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Framework to Analyse Automotive Interiors with a Focus on Ergonomics

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Abstract
The small car market in India is increasing by leaps and bounds. The market for small cars now occupies a substantial share of around 70% of the annual car production in India of about one million. The main players in the car market like Tata Motors, Maruti Udyog and Hyundai etc. are fiercely competitive and are trying to outdo each other in terms of design and technology. However, ultimately the focus of a manufacturer is providing customer satisfaction which is driven by comfort and ease of use. Automotive ergonomics is the study of how automotive can be designed better for human use. The human factor aspect of designing automobiles is first considered at the Vehicle Packaging stage. The term Vehicle Packaging comes to use whenever a new model is in the early stage of study. It is a method to safeguard and protect space for the human user and necessary components that make up the vehicle being designed. The improvement in the vehicle ergonomics requires a basic understanding of the problems that arise due to the conventional automotive interior design.
***Keywords*:** vehicle packaging, automotive ergonomics, car.

I. Introduction

Vehicle Packaging actually dictates how a vehicle should be designed. It provides all the necessary information for the styling designers and part designers to proceed with at the following stage. Without vehicle packaging input, all the design engineers will not be able to proceed with the design concept in details. On the other hand, since Vehicle Packaging is meant to provide suitable space for people and parts in vehicle, human factor consideration is a must for the integration of the total design. Automotive ergonomics is the study of how automotives can be designed better for human use. The human factor aspect of designing automobiles is first considered at the Vehicle Packaging stage. The term Vehicle Packaging comes to use whenever a new model is in the early stage of study. It is a method to safeguard and protect space for the human user and necessary components that make up the vehicle being designed. [Zamri Mohamed et. al., 2000]. The human body is commonly represented in ergonomic and biomechanical investigations as an open chain of rigid segments. The number of segments and the nature of the joints between segments vary widely depending on the application of the resulting kinematic model. A classic representation of the body for design purposes by Dempster, W.T. (1955) divided the body into 13 planar segments, including a single segment from the hips to the top of the head. For automotive applications, two kinematic representations of the body have been most widely used. The Society of Automotive Engineers (SAE) J826 H-point manikin [Society of Automotive Engineers (1998)] provides four articulating segments (foot, leg, thigh/ buttocks, and torso) to represent a vehicle occupant's posture. A two-dimensional template with similar contours is used with side view design drawings. The joints of the H-point manikin and the two-dimensional template have a single degree of freedom, pivoting in a sagittal plane. These two tools are the standard occupant representations of vehicle interior design [Roe, R.W. (1993)].

II. Musculoskeletal Problems

Discomfort and lower back pain are frequent complaints reported by drivers. Often, the term "repetitive driving injury" (RDI) has been used. These injuries include foot cramps, low back pain, stiff neck, and sore shoulders from poor posture, stress, tension, and staying in one posture or position for an extended period. RDI is a form of a work-related musculoskeletal disorder (WMSD).

Several epidemiological studies show that professional drivers of various earth moving vehicles have increased risks for musculoskeletal symptoms and disorders in the lower back, neck and shoulders, see review by Griffin (1990). Thus, drivers have musculoskeletal problems in the same anatomical body regions as other professions at risk for WMSDs though the exposure situation is different, i.e. drivers are exposed to whole-body vibration (WBV) and other occupational groups are generally not. It seems as if these body regions are more susceptible for WMSDs than other body regions. It is however close to suspect exposure to WBV as a risk factor among drivers since several studies have indicated an association between exposure to WBV and musculoskeletal symptoms and disorders, preferably in the lower back [Bovenzi & Hulshof 1998]. The driver seats in many earth moving vehicles vibrate at a frequency close to the natural frequency of the spine, which may serve as a reason for spinal damage [Wilder 1993]. Further, it is evident that WBV can have the function as a mechanical load, although oscillating, resulting in biomechanical forces acting on and in various regions of the body, depending on the location of input and body posture.

Keegan, 1953 was one of the first authors to discuss the anatomy of sitting position in relation to the problem of low back pain in sedentary work. In the sitting position the increased pull of hamstrings and gluteals against the weakened hip flexors causes the pelvis to tilt rearward and the lumbar lordosis to be lost. Loss of the lumbar lordosis occurs reflexively as a way of compensating for the rearward tilting of pelvis which occurs in driving position. As the pelvis tilts rearwards when a person sits down, the lumbar spine flexes to keep the trunk and head erect.

The wrist motions of workers engaged in jobs entailing high or low risk of contracting Carpel Tunnel Syndrome such as in the case of driving was analysed and was characterized in terms of flexion/extension, pronation/supination and ulnar/radial deviation [Marras and Schoenmarklin, 1993]. The angular velocity and accelerations of wrist when moving in the corresponding spatial planes were also recorded. No significant distances were found between the high (minimum 8 hours a day) and low risk (maximum of 3 hours a day) groups in wrist posture. However, wrist movements in high risk groups had greater velocity and acceleration. The findings were interpreted by the authors in terms of Newton's Second Law of Motion. In order to produce greater accelerations of the wrist, larger muscle forces are required which are transmitted to the bones via tendons. The tendons will also be exposed to greater friction by contact with the surrounding structures.

Analysing the musculoskeletal problems was essential as it provides a base for creating an environment in the vehicle interior for the different physical tasks to be carried out in a safe and comfortable manner. Knowledge of the anatomy of the human body is valuable here as is an understanding of the mechanism of physical fatigue.

III. Types of Anthropometric Data

Structural Anthropometric Data

It consists of measurements of bodily dimensions in static positions [Bridger et al, 1995]. The measurements are made from an identifiable anatomical point to another or to a fixed point in space. Few examples of these measurements include the height of knuckles above the floor, the height of the popliteal fossa etc. These measurements are implemented in determining ranges when constructing furniture or for clothing sizes.

Functional Anthropometric Data

It consists of measurements to describe the motion of a body part with respect to a fixed reference point [Bridger et al, 1995]. The measurement data includes forward reach of standing objects, area swept out by the movement of hand (workspace envelopes) etc. This data assist when optimizing the layout of controls in panel design. Although the size and shape of the workspace depends on the degree of bodily constraint imposed on operator and the size increases with increase in the number of unconstrained joints. These measurements are implemented particularly in design of aircraft cockpits, vehicle interiors and complex control panels [Bainbridge L., 1974].

Newtonian Anthropometric Data

It consists of measurements that are used in analysing mechanical loads on human body [Bridger et al, 1995]. The body is regarded as an assemblage of link segments of known length and mass, sometimes expressed as a percentage of stature and body weight. Ranges of the appropriate angles to be subtended by adjacent links are also given to enable suitable ranges of working postures to be defined. This defining enables designers to specify those regions of the workspace in which displays and controls may be most optimally positioned. Newtonian data may be used to compare the loads on the spine from different lifting techniques.

The scope of the study involves the use of a combination of structural and functional anthropometric data. The structural data relates to the static position of the occupants in a vehicle with respect to the dimensions of the interior. The functional data relates to the movements of the occupants, specially the driver, in a vehicle with respect to positioning of controls etc.

Task Requirements

Driving as a task can be considered to have 3 sets of requirements [Bridger et al, 1995]:

1. Visual Requirements
2. Postural Requirements
3. Temporal Requirements

Visual Requirements

The position of the head is a major determinant of the posture of the body and is very strongly influenced by the visual requirements of the task. If the main visual area is 30 degrees below the straight-ahead line of sight, it is accessed by tilting the head forward. This position places a static load on the neck muscles and displaces the centre-of-gravity of the body anterior to the lumbar spine, causing the characteristic forward slump posture in which the backrest or lumbar support of the seat is not utilized by the occupant. The eye is sensitive to stimuli up to 95 degrees to the left and right assuming binocular vision. The optimum position of placing the controls and utilities in the vehicle interior should be 15 degrees either side of the straight-ahead line of sight of the occupant. Thus, static loading of neck muscles and other soft tissues in the neck can be avoided if the visual component of the tasks is kept within a cone from straight-ahead line of sight to 30 degrees below and 15 degrees to the left and right [Woodson, 1981].

Postural Requirements

The position of the hands, arms and feet is another major determinant of posture and postural load. In vehicle design, the comfort of the driver's seat depends not just on its particular dimensions but its positioning in relation to the foot pedals and manual controls [Rivas et al, 1984]. When driving in a conventionally designed interior, the drivers are usually unable to maintain an erect trunk because of the requirement that both the driving hand and forearm be in a level lower than the steering wheel for a relaxed position and in level with the steering wheel for better control. The continuous exchange of arm positions prevents the driver from maintaining an erect posture. Resting the forearm on the door requires sideways and occasionally forward flexion of the trunk. Thus it becomes essential to consider postural requirements for providing a satisfactory and ergonomically fulfilling vehicle interior [Brouwer W. H. et al, 1991].

Temporal Requirements

The temporal requirements of tasks are a major consideration in the design of workspaces and exert a moderating influence on the effects of other factors [Bridger, 1995]. The time spent by driver in vehicle depends on nature of usage. A vehicle for personal use will require a maximum of three hours of daily driving whereas a vehicle for cab purpose requires an average of eight hours of daily driving. The latter poses a high degree of postural constraint as the body remains in same position for long time. Jobs falling into the highly constrained category require maximum flexibility to be built in vehicle interior to compensate for the lack of flexibility in the design of job [Eason, 1986].

Ergonomic Variables in Vehicle

The different design parameters that constitute the ergonomics of a regular passenger vehicle are:

1. Seat Height
   a. Seat can be raised to ensure the driver has maximum vision of the road.
   b. Adequate clearance from the roof must be ensured.
2. Lower Limb Position
   a. Knees should be bent to comfortably operate the accelerator, clutch and break.
   b. The knees should have clearance from the steering wheel.
3. Seat Pan
   a. Support for thighs along the length of the cushion.
   b. Pressure behind the knees must be avoided.
4. Back Rest
   a. Continued support along the length of the back must be provided.
   b. Shoulders' position must be naturally slightly behind the hips.
5. Lumbar Support
   a. There should be no pressure points or gaps between the spine and the car seat.
6. Steering Wheel
   a. All controls should be in easy reach to prevent unnecessary reaching.
   b. Elbows and shoulders should be in a relaxed position.
   c. Clearance for thighs and knees must be adequate.
   d. The display panel must be in full view and clarity must be maintained.
7. Headrest
   a. The neck should be in a neutral position with the headrest directly behind the head.
8. Mirrors
   a. The rear and side view mirrors must be adjustable enough to ensure adequate vision of surrounding areas.

IV. Principles of Applied Anthropometry in Ergonomics

The normal distribution

For design purposes, two key parameters of the normal distribution are the mean and the standard deviation. The mean is the sum of all the individual measurements divided by the number of measurements. It is a measure of central tendency. The standard deviation is calculated using the difference between each individual measurement and the mean. It is a measure of the degree of dispersion in the normal distribution. In order to estimate the parameters of stature in a population (the mean and standard deviation) it is necessary to measure a large sample of people who are representative of that population. The formulae given in Figure can then be used to calculate the estimates of the mean and standard deviation.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Estimates of *population parameters* obtained from calculations on data from samples are known as *sample statistics*. The distribution of stature in a population exemplifies the statistical constraints on design. An important characteristic of the normal distribution is that it is symmetrical – as many observations lie above the mean as below it (or in terms of the figure, as many observations lie to the right of the mean as to the left). If a distribution is normally distributed, 50% of the scores (and thus the individuals from whom the scores were obtained) lie on either side of the mean.

Estimating the range

The standard deviation contains information about the spread of scores in a sample. It is known, for a normal distribution that approximately two-thirds of the observations in the population fall within one standard deviation above and below the mean. Thus, for a population with a mean stature of 1.75 metres and standard deviation of0.10 metres, approximately two-thirds of the population would be between 1.65 and1.85 metres tall. The remaining one-third would lie beyond these two extremes, at either side. Using the standard deviation and the mean, estimates of stature can be calculated below which a specified percentage of the population will fall. The area under the normal curve at any point along the *x*-axis can be expressed in terms of the number of standard deviations from the mean. For example, if the standard deviation is multiplied by the constant 1.64 and *subtracted* from the mean, the height below which 5% of the population falls is obtained. If 1.64 standard deviations are *added* to the mean, the height below which 95% of the population falls is obtained. These are known as the 5th and 95th percentile heights.

Measuring Vehicle Seating Accommodation

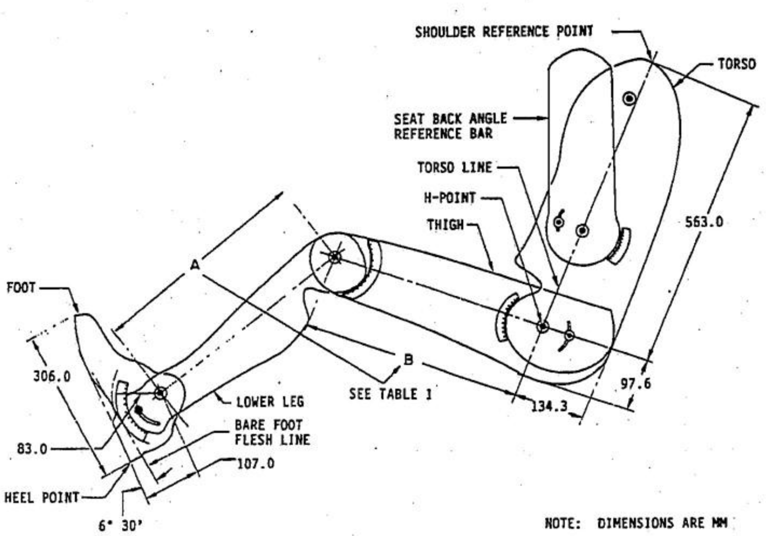

Fig. 1

1. Passenger compartment space and seating attitude during conception, engineering, and development stages of any new vehicle.
2. Passenger compartment space and seating attitude for comparison and reporting purposes.
3. Data obtained from checks made with the H-Point machine.

Positioning Procedure

1. Torso positioning for any specified Seating Reference Point and back angle.
2. Position the H-Point of the H-Point template on the Seating Reference Point (SgRP) location on the layout.
3. Set the seatback angle reference bar quadrant scribe line marked on the torso back angle quadrant to the specified back angle. Lock this quadrant in place.
4. Position the vertical reference scribe lines on the seatback angle reference bar parallel to the body grid lines on the layout drawing.

5. FRONT SEAT—DRIVER POSITION—Leg and foot positioning for any specified Accelerator Heel Point location.
   - 5.1 Holding the torso portion of the template in position as outlined in 2 to 4, position the heel point of the template at the specified heel point location. This point on the layout is located on top of the heel pad or the depressed floor covering surface at the Y plane centerline of the accelerator pedal.
   - 5.2 Holding the heel point at the specified location, rotate the foot forwards until the Ball of the Foot contacts the un-depressed accelerator pedal without infringing upon the 87 degrees minimum foot angle.
   - 5.3 The un-depressed accelerator pedal (point of contact with Ball of Foot) may be determined by locating the heel point as described previously and presetting and locking the foot angle to 87 degrees.
   - 5.4 Draw in the template outline and pivot centers.
6. FRONT SEAT—DRIVER POSITION—Leg and foot positioning for any specified un-depressed accelerator pedal location.
   - 6.1 Holding the torso portion of the template in position as outlined in 2 to 4, position the Ball of the Foot on the specified un-depressed accelerator pedal with the sole of the foot on the pedal and the heel as far forward as allowable. However, the foot angle is never less than 87 degrees. Lock foot angle quadrant.
   - 6.2 Draw in the template outline and pivot centers.
7. FRONT SEAT—DRIVER POSITION—Leg and foot positioning for any specified leg room and SgRP-front to heel.
   - 7.1 Holding the torso portion of the template in position, as outlined in 2 to 4, position the heel point of the template at the specified height. SgRP-front to heel and the foot angle locked at 87 degrees.
   - 7.2 Move the foot forward along the heel point line until the distance between the angle pivot point and the SgRP is equal to the specified leg room less 254 mm (10 in).
   - 7.3 Draw in the template outline and pivot centers.
8. SECOND SEAT—
   LEFT SIDE OCCUPANT POSITION—Leg and foot positioning with the front seat in its rear-most normal driving and riding position.
   - 8.1 Holding the torso portion of the template in position as outlined in 2 to 4 but on the SgRP second, place the foot (heel and ball) on the depressed floor covering line. The foot is to be placed on the Y plane centerline of the occupant or up to 127 mm (5 in) on either side of the Y plane centerline on the floor pan section.
   - 8.2 Move the foot forward along the depressed floor covering line to the nearest interference of the toe, instep, lower leg, or knee with the front seat. The foot angle is to be restricted to a maximum of 130 degrees.
   - 8.3 Draw in the template outline and pivot centers.
9. THIRD SEAT—
   LEFT SIDE OCCUPANT POSITION—
   FORWARD FACING
   - 9.1 Follow the procedure as outlined for the second seat, left side occupant position except that the template is positioned in the third seat compartment.
10. THIRD SEAT—
    LEFT SIDE OCCUPANT POSITION—
    REARWARD FACING
    - 10.1 Follow the same procedure as outlined for the third seat—side occupant position—forward facing except that the foot is positioned in the footwell to the interference with the rear end or closure.
    - 10.2 H-Point template layout using data obtained during H-Point machine installation.
    - 10.3 Position the H-Point pivot of the template at the measured H-Point location on a layout drawing or grid system.
    - 10.4 Follow the procedure as outlined in 2 to 4 using the measured back angle instead of the design back angle.
    - 10.5 Holding the torso portion of the template in position as outlined previously, move the upper leg segment to measured hip angle shown on the hip angle quadrant.
    - 10.6 Lock this quadrant in place.
    - 10.7 Position and lock the foot angle quadrant to the measured foot angle.
    - 10.8 Allowing the knee angle to vary as necessary, position the ankle pivot center on an arc from the hip pivot center equal to the measured effective leg room less 254 mm (10 in).

H Point Description — A machine (Figures 2 and 3) with back and seat pan representations of deflected seat contours of adult males. Constructed of reinforced plastic and metal, these separate back and seat pans simulate the human torso and thigh and are mechanically hinged at the H-Point. A graduated sliding probe is hinged from the H-Point to measure the headroom in the compartment. A quadrant is fastened to the probe to measure the back angle. An adjustable thigh bar, attached to the seat pan, establishes the thigh centerline and serves as a baseline for the hip angle quadrant. Lower leg segments, also adjustable in length, are connected to the seat pan assembly at the knee joining T-bar, which is a lateral extension of the adjustable thigh bar. Quadrants are incorporated in the lower leg segments to measure knee angles. Shoe and foot assemblies are calibrated to measure the angular relation to the lower leg segment.

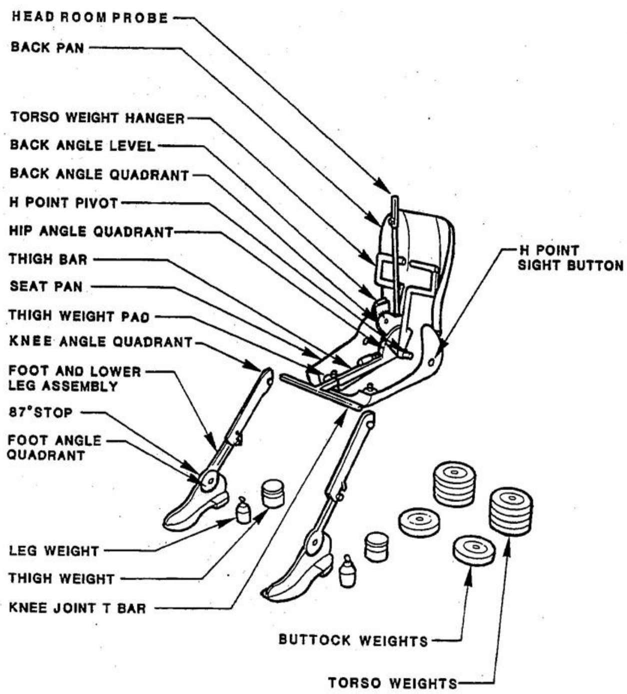

Fig. 3

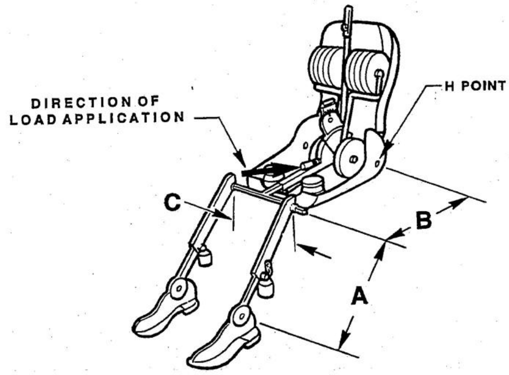

Fig. 2

V. Survey Questionnaire

Rating Parameters	1	2	3	4	5
Leg Room: Front					
Leg Room: Rear					
Knee Clearance: Front					
Knee Clearance: Rear					
Under Knee Support: Front					
Under Knee Support: Rear					
Seat Cushion Height: Front					
Seat Cushion Height: Rear					
Seat Cushion Length: Front					
Seat Cushion Length: Rear					
Seat Cushion Width: Front					
Seat Cushion Width: Rear					
Seat Cushion Contour: Front					
Seat Cushion Contour: Rear					
Buttock Support: Front					
Buttock Support: Rear					
Back Rest Height: Front					
Back Rest Height: Rear					
Back Rest Contour: Front					
Back Rest Contour: Rear					
Neck Support: Front					
Neck Support: Rear					
Head Clearance: Front					

Head Clearance: Rear					
Head Support: Front					
Head Support: Rear					
Reachability of rear view mirror					
Reachability of gear knob					
Reachability of controls					
Reachability of pedals					
Visibility of Odometer and Speedometer panel					
Visibility of Rear View – In terms of mirror					
Visibility of Peripheral View – Considering A-Pillar obstruction					
Visibility of Side View – In terms of mirror					

VI. Conclusion

From the survey perspective, the surety of results is inconceivable since the factor of bias could have take place. People who prefer low price and better mileage would give a better rating for all questions asked even though ergonomically designed cars have the better measurement result. Since some questions may not be clear to respondent, the answer may as well be uncertain. Also the external factor such as time, environment may have affected their answers. Generally, quality of components could be the big factor since one who has experienced at least one part of defect in their car will actually affect their judgment towards other factors in the car. So it is suggested that along with the qualitative analysis, quantitative measurements and feature by feature comparison be used, which will give a better understanding of how packaging of car interior contributes to automotive ergonomics and how conventional designs can be improved to benefit the user in terms of comfort.

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