Chapter 7

Weight Transfer and its relation with Driving Comfort
7.1. Introduction -

From ergonomics point of view, comfort integrates a sense of well-being with health and safety; conversely, discomfort seems to be mainly related to biomechanical factors involving muscular and skeletal systems. A good seat is thus essential to prevent a lot of painful disorders such as low back pain, a typical implication arising from a bad sitting posture. The design and assessment of the car driver posture introduce additional complexity with respect to the study of a traditional sitting posture.

The feet of a car driver do not assist the support of the body because they are primarily devoted to the use of pedals. Body balance and its control is thus to be assured by a seat equipped with a long inclined backrest and lateral supports. But these elements also produce a 'constrained' posture and this fixity is an important negative factor for comfort. For safety requirements, a headrest and an anti-submarine system must be included in the structure of the seat. These and in particular the latter, even if covered by foam in suitable size and density, could potentially introduce zones at high pressures when driver is seated. Driving posture must assure wide visibility and easy reach of all the car displays and controls. Considering these three simple factors alone it is clear that real progress of the car driver seat depends strongly on the ergonomic details available for the seat design and on the assessment criteria used to measure and analyze the interactions between driver and car.

Pressure mapping is used to find the occupant weight distribution on seat. Interface pressure measurement is useful in the evaluation of seat comfort. It is also useful for its prediction and providing rapid information early in for design/prototype phase. In fact understanding of the pressure patterns that are appropriate for the human body can make product design and usage very satisfying. The simple quantification of interface pressure assuming peaks and
high values as indicators of discomfort. An extended, parametric exploration to draw significant conclusions on this aspect is necessary. The same also applies to postural assessment in different driving situations.

Because of human torso weight on seat foam, there will be different pressure zones at the body to foam interface area. The high pressure zone will reduce blood supply at interface area and result in numbness. This also results in local heated zone and uncomfortable feeling. It is evident that uniform pressure distribution.

7.2. Data collection -

7.2.1. Equipment used for the study

Equipment used for this study was pressure pad developed by M/s Xensor Technology Corporation, Canada.

It uses advanced capacitive technology for measuring interface pressure between the human body and various support surfaces. The pressure pad utilizes ultra thin sensors. The sensors are less than a millimeter thick and the pad is flexible enough to conform to the natural contour of the seat / human body.

Figure 7.1 “Xensor” pressure measurement pad
Porter et al. have confirmed that pressure measurement can be used for understanding driving discomfort. The system allows the recording of the loads exerted on a suitable thin flexible matrix of piezo-resistive sensors. The matrix used in the present study has 40 X 40 cells and 0.5mm thick sensors, measuring 50×50 cm² area. Each sensor is a square of 50 mm² and the inter-sensor distance was 3 mm. The sampling rate of the whole matrix is set at 20 Hz and each acquisition lasted for 1 sec. The working range was 10-200 mmHg, with a resolution of 1 mmHg the recording could be done with 5000 sensor/sec. speed.

The subject was asked to adjust the seat for normal driving posture, keep feet on pedals and hands on steering wheel.

7.2.2 Data collection -

In order to obtain best reliability of output data, the mat was calibrated with known load which simulated experimental conditions. The subject was asked to sit for few minutes to become “familiar” with the cockpit and to choose the most comfortable seat position (anterior–posterior position and backrest inclination). Subjects were asked to remove all hard articles from their pockets or on the body like belts, keys, etc. to avoid unnatural loading at specific points. The subjects were then asked to drive the car for about 20-30 minutes, adjust the seat for optimum comfort level.

The subjects were then asked to come out of the vehicle with the same seat location to place the pressure mat on the seat. The subject again boarded the vehicle and adjusted his body for comfortable position, emulating the driving posture.

Nine subjects participated in this study. Details of which are given in Table 3.4. Pressure map data was collected for all ten car seats for above subjects. Even though this experiment subjects should be selected based on their body mass index to maintain co-relation with other attributes like posture, same subjects were requested to participate.
7.2.3, Measurement -

Using Pressure mat, every subject's weight transfer through seat foam and structure was measured. While collecting this data utmost care was taken to avoid abnormal measurements due to external objects in driver's pocket, excess pressure applied by the driver on backrest by pressing pedals or odd sitting posture. In addition to this the driver was asked to rest his foot on accelerator pedal. The sample data for one subject and one seat is given in Figure 7.2.

![Pressure map data for Subject “H” on Car “A” Seat cushion](image)

**Figure 7.2 - Pressure map data for Subject “H” on Car “A” Seat cushion**

Every data snap shot collects pressure at 1600 cells (40X40 matrix). 90 such data-spread sheets were collected. The data may also be collected with reference to time when person or vehicle is in motion how ever to reduce variables and data complexity such data is not used for this study.
7.3 Analysis -

7.3.1 Curves in Longitudinal and cross directions –

To understand weight distribution pattern for every vehicle seat, first and foremost requirement was to check how uniformly it is distributed. Comparison of visual 2D graphs of pressure maps for every vehicle and every subject provided some information at macro level. The 2D graph for this is shown in Figure 7.3.

![Figure 7.3: 2D visual graph for all Seat Cushion](image)

From the output few observations can be drawn

a) For subject “7” with car “E” shows excessive pressure peaks followed by subject “8” with car “A”.

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b) Over all Car "C plot looks uniformly distributed where as Car "D,E and I" looks worst.

Similarly for backrest car "C andD" shows god uniformity of pressure distribution where as car "E,G and I shows non uniform pressure distribution with contact above lumber area.

Figure 7.4: 2D visual graph for all seat Back Rests.
7.3.2 Longitudinal curves -

To understand pressure distribution pattern in longitudinal direction for a particular seat (cushion / back rest), cell with peak pressure value cell was selected as master cell. The longitudinal and cross curve going through this cell for all cars are plotted. Longitudinal curve for Car “A” was nominated as curve (A) where as cross curve was nominated as (A'). All such curves are given in Figure 7.5.

Figure 7.5: Longitudinal and cross curves for all Seat Cushions
Figure 7.6: Longitudinal curves for all Seat Cushions.

a) Car "C" show peak pressure in Isichial tubrosites which fades uniformly towards thigh region which could be seen in Longitudinal as well as in cross direction. It also shows two additional pressure bumps in cross curve area which represents support provided by cushion side bolsters useful in cornering body slip. Similar behavior is seen for Car "G" seat.

b) Car "E" shows shift of peak pressure bumps away from D point or normal Isichial tubrosite region. This clearly indicates drivers must be sitting in lumped position or sliding forward with reference to seat back rest.

c) All other cars show similar trend like car "C" while side bolster support is missing in most cases. Most of cars also show the longitudinal curve tapering quickly to zero in forward direction which means no support / less support to driver in thigh region. This also could be compared with posture analysis in next chapter. These curves in longitudinal and cross direction for back rests of all cars are shown in Figure 7.7.
Figure 7.7: Averaged longitudinal and cross curves for all Seat Back rest

From above graphs for seat backrest following observations may be derived.

a) Car “A and B” shows uniform back rest support as well as good side bolster support to body torso in cornering.

b) Car “C” has similar trend like above how ever there is sudden pressure drop between lumber and shoulder region.

c) Car “E” shows higher pressure peak in shoulder area and very less contact / support to lumber region. This also may be one of the reason drivers are shifted forward and forced to take lumped posture - not comfortable for long driving.
d) Car “D, F, H, I, and J” show marginal support in lumber area but some cases the pressure is uniform. This optimum support in lumber area is governing factor while rating the good or bad seat back rest. This is worst scenario which will result in low back pain.

To differentiate between the best and worst subjective rated car seats (Car “C” and Car “E” respectively) let us re-look various curves of the cars are revisited.

Figure 7.9: 3D visual graphs for best and worst car seat cushion.
3Dimensional graphical representation of Car "C" seat cushion show uniform pressure distribution where as Car "E" seat cushion shows heavy pressure peaks which will result in compression of nerves and fine blood vessels after prolong seating, resulting in less blood circulation at Ischial tuberosites resulting in numbness or irritation after prolong driving.

Behavior of cars are for all three percentile subject data is extracted based on row and column pressure values going through peak pressure value. These graphs are compared with average pressure values as shown in Figure 7.10 and 7.11.

![Graph of cushion longitudinal curves for Car "C" and Car "E"](image)

![Graph of cushion cross curves for Car "C" and Car "E"](image)

**Figure 7.10: Peak curves for seat cushions**

For car "E" cushion curves show 20% higher peak values as well as large spread across 5th to 95th percentile with reference to Car "C".
Peak pressure curves for Car “A” and car “E” back rest do not show any specific trend.

7.3.3 Best average pressure distribution curves –

Based on above data analysis and findings there can be best average pressure curves for a theoretical designed seat. Fitting best possible polynomial equation one may get smooth as well as optimum curve for a most comfortable seat cushion. The equation is given below and normalized data of best seat cushion and backrest equation (7.1) is derived.

\[ Y_{\text{cushion}} = 0.0000052 X^3 - 0.0043 X^2 + 0.94 X - 21.95 \]  

..............(7.1)
Where Y is average pressure in PSI per cross row and X is distance from D point in mm. The curve for best seat cushion is shown in Figure 7.12

![Average Pressure per cross row](image)

**Figure 7.12: Best Average cushion curve in longitudinal direction.**

To understand the difference let us compare highly and poorly rated Car ( Car"C" and Car "E" respectively) Seat cushion curves with the theatrically defined best seat cushion curve. The combined curve are shown in Figure 7.13

![Average Pressure per cross row](image)

**Figure 7.13: Comparison of theoretical best, actual best and worst curves.**

The difference of highly rated car seat cushion values are less than 5% with reference to theoretical curve where as same difference for worst car seat is almost 25%. As there are various mechanisms available for adjusting the lumber support as well as tilt back rest similar best optimum curve fitting for a modern
seat back rest is difficult as well as not necessary. Only care should be taken for placing the lumber support mechanism at optimum location.

7.4 Weight Distribution factors –

To get some weight distribution numbers (index) based on the measured data, the data is simplified the data to reduce the complexity without losing the content. For Pressure distribution worst scenario is with heaviest subject.

Static Body Pressure Distribution between the occupant and vehicle seat can give additional data about seat comfort. There is little knowledge concerning exact body pressure distribution required to achieve a certain degree of comfort. Some expert state that the weight of the body should be mainly supported by the ischial tuberosites while few others talk about uniform pressure distribution is better scenario. From pressure distributions mapping various curves are generated. Similarly to get some weight distribution index for every seat research work of Johan Lindan \(^{(53)}\) et.al. was found to be most appropriate. Johan Lindan has defined three important factors based on pressure mapping data viz. Seat Pressure Distribution (SPD) index, Pressure Factor (Pr Index) and Comfort weight Factor (CWF).

9.4.1 Seat Pressure Distribution (SPD %) –

\[
SPD\% = \frac{\sum_{i=1}^{n} (p_i - P_m)^2}{4np_m^2} \times 100 = \frac{(n-1)}{4n} \left[ \frac{\text{Std Dev}}{\text{Mean}} \right]^2 \times 100
\]

\[\text{........... (7.2)}\]

This method is used in conjunction with a body pressure mapping system where \( n \) is the total number of cell elements (1600 for this study), \( P_i \) is the pressure at \( i_{th} \) cell, and \( P_m \) is the mean pressure of the matrix of “n” cells.
7.4.2 Pressure Factor -

Similarly Pressure factor (Pr) can be defined as ratio of peak pressure and standard deviation. This is defined in equation 3.

\[
\text{Pressure Factor (Pr)} = \frac{P_{\text{Peak}}}{P_{\text{Std Dev}}} \tag{7.3}
\]

Seat Pressure distribution (SPD) and Pressure factor comparison for all seat cushions and back rests is given below.

![SPD Index all Seat Cushions](Image)

**Figure 7.14: SPD Index all Seat Cushions.**

![Pressure Factor - Cushion](Image)

**Figure 7.15: Pr Factor Index all Seat Cushions.**
From these charts it is evident that

a) For seat cushion car “C” shows low SPD as well as Pr factor where as car “A, E and H” has high SPD value where as Car “A,B and I” shows more pressure peaks through high Pressure factor value.

b) Similarly “A and G” shows uniform pressure distribution through Back rest with low SPD value where as cars “D, H,I and J” shows non uniform pressure distribution.

c) For back rest pressure factor range difference across all cars is low hence difficult to conclude any thing.
7.4.3 Comfort Weight Factor (CWF) –

Pressure factor multiplied with Seat Pressure distribution Factor gives comfort weight Factor.

**Comfort Weight Factor (CWF) = SPD \* P_r factor** \hspace{1cm} (7.3)

Values of this factor for all vehicles are shown in Figure 7.18

![Figure 7.18: Comfort Weight Factor for Seat cushions.](image)

![Figure 7.19: Comfort Weight Factor for Seat Back Rests](image)
Combined Comfort Weight Factor show following results

a) Seat cushion of Car “C” has lowest CFT value followed by Car “F and G” where as Car “E, A and H” shows worst CWF value.

b) Similarly for back rest Car “A and B “shows lowest CWF value followed by Car “G and C”. Where as Car “H, I and J” shows worst CWF value.

Similar study also has been done by Padoloff (54) et.al. and Southall (55) et.al.

7.5 Summary and conclusion –

Various index values are combined as shown in Figure 7.20 and 7.21

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<table>
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<tr>
<th>Car</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
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<tr>
<td>Peak Pressure (P max)</td>
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<td>93.17</td>
<td>66.50</td>
<td>96.27</td>
<td>95.38</td>
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<td>77.56</td>
<td>88.00</td>
<td>91.19</td>
<td>95.89</td>
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<td>Seat Press Distribution(%SPD)</td>
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<td>0.31</td>
<td>0.20</td>
<td>0.36</td>
<td>0.37</td>
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<td>0.25</td>
<td>0.43</td>
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<tr>
<td>Comfort weight Factor</td>
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<td>1.48</td>
<td>0.90</td>
<td>0.96</td>
<td>1.59</td>
<td>0.97</td>
<td>1.39</td>
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</tbody>
</table>

Figure 7.20: Weight Distribution Factor Index - Cushion.
Figure 7.21: Weight Distribution Factor Index – Back Rest

This study is very useful to understand effect of pressure distribution on driving comfort. The study was conducted to understand difference between two seats with reference to their comfort assessment.

Heavily contoured seats may show good body support. However in dynamic driving conditions may restrict driver's free movement, resulting in low comfort ratings.

When people were asked to adjust the seat in their most comfortable position one of the criteria used by every subject was to have good support to torso though backrest adjustment.

For designing new seat above factors could be used in early stage of development to assess the perceived comfort objectively. For best seat CWF value should be between 0.6 to 0.9 and difference of actual and theoretical average curve in longitudinal direction curve should be less than 5%.