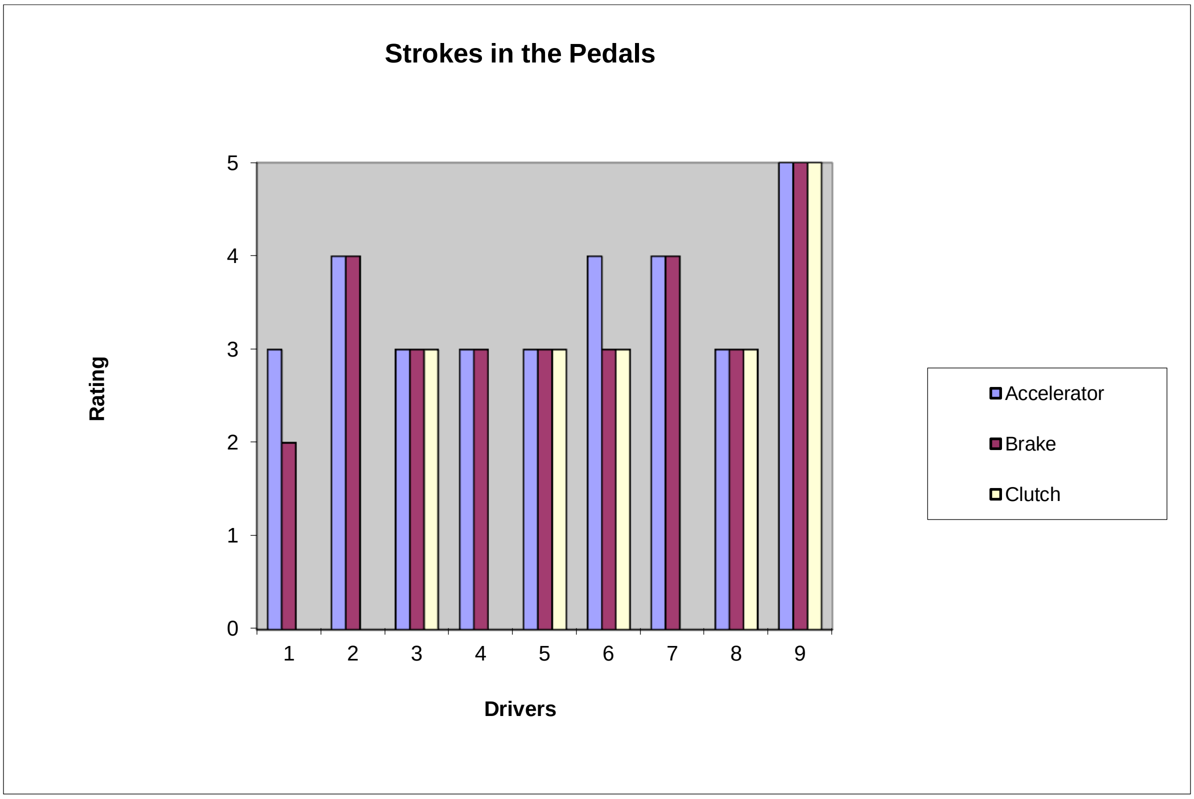
11) Feedback from the Gear Shift lever



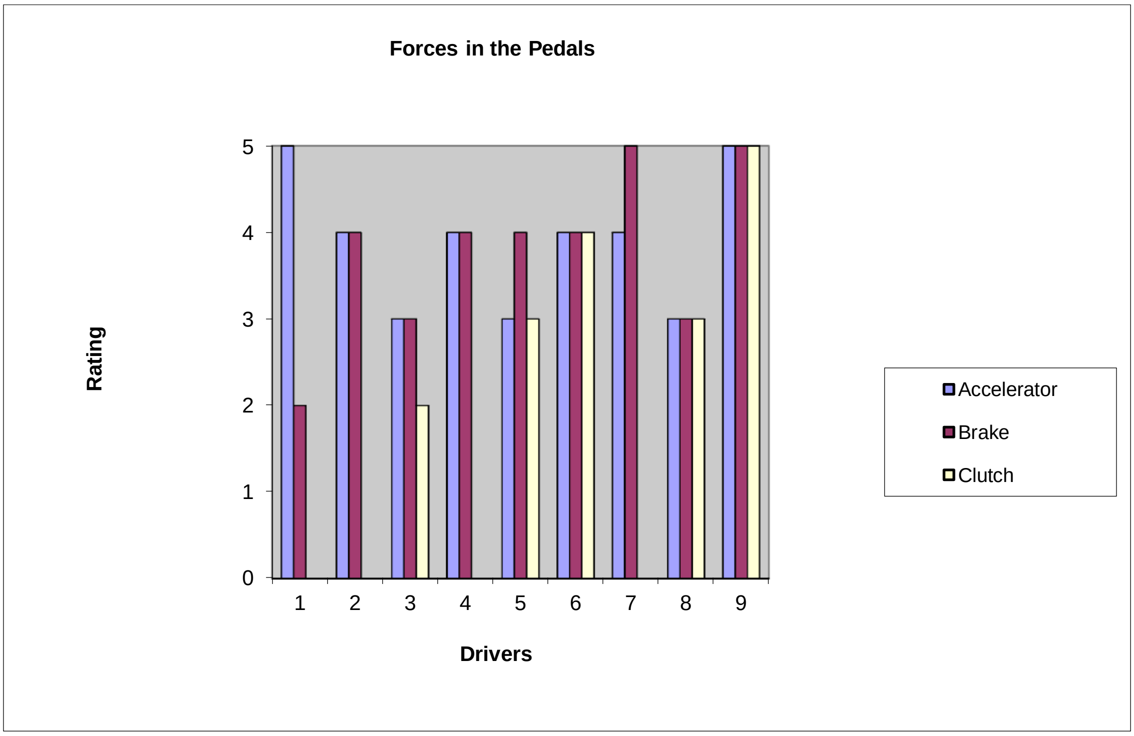

12) Size, Shape and Friction of the Pedal



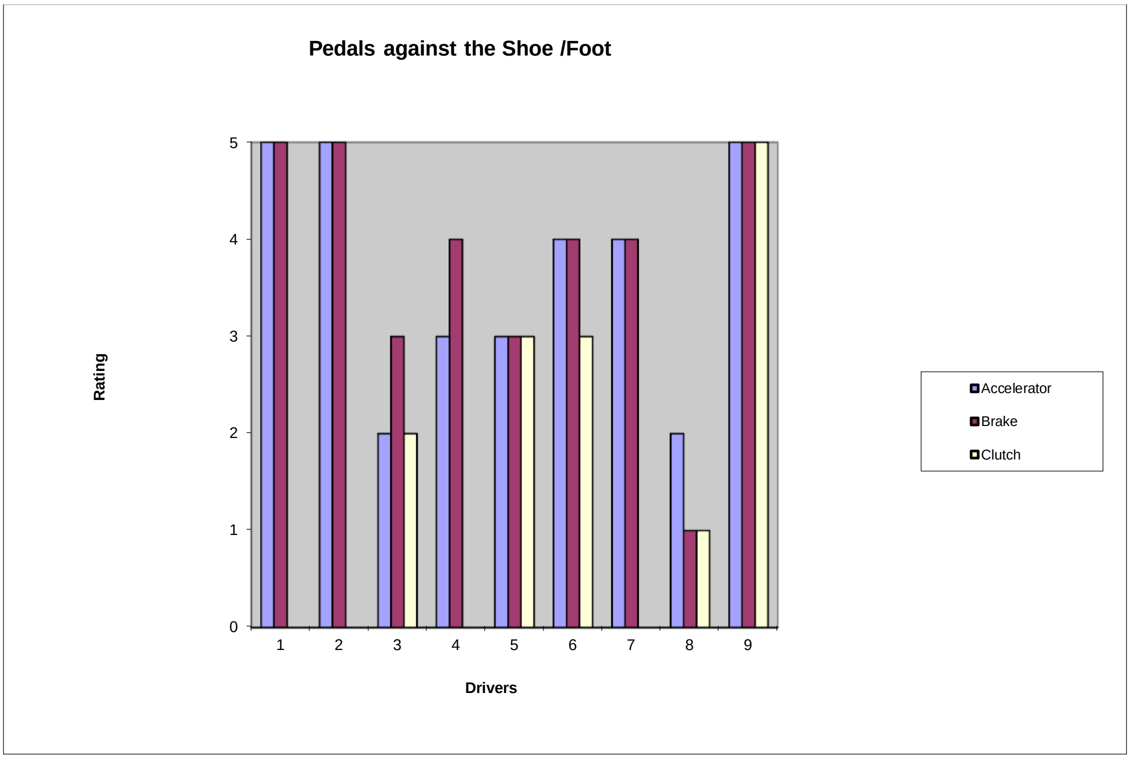
13) Stroke in the Pedals



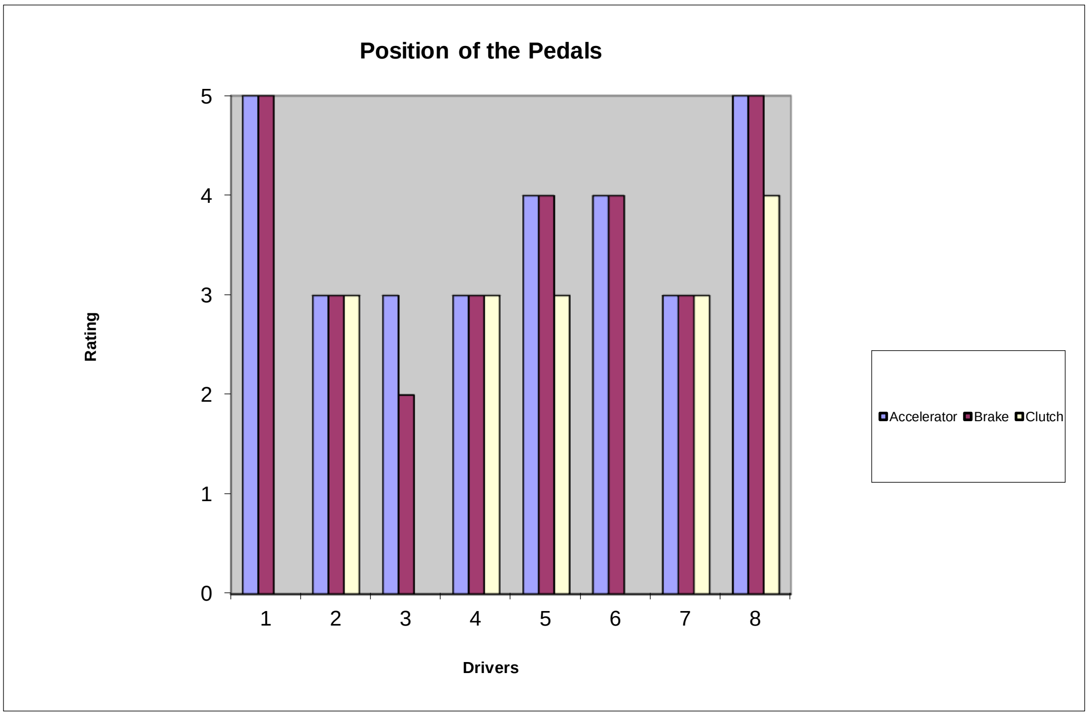

14) Forces in the Pedals



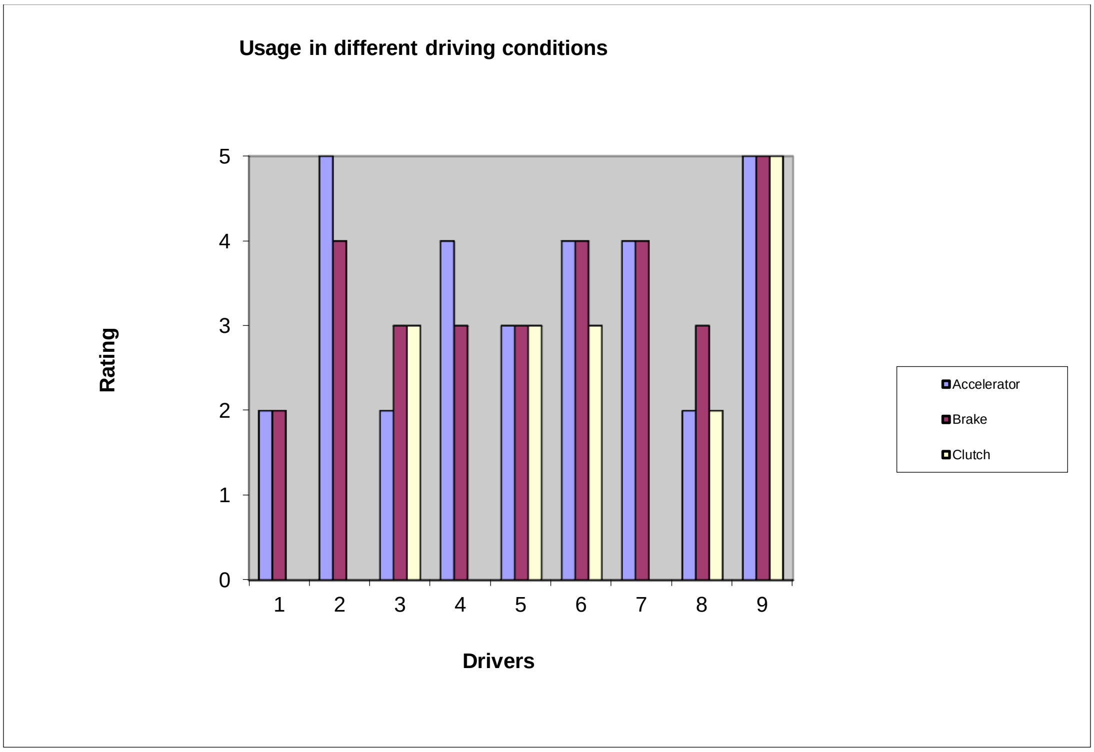
15) Pedals against the shoe and barefoot




16) Position of the Pedals



17) Usage of Pedals in different driving conditions



# APPENDIX - D

## Comments about the steering wheel

**Ease of using the steering wheel**

1. Adjustment needs to be improved – 2 persons
2. Size is good

**Size of steering Wheel**

1. Size of 450mm diameter is good -2 persons
2. Different sizes were preferred
3. Thick rim – 3 persons
4. Thickness has to be reduced -2 persons
5. Smaller steering wheel diameter would be good -2 persons

**Friction Patterns**

1. Slippery -3 persons
2. Cannot grip in many ways due to thick spokes -2 persons
3. Prefer friction patterns around the spokes
4. Friction material is poor in summer -2 persons
5. Material is good

**Opinion about Shape of steering wheel**

1. Shape is fair, clumsy

**Opinion about the Material of steering wheel**

2. Wooden grippers were preferred
3. Material is very good

**Opinion about Position of steering wheel**

1. Position needs to be improved

**Opinion about the Forces**

1. Less force was preferred when driving on bumpy roads at low and high speeds -4 persons
2. Steering wheel forces were good in windy road conditions
3. Forces are high while turning the steering wheel at lower speeds -3 persons
4. Trailer unit is affected in windy conditions
5. Heavy strokes and forces -2 persons
6. High forces – Individual Opinions
7. Forces need to be reduced -3 persons

**Rotation of the Steering Wheel for making Turns**

1. Too much rotation at lower speeds - 3 persons
2. Fewer strokes were preferred - 6 persons
3. Turning right requires only 1.5 turns of the steering wheel while turning left requires 2.5 turns, this needs to be improved.
4. Less steering wheel rotation is preferred.
5. The steering wheel ratio is around 22-26. It should be reduced to 14-15
6. The steering wheel should return to its original position when exiting from the truck cab. The contact with the road is good.

**Feeling and Feedback**

1. It is in good range
2. In cold weather conditions this needs to be improved
3. Feedback is poor -2 persons
4. Filters most of the information about the road at higher speeds
5. Feedback is poor in poor road conditions -2 persons
6. Feedback is poor on slippery roads
7. Direct feedback from the steering wheel at higher speeds -2 persons
8. Feeling from steering wheel has to be improved at low friction roads
9. Most of the information is filtered with some feeling -2 persons

**Gripping Comfort**

1. The gripping comfort is limited in the centre part of the steering wheel.

**Vibrations in the Steering Wheel**

1. Low vibrations at lower speeds were preferred -3 persons
2. High vibrations at higher speeds in bumpy roads
3. Poor in rough roads
4. Vibration has to be reduced

**Stability of the Steering Wheel**

1. Response is slow and no direct feedback
2. On rough roads there is a stability problem

## Comments about the Gear Shift Lever

**Opinion of the Gear shift lever**

1. Easy to operate
2. Quality impression can be improved – 2 persons
3. Good and easy shift
4. Better quality impression
5. Shape needs to be improved for female drivers

6. The lever is slow and it is easy to shift gears

**Forces**

1. Distinct feeling
2. Forces need to be reduced - 2 persons
3. Forces need to be reduced while downshifting
4. Too high forces at certain gear changes
5. Sideways to engage crawl/reverse requires both hands
6. Rearward movement requires forces that are too high with too little elbow space
7. Force levels for male drivers are good; but they need to be reduced for female drivers
8. Backward strokes require heavy forces

**Friction Material**

1. Plastic material needs to be replaced
2. Rubber feels like it is flexing too much in relation to the stick/lever
3. Friction material has to be changed
4. Friction material should be leather - 2 persons

**Strokes**

1. Shorter strokes were preferred - 3 persons
2. Strokes to large forwards and backwards
3. Smoothness in the ride
4. Moving to reverse needs to be improved
5. Forward stroke is long and needs to be improved

**Comfort**

1. Quality feeling needs to be improved
2. Logical gear shift movement in the form of step movement in racing cars
3. Female drivers will find it difficult because it is big

**Position**

1. Very good in bumpy road conditions
2. Takes a lot of space in the living area – 2 persons
3. Gear knob is too far back (especially in the rear - most position) in relation to how I have to sit (farthest back)
4. It needs to be positioned forward
5. Position needs to be customizable

**Understanding the gear shift position for gear change**

1. Feedback could be better
2. Information on the controls and cluster is good
3. Confusion between the range and split switch

4. Complexity in handling range switch
5. Range switch between low and high range makes gear changes complicated. Great if this could be automatically speed dependent.
6. Easy to feel due to big strokes and few positions (only three in ordinary driving and range and split switch positions)
7. You cannot operate too fast, contributes to less stressful driving.
8. Short time lag in changing gears
9. Smooth operation

**Feedback**

1. Direct feedback
2. Filtration of forces results in poor feedback - 2 persons
3. Delay in gear changes in range and split switches
4. Delay in gear activation in cold conditions - 4 persons
5. It is felt when the lever comes into the correct position. The gear engagement sound gives more input about the transmission and engine.
6. Sound feedback from the gear engagement is good
7. Feedback needs to be improved
8. No feedback from the gear shift lever
9. Switches were good

**Vibrations**

1. You cannot drive with hand on the gear lever due to vibrations
2. The vibrations in manual transmission trucks are very high
3. Vibrations are high in some positions
4. The gear lever moves slightly away from its original default position

**Different driving situations**

1. You feel more stress in dense traffic and might want to change gear more quickly than is feasible
2. Going uphill with a load means gear changes must work; otherwise you lose speed and annoy other drivers – 2 persons
3. Going downhill where engine braking by using lower gear is important
4. Slippery conditions could affect driving behaviour
5. If the truck is cold it demands more force from the driver
6. Low gears were preferred for driving in slippery road conditions.

**Issues needs to be addressed**

1. Slippery in cold weather conditions and in muddy terrain - 2 persons
2. Steep uphill driving
3. Difficult in gear changes
4. Difference in time delay between upshifting and downshifting - 2 persons
5. Arm, elbow, hand clearance
6. Sound feedback

7. Switch operation range/split needs to be improved
8. There is a short and sharp time lag in changing gear from 6th to 7th gear in gearbox
9. At low temperatures gearbox response is worse and much better at high temperatures
10. Lack of smoothness
11. Gear engagement and high forces
12. Poor performance in cold conditions – 2 persons
13. Shift by wire could be best solution
14. Downshifting uphill on winter roads
15. Logical movements with effective display in the instrument cluster in fast boats could be beneficial.

## Comments about the Accelerator Pedal

**Pedal Size**

1. Length should be longer than width
2. The size should be improved for barefoot driving.
3. Accelerator Pedal is too rigid and foot angle is too steep in barefoot driving

**Pedal Shape**

1. Accelerator pedal needs more curvature
2. The curvature of accelerator pedal needs to be improved
3. The edges need to be rounded
4. The contact area is very minimal. I prefer a larger contact area for better control
5. The shape of the accelerator pedal (y-axis) curvature can be improved by increasing the radius of curvature
6. I prefer flat pedals
7. Sharp edges and corners, these need to be rounded

**Friction Pattern**

1. Low friction in the accelerator Pedal
2. Gripping comfort needs to be improved
3. Accelerator pedal is very slippery
4. Friction can be improved between the pedal and foot by establishing better contact
5. Especially at lower speeds the gripper patterns are sharp and as the pedal moves along the stroke the sharpness disappears. Small pivot in the pedal could be an option
6. Accelerator Pedal grippers are quite sharp and edges needs to be rounded to smooth surface
7. The gripper patterns are slippery

8. Grippers are too rough
9. The material of the grippers can be made soft for barefoot driving
10. Better support and grip
11. Too slippery when driving with socks
12. Accelerator pedal feels like plastic, the gripper material can be replaced with rubber.
13. The accelerator needs to be improved

**Position**

1. Inclination is not good
2. Too far back
3. Too far to the side
4. Clearance of foot and knee
5. Position needs to be lowered -2 persons

**Feeling and Feedback**

1. Less feedback from the accelerator pedal
2. Sound feedback from the engine
3. Less feedback in poor road conditions
4. No feedback through the pedal
5. Feeling and feedback should be progressive
6. Shorter people may find difficulty in using the pedals

**Against the Shoe & Barefoot**

1. Not good with barefoot – 2 persons

**In Bumpy roads when Cab moves or vibrates**

1. Floor Mounted Pedal would be better for bumpy roads
2. There is a possibility to rest the foot against the engine tunnel.
3. Still, big seat suspension can change accelerator pedal position slightly
4. Response is slow, that is quite good

**Aspects that need attention**

1. Relationship between the seats and the pedals are not good
2. Quality impression of the accelerator pedal
3. Problems with the responses from the accelerator pedal are different for different trucks. It should be standardized.
4. The forces across the pedal in all FH, FM, FMX need to be standardized
5. Enough space between the pedals
6. Hanging pedals were preferred

**Distance between the Pedals**

1. The distance needs to be increased

2. The distance between the pedals is not adequate for winter shoes / mining boots
3. Both brake pedal and accelerator pedal should be lowered and brake pedal plane should be the same as the accelerator pedal plane
4. Shape of the accelerator pedal

**Distance between the Pedal and Engine tunnel wall**

1. The clearance is very minimum and not adequate. So, I prefer an asymmetrical pedal
2. Support in the engine tunnel wall would be welcomed
3. The side support in the engine tunnel wall would be beneficial for long-haul drivers

## Comments about the Brake Pedal

**Pedal Size**

1. Brake Pedal width needs to be reduced -2
2. Brake pedal seems to be too big when driving with barefoot

**Pedal Shape**

1. Roundness needs to be improved – 2 persons
2. Pedal shape is good

**Friction Pattern**

1. Friction Pattern is sensitive – 3 persons
2. Friction is good with a large surface area – 1 persons
3. Rubber grip needs to be changed
4. The friction patterns also impact the drivers decision whether to use shoes or bare foot
5. Sometimes brake pedal feels very slippery when driving with shoes
6. The brake pedal patterns are better than the accelerator's
7. Brakes are good
8. Better friction in barefoot driving than when driving with shoes. Patterns need to be changed, not good enough, too slippery with socks
9. Softer rubber, less slippery, rounded corners

**Position of the Brake Pedal**

1. Should not be low -2 persons
2. Brake pedal should be offset to the accelerator pedal -2 persons
3. Position needs to be lowered -4 persons
4. The position is too high in relation to the accelerator pedal-2 persons

**Stroke**

1. Long stroke with Pneumatic is normally used along with Electric Combination that results in high force levels -2 persons
2. Stroke should be well defined -4 persons
3. Stroke needs to be reduced -4 persons

**Forces**

1. Forces are heavy in backup Mode -3 persons
2. Hysteresis is too high in Pneumatic -2 persons
3. Forces are high -3 persons
4. Feels adequate

**Feeling**

1. Forces should be adequate for feeling and feedback
2. Sensitive
3. Short delay in applying the brake
4. Poor feedback in driving in snow or in sandy terrain
5. Best among other pedals

**Against the Shoe & Barefoot**

1. Barefoot driving needs to be improved - 1 persons
2. Foot needs to lift too much. The pedal is too close due to the lack of leg room.
3. Depends on the shoe/feet size
4. Operation when driving with shoes is good while with bare feet it needs improvement
5. The pedal plate needs to be improved for barefoot driving
6. Much better than accelerator

**In Bumpy roads when Cab move or vibrate**

1. Floor mounted brake pedal would be good

**Different driving Conditions**

1. Brake pressure is high -2 persons
2. Normal driving is good
3. No high forces were involved
4. Standstill mode is really good -2 persons
5. Could become cumbersome with active driving in dense traffic -2 persons

**Brake Pedal Plane position**

1. The brake pedal pane should be positioned above the accelerator pedal plane. However, with minimum clearance
2. Both the brake pedal plane and accelerator plane need to be co-planar

**Aspects that needs attention**

1. In dense traffic the pedal should be with touch sensitive with low effort
2. Relationship between the seats and the pedals are not good
3. The forces across the pedal in all FH, FM, FMX need to be standardized
4. Enough space between the pedals
5. The step between the accelerator and brake pedal needs to be improved.
6. The legroom space should be improved
7. Brake pressure and retardation should be same when the vehicle is loaded and unloaded. The linear characteristics should be improved.

## Comments about the Clutch Pedal

**Pedal Size**

1. Size needs to be reduced – 3 persons

**Pedal Shape**

1. Shape is very good

**Friction Pattern**

1. Friction between the clutch pedal and brake pedal in movement of feet
2. The friction is good

**Position**

1. Position needs to be lowered – 7 persons
2. Clutch pedal arm close to the steering column
3. Foot rests close to the clutch pedal
4. The position gets worse with too little leg room.
5. Pedal is positioned far to the left with little clearance for foot to rest next to it.
6. The position is higher because of the higher foot placement on the pedal due to the driver assisting booster

**Comfort**

1. The foot is tilted upwards a lot so that the rear edge tends to rub against the sole initially

**Stroke**

1. Shorted strokes were preferred – 8 persons
2. Longer strokes are preferred – 1 person
3. Stroke is progressive

**Forces**

1. Forces need to be reduced – 5 persons
2. Forces are high – 3 persons
3. Too low forces could make it loose when applying the clutch.

**Feeling and Feedback**

1. The feeling and feedback is mostly felt in the leg and not in the feet
2. Run out in the engine can be felt in the clutch pedal.
3. Feedback is good – 2 persons

**On Bumpy roads when Cab moves or vibrates**

1. In distribution trucks it needs to be improved

**Different driving Conditions**

1. Active driving was problematic due to the pedal location in relation to the seat

**Vibrations**

1. Vibrations can be felt from the hydraulic unit

**Aspects that needs attention**

1. Ingress in clutch needs attention
2. Relationship between the seats and the pedals was not good
3. Foot clearance between the steering column and the pedal is poor
4. The force across the pedal in all FH, FM, FMX needs to be standardized
5. Force and stroke relation ratio should be efficient
6. Quite low stroke has high force.
7. Stroke in the modulation of the clutch is high
8. It is high in the start and minimum at the lower end
9. Quick return mechanism must be optimized.

# APPENDIX - E

Supplier Information and cost of the measurement systems

| S.No | Measurement Technique | Cost | Supplier | Website |
|---|---|---|---|---|
| | **Steering Wheel Control** | | | |
| 1 | Steering effort sensor | 5000 USD | Sensor Development Inc | www.sendev.com |
| 2 | Measuring Steering Wheel Adaptor | 12875 USD | Sensor Development Inc | www.sendev.com |
| 3 | Glove Pressure Sensor | 5700 USD | Nexgen Ergonomics | http://www.nexgenergo.com/ergonomics/nexglove.html |
| 4 | Pressure Mats | 2000 USD | Nexgen Ergonomics | http://www.nexgenergo.com/ergonomics/fsast1500.html |
| 5 | Force Gauges | 500 USD | Nexgen Ergonomics | http://www.nexgenergo.com |
| 6 | Steering Robot | 20000 Euro | Anthony Best Dynamics | www.abd.uk.com |
| | **Gear Shift Lever** | | | |
| 7 | Ricardo Gear Shift Quality Assessment | UNKNOWN | Ricardo | www.ricardo.com |
| 8 | Shift Knob Load Cell | 2450 USD | Sensor Development Inc | www.sendev.com |
| 9 | Hand Sensor Array | 1875 USD | Nexgen Ergonomics | http://www.nexgenergo.com/ergonomics/nexhand.html |
| | **Pedals** | | | |
| 10 | Accelerator Robot | 18000 Euro | Anthony Best Dynamics | www.abd.uk.com |
| 11 | Brake Robot | 18000 Euro | Anthony Best Dynamics | www.abd.uk.com |
| 12 | Brake Pedal Force Sensor | 2000 USD | Loadstar Sensor/Futek | www.futek.com; http://www.loadstarsensors.com |
| 13 | Pedal Load Cell | 1800 USD | Loadstar Sensor/Futek | www.futek.com; http://www.loadstarsensors.com |

# APPENDIX - F

Steering Wheel:

| | Steering Wheel | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aspects** | Grips | Vibrations | Forces | Strokes | Feeling | Shape | Adjustment | Size | Laps | Strokes | Friction Patterns | Position |
| **Drivers** | | | | | | | | | | | | |
| 1 | Prefer | | Prefer | Prefer | | | | | | | | |
| 2 | Prefer | | | | | | Prefer | Prefer | Prefer | Prefer | | Prefer |
| 3 | Prefer | | Prefer | | | | | | | | Prefer | Prefer |
| 4 | | | Prefer | Prefer | Prefer | Prefer | | | | | | |
| 5 | | | Prefer | | | | Prefer | Prefer | | | | Prefer |
| 6 | Prefer | Prefer | | | | | | Prefer | Prefer | | | |
| 7 | Prefer | | | | Prefer | | | Prefer | | | | |
| 8 | | | | | Prefer | | | | | | | |
| 9 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | |
| 11 | | | | | | | | Prefer | | | | |
| 12 | | | | | | | | | | | | |
| 13 | | | Prefer | | Prefer | | | Prefer | | | | Prefer |
| 14 | Prefer | Prefer | Prefer | Prefer | | Prefer | | Prefer | Prefer | Prefer | Prefer | |
| 15 | Prefer | | Prefer | | Prefer | | | Prefer | Prefer | | | |
| Total | 7 | 3 | 7 | 3 | 5 | 2 | 2 | 8 | 4 | 2 | 2 | 4 |

Pedals:

| | Pedals | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aspects** | Easy to clean | Senstivity | Position | Friction | Robustness | Shape | Sixe | Feeling | Material | Clearance | Forces | Stroke |
| **Drivers** | | | | | | | | | | | | |
| 1 | Prefer | | | Prefer | | | | | | | | |
| 2 | | | | Prefer | | Prefer | | | | Prefer | Prefer | Prefer |
| 3 | | | Prefer | Prefer | Prefer | | | | Prefer | Prefer | Prefer | Prefer |
| 4 | | | | | | | | | | Prefer | | |
| 5 | | | | | | | | | | Prefer | Prefer | Prefer |
| 6 | | | | Prefer | | Prefer | Prefer | Prefer | | | | |
| 7 | | | | | | | | | | | | |
| 8 | | | | | | | | Prefer | | | | |
| 9 | | | | Prefer | | Prefer | Prefer | | | | Prefer | Prefer |
| 10 | | | Prefer | Prefer | | | | Prefer | | | Prefer | Prefer |
| 11 | | | | | | | | | | | | |
| 12 | | Prefer | Prefer | | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer |
| 13 | | | Prefer | Prefer | | | | Prefer | | | Prefer | Prefer |
| 14 | | Prefer | | | | | | Prefer | | | | |
| 15 | | Prefer | Prefer | Prefer | | Prefer | | Prefer | | Prefer | Prefer | Prefer |
| Total | 1 | 3 | 5 | 8 | 2 | 5 | 3 | 7 | 2 | 6 | 8 | 8 |

Gear Shift Lever:

| | Gear Shift lever | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Aspects** | Position | Material | Gripping Comfort | Feeling | Robustness | Friction | Shape | Stroke | Force |
| **Drivers** | | | | | | | | | |
| 1 | | | | | | | | | |
| 2 | Prefer | | | | | Prefer | Prefer | Prefer | Prefer |
| 3 | Prefer | Prefer | Prefer | | | | | Prefer | Prefer |
| 4 | Prefer | | Prefer | | | | | Prefer | |
| 5 | | | | Prefer | Prefer | | | Prefer | |
| 6 | Prefer | | | | | | Prefer | | |
| 7 | | | | | | | | | |
| 8 | Prefer | | | | | | | Prefer | |
| 9 | | | | | | | | | |
| 10 | Prefer | Prefer | | Prefer | | Prefer | Prefer | Prefer | Prefer |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer | Prefer |
| 14 | Prefer | | | Prefer | | | | | |
| 15 | | | | Prefer | | | Prefer | Prefer | Prefer |
| Total | 8 | 3 | 3 | 5 | 2 | 3 | 5 | 8 | 5 |

## Overall ratings of Steering Wheel and Accelerator Pedal

| S.No | Evaluation Criteria's | Driver 1 | Driver 2 | Driver 3 | Driver 4 | Driver 5 | Driver 6 | Driver 7 | Driver 8 | Driver 9 | Driver 10 | Driver 11 | Driver 12 | Driver 13 | Driver 14 | Driver 15 | Driver 16 | Driver 17 | Driver 18 | Driver 19 | Driver 20 | Driver 21 | Driver 22 | Average Scores | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Steering Wheel | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Size | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | | | | | | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 2 | 5 | 3.41 | 6.82 |
| 2 | Shape | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | | | | | | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 2 | 5 | 3.41 | 6.82 |
| 3 | Feeling | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | | | | | | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 2 | 5 | 3.41 | 6.82 |
| 4 | Sensitivity | 2 | 4 | 3 | 4 | 2 | 1 | 3 | 3 | 4 | | | | | 4 | 4 | 3 | 4 | | 4 | 4 | 3 | 5 | 3.35 | 6.7 |
| 5 | Friction | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Friction Material | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 3 | | | | | | 3 | 4 | 3 | 4 | 4 | 4 | 3 | 2 | 5 | 3.41 | 6.82 |
| 7 | Comfort | 3 | 3 | 2 | 4 | 3 | 2 | 3 | 2 | | | | | | 1 | 5 | 3 | 4 | 3 | 4 | 5 | 3 | 5 | 3.23 | 6.46 |
| 8 | Position | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | Robustness | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Forces | 3 | 4 | 3.5 | 3 | 3 | 3 | 3 | 3 | | | | | | 3 | 5 | 3 | 3 | 3 | 4 | 4 | 3 | 5 | 3.44 | 6.88 |
| 11 | Strokes | 3 | 3 | 4 | 4 | 5 | 4 | 3 | 4 | | | | | | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 5 | 3.82 | 7.64 |
| | Accelerator Pedals | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Size | | 4 | 4.5 | 4 | 4 | 3 | 4 | 3 | 3 | | | | | 5 | 5 | 3 | 4 | 3 | 4 | 4 | 3 | 5 | 3.85 | 7.7 |
| 2 | Shape | | 4 | 4.5 | 4 | 4 | 3 | 4 | 3 | 3 | | | | | 5 | 5 | 3 | 4 | 3 | 4 | 4 | 3 | 5 | 3.85 | 7.7 |
| 3 | Feeling | | 4 | 4 | 4 | 5 | 3 | 2 | 3 | 3 | | | | | 3 | 5 | 3 | 4 | 3 | 4 | 4 | 3 | 5 | 3.64 | 7.28 |
| 4 | Sensitivity | | 4 | 3 | 3 | 4 | 3 | 4 | 2 | 2 | | | | | 3 | 3 | 2 | 3 | 3 | 4 | 4 | 2 | 5 | 3.17 | 6.34 |
| 5 | Friction | | 4 | 4.5 | 4 | 4 | 3 | 4 | 3 | 3 | | | | | 5 | 5 | 3 | 4 | 3 | 4 | 4 | 3 | 5 | 3.85 | 7.7 |
| 6 | Friction Material | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Comfort | | 4 | 4 | 4 | 3 | 3 | 4 | 2 | 2 | | | | | 5 | 5 | 2 | 3 | 3 | 4 | 4 | 2 | 5 | 3.47 | 6.94 |
| 8 | Position | | 4 | 4 | 4 | | 2 | 4 | 3 | 3 | | | | | | 5 | 3 | 3 | 3 | 4 | 4 | 3 | 5 | 3.6 | 7.2 |
| 9 | Robustness | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Forces | | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 3 | | | | | 5 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 5 | 3.94 | 7.88 |
| 11 | Strokes | | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 3 | | | | | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 3 | 5 | 3.76 | 7.52 |

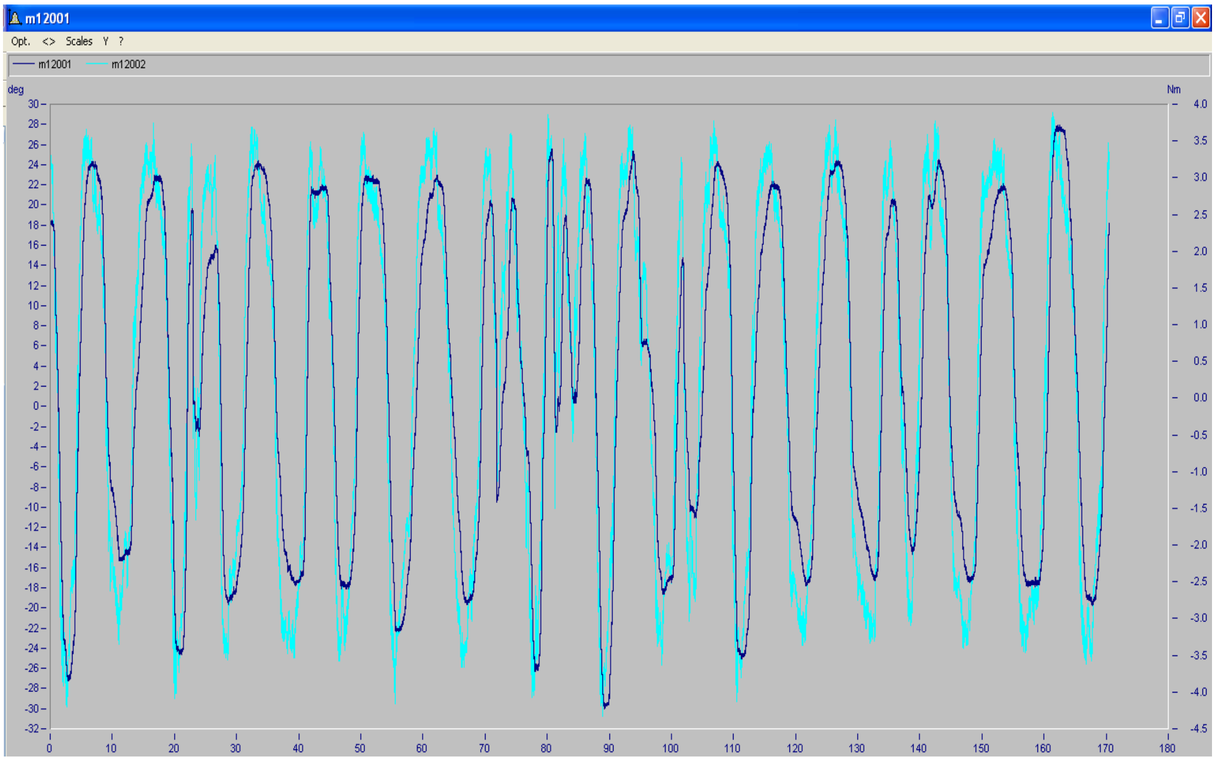
## Overall ratings of Brake pedal, Clutch pedal and Gear shift lever

| S.No | Evaluation Criteria's | Driver 1 | Driver 2 | Driver 3 | Driver 4 | Driver 5 | Driver 6 | Driver 7 | Driver 8 | Driver 9 | Driver 10 | Driver 11 | Driver 12 | Driver 13 | Driver 14 | Driver 15 | Driver 16 | Driver 17 | Driver 18 | Driver 19 | Driver 20 | Driver 21 | Driver 22 | Average Scores | Total Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Brake Pedal | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Size | | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | | | 4 | | 4 | 5 | 3 | 4 | 3 | 4 | 4 | 2 | 5 | 3.77 | 7.54 |
| 2 | Shape | | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | | | 4 | | 4 | 5 | 3 | 4 | 3 | 4 | 4 | 2 | 5 | 3.77 | 7.54 |
| 3 | Feeling | | 5 | 4 | 4 | 5 | 4 | 4 | 3 | 4 | | | 4 | | 3 | 4 | 3 | 4 | 3 | 4 | 5 | 2 | 5 | 3.88 | 7.76 |
| 4 | Sensitivity | | 4 | 3 | 4 | 4 | | 4 | 3 | 3 | | | 2 | | 2 | 4 | 3 | 3 | 3 | 3 | 4 | 2 | 5 | 3.29 | 6.58 |
| 5 | Friction | | 4 | 4 | 4 | 3 | 4 | 4 | 3 | 4 | | | 4 | | 4 | 5 | 3 | 4 | 3 | 4 | 4 | 2 | 5 | 3.77 | 7.54 |
| 6 | Friction Material | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Comfort | | 4 | 4 | 4 | 5 | 3 | 3 | 4 | 4 | | | 4 | | 5 | 5 | 3 | 4 | 3 | 4 | 4 | 1 | 5 | 3.83 | 7.66 |
| 8 | Position | | 3 | 4 | 4 | | 3 | 4 | 3 | 2 | | | 3 | | | 5 | 3 | 2 | 3 | 4 | 4 | 3 | 5 | 3.43 | 6.86 |
| 9 | Robustness | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Force | | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 5 | | | 3 | | 2 | 4 | 3 | 4 | 4 | 4 | 5 | 3 | 5 | 3.94 | 7.88 |
| 11 | Stroke | | 3 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | | | 3 | | 2 | 4 | 3 | 3 | 3 | 3 | 4 | 3 | 5 | 3.61 | 7.22 |
| | Clutch Pedal | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Size | 3 | 2 | 4 | 4 | 2 | 3 | 3 | | | 2 | 2 | | 3 | | | 3 | | 3 | 4 | | 3 | 5 | 3 | 6 |
| 2 | Shape | 3 | 2 | 4 | 4 | 2 | 3 | 3 | | | 2 | 2 | | 3 | | | 3 | | 3 | 4 | | 3 | 5 | 3 | 6 |
| 3 | Feeling | 4 | 4 | 4 | 4 | 4 | 3 | 3 | | | 3 | 3 | | 4 | | | 3 | | 3 | 3 | | 2 | 5 | 3.46 | 6.92 |
| 4 | Sensitivity | 4 | 4 | 3 | 4 | | | 3 | | | 3 | 3 | | 3 | | | 3 | | 3 | 3 | | 3 | 5 | 3.38 | 6.76 |
| 5 | Friction | 3 | 2 | 4 | 4 | 2 | 3 | 3 | | | 2 | 2 | | 3 | | | 3 | | 3 | 4 | | 3 | 5 | 3 | 6 |
| 6 | Friction Material | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Comfort | 4 | 4 | 4 | 4 | 3 | 2 | 3 | | | 2 | 2 | | 3 | | | 2 | | 3 | 3 | | 1 | 5 | 3 | 6 |
| 8 | Position | 4 | 3 | 3 | 4 | | 1 | 3 | | | 2 | 1 | | 2 | | | 3 | | 3 | 3 | | 3 | 4 | 2.78 | 5.56 |
| 9 | Robustness | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Force | 2 | 3 | 3 | 4 | 3 | 2 | 3 | | | 3 | 2 | | 2 | | | 2 | | 3 | 4 | | 3 | 5 | 2.93 | 5.86 |
| 11 | Stroke | 4 | 3 | 4 | 4 | 3 | 3 | 3 | | | 3 | | | 5 | | | 3 | | 3 | 3 | | 3 | 5 | 3.5 | 7 |
| | Gear Shift Lever | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Size | 4 | 3 | 4 | 4 | 4 | 2 | 3 | 3 | 4 | | | | 4 | 5 | | 2 | 4 | 4 | 2 | | 2 | 3 | 3.35 | 6.7 |
| 2 | Shape | 4 | 3 | 4 | 4 | 4 | 2 | 3 | 3 | 4 | | | | 4 | 5 | | 2 | 4 | 4 | 2 | | 2 | 3 | 3.35 | 6.7 |
| 3 | Feeling | 3 | 3 | 3 | 4 | 5 | 3 | | 4 | 5 | | | | 2 | 4 | | 3 | | 3 | 2 | | 3 | 4 | 3.4 | 6.8 |
| 4 | Sensitivity | 3 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 2 | | | | 3 | | | 3 | | 4 | 4 | | 2 | 4 | 3.46 | 6.92 |
| 5 | Friction | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Friction Material | 4 | 3 | 4 | 4 | 4 | 2 | 3 | 3 | 4 | | | | 4 | | | | | | | | | | 3.5 | 7 |
| 7 | Comfort | 4 | 4 | 4 | 3 | | | 2 | 4 | 3 | | | | 3 | 5 | | 2 | 4 | 4 | 2 | | 2 | 3 | 3.26 | 6.52 |
| 8 | Position | 3 | 3 | 4 | 4 | 4 | 2 | 3 | 4 | 5 | | | | 2 | 5 | | 2 | 4 | 4 | 2 | | 1 | 3 | 3.23 | 6.46 |
| 9 | Robustness | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | Force | 2 | 4 | 3 | 3 | 3 | 1 | 3 | 3 | 5 | | | | 1 | 5 | | 2 | 4 | 4 | 3 | | 2 | 3 | 3 | 6 |
| 11 | Stroke | 2 | 2 | 4 | 4 | | | 3 | 4 | 4 | | | | 4 | 5 | | 2 | 3 | 4 | 4 | | 2 | 3 | 3.33 | 6.66 |

# APPENDIX - G

The driving sessions

Driving session 2: Test carried out on a straight road at Hällered Proving Ground by me

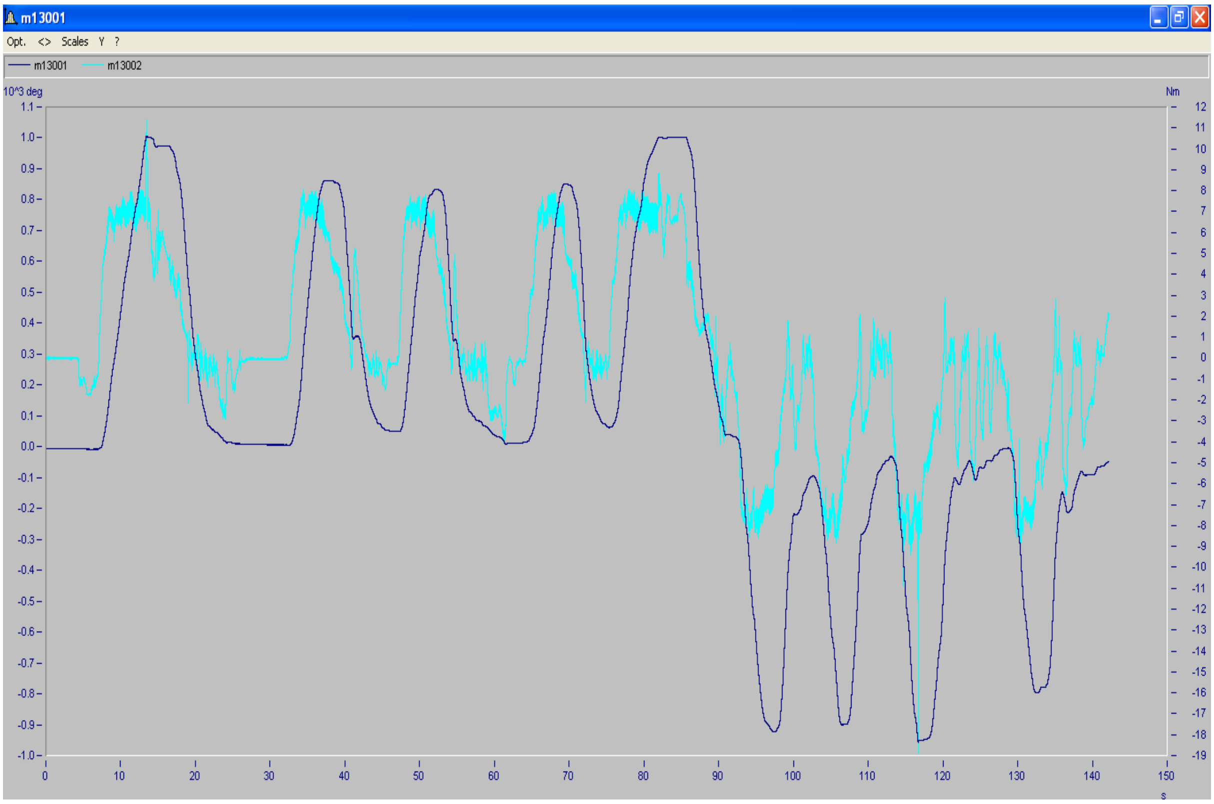



Steering angle & steering torque in Driving Session 2

The graph illustrates the results of the second driving session held on the straight road at the Hällered Testing Grounds. The x-axis represents the time in seconds, the y-axis scale at the left side represents the steering angle and the y-axis scale at the right side represents the steering torque. The values were plotted while driving on the straight road by steering the vehicle in left-right-left-right combinations for the given time period. During the driving session the maximum torque reached 4Nm when turning left and 4.2Nm when turning right.

Driving Session 3: Test carried out in 90 degree left and right turns at the Hällered Testing Grounds by me

The graph shown below illustrates the results of the third driving session at the Hällered proving grounds. The x-axis represents the time in seconds, the y-axis scale at the left side represents the steering angle and the y-axis scale in the right side represents the steering torque. The values were plotted while driving on the test road by steering the vehicle to 90 degrees left and 90 degrees right for the given time period. During the driving session, sharp turning a the corner would increase the steering torque up to 11Nm when turning left and 19 Nm when turning right.




Steering angle and steering torque in driving session 3

The steering torque and the steering angle measurements could be used by the ergonomics department for conclusions regarding the steering wheel forces and torque. The results do not show any information about the grip forces in the steering wheel.

# APPENDIX - H

This section discusses the Ricardo Gear Shift Quality Assessment System

The GSQA consists of a laptop PC with Mat-lab installed to run the GSQA software and record the test data. The system consists of the strain gauge gear knob which replaces the existing gear shift knob. The strain gauge consists of a full bridge configuration for the measurement of applied force in three planes. With automatic temperature and shear effect compensation, the maximum limits for applied force are:

- Sideways +/- 400 N
- Vertical +/- 400N
- Cross gate +/- 100N

There is potentiometer assembly that needs to be attached to the strain gauge gear knob to measure the position in three dimensions. The polar coordinates produced were converted to Cartesian coordinates. The rotary potentiometer had +/- 60 degrees sweep and linear potentiometers with 250 mm travel. The mounting pole carries the potentiometer assembly and it needs to be mounted rigidly between the vehicle floor and windscreen or ceiling in the truck or car. The mounting pole, which is assembled from the combination of different lengths, allows the GSQA to be fitted in various sizes.
The entire GSQA system is powered by 24VDC input.

The GSQA system is capable of acquiring data from
- 3 x Gear Knob Force
- 3 x Gear Knob Travel
- 2 x Speed (Frequency input)
- 2 x Temperature (Type K Thermocouple)

The GSQA kit for trucks has additional components to the standard GSQA system for controlling and recording data for truck transmissions with split ratios and range changes. The hardware also provides output to the standard GSQA acquisition hardware to inform the software of the current selected gear and controls the split ratios and range changes within the vehicle transmission via gear lever mounted switch box.

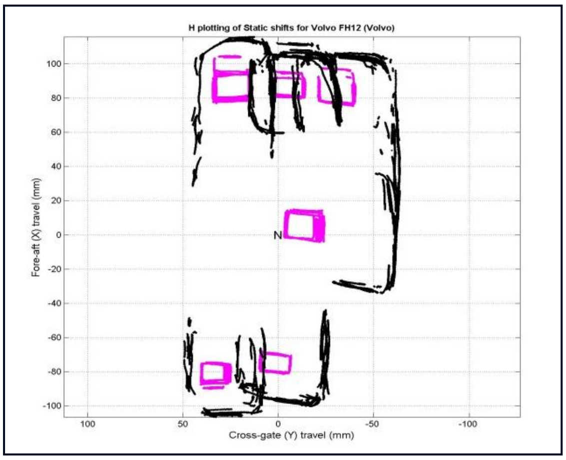
Measurements in the Gear Shift Quality Assessment (GSQA)

- H-Gate Plots
- Mean Shift Forces
- Static and Dynamic Measures

- Total Shift Travel
- Maximum Effort in XYZ
- Gear Pull out Force
- Force at Neutral
- Maximum Y travel
- Synchronization Ratio of the gears
- Total Synchronization Power

## Forces from the gear shift lever

The forces from the gear shift lever were measured using the Ricardo Gear Shift Quality Assessment system in a manual transmission Volvo FH Truck. These tests were carried out in a Volvo Right hand drive (RHD) truck.




Gear shift lever

The pink zone in the figure above is called gear voids and the black zone represents the limits of compliance. The gear voids are of similar dimension and they are well distributed. The Limits of compliance are clearly defined although there was marginal overlap between the planes. The picture above represents the stroke of the gear shift movement while shifting gears.

According to the standards for good gear shift quality, the overlaps in the limits of compliance should be eliminated for comfortable gear-shifting.

The average forces from the gear shift lever, while shifting gear in the manual transmission Volvo FH, were documented both for the up-shifting and downshifting of gears. The x-axis scale represents the gear shift travel or strokes and the y-axis scale represents the force measured for changing the gears.

Results:
In figure 32, the gear shift lever is positioned from neutral to $1^{st}$ lower and neutral to $2^{nd}$ lower and neutral to $3^{rd}$ lower. When the gear shifter is moved from neutral to $1^{st}$ low gear the forces for gear shifting reach 110N. When the gear shifter is moved from neutral to $2^{nd}$ low gear the forces for gear shifting reach 135 N. When the gear shifter is moved from neutral to $3^{rd}$ low gear the forces for gear shifting reach 140N.

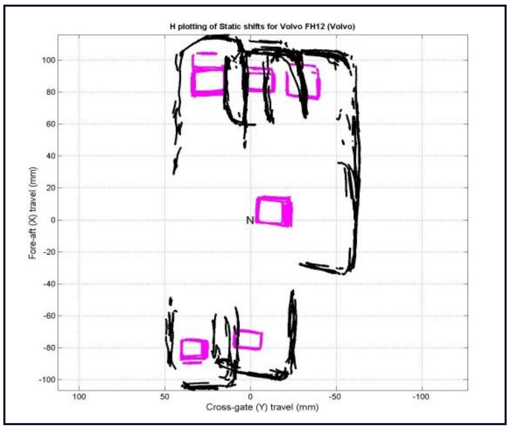
In figure 33, the forces in the gear shift lever when downshifting the gears is discussed. The x-axis scale represents the gear shift travel and the y-axis represents the shift lever forces. When the gear shifter is moved from $6^{th}$ low to $5^{th}$ low the forces for gear shifting reach 160N. Further, downshifting from $5^{th}$ low to $4^{th}$ low accounts for a force level of 130N and downshifting further from $4^{th}$ low to $3^{rd}$ low has recorded a force level of 170N.

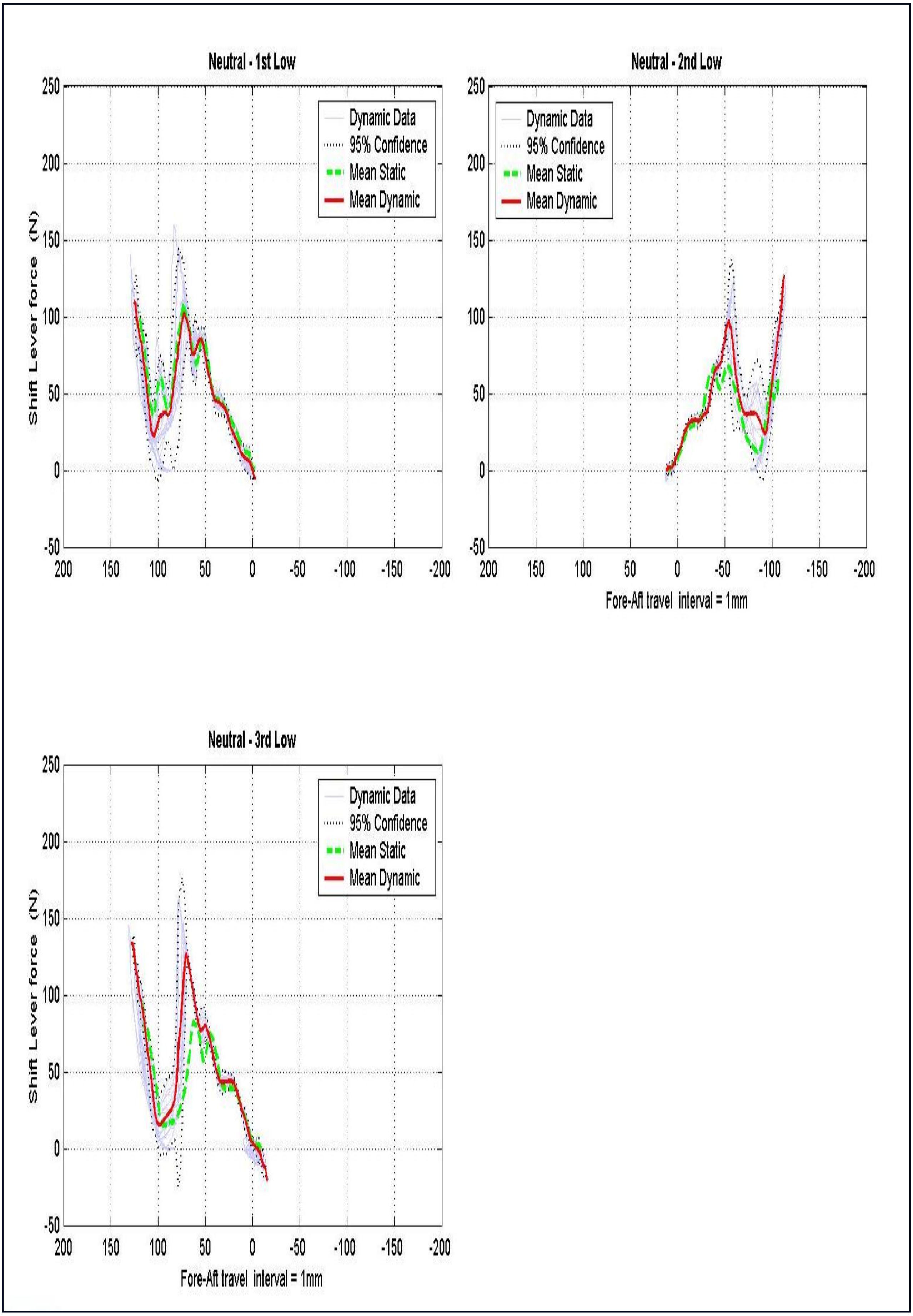
In figure 34, the forces in the gear shift lever for upshifting the gears is discussed. When the gear is shifted from $3^{rd}$ low to $4^{th}$ low the force level for shifting accounts to about 110N. For shifting from $4^{th}$ low to $5^{th}$ low it takes 145N and from shifting from $5^{th}$ low to $6^{th}$ low it is around 170N.

Discussion:
The results from the gear shift quality system show that when the driver performs the upshifting function the force levels increase steadily from 110 N to 140 N. Whereas in downshifting it increases further with the minimum force on 130N to the maximum force of 170N because the gearbox demands more force for downshifting compared with upshifting. Through the gear shift assessment system force level could be recorded precisely during the driving session. The force level was also dependent upon the load in the truck.

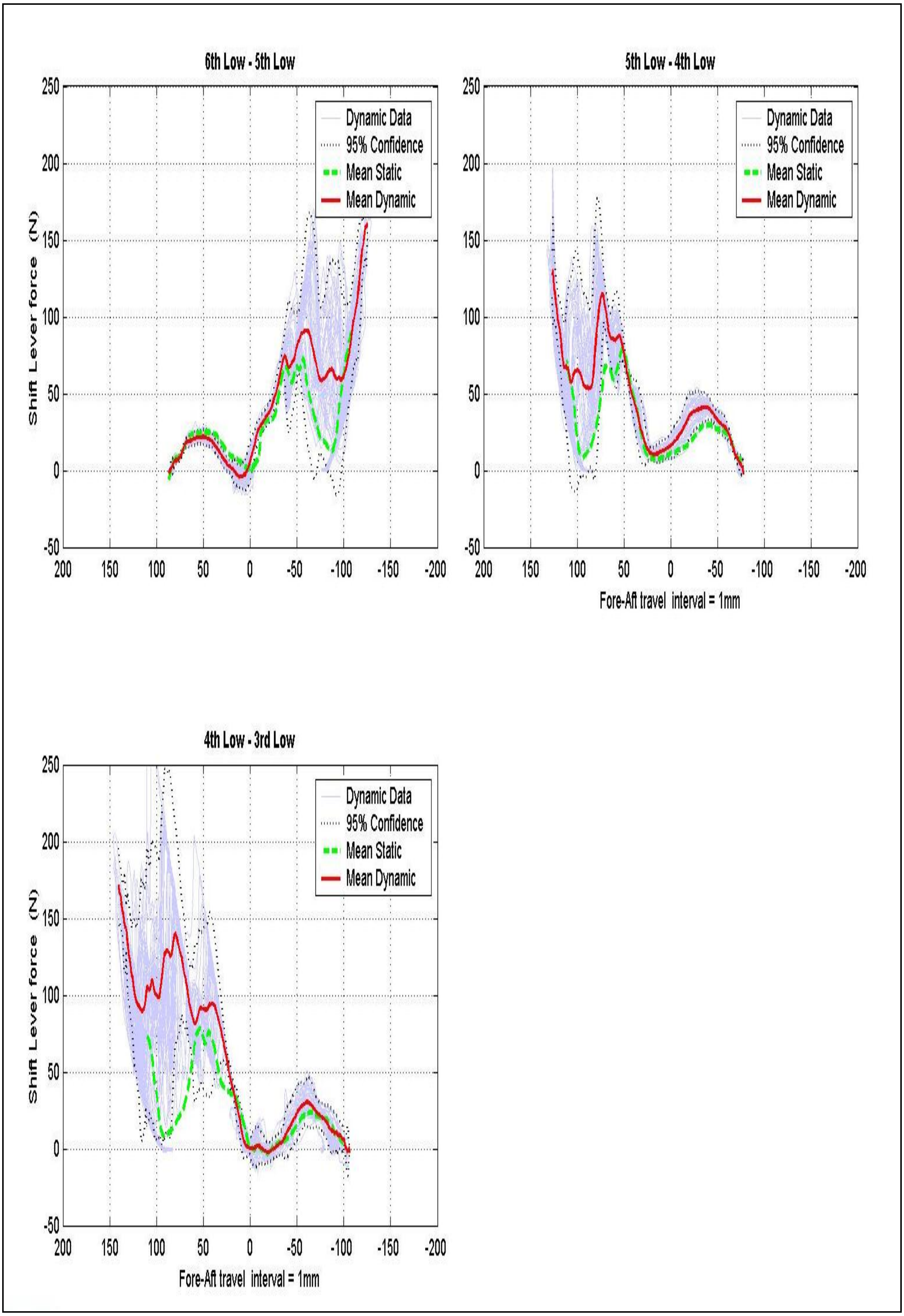
Conclusion:
The Ergonomics team can use these results for investigation of the force levels of the gear shift lever in manual transmission trucks. The force level needs to be measured from the I-shift gear shift lever to have a detailed comparison on the force levels. The results from the GSQA were accurate and reliable based on the opinion from the test engineer.

### H-Plotting of static shifts

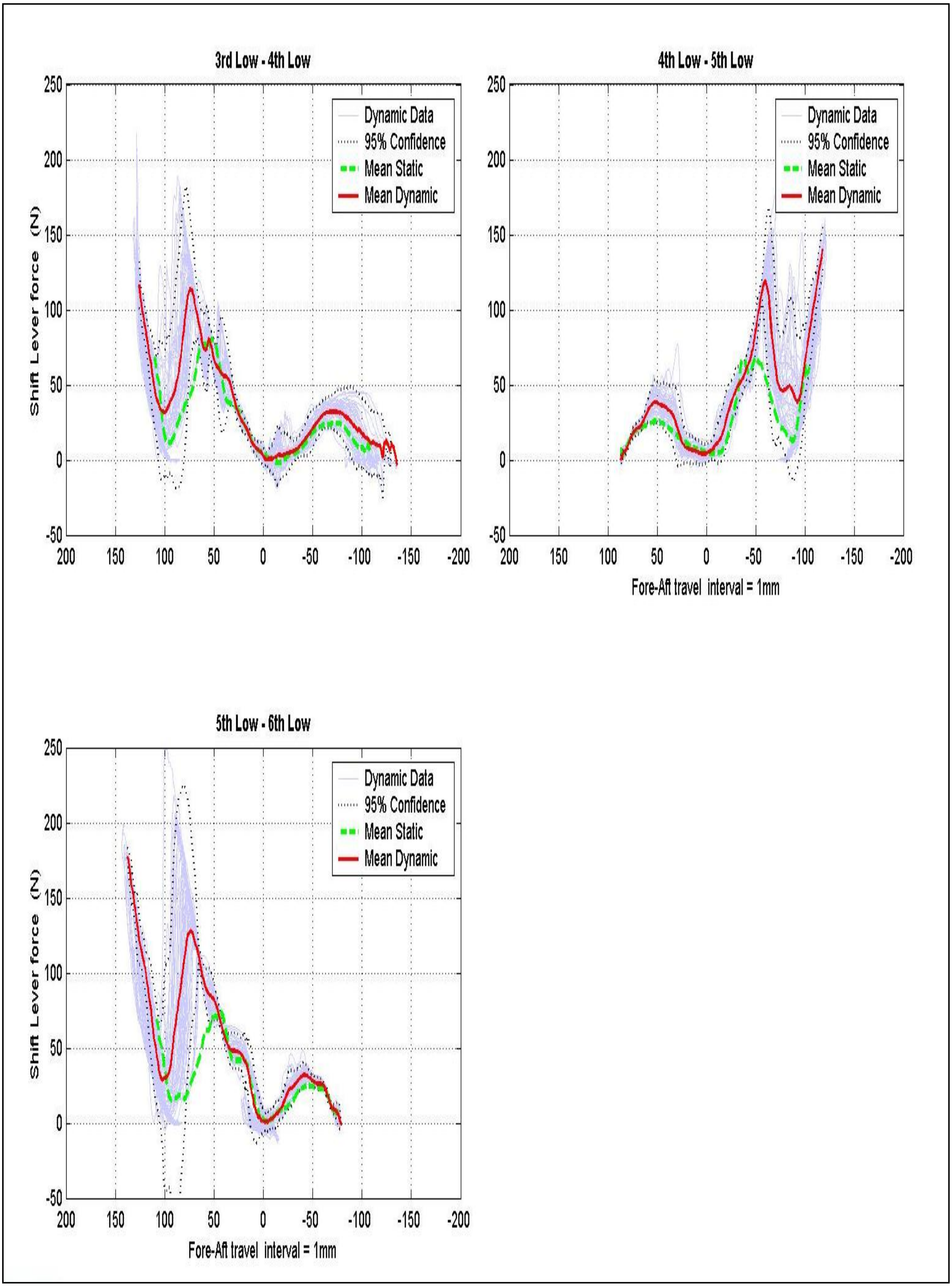





Gear shift lever force measurement through Gear Shift Quality Assessment




**Gear shift lever force measurement through Gear Shift Quality Assessment**




Gear shift lever force measurement through Gear Shift Quality Assessment

# APPENDIX - I

EUROFOT Material

The EuroFOT material includes a large quantity of video material. It was impossible to analyse all the videos for the usage of pedals. So, the videos were sorted from the master database through set of parameters to make the study even more focused towards the usage of pedals.

**Step 1: Input in MySQL Workbench**

The first step was to define the parameters for sorting the videos from the EuroFOT materials based on our requirements. The sample command list was given below. Trip_id represents the identification number of the trip recorded in the driving session and this parameter was mandatory in filtering the videos from the EuroFOT material. Timeindex denotes the time duration of the trip followed by mVehicleSpeed which represents the speed of the vehicle.

mAccelePedalPos represents the accelerator pedal position; the mACCState parameter represents the status of the adaptive cruise control system. The following parameters (1) mAcclePedalPos (2) mACCState were useful for confirming that the driving session was carried out with the adaptive cruise control system in deactivated mode.

During the studies, the videos were analysed in two different ways.

1) City driving
2) Highway driving

The following parameters mGetCountry_MAP represent the country in which the videos were filmed and parameters like mLongitude_GPS represent the longitude position, mLatitude_GPS represent the latitude position and mAltitude_GPS represent the altitude position. All these parameters provide the geographical location and map information of the driving session. The geographical parameters were used to differentiate the city driving from highway driving

There were other additional parameters like mEurofotMonth which represents the month in which the driving session was filmed and NightOrDay representing the videos captured in daytime or at night. These parameters were useful for classifying the videos based on daytime or night-time driving.

The videos were filtered in four different set of categories

1) Accelerator Pedal usage at speeds less than 60 KMPH

2) Accelerator Pedal usage at speeds more than 60 KMPH
3) Brake Pedal usage at speeds less than 60 KMPH
4) Brake Pedal usage at speeds more than 60 KMPH

1) Accelerator Pedal Parameters when speed less than 60 Kmph

```
Select
  trip_id
  , timeindex
  , mVehicleSpeed
  , mAccelPedalPos
  , mACCState
  , mGetCountry_MAP
  , mSpeedkmph_MAP
  , mLongitude_GPS
  , mLatitude_GPS
  , mAltitude_GPS
  , mEurofotMonth
  , NightOrDay
  , mDriverID

from
  trip_volvo_main

where
  mVehicleSpeed <60
  and
  mACCOnOff
  and
  mAccelPedalPos

Group by
  trip_id
```

The command list above illustrates the input given in MySQL workbench to sort videos with a vehicle speed of less than 60 KMPH in order to analyse the accelerator pedal usage.

2) Accelerator Pedal Parameters when speed more than 60 kmph

```
select
  trip_id
  , timeindex
  , mVehicleSpeed
```

```
   , mAccelPedalPos
   , mACCState
   , mAccelPedalPos
   , mGetCountry_MAP
   , mSpeedkmph_MAP
   , mLongitude_GPS
   , mLatitude_GPS
   , mAltitude_GPS
   , mEurofotMonth
   , NightOrDay
   , mDriverID

from
   trip_volvo_main

where
   mVehicleSpeed >60
   and
   mACCOnOff
   and
   mAccelPedalPos

Group by
   trip_id
```

The command list above illustrates the input given in MySQL workbench to sort videos with a vehicle speed of more than 60 KMPH in order to analyse the accelerator pedal usage.

3) Brake Pedal Parameters when speed less than 60 kmph

```
select
   trip_id
   , timeindex
   , mVehicleSpeed
   , mGetCountry_MAP
   , mSpeedkmph_MAP
   , NightOrDay
   , mBrakePedalPos
   , mLongitude_GPS
   , mLatitude_GPS
   , mAltitude_GPS
   , mBrakePedalVel
   , BrakePedalPos
```

```
   , mEurofotMonth
   , mDriverID
   , BrakePedalPos

from
   trip_volvo_main

where
   mVehicleSpeed <40
   and
   mACCOnOff
   and
   BrakePedalPos

Group by
   trip_id
```

The command list above illustrates the input given in MySQL workbench to sort videos with a vehicle speed of less than 60 KMPH in order to analyse the brake pedal usage.

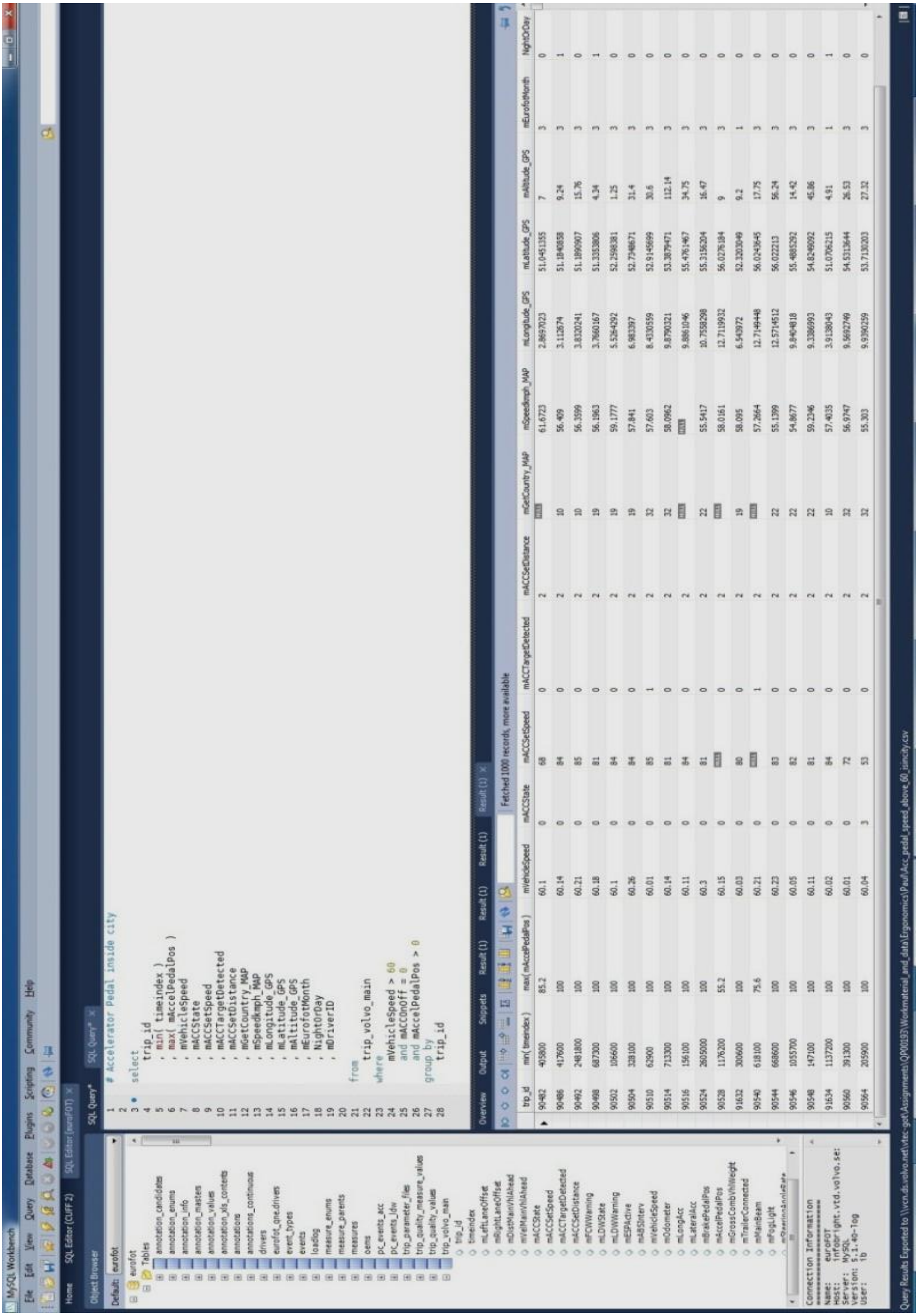
4) Brake Pedal Parameters when speed more than 60 kmph

```
select
   trip_id
   , timeindex
   , mVehicleSpeed
   , mGetCountry_MAP
   , mSpeedkmph_MAP
   , NightOrDay
   , mBrakePedalPos
   , mLongitude_GPS
   , mLatitude_GPS
   , mAltitude_GPS
   , mBrakePedalVel
   , BrakePedalPos
   , mEurofotMonth
   , mDriverID
   , BrakePedalPos

from
   trip_volvo_main
```

```
where
   mVehicleSpeed >40
   and
   mACCOnOff
   and
   BrakePedalPos

Group by
   trip_id
```

The command list above illustrates the input given in MySQL workbench to sort videos with a vehicle of more than 60 KMPH to analyse the brake pedal usage.

## MySQL Workbench Tool Screen

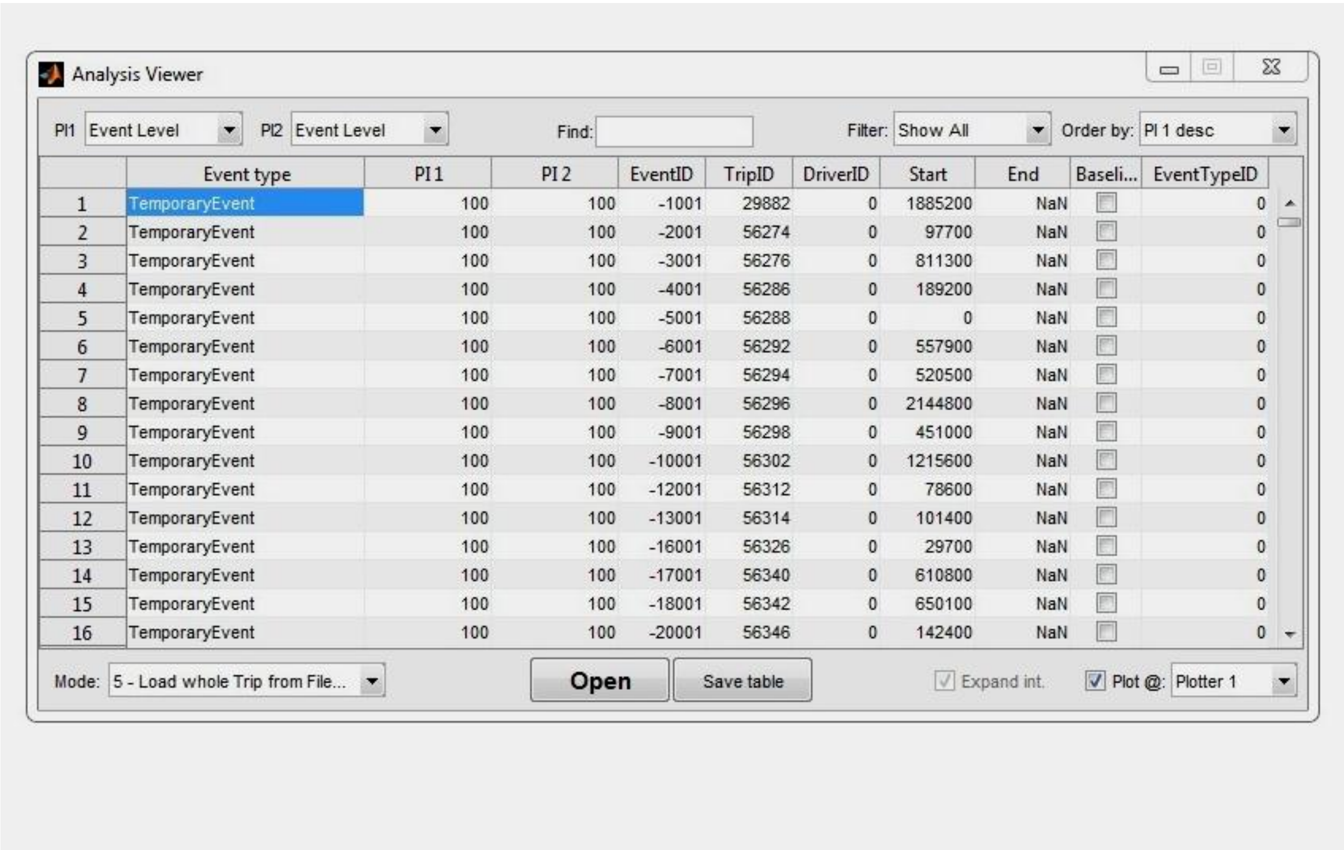


The picture above illustrates the videos being filtered in MySQL workbench. The upper section in the picture illustrates the given command input and the lower section illustrates the filtered data based on the input.

**Step 2: Inputs to Mat lab:**

The input from the MySQL workbench was saved in an excel file which was uploaded to the customized FOTware in VTECH to list the videos for analysis. The picture shows the list of the videos with specific parameters like TripID and DriverID.

**Mat lab filtered the videos based on MySQL inputs**

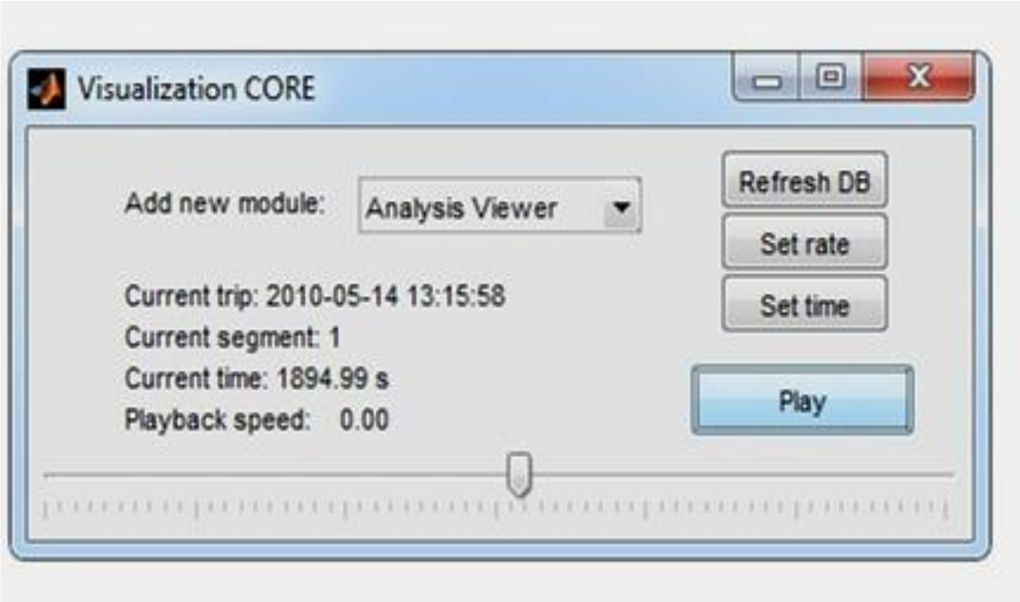



| | Event type | PI 1 | PI 2 | EventID | TripID | DriverID | Start | End | Baseli... | EventTypeID |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TemporaryEvent | 100 | 100 | -1001 | 29882 | 0 | 1885200 | NaN | | 0 |
| 2 | TemporaryEvent | 100 | 100 | -2001 | 56274 | 0 | 97700 | NaN | | 0 |
| 3 | TemporaryEvent | 100 | 100 | -3001 | 56276 | 0 | 811300 | NaN | | 0 |
| 4 | TemporaryEvent | 100 | 100 | -4001 | 56286 | 0 | 189200 | NaN | | 0 |
| 5 | TemporaryEvent | 100 | 100 | -5001 | 56288 | 0 | 0 | NaN | | 0 |
| 6 | TemporaryEvent | 100 | 100 | -6001 | 56292 | 0 | 557900 | NaN | | 0 |
| 7 | TemporaryEvent | 100 | 100 | -7001 | 56294 | 0 | 520500 | NaN | | 0 |
| 8 | TemporaryEvent | 100 | 100 | -8001 | 56296 | 0 | 2144800 | NaN | | 0 |
| 9 | TemporaryEvent | 100 | 100 | -9001 | 56298 | 0 | 451000 | NaN | | 0 |
| 10 | TemporaryEvent | 100 | 100 | -10001 | 56302 | 0 | 1215600 | NaN | | 0 |
| 11 | TemporaryEvent | 100 | 100 | -12001 | 56312 | 0 | 78600 | NaN | | 0 |
| 12 | TemporaryEvent | 100 | 100 | -13001 | 56314 | 0 | 101400 | NaN | | 0 |
| 13 | TemporaryEvent | 100 | 100 | -16001 | 56326 | 0 | 29700 | NaN | | 0 |
| 14 | TemporaryEvent | 100 | 100 | -17001 | 56340 | 0 | 610800 | NaN | | 0 |
| 15 | TemporaryEvent | 100 | 100 | -18001 | 56342 | 0 | 650100 | NaN | | 0 |
| 16 | TemporaryEvent | 100 | 100 | -20001 | 56346 | 0 | 142400 | NaN | | 0 |

**Step 3: Video Observations**

The FOTware program enables easy viewing of the videos with the seek bar function. The seek bar could be used to forward and repeat the videos of the driving session. The picture below shows the FOTware window.

**Mat lab FOTware to play the shortlisted videos with the seek bar function**



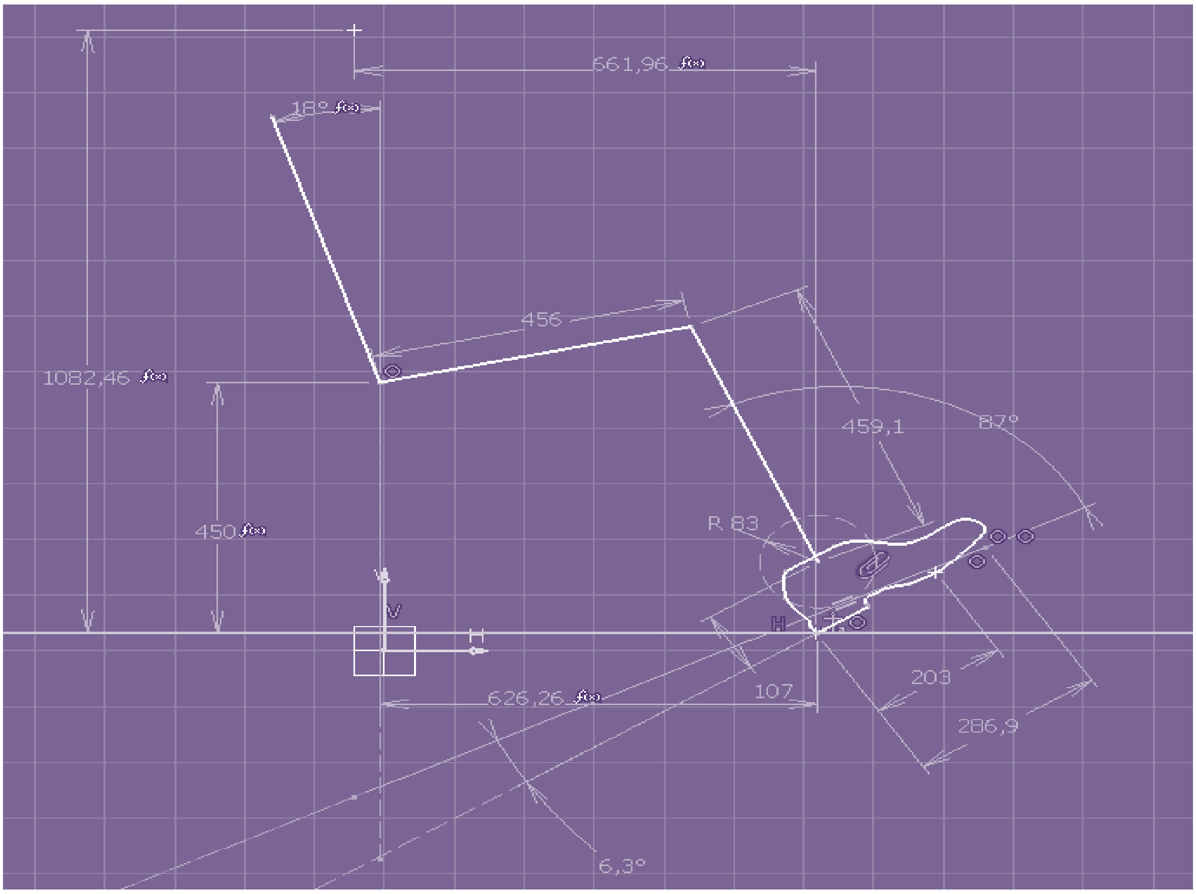
# APPENDIX - J

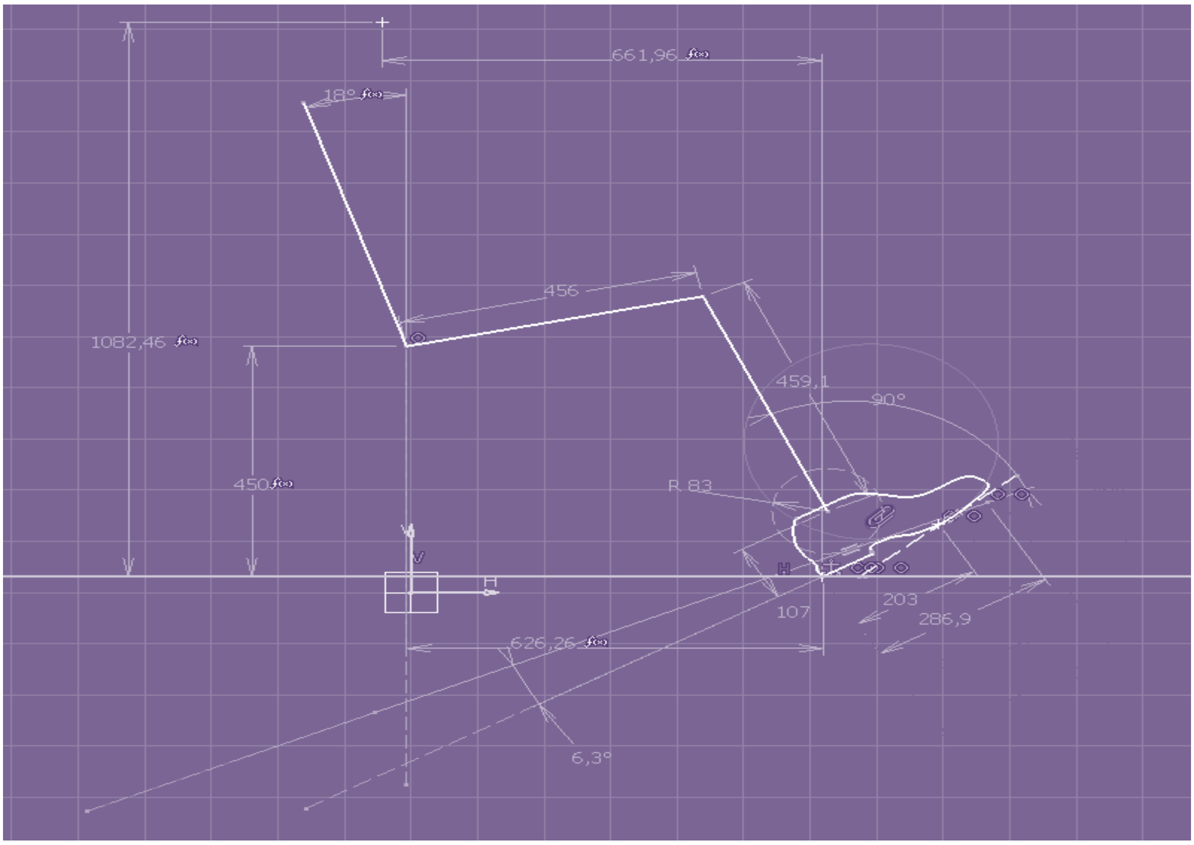
Pedal Angles in 2D (SAE Manikin)

The pedal angle corresponds to the layout of the pedals with respect to the mounting type and contact points between the foot and the pedal. In order to better understand the pedal contact point and foot contact points the 2D sketch is prepared for analysis.

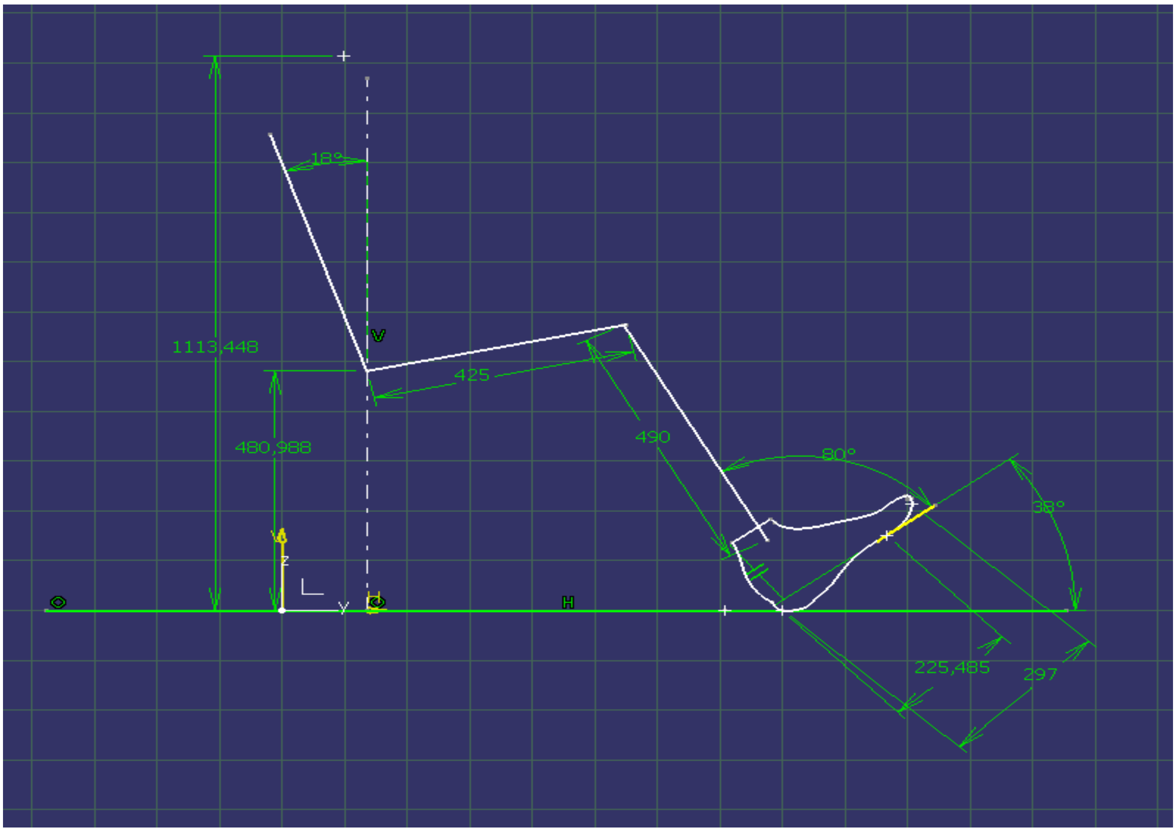
The drawings are used as preliminary data before the field operative test is performed.

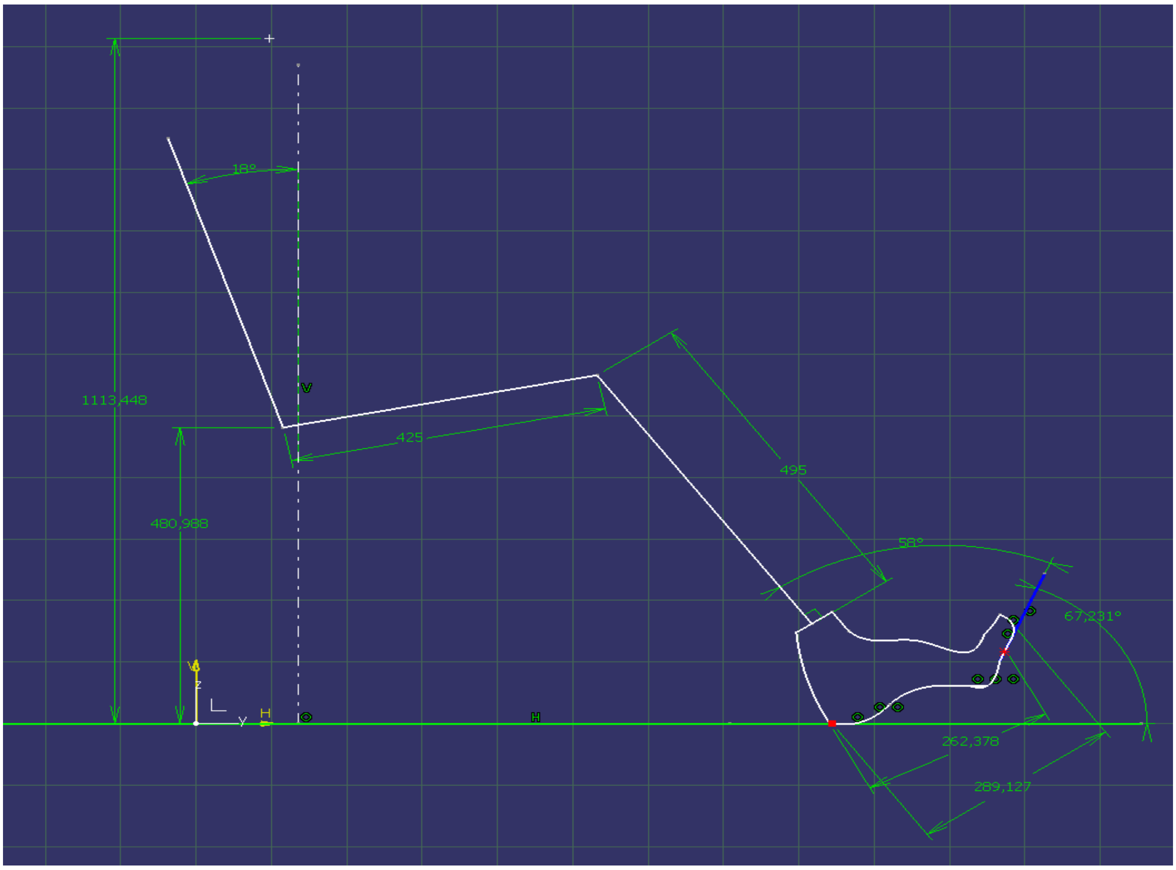
1) Suspended Pedals and Floor Mounted Pedal operated by Shoes






2) Suspended Pedals and Floor Mounted Pedals operated by Bare Foot





18°
1113,448
425
480,988
495
58°
67,231°
262,378
289,127

# APPENDIX - K

Method Documentation



## Pedal usage observation method

Method owner: Team Leader Ergonomics Gothenburg
Document updated by: Paul Praveen Peter
Dept: BF71321
Create Date: 05-09-2012
Last update: 15-09-2012

**Input:** To analyze the usage of pedals in trucks and then to measure (1) the foot contact point with shoe & foot in relation to accelerator heel point position (2) foot angles

**Output:** Contact point between the foot/shoe with the pedal was measured in relation to accelerator heel point position, ankle angles, driver behavior during the driving session in driving with shoes and barefoot were studied

**Tools:** Sony Cyber Shot compact camera, Casio compact camera, Snake scope USB camera, mounting fixtures – 2 units for two compact cameras, laptop, measurement tapes, papers scale from IKEA, questionnaire for subjective evaluation, Truck or Car

**Summary:** This method was used to have thorough study about the pedal usage in trucks. The main goal was to analyze and compare the pedal usage with shoes and barefoot. The pedal usage observation was carried out in a Volvo FH truck with 11 drivers (male drivers -9; female drivers: 2)

# Goal

The goal of the method was to observe the following parameters

(1) Pedal contact point

(2) Accelerator heel point (AHP)

(3) Foot angles

(4) Compare the pedal usage between driving with shoes and Barefoot.

For analysing the above landmarks three cameras were used during the studies

(a) The first camera was focused towards the accelerator heel point position – Sony Cyber Shot

(b) The second camera to capture the feet movement between the pedals – Casio compact camera

(c) The third camera was employed to observe and measure the exact contact point between the shoe/barefoot and pedal – Snake scope USB Camera

## Installation of Mounting Fixtures


Mounting Fixture 1

Mounting Fixture 2

The pedal usage observation method has two cameras that need to be mounted within the cab to capture the pedal usage, so two mounting fixture were used

(1) Mounting Fixture 1 was received from the Ergonomics team
(2) Mounting Fixture 2 was manufactured at the workshop within Volvo

## Camera mounted in the fixtures

Camera 1 being attached with Mounting Fixture 1

The fixture for camera 1 was attached on the cab floor near the door with adhesive tapes. There was a bolt attached to the fixture which easily held the camera for the pedal usage observations.

## Camera mounted in the fixtures

Camera 2 being attached with Mounting Fixture 2

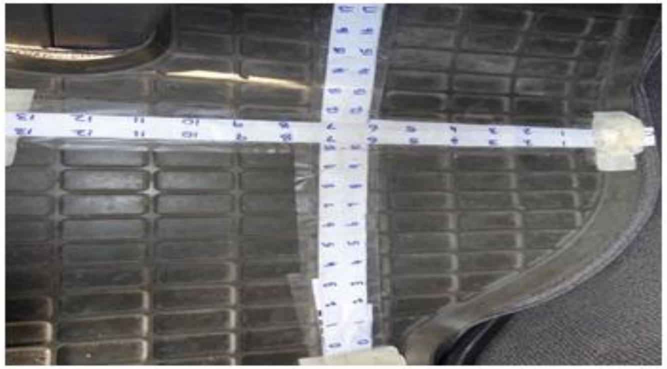
The fixture for camera 2 was attached to the dashboard with adhesive tapes. There was a bolt attached to the fixture to hold the camera easily with the fixture for the pedal usage observations.

## Camera attached to the wall

Camera 3 being attached to the engine tunnel wall

Camera 3 (snake scope) was attached to the engine tunnel wall to observe the exact contact point of the shoe/foot with the pedal. Since the Snake Scope has a flexible arm there is need for mountings to hold the camera. An illumination lamp was used to illuminate the leg room during the driving session.

## Measurement Scale



Measurement scale attached to the floor in the cab

Two measurement scales were attached to the floor to observe driver behavior and to view the accelerator heel point position during the pedal usage.

(1) The vertical scale was used to view the accelerator heel point position

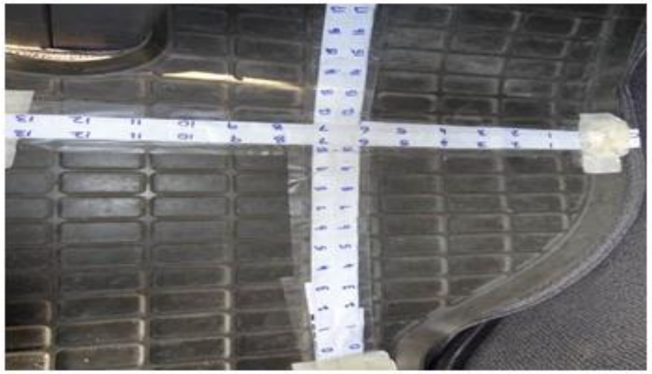
(2) The horizontal scale was used as a reference to observe foot movement between the pedals

## Measurement Scale attached to the Shoe/Foot

Measurement scale attached to the shoe/foot

Two paper measurement scale was attached to the shoe/foot during the driving sessions. In order to find the contact point in the pedal when driving with shoe or foot.

## Measurement Scale attached to the Shoe/Foot



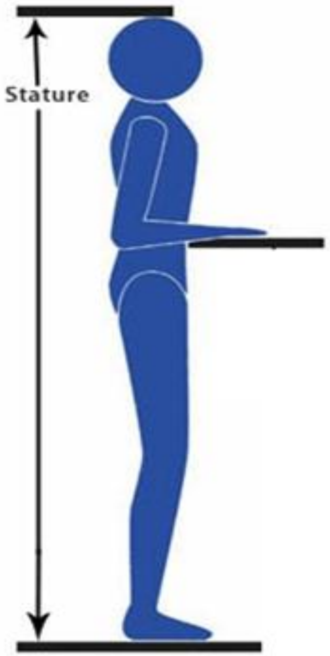
Measurement scale attached to the floor in the cab

Two measurement scales were attached to the floor to observe driver behavior and to view the accelerator heel point position during the pedal usage.

(1) The vertical scale was used to view the accelerator heel point position

(2) The horizontal scale was used as a reference to observe foot movement between the pedals

## Driving Session 2




1) Before driving session 1 the stature height of the driver and the length or size of the shoe were measured using the measuring tape.

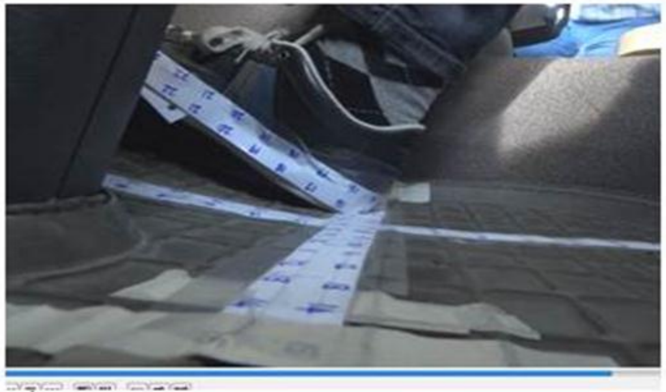
2) As discussed earlier, the paper measurement scale was attached to the shoes before the driving session

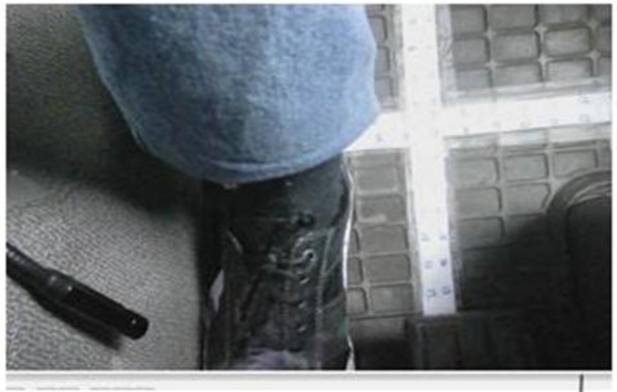
3) All the cameras were activated to record the driving session with shoes.

4) During the driving session the drivers were asked questions regarding various aspects related to pedal usage in driving with shoes. The drivers were also asked questions related to the pedal usage in different truck segments.

5) After the driving session all the cameras were deactivated.

## Videos from the Driving Session (Shoes)





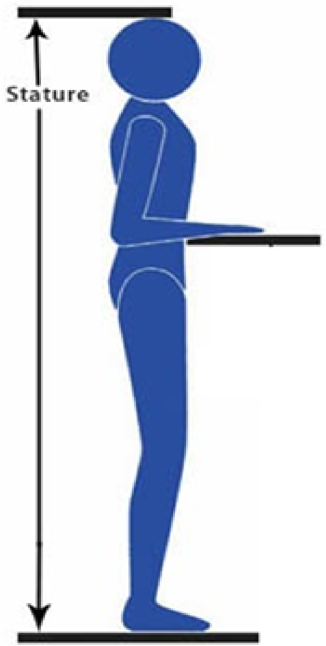
Camera 1

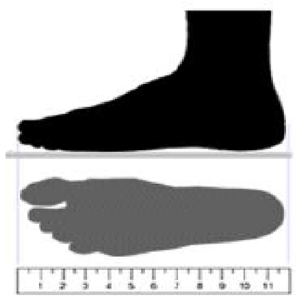
Camera 2

Camera 3

## Driving Session 1

## Driving Session 2



1) Before driving session 2 the length of the foot was measured using the measuring tape.

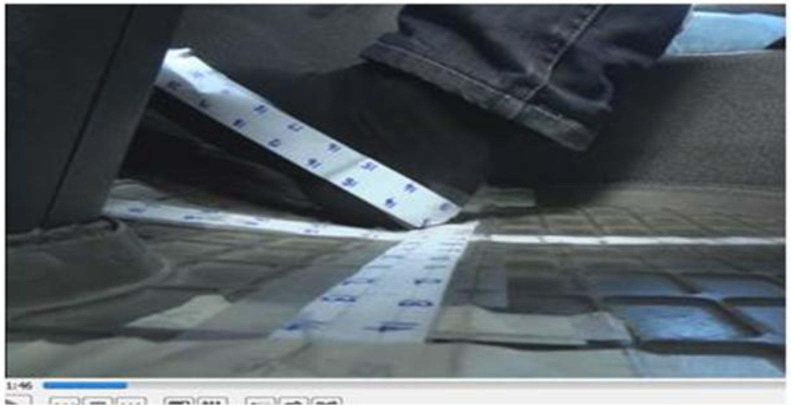
2) As discussed earlier, the paper measurement scale was attached to the foot before the driving session

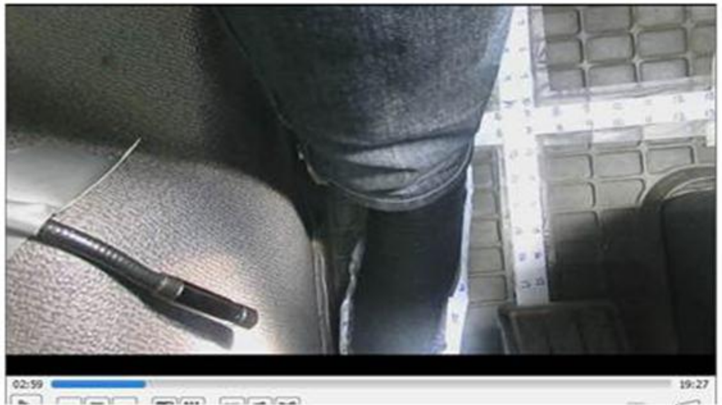
3) All the cameras were activated to record the driving session with barefoot

4) During the driving session the drivers were asked questions regarding various aspects related to pedal usage when driving barefoot. The drivers were also asked to compare barefoot driving with driving with shoes to explore the areas of improvement.

5) After the driving session all the cameras were deactivated.

# Videos from the Driving Session (Barefoot)



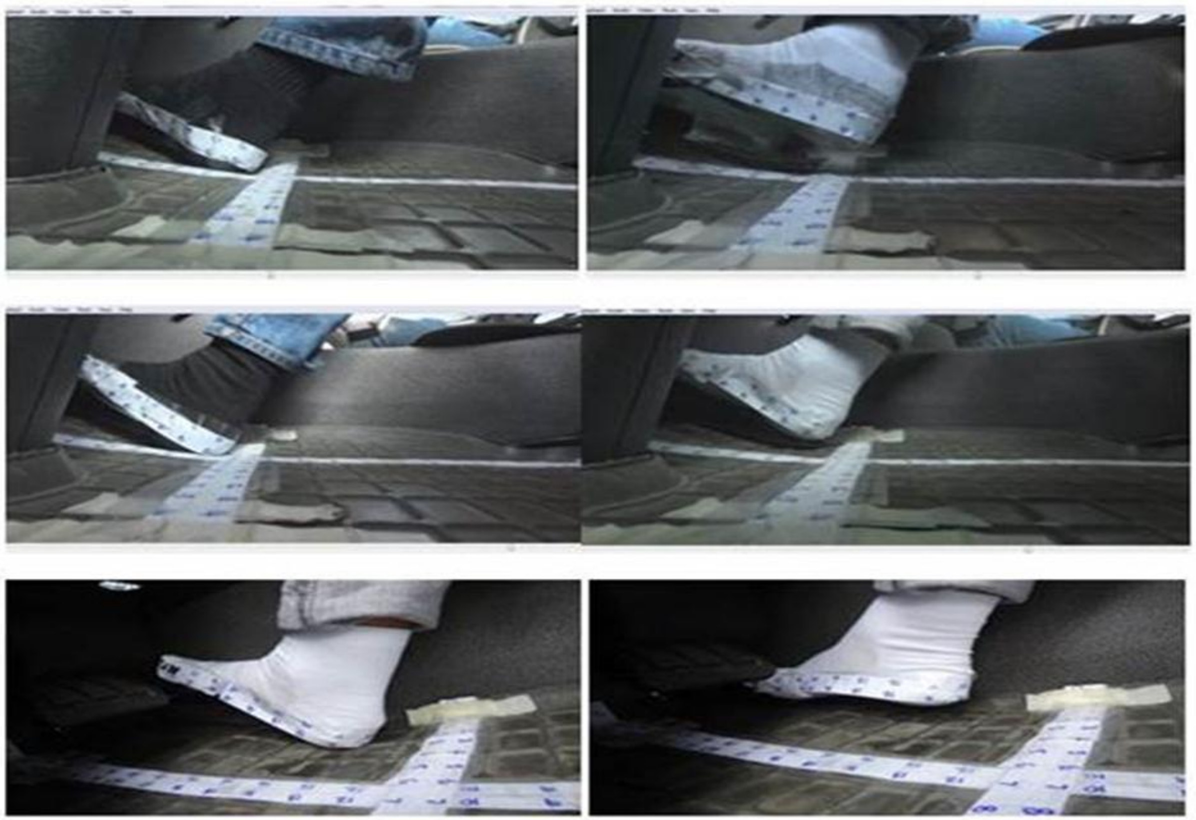


Camera 1

Camera 2

Camera 3

## Driving Session 2



# Result from Camera 3



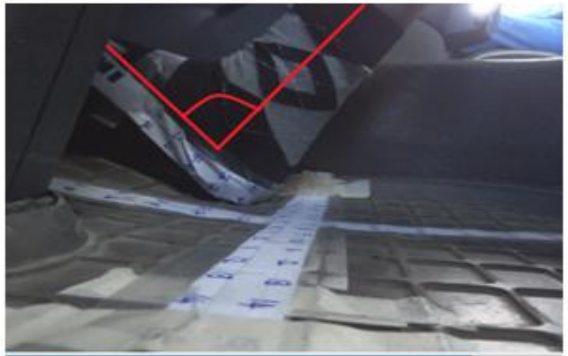
**From Shoe**

The exact contact point between the pedal and shoe was at 3.7 Inch ~ 93.3 mm

**From Barefoot**

The exact contact point between the barefoot and pedal was at 3 Inches ~ 76.2 mm

# Results from Camera 1



The foot angle was measured by taking the picture frames from the video material of camera 1.

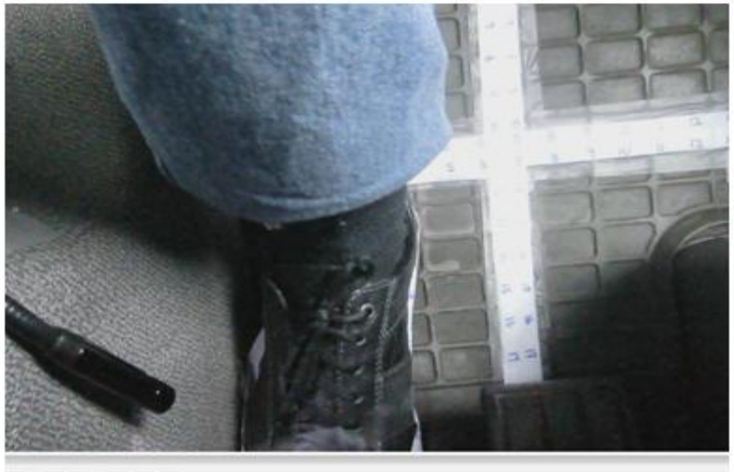
**From Shoe**

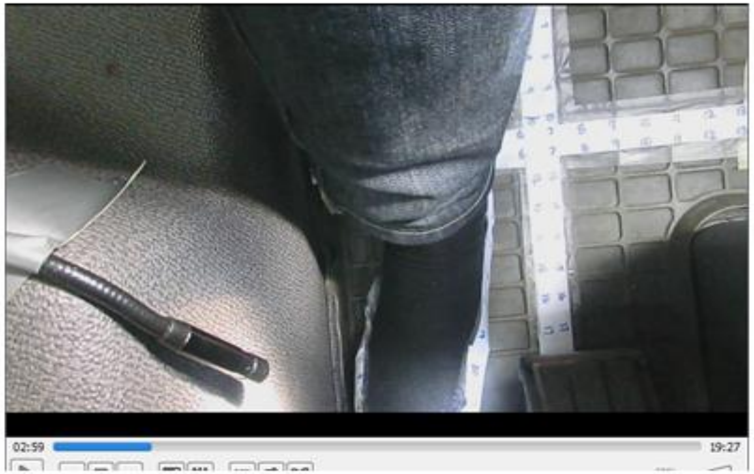
The exact foot angle from driving with shoes measured from camera 1 was 83 degrees

**From Barefoot**

The exact foot angle when barefoot driving as measured from camera 1 was 88 degrees

## Results from Camera 2






The video material acquired from camera 2 was used to study the (1) movement between the pedals during the driving session, (2) accelerator heel point (AHP) position and (3) Driver foot position and behavior during the driving session

# Results

Physical Measurements:

- Stature height was measured
- Length of the shoe was measured
- Length of the foot was measured

Video Material (Camera 1, Camera 2, Camera 3)

- Pedal contact point between pedal and shoe was measured from camera 3
- Pedal contact point between pedal and barefoot was measured from camera 3
- Foot angles or ankle angles were measured from camera 1
- Driver foot position and driver behavior studies were made from videos of camera 2 in combination with other cameras

# APPENDIX - L

Questionnaire during the driving session about driving with shoes & barefooted

Name:

1) What is your opinion about the size of the pedals?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

2) Do you prefer driving the trucks with shoes or barefooted?

| | Shoes | Barefoot |
|---|---|---|
| Long Haul | | |
| Distribution | | |
| Construction | | |

Comment

3) What is your opinion of the curvature in the pedal with shoes?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

4) What is your opinion of the gripper pattern in the pedal when wearing shoes?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

5) What is your opinion of the friction of the gripper in the pedal when driving with shoes?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment

6) What is your opinion about the lateral separation (distance) between the pedals?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

7) What is your opinion about the clearance distance between the accelerator pedals and the engine bay?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

8) What is your opinion about the clearance distance between the brake pedal and the steering column?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

9) Which pedal plane would you prefer (the brake pedal plane is positioned offset to the gas pedal plane)

| Above | Co-Planar | Below |
|---|---|---|
| | | |

Comment:

10) What is your opinion about the foot angle when moving from the default position to the maximum stroke length?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

11) What is your opinion about the foot angle and position between the brake pedal and floor at maximum stroke?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

12) What is your opinion about the distance between the pedals and the seats and the ease of reach?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

13) What is your opinion about the ease of reach of travel between the accelerator and the brake pedals with shoes?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

# APPENDIX - M

1) What is your opinion about the size of the pedal in barefoot driving?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

2) What is your opinion of the curvature of the pedal in driving with barefeet?

| | Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|---|
| Long Haul | | | | | |
| Distribution | | | | | |
| Construction | | | | | |

Comment:

3) Which you prefer to use when barefoot driving?

| Ball of Foot | Toes |
|---|---|
| | |

4) What is your opinion of the gripper patterns on the pedal in driving barefooted?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

5) What is your opinion of the gripper patterns on the gas pedal when driving with toes?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

6) What is your opinion of the friction from the gripper on the pedal when barefooted?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

7) What is your opinion about the foot angles as the pedal moves down the stroke?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

8) What is your opinion about the ease of travel between the accelerator and brake pedals with the barefoot?

| Poor | Fair | Good | Very Good | Excellent |
|---|---|---|---|---|
| | | | | |

Comment:

9) Are you satisfied with the current pedal layout?

| Yes | No |
|---|---|
| | |
| | |

10) If you were given an opportunity to change the pedal layout or its dimensions what would it be?

Comment:

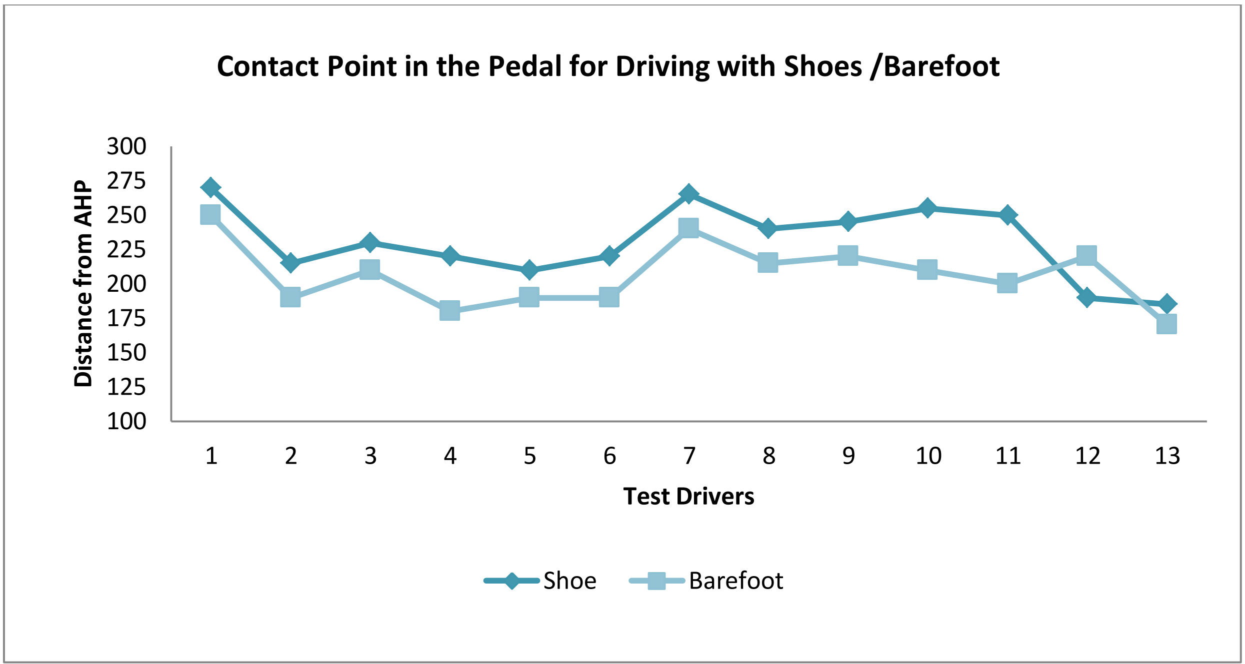
11) What changes would you like to see regarding pedals in future trucks?

Comment:

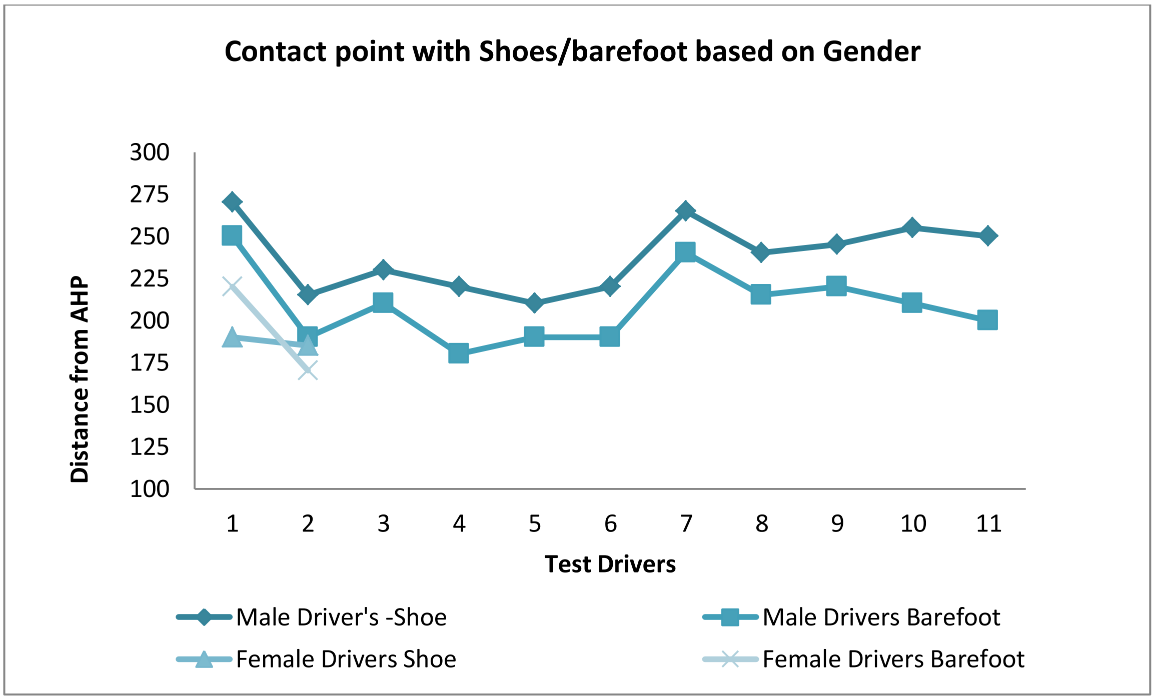
# APPENDIX - N

Pedal usage observations

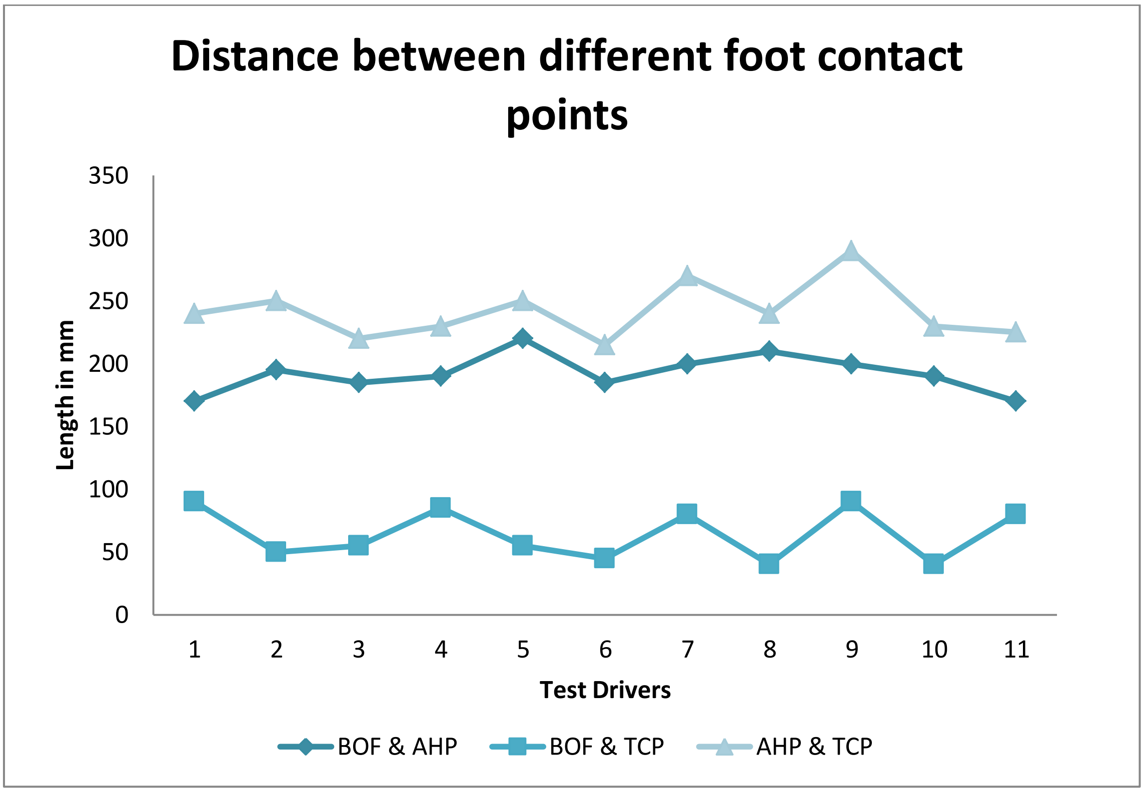
The contact point on the Pedal (PCP) with shoe/barefoot compared to the AHP



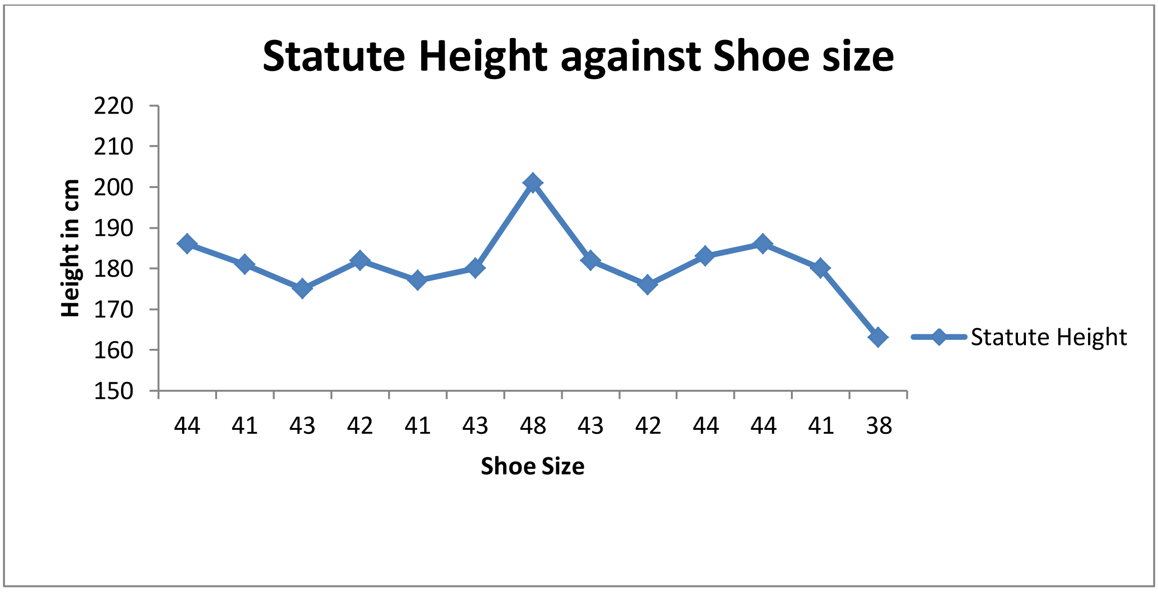

The contact point on the Pedal with Shoes & Barefoot (Male/female drivers)



Distance between BOF & AHP and BOF and TCP and AHP & TCP




Stature height of the drivers against the drivers shoe size



# APPENDIX - O

| S.No | Details | Driver 1 | Driver 2 | Driver 3 | Driver 4 | Driver 5 | Driver 6 | Driver 7 | Driver 8 | Driver 9 | Driver 10 | Driver 11 | Driver 12 | Driver 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Accelerator and Brake Pedal Corellation Study (Driving with Shoes / Driving with Barefoot)** | | | | | | | | | | | | | |
| 1 | Height | 186 | 181 | 175 | 182 | 177 | 180 | 201 | 182 | 176 | 183 | 186 | 180 | 163 |
| | | | | | | | | | | | | | | |
| | **Observations with Shoes** | | | | | | | | | | | | | |
| 2 | Type of Shoe | Sports | Sandals | Sports | Sports | Casual | Sports | Sports | Sports | Formal | Casual | Business/Formal | Women High Heels | Sports |
| 3 | Size of Shoe | 44 | 41 | 43 | 42 | 41 | 43 | 48 | 43 | 42 | 44 | 44 | 41 | 38 |
| 4 | Length of the Shoe (mm) | 310 | 285 | 295 | 295 | 290 | 305 | 330 | 298 | 300 | 320 | 325 | 241 | 250 |
| 5 | Width of the Shoe (mm) Ball of Foot | 110 | 100 | 96 | 105 | 110 | 104 | 125 | 105 | 110 | 115 | 113 | 95 | 83 |
| 6 | Width of the Shoe (mm) Ankle | 70 | 80 | 65 | 80 | 80 | 80 | 95 | 80 | 75 | 90 | 78 | 35 | 45 |
| 7 | Distance between the edge of Shoe to toe | 10 | 15 | | | | | | | | | | | |
| 8 | Foot Length | 280 | 285 | 270 | 265 | 250 | 260 | 300 | 250 | 265 | 255 | 280 | 255 | 230 |
| 9 | Foot Width | 100 | 100 | 115 | 105 | 105 | 95 | 80 | 95 | 110 | 105 | 100 | 110 | 85 |
| 10 | % of the first contact point in the Shoe with the pedal (with respect to AHP) | 260 | 215 | 230 | 210 | 210 | 220 | 265 | 240 | 245 | 255 | 240 | 185 | 180 |
| 11 | Clearance between the Pedal and Shoe after the contact point | 28 | | | | | | | | | | | | |
| 12 | Min Ankle Angle | 90 | 90 | 90 | 88 | 92 | 88 | 91 | 92 | 88 | 92 | 90 | 91 | 90 |
| | Max Ankle Angle | 119 | 112 | 118 | 122 | 124 | 119 | 118 | 121 | 121 | 118 | 113 | 116 | 125 |
| | **Observations with Barefoot Driving** | | | | | | | | | | | | | |
| 13 | Length of the Foot | 280 | 285 | 270 | 265 | 250 | 260 | 300 | 250 | 265 | 255 | 280 | 255 | 230 |
| 14 | Width of the Foot (ankle) | 70 | 70 | 60 | 60 | 75 | 65 | 80 | 75 | 55 | 78 | 85 | 70 | 50 |
| 15 | Width of Foot (Ball of Foot) | 100 | 110 | 115 | 105 | 105 | 95 | 115 | 95 | 110 | 105 | 100 | 110 | 85 |
| 16 | Ankle Angle | 90/ | | | | | | | | | | | | |
| 17 | Distance between the BOF and AHP | 190 | 190 | 170 | 195 | 185 | 190 | 220 | 185 | 200 | 210 | 200 | 190 | 170 |
| 18 | Distance between the BOF and TCP | 50 | 50 | 90 | 50 | 55 | 85 | 55 | 45 | 80 | 40 | 90 | 40 | 80 |
| 19 | Distance between the AHP and TCP | 240 | | 240 | 250 | 220 | 230 | 250 | **215** | 270 | 240 | 290 | 230 | 225 |
| 20 | Toe Length | 50 | 60 | 50 | 60 | 55 | 50 | 70 | 55 | 60 | 60 | 40 | 60 | 50 |
| 21 | Toe Width | 60 | 50 | 55 | 45 | 45 | 50 | 50 | 45 | 40 | 48 | 40 | 40 | 50 |
| 22 | Distance between the Toe and BOF | | | 95 | 80 | | 80 | 90 | | 80 | | 90 | | 70 |
| 23 | % of the first contact in the foot with the Pedal (with respect to AHP) | 250 | 190 | 210 | 180 | 190 | 190 | 240 | 218 | 220 | 210 | 200 | 220 | 170 |
| 24 | % of the second contact in the foot with the Pedal (with respect to AHP) | | | | | | | | | | 250 | | | |
| 25 | Clearance between the Pedal and foot after the contact point | 10 | 12 | | | | | | | | | | | |

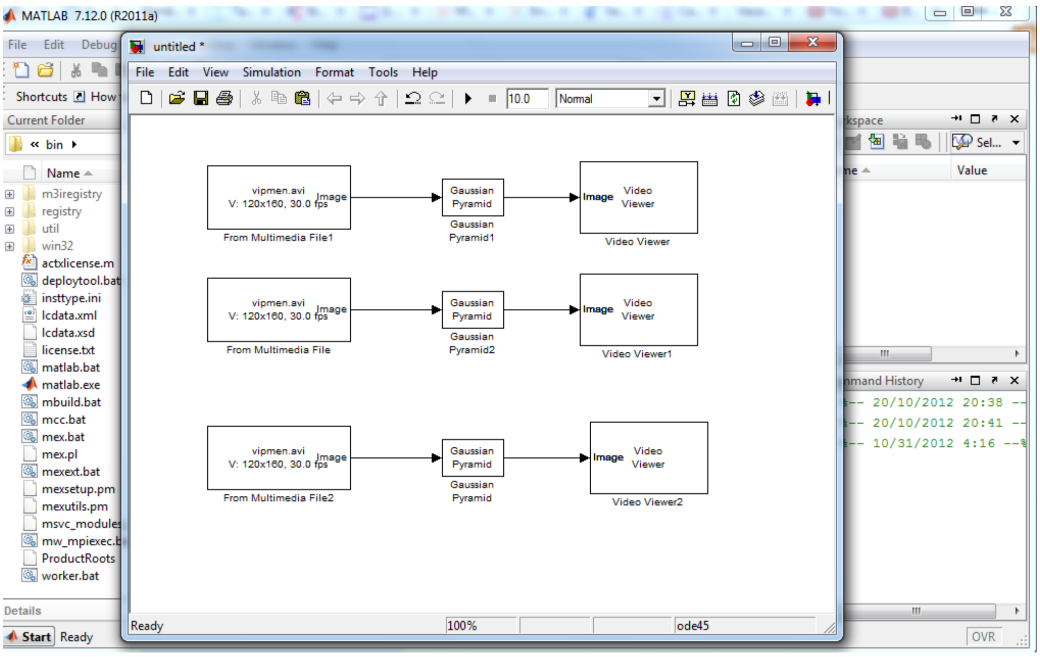
# APPENDIX - P

Post-processing tool to view the video material

During the post processing of the videos from the driving sessions the videos were converted to AVI format. The window shows the simple Simulink model that was constructed to view the videos from the three cameras simultaneously. The Simulink model was developed through the Computer Vision Toolbox function in the software.

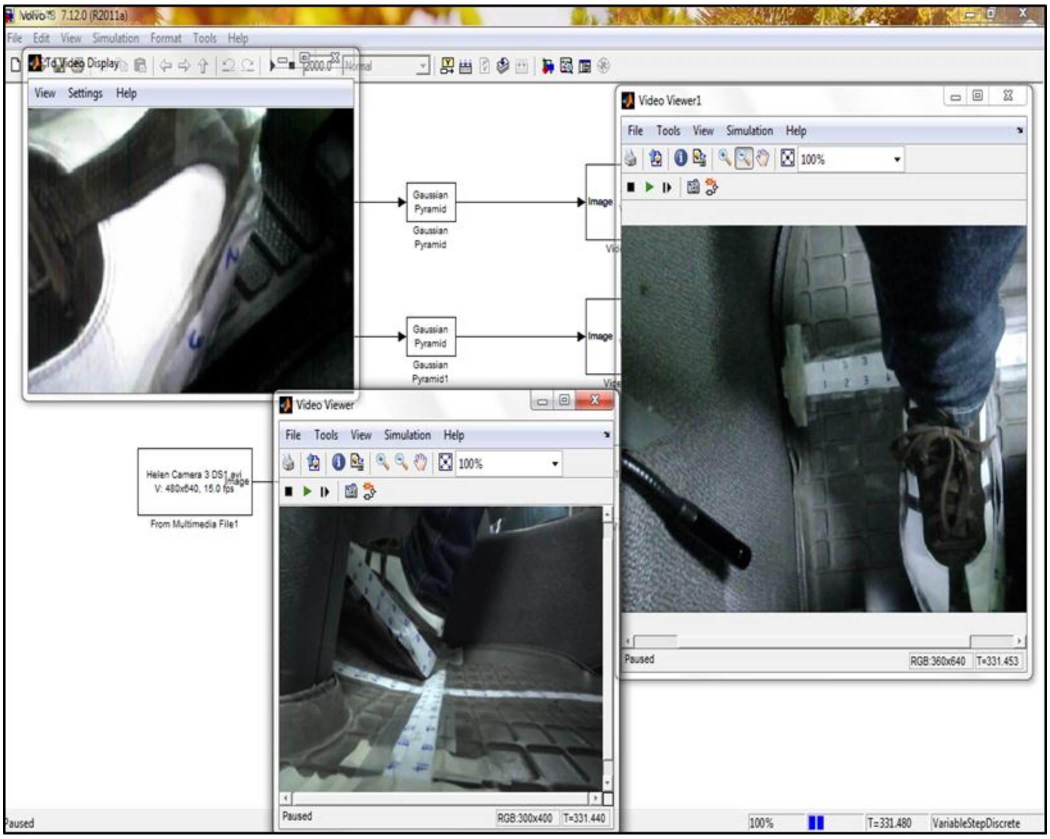
The model consists of three input block sets on the left in which the videos files were loaded. The three Gaussian pyramid blocks were used to stabilize the picture frames in videos to be viewed and through the video viewer block sets the videos were viewed simultaneously in three different windows.

The picture below illustrates the model and the video viewer function.




Limitation of the Post-processing tool:

1. Time consuming to synchronize the videos from three inputs at the same time.
2. The playback is relatively slow in viewing the videos because of the computer graphics capability in retrieving three inputs into one window


Volvo 7.12.0 (R2011a)
File Edit View Simulation Format Tools Help
To Video Display
View Settings Help
Gaussian Pyramid
Gaussian Pyramid
Gaussian Pyramid
Gaussian Pyramid1
Image
Video Viewer1
File Tools View Simulation Help
100%
Paused
RGB:360x640
T=331.453
Video Viewer
File Tools View Simulation Help
100%
Paused
RGB:300x400
T=331.440
Helen Camera 3 DS1.avi
V: 480x640, 15.0 fps
Image
From Multimedia File1
Paused
100%
T=331.480
VariableStepDiscrete

# APPENDIX - Q

Ratings from the subjective evaluation session in driving with shoes and with barefoot

| S.No | Questions | | | | | | | | | | | | Average Scores |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Experience | 22 | 25 | 38 | 30 | 18 | 20 | 38 | 20 | 40 | 15 | 8 | |
| | **Pedals -Driving with Shoes** | | | | | | | | | | | | |
| | Opinion about the Size of the Pedal | | | | | | | | | | | | |
| 1 | Longhaul | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 3.72 |
| 2 | Distribution | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 3.72 |
| 3 | Construction | 4 | 2 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 3.63 |
| | Do you Prefer Driving the trucks with Shoe or Barefoot | | | | | | | | | | | | |
| 4 | Longhaul | Shoes | Shoes | Shoes | Shoes | Barefoot | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes |
| 5 | Distribution | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes |
| 6 | Construction | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes | Shoes |
| | What is your opinion of the Curvature in the Pedal | | | | | | | | | | | | |
| 7 | Longhaul | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3.9 |
| 8 | Distribution | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3.9 |
| 9 | Construction | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 3.9 |
| | What is your opinion on the gripper patterns in the Pedal | | | | | | | | | | | | |
| 10 | Longhaul | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3.81 |
| 11 | Distribution | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3.81 |
| 12 | Construction | 5 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3.81 |
| | What is your opinion of the friction from the gripper in the Pedal | | | | | | | | | | | | |
| 13 | Longhaul | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3.81 |
| 14 | Distribution | 4 | 3 | 4 | 4 | 4 | 4 | 4 | | 4 | 3 | 4 | 3.8 |
| 15 | Construction | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3.81 |
| | What is your opinion about the lateral separation (distance) between the Pedals? | | | | | | | | | | | | |
| 16 | Longhaul | 4 | 4 | 4 | 3 | 2 | 3 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| 17 | Distribution | 4 | 4 | 4 | 3 | 2 | 3 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| 18 | Construction | 4 | 4 | 4 | 3 | 2 | 3 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| | What is your opinion about the clearance distance between the accelerator pedal and the engine bay? | | | | | | | | | | | | |
| 19 | Longhaul | 4 | 3 | 2 | 4 | 3 | 4 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| 20 | Distribution | 4 | 3 | 2 | 4 | 3 | 4 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| 21 | Construction | 4 | 3 | 2 | 4 | 3 | 4 | 2 | 4 | 4 | 4 | 4 | 3.45 |
| | What is your opinion about the clearance distance between the brake pedal and the steering column? | | | | | | | | | | | | |
| 22 | Longhaul | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 23 | Distribution | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 24 | Construction | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Which pedal plane would you prefer (brake pedal plane in relation to the accelerator pedal plane) | | | | | | | | | | | | |
| 25 | Above/Co-Planar/Below | Above | Above | Above | Above | Co-Planar | Above | Above | Above | Co-Plana | Above | Co-Planar | |
| 26 | What is your opinion about the foot angle at the minimum to maximum stroke in brake pedal? | 3 | 5 | 4 | 4 | 3 | 4 | 2 | 4 | 3 | 4 | 4 | 3.63 |
| 27 | What is your opinion about the foot angle at the minimum to maximum stroke in gas pedal? | 3 | 4 | 4 | 4 | 3 | 4 | 2 | 4 | 3 | 4 | 4 | 3.54 |
| 28 | What is your opinion about the distance between the pedals and the seats the easiness of reach? | 4 | 2 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 2 | 5 | 3.45 |
| 27 | What is your opinion about the easiness to travel between the accelerator and brake pedal with shoes? | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 4 | 2 | 4 | 3 | 3.54 |

| S.No | Questions | | | | | | | | | | | | Average Scores |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Pedals -Driving with Barefoot** | | | | | | | | | | | | |
| | Opinion about the Size of the Pedal | | | | | | | | | | | | |
| 28 | Longhaul | 3 | 4 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | 2 | 4 | 3.45 |
| 29 | Distribution | 3 | 4 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | 2 | 4 | 3.45 |
| 30 | Construction | 3 | 4 | 4 | 3 | 4 | 4 | 2 | 4 | 4 | 2 | 4 | 3.45 |
| | What is your opinion of the Curvature in the Pedal | | | | | | | | | | | | |
| 31 | Longhaul | 2 | 4 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 3 | 2.63 |
| 32 | Distribution | 2 | 4 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 3 | 2.63 |
| 33 | Construction | 2 | 4 | 2 | 2 | 2 | 4 | 2 | 4 | 2 | 2 | 3 | 2.63 |
| 34 | Do you prefer to use when driving with barefoot | | | | | | | | | | | | |
| | Ball of Foot/Toes | Toes | Ball of Foot | Ball of Foo | Ball of Foo | Ball of Foo | Ball of Foo | Ball of Foo | Toes | Toes | Ball of Foo | Toes | |
| 35 | What is your opinion of the gripper patterns in the pedal in driving with barefoot? | 2 | 4 | 2 | 2 | 2 | 2 | 4 | 2 | 3 | 2 | 4 | 2.63 |
| 36 | What is opinion of the gripper patterns in the pedal in driving with toes in gas pedal? | 3 | 4 | 2 | 2 | 2 | 2 | 4 | 2 | 3 | 3 | 4 | 2.81 |
| 37 | What is your opinion of the friction from the gripper in the pedal with barefoot? | 2 | 4 | 2 | 2 | 2 | 3 | 4 | 2 | 4 | 4 | 3 | 2.9 |
| 38 | What is your opinion about the foot angle at the minimum to maximum stroke in brake pedal? | 4 | 4 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 1 | 4 | 2.72 |
| 39 | What is your opinion about the foot angle at the minimum to maximum stroke in gas pedal? | 3 | 4 | 3 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 2.72 |
| 40 | What is your opinion about the easiness to travel between the accelerator and the brake pedal? | 3 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2.63 |
| 41 | Are you satisfied with the current pedal layout? | Yes | Yes | No | Yes | No | No | No | No | No | Yes | No | |
| 42 | If you were given an oppurtunity to change the pedal layout or pedal dimensions what will it be? | | FM | | FM | FM | | | FM | FM | FM | | |
| 43 | What would you think about the pedals in future trucks? | No | Yes | No | Yes | Yes | No | No | Yes | Yes | Yes | No | |

# APPENDIX - R

## Questionnaire

**The Questionnaire is prepared to get insight about the pedal type, gripper patterns in the different pedal concepts and how they influence the pedal design.**

**The questionnaire contains different pedal concepts used in Trucks and passenger cars.**

**Please take the concepts as an inspiration and provide your answers based on you experience in driving trucks on different applications**

**Give rating in the tabular column based on 5-point Scale and your chosen concept? Why you prefer the concept? in the comment section.**

*Please give your ratings (5-point scale) in the column and selected/preferred concept in the comment section.*

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

Name: ____________________________

"General concept" for Accelerator Pedal

Suspended Pedal


1A


1B


1C


1D


1E


1F


1G


1H


1I


1J


1K

Floor Mounted Pedal


2A


2B


2C


2D


2E


2F


2G


2H


2I


2J


2K

| | Suspended | Floor Mounted | Comments (Please mention the concept and why you prefer the concept) |
|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | |
| Distribution (Keep city driving in Mind) | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | |
| Barefoot | | | |

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

## Accelerator Pedal Gripper Patterns

Lines in x-direction


5A


5B

Lines in y-direction


6A


6B


6C


6D


6E


6F


6G

Rubber dots


7A

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

| | Lines in X-direction | Lines in y-direction | Rubber Dots | Comments |
|---|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | | |
| Distribution (Keep city driving in Mind) | | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | | |
| Barefoot | | | | |

"General concept" **BRAKE PEDAL**

**Suspended Pedal**


8A


8B


8C


8D


8E


8F


8G


8H


8I


8J


8K


8l

**Floor Mounted Pedal**


9A


9B


9C


9D


9E

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

| | Suspended Pedal | Floor Mounted Pedal | Opinion (Concept you prefer) | Comments (Please mention the concept and why you prefer the concept) |
|---|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | | |
| Distribution (Keep city driving in Mind) | | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | | |
| Barefoot | | | | |

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

**Brake Pedal (Gripper Patterns)**

**Lines along x-direction**


12A


12B


12C


12D


12E


12F


12G

**Lines along y-direction**


13A


13B


13C


13D


13E


13F


13G

**Rubber dots**


14A


14B


14C

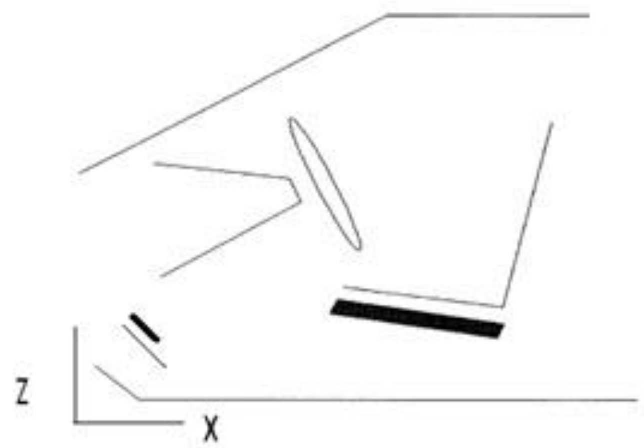
Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

| | Lines in X-direction | Lines in Y-direction | Rubber Dots | Comments (Please mention the concept and why you prefer the concept) |
|---|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | | |
| Distribution (Keep city driving in Mind) | | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | | |
| Barefoot | | | | |

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

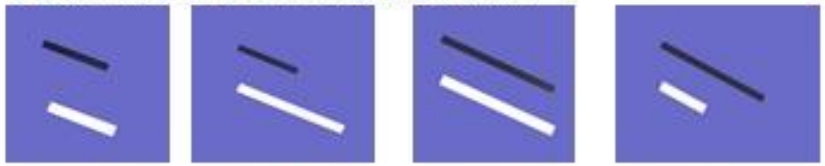



The picture above illustrates the pedal position along the x-axis (distance) and z-axis (height)
The following questions are based on the z axis height and x-axis distance in different pedal combinations

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

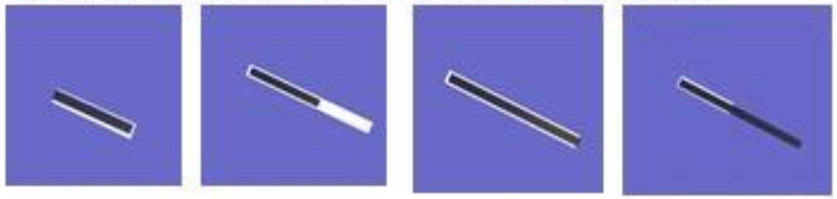
Please mention your preferences in the comment section

Brake pedal plane above accelerator pedal plane



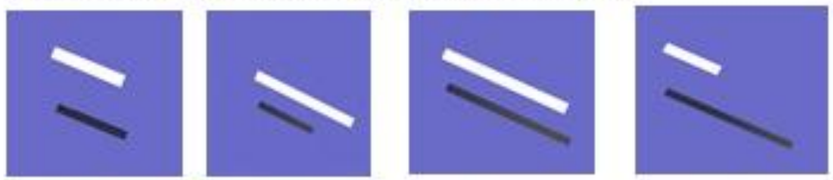
16A 16B 16C 16D

Brake pedal plane is in same level of the accelerator pedal plane



17A 17B 17C 17D

Brake pedal plane is in below the accelerator pedal plane



18A 18B 18C 18D

Note:

Concepts:

16A, 17A, 18A -Both Brake & Accelerator Pedals are suspended

16B, 17B, 18B – Brake pedal is suspended and Accelerator Pedal is Floor Mounted

16C, 17C, 18C – Both Brake and Accelerator Pedals are Floor Mounted

16D, 17D, 18D –Brake Pedal is Floor mounted and Accelerator Pedal is suspended

☐ White Pedal –Accelerator

■ Black Pedal - Brake

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

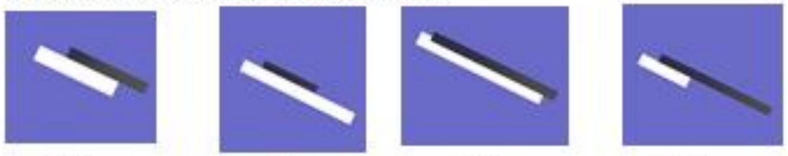
| | Above | Co-Planar | Below | Comments (Please mention the concept and why you prefer the concept) |
|---|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | | |
| Distribution (Keep city driving in Mind) | | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | | |
| Barefoot | | | | |

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

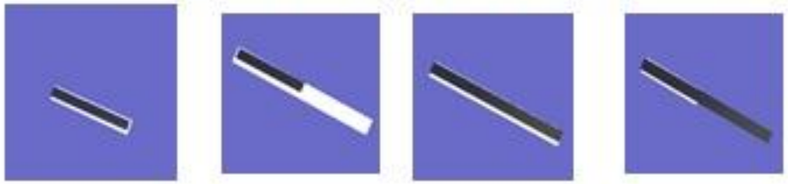
**Brake Pedal layout in relation to accelerator pedal (x axis distance between Pedals)**

**Brake pedal mounted closer to the Driver**



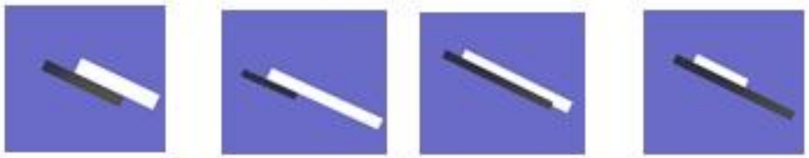
19A 19B 19C 19D

**Brake pedal plane is in same level of the accelerator pedal plane**

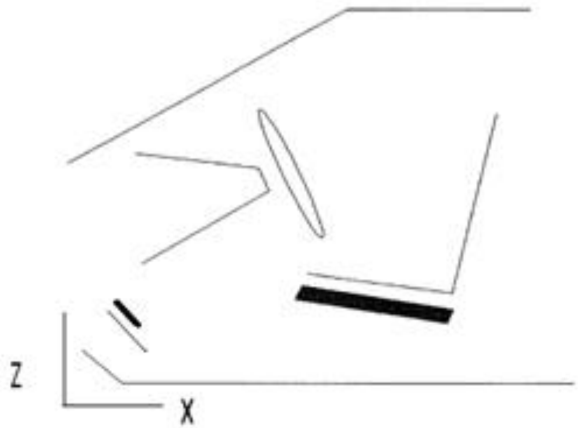


20A 20B 20C 20D

**Brake pedal mounted away from the Driver**



21A 21B 21C 21D




Note:

Concepts:

19A, 20A, 21A -Both Brake & Accelerator Pedals are suspended

19B, 20B, 21B – Brake pedal is suspended and Accelerator Pedal is Floor Mounted

19C, 20C, 21C – Both Brake and Accelerator Pedals are Floor Mounted

19D, 20D, 21D –Brake Pedal is Floor mounted and Accelerator Pedal is suspended

☐ White Pedal –Accelerator

■ Black Pedal - Brake

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

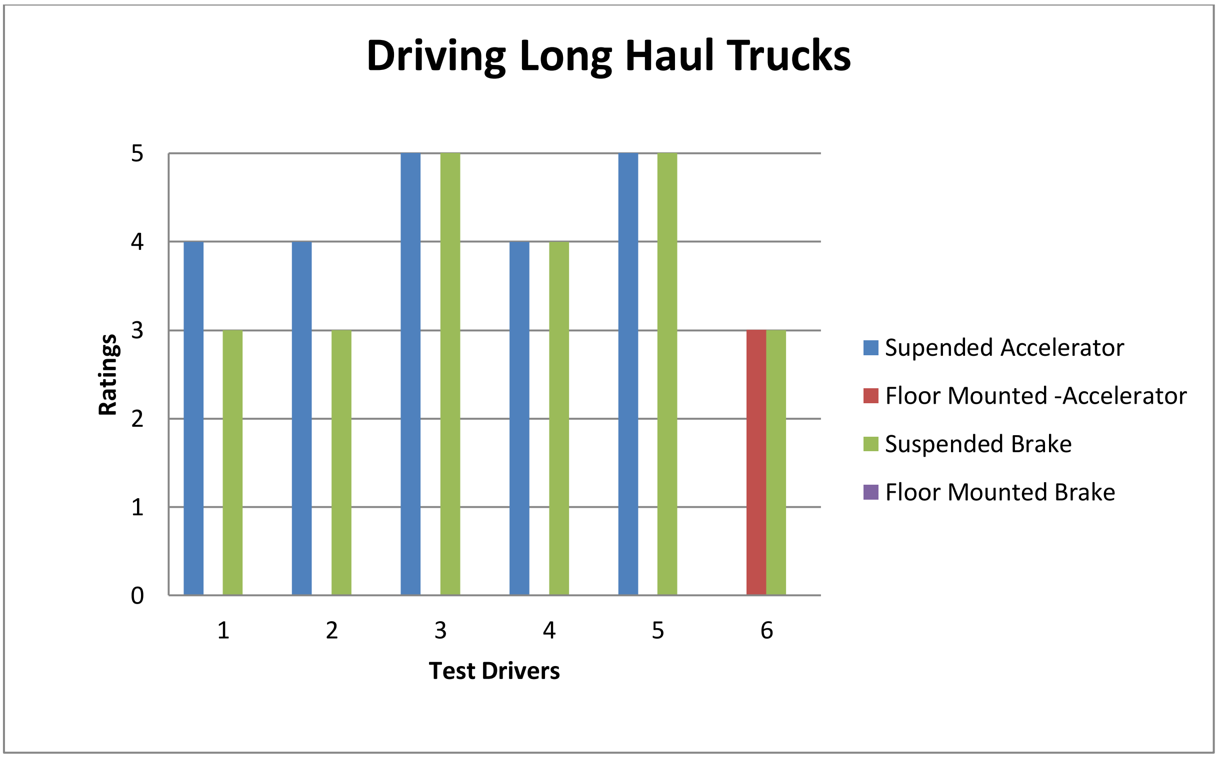
| | Closer to Driver | Normal Distance | Away from Driver | Comments (Please mention the concept and why you prefer the concept) |
|---|---|---|---|---|
| Long Haul Driving (Keep freeway driving in mind) | | | | |
| Distribution (Keep city driving in Mind) | | | | |
| Construction (Keep driving in rough roads & shoes in mind) | | | | |
| Barefoot | | | | |

Ratings Scale: 1-Poor, 2-Fair, 3-Good, 4-Verygood, 5-Excellent

Please mention your preferences in the comment section

# APPENDIX - S

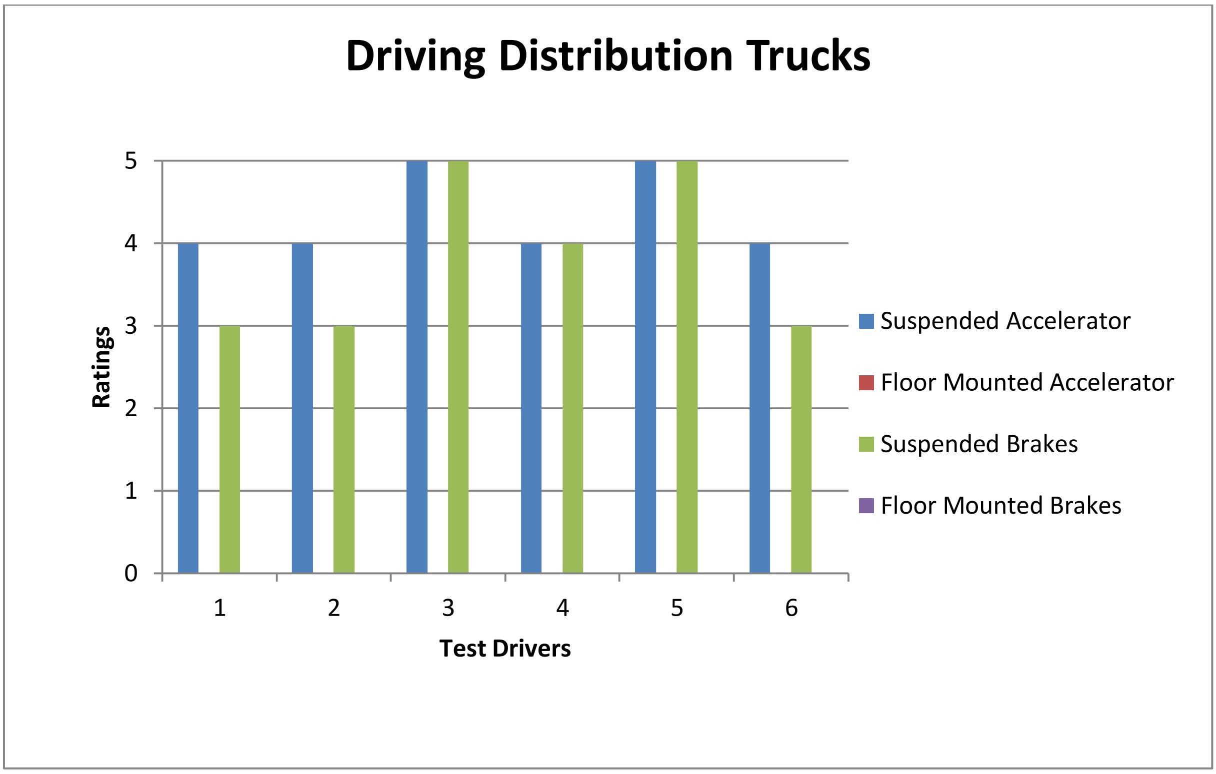
Six Drivers participated in the driving session. The questions were focused on the friction patterns and the position of the brake pedal in relation to the accelerator pedal.




The figure above shows the drivers preferences regarding the pedal types for accelerator and brake pedal.

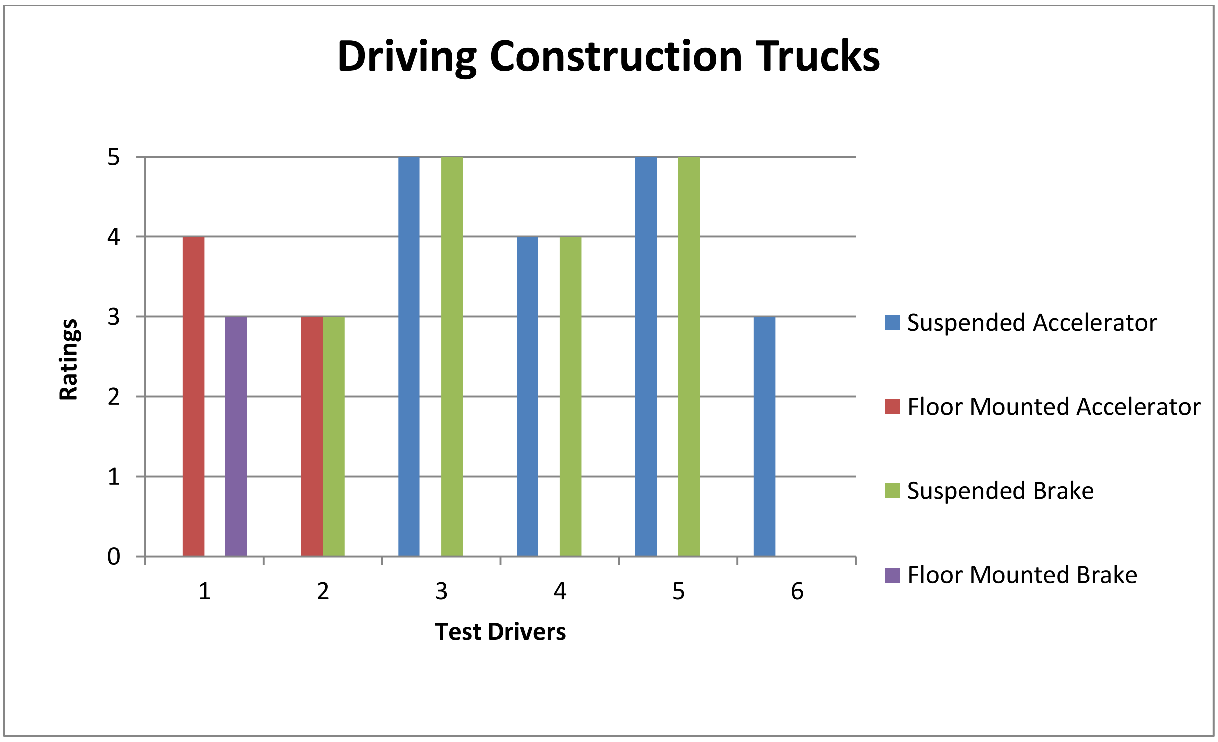
Among the six drivers, five drivers prefer the suspended accelerator pedal because they are accustomed to driving trucks with a suspended pedal and have never experienced driving with a floor mounted accelerator pedal. One driver prefers the floor mounted pedal because this pedal offers more relaxing comfort in long haul driving and with better support without having to look for another place to rest the foot. The floor mounted pedals were larger and provided excellent support for the feet in barefoot driving as well as when driving with a big boot.

Among the six drivers, all the drivers prefer the suspended brake pedal and are uncomfortable with the floor mounted brake pedal because of the poor comfort that the drivers experienced with the DAF floor mounted brake pedal. The suspended brake pedal seems more natural to use for braking, independent of transport. In long haul trucks the brake pedal is seldom used, but it is important to be able to quickly move the feet in an emergency situation. A large pedal surface would enable the pressure to be distributed in barefoot driving.



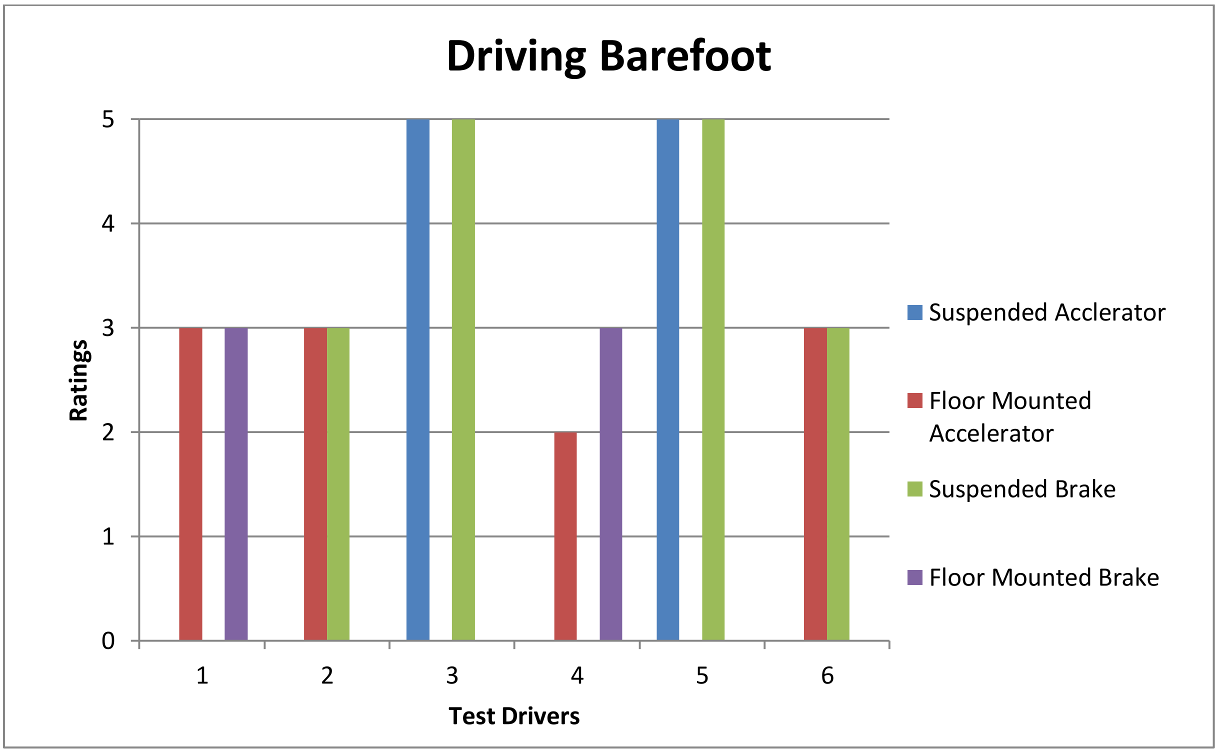

The figure above shows the drivers' preference for a suspended accelerator pedal for distribution applications. The distribution truck drivers move their feet between the pedals often, unlike long haul truck drivers, so long-term foot support is not important. The pedal should instead make sideways movements as easy as possible.

The figure shows the drivers preference for a suspended brake pedal. Almost all the drivers prefer a suspended brake pedal for distribution applications. The suspended pedal seems more natural to use with shoes and allows for easy movement between the brake and accelerator pedal.



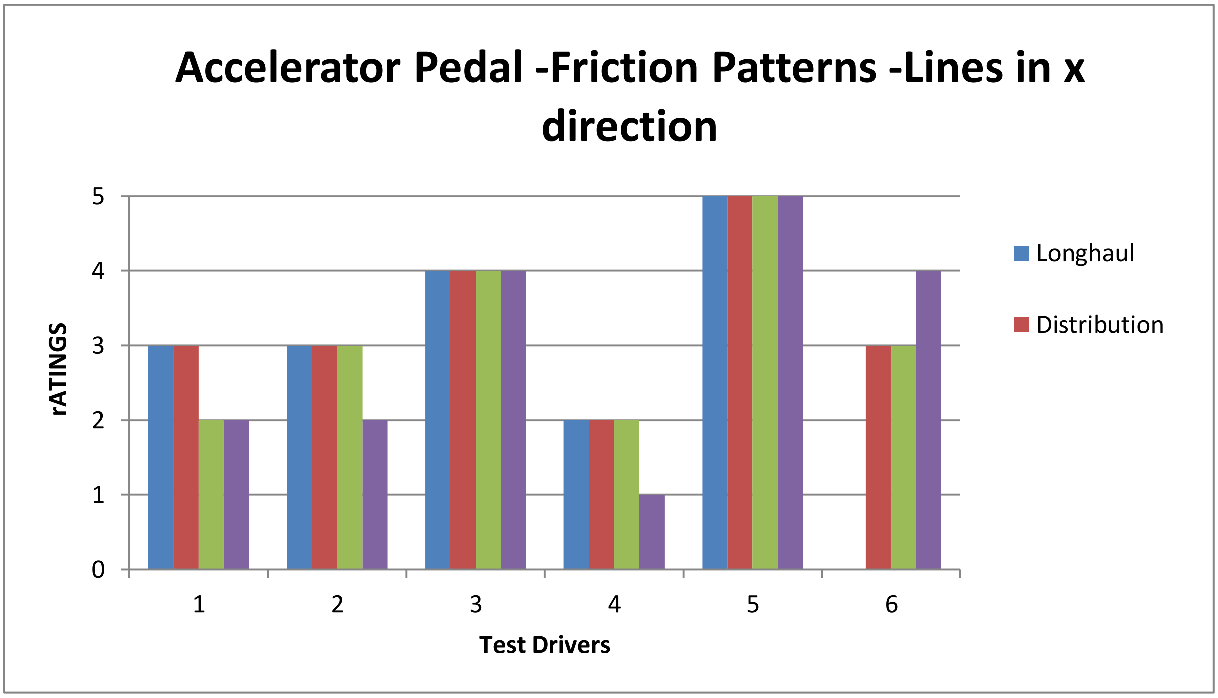

The figure shows the driver's preferences for accelerator and brake pedals in construction applications. Among the drivers, 4 drivers preferred a suspended accelerator pedal because the suspended pedals were sturdy and easy to use for construction applications while two drivers preferred a floor mounted accelerator pedal because the vibration in the cab while driving in rugged terrain causes the drivers to frequently move their feet between the accelerator and brake. The pedal should have excellent friction against a wet or dirty environment.

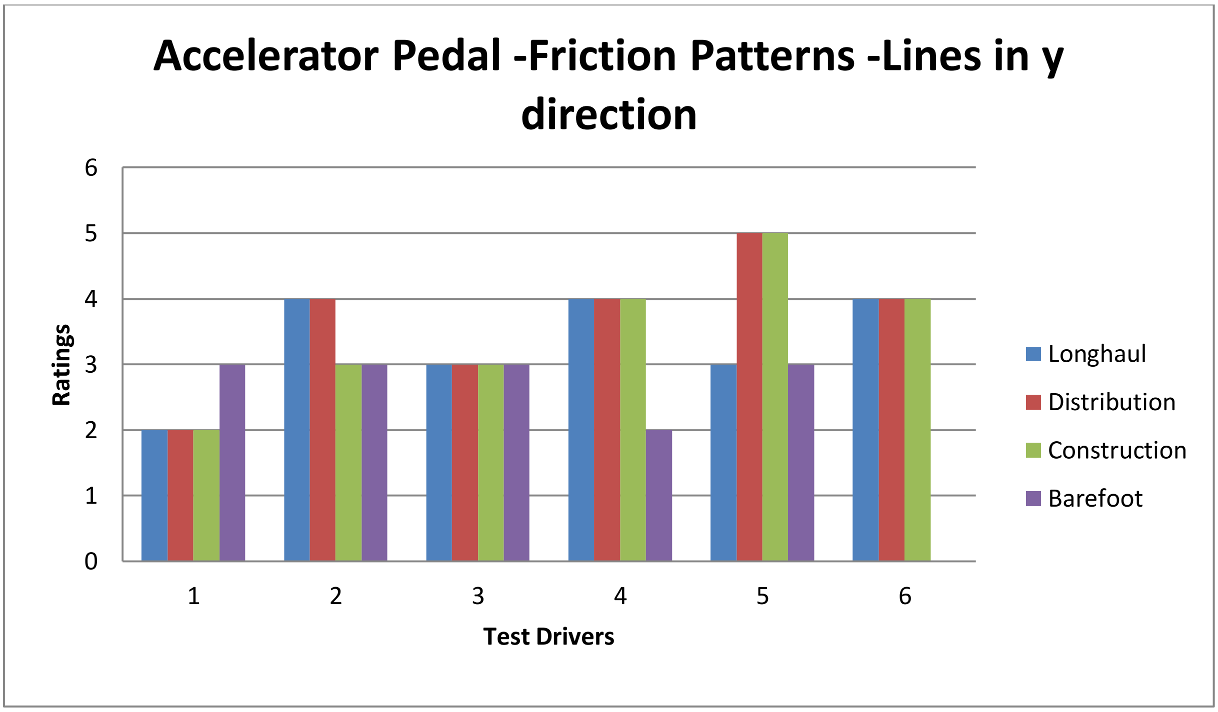
Most of the drivers prefer suspended brake pedals and one driver prefers a floor mounted brake pedal. The suspended pedal seems more natural for brake application in construction trucks. The brake pedal for construction transport should be rugged and provide very good friction for heavier shoes with a large rubber surface that should not be worn.

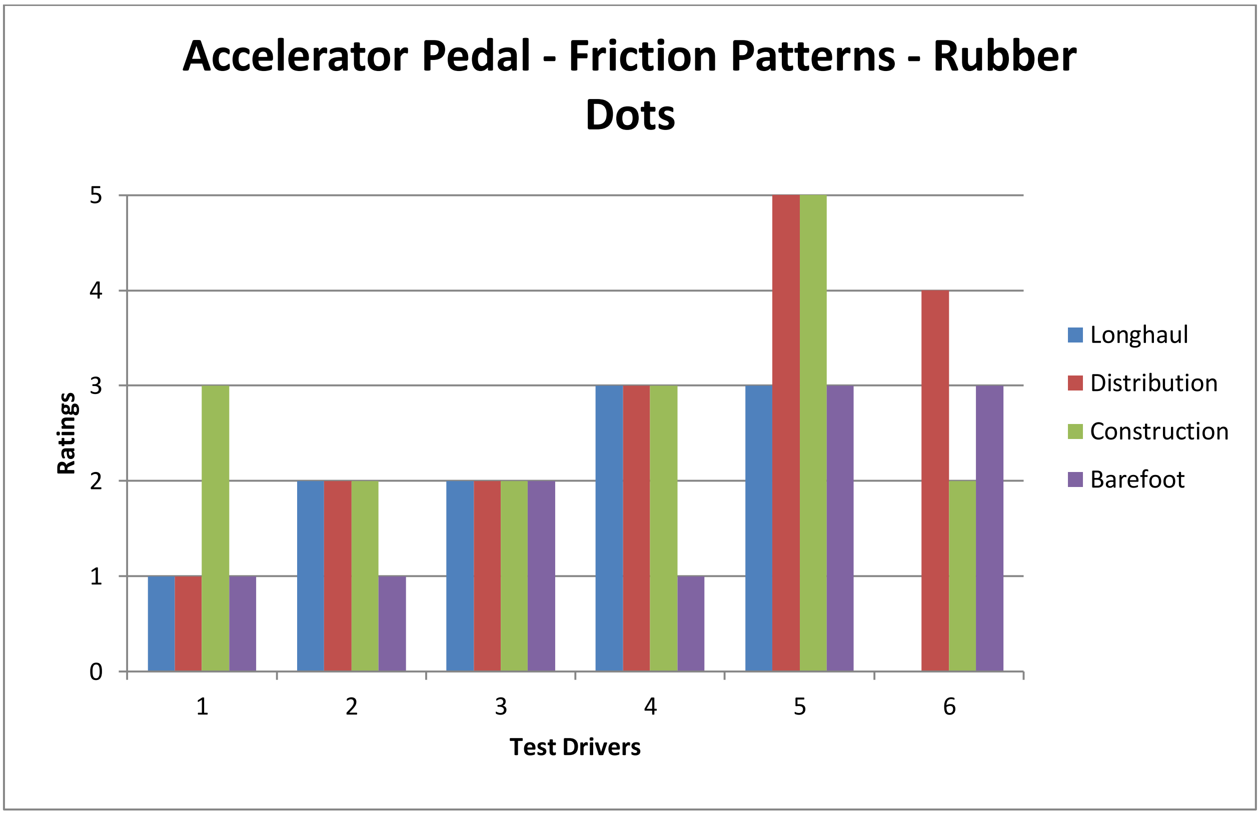



The figure shows that four drivers prefer a floor mounted accelerator pedal for barefoot driving and two drivers prefer a suspended accelerator pedal. Barefoot driving is mainly carried out in long haul applications. The comfort against the foot is most important. No edges and a softer and larger surface that follows the shape of the foot were usually preferred.

The figure shows that four drivers prefer a suspended brake pedal and two drivers prefer a floor mounted brake pedal for barefoot driving. A suspended brake pedal seems more natural to use for braking independent of transport. However, larger surface area provides good support.


Accelerator Pedal -Friction Patterns -Lines in x direction
rATINGS
0
1
2
3
4
5
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution


Accelerator Pedal -Friction Patterns -Lines in y direction
Ratings
0
1
2
3
4
5
6
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot



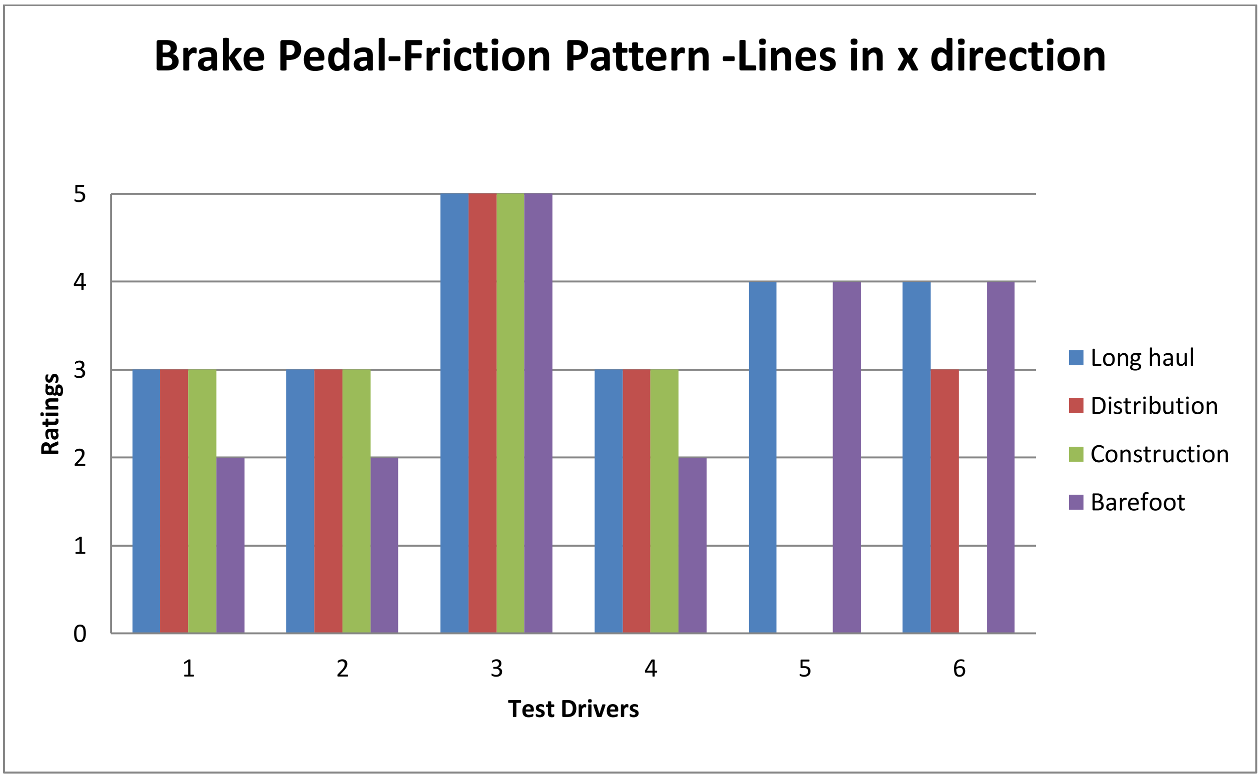

The figures illustrate the friction pattern in x-direction, y-direction and rubber dots on the accelerator pedal for different truck applications.

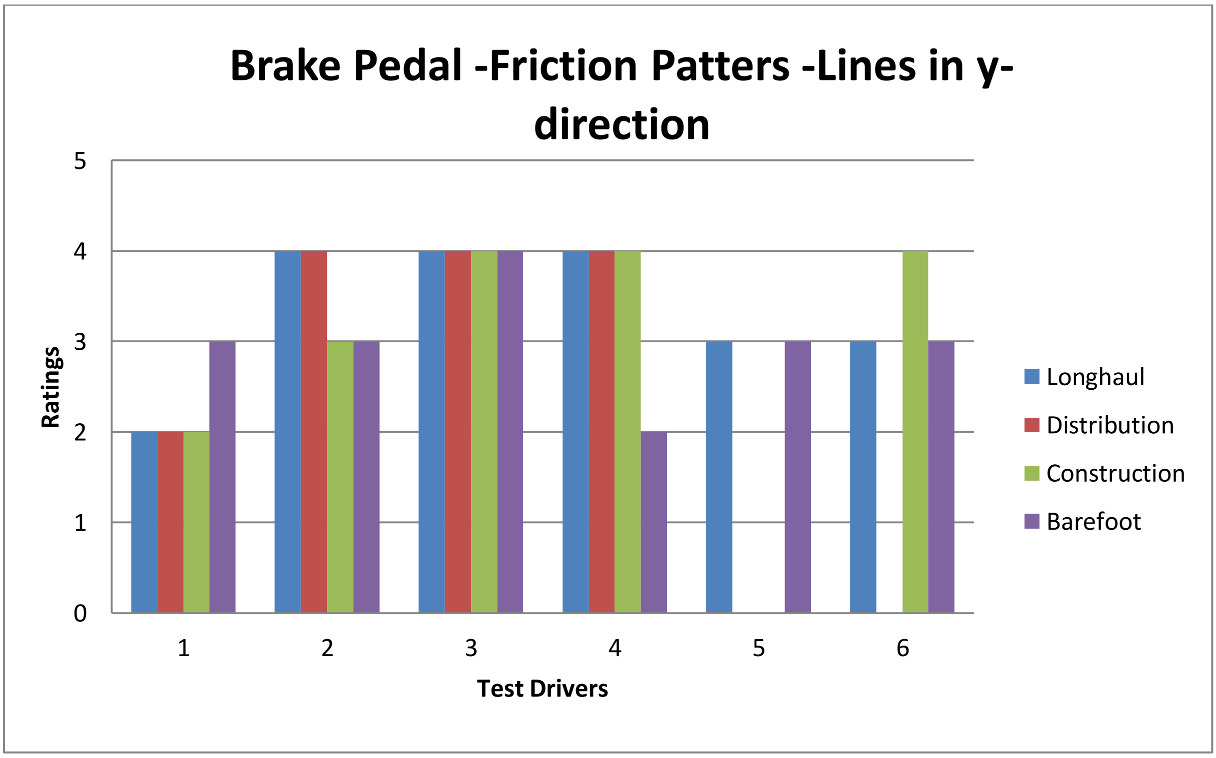
Long Haul Application: The lines in longitudinal direction were better if we talk about the suspended pedals. Then the foot needs to slide against the pedal surface as it is being pressed. Longitudinal lines offer support to the feet. In floor mounted pedals this might not be as important, but longitudinal lines will make it easier to press the pedal.

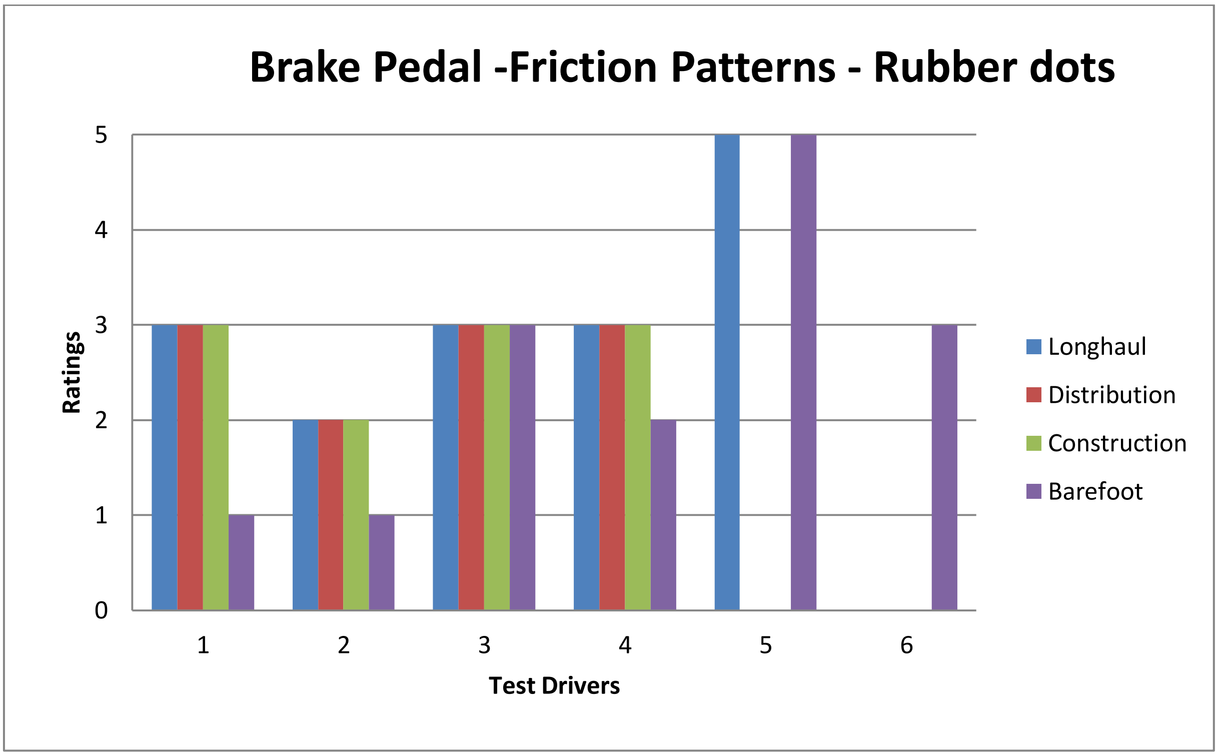
Distribution Application: In distribution traffic, with lots of movement between the accelerator and brake pedal, a transversal pattern could beneficial. It should be easy to slide sideways while at the same time it should be possible for the foot to slide in the longitudinal direction, so a double-direction pattern could be ideal for this application.

Construction Application: In construction application a transverse and longitudinal pattern combination adapted for heavy shoes was needed. The pattern should provide good friction and not become worn over time.

Barefoot Driving: When driving barefoot any sharp edges and large shape transitions can be disturbing, still the friction between socks and the pedal material needs to be considered. This can, however, probably be provided by the graining the pedal surface.


Brake Pedal-Friction Pattern -Lines in x direction
Ratings
0
1
2
3
4
5
1
2
3
4
5
6
Test Drivers
Long haul
Distribution
Construction
Barefoot


Brake Pedal -Friction Patters -Lines in y-direction
Ratings
0
1
2
3
4
5
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot



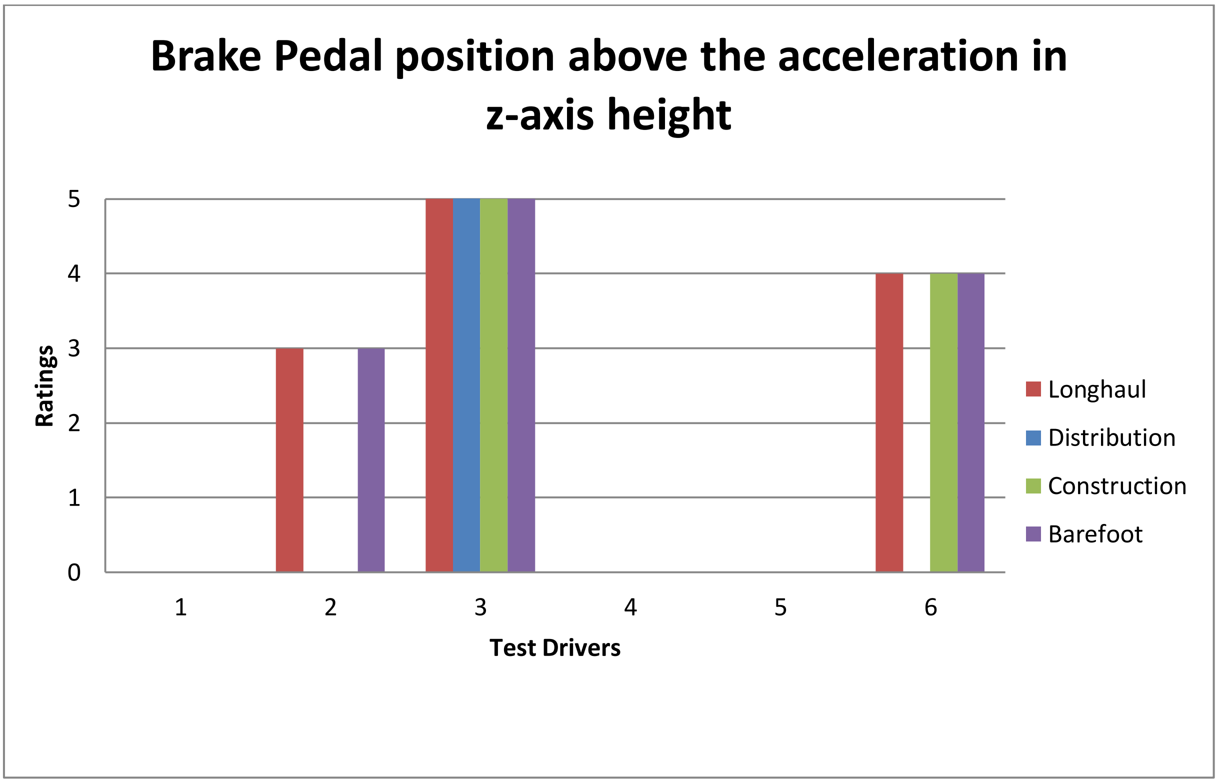

The figures illustrate the friction pattern in x-direction, y-direction and rubber dots on accelerator pedals for different truck applications.

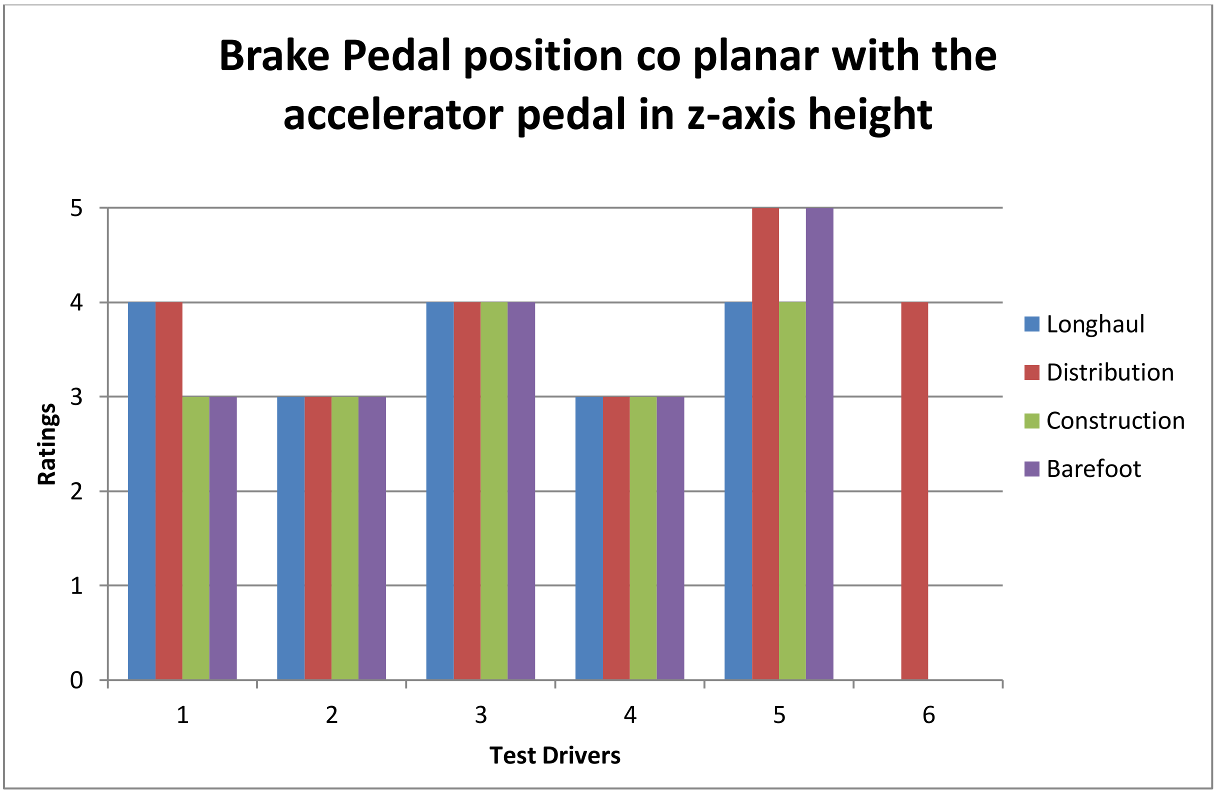
Long Haul Application: A transversal pattern would be beneficial and helpful when moving the foot from the accelerator to the brake pedal. The surface of the pedal should also facilitate getting the foot onto the pedal and other surfaces with a longitudinal pattern that insures that the foot keeps the sideways position while pressing the pedal through the stroke.

Distribution Application: In distribution traffic with lots of movement between accelerator and brake pedal, a transversal pattern could beneficial.

Construction Application: A transversal pattern would be beneficial. The pattern , however, also be able to cope with dust, dirt, ice and snow without becoming slippery and heavy shoes should not wear out the pedal surface over time.

Barefoot Driving: The comfort of the foot against the pedal and rubber dots should feel ideal against the foot.


Brake Pedal position above the acceleration in z-axis height
Ratings
5
4
3
2
1
0
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot


Brake Pedal position co planar with the accelerator pedal in z-axis height
Ratings
5
4
3
2
1
0
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot

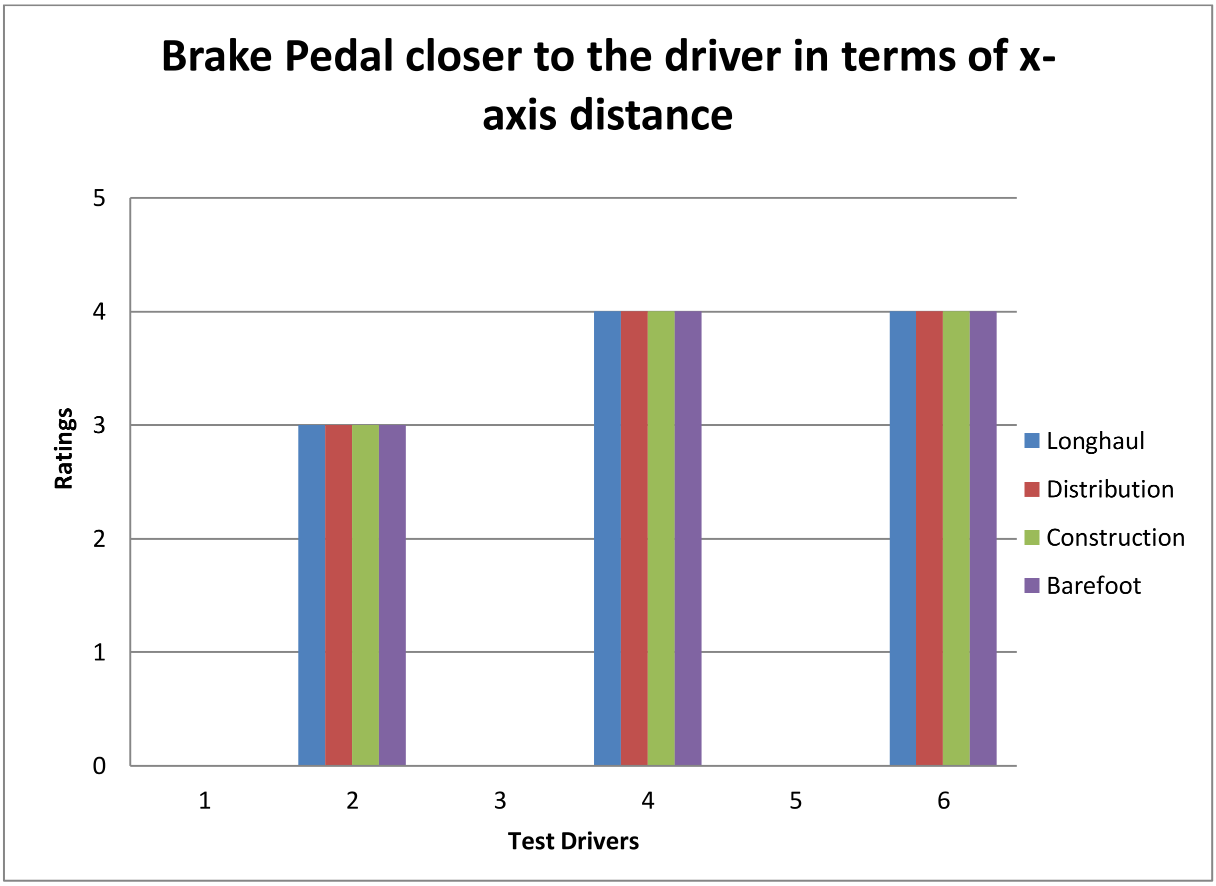
The figure above shows the brake pedal position in relation (z-axis distance) to the accelerator pedal position.

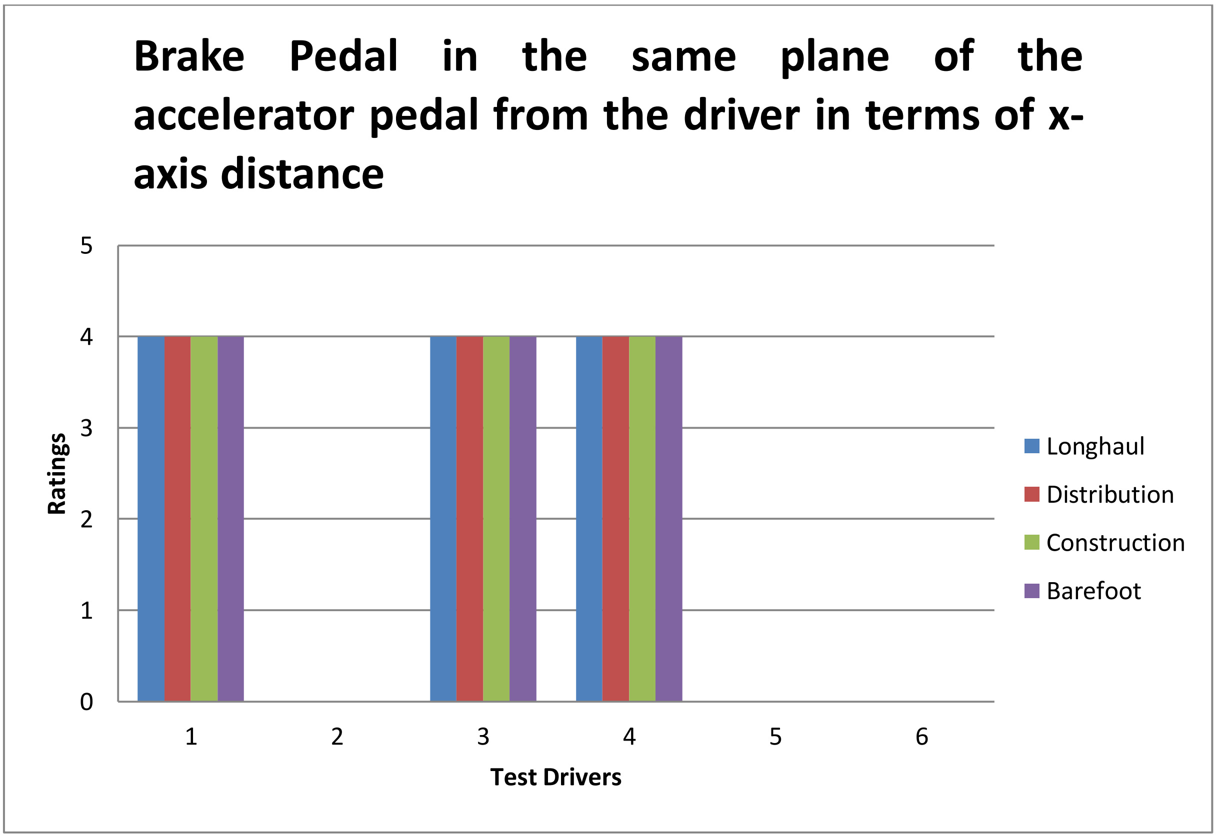
Long Haul Application:
A little difference in the brake pedal, with a position somewhat higher than the accelerator pedal, could be beneficial to avoiding pressing both pedals simultaneously. A floor-mounted accelerator would be more comfortable than a suspended one.

Distribution Application:
Normally, it is easier to move between pedals that are co-planar. In distribution transport, drivers tend to sit higher which means it can be more difficult with a z-difference between the pedals. It must, however, still be possible to distinguish between the pedals. Suspended pedals for both accelerator and brake would be more appropriate in distribution transport as the feet move a lot between the pedals.

Construction Application:
Suspended pedals with the brake pedal mounted higher than the accelerator will allow comfortable pedal usage with bigger shoes. When driving off-road it will be beneficial to have the brake mounted higher than the accelerator otherwise one might risk mistaking the pedals for each other.

Barefoot Driving:
The floor-mounted, longer accelerator is more comfortable due to its size against the naked foot. As the foot is more sensitive without a shoe it can be mounted in co-planar arrangement. The difference is that the pedals need to be distinctly different since they are mounted co-planar.


Brake Pedal closer to the driver in terms of x-axis distance
Ratings
5
4
3
2
1
0
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot


Brake Pedal in the same plane of the accelerator pedal from the driver in terms of x-axis distance
Ratings
5
4
3
2
1
0
1
2
3
4
5
6
Test Drivers
Longhaul
Distribution
Construction
Barefoot

The figure above shows the brake pedal position in relation (x-axis distance) closeness to the driver.

Long Haul Application:
To facilitate providing more leg room for tall long-haul drivers who keep their foot on the accelerator most of the time, the brake pedal should be mounted closer to the driver. With a suspended brake pedal, it must also be possible for shorter drivers to handle the stroke. This is also facilitated by putting the brake pedal closer to the driver

Distribution Application:
It would be easier to move between pedals that are at the same level. Suspended pedals for both would be more appropriate in distribution trucks as the feet move a lot between the pedals.

Construction Application:
It would be easiest to handle the pedals in construction driving if they were placed at the same distance from the driver. It is still important to have a difference in level between the pedals due to all motions during off-road driving.

Barefoot Driving:
Barefoot driving is mainly found in Long Haul Driving, therefore an equidistant relationship between the pedals and the driver is chosen for this one. The shape of the pedal edges should still be able to support ease of moving the foot up onto the brake pedal.

# APPENDIX - T