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ACCOMMODATION MODELS FOR TRUCK DRIVER KNEE CLEARANCE, ABDOMEN CLEARANCE, AND SHIFTER LOCATION

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<tr><td colspan="3">16. Abstract
New interior design models for trucks are presented. The models are based on statistical analysis of driver posture and body contour using data from a laboratory study of truck and bus driver posture. The knee clearance model represents the distribution of drivers' knees for normal rest positions and during clutch operation. The abdomen profile model is intended for assessment of steering wheel interference. Two three-dimensional volumes developed from the data provide design guidance for shift pattern size and location. All of the models can be adjusted to account for population anthropometric distributions and gender mix. The placement of the models within the vehicle package is accomplished using a previously developed seating accommodation model that takes into account the effects of vehicle interior geometry and adjustment ranges on the distributions of driver-selected seat positions.</td></tr>
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1.0 INTRODUCTION

This report presents statistical models representing driver posture and preference for use in designing and analyzing truck cabs. The models are based on data gathered in a laboratory study of truck and bus driver posture (Reed et al. 2000). These data have previously been used to develop posture-prediction models for SAE Class-B vehicles (i.e., trucks and buses). Recently, these laboratory data and a set of similar data gathered in trucks driven on a test track (Jahns et al. 2001) were used to develop a new seating accommodation model and a new eyellipse for trucks and buses (Reed 2005). The seating accommodation model and eyellipse provide greater accuracy and customization than the SAE tools that they replace.

The current report presents new models for driver shifter location preference and clearance models for the driver's knees and abdomen. Current Society of Automotive Engineers (SAE) Recommended Practices (SAE 2005) include a clearance models for truck driver shin/knee location and for the truck driver abdomen, but these models have significant limitations. The knee clearance model, described in SAE J1521, Truck Driver Shin-Knee Position for Clutch and Accelerator, is based on data from a photogrammetric study of truck driver postures (Sanders and Shaw, 1985). The distributions of measured knee points were modeled in side view assuming a multivariate normal distribution. Using four different gender mixes, 95% cutoff contours were established using procedures similar to those used for the eyellipse (see Reed, 2005, for details of this statistical approach). The J1521 has substantial limitations that make it unsuitable for use in the design and assessment of current vehicles. The test conditions from which the data were extracted did not include height-adjustable seats, whereas most commercial trucks and buses are now designed with seat-height adjustment. The driver population used to develop the SAE models is not configurable, except for gender mix, meaning that the effects of changes in driver population anthropometry cannot be included. Finally, the model is not linked to a modern seating accommodation model, and hence it does not adequately take into account important package factors such as steering wheel position.

The SAE Handbook also includes SAE J1522, Truck Driver Stomach Position. The J1522 model is based on data from the same study extracted and modeled using similar techniques (Phillipart et al. 1985, Stanick et al. 1987). The distribution of the point of maximum prominence of the abdomen was modeled in side view as a multivariate normal distribution. As with the J1521 model, J1522 is not configurable for population characteristics beyond fixed gender-mix ratios, is based on test conditions that are not representative of modern vehicles, and does not take into account important package factors.

This report presents new accommodation models for knee/shin and abdomen clearance. The driver knee model is constructed in a manner similar to the eyellipse. A side-view ellipse is developed by statistical analysis of patella landmark data such that tangents to the ellipse cut off a desired percentage of the expected driver knee locations. The patella ellipse is translated to incorporate the offset between the top of the shin and the top of the knee and a composite three-dimensional ellipsoid is constructed that also brings in the knee width. The knee clearance model is positioned in the vehicle package through reference to the seating accommodation model developed previously so that it can accurately represent knee locations across a range of package configurations. The knee clearance requirements for using the clutch are simulated by pivoting the knee clearance envelope around the mean driver-selected seat position.

An abdomen clearance model was constructed in a somewhat similar manner. The purpose of the abdomen clearance model is to assess the likelihood of contact between the driver's abdomen and the steering wheel. Longitudinal torso profiles recorded with the FARO Arm in the laboratory mockup were expressed relative to seat H-point. A statistical model that predicts the profile as a function of sitter stature and body mass index was combined with the seating accommodation model to obtain a model of the distribution of fore-aft abdomen profiles in package space for a population of drivers.

In one of the test conditions in the laboratory study, drivers manipulated a simulated shifter to demonstrate their range of preferred shifter positions. The FARO Arm was used to record 10 locations at the outer boundaries of the drivers' preferred shifter volume. Following a statistical analysis of the data, a geometric model of the preferred shifter volume was developed. As with the other models in this report, it is positioned in package space using the seating accommodation model developed previously.

2.0 METHODS

The data used in this report were drawn from a laboratory study of truck driving postures (Reed et al. 2000). The postures of 49 men and 14 women were measured in a mockup of a truck cab in 27 different test conditions. Among the men, 32 were experienced truck drivers, 4 were bus drivers, and 13 had no truck- or bus-driving experience. Among the women, 3 were experienced truck drivers, 3 were bus drivers, and 8 had no truck- or bus-driving experience. Overall, 42 of the 63 participants had experience driving a truck or bus. Driver stature ranged from 1478 to 1919 mm, with a mean of 1724 mm. Body weight ranged from 105 to 274 lb. Mean body mass index was 28 kg/m^2, with a range from 17 to 38 kg/m^2.

The analyses for the abdomen and shifter models relied on data from a single test condition in which more-detailed measurements were taken. Condition 3 placed the center of an 18-inch-diameter steering wheel at the middle of its vertical and fore-aft adjustment range, 810 mm above and 168 mm aft of accelerator heel point (AHP). After the driver had adjusted the seat fore-aft and vertically to his or her preferred position and adjusted the seat back angle and seat cushion angle, the experimenter measured abdomen contours and the driver's preferred range of shifter positions.

The knee clearance model was based on data from nine test conditions spanning a range of fore-aft and vertical steering wheel positions. In each condition, the driver adjusted the fore-aft and vertical seat position, seat back angle, and seat cushion angle prior to posture measurement. The measured location of the right suprapatella landmark at the top-front surface of the knee was analyzed. The model accounts for the three-dimensional shape of the knee around this point as well as the effects of anthropometric variance, postural variance, and package dimensions.

For all three of these models, the findings from the particular laboratory test conditions are generalized through the application of the driver-selected seat position model reported previously (Reed 2005). The analyses make extensive use of the properties of multivariate normal distributions. Background on this analysis methodology can be found in Reed (2005).

For the calculations in this report, the X axis is positive rearward, Z axis is positive upward, and Y axis is positive to the right of the driver, following the SAE J100 and J1100 conventions. Measurements are defined with respect to accelerator heel point

(AHP) or seat H-point (HPt) defined and measured using SAE J826-1995. Note that the H-point moves with the seat and is not a fixed location in package space. As used in this report, the H-point and seating reference point (SgRP) are not necessarily coincident.

This report presents an overview of the data analysis method and model formulation. For detailed calculations, the reader is referred to the Microsoft Excel spreadsheet accompanying the report.

3.0 RESULTS

3.1 Knee Clearance Model

Knee clearance was modeled for the right knee in the normal driving position. The location of the suprapatella landmark at the upper, forward margin of the right patella was recorded for each driver in a normal driving posture with the right foot on the accelerator pedal. Data from 9 test conditions representing a 3 x 3 matrix of steering-wheel height and fore-aft position were used for the current analysis. A statistical model of the patella landmark location was developed based on a linear regression analysis, using driver and vehicle factors as predictors. However, because the suprapatella landmark is often not the interference point for contact between the knee and the instrument panel, the model is expanded to encompass the tibial tuberosity landmark, which is located at the site of the attachment site of the patellar ligament on the tibia (upper end of the shin). The model is likewise expanded laterally to account for the width of the knee. Consequently, the model can be used to analyze the locations of instrument panels, consoles, control stalks, the steering wheel, or other surfaces that might be contacted by the top, front, or side of the driver's knees.

The calculations rely on an average knee geometry, which was obtained by three-dimensional measurements of the right knees of 10 men and 10 women with a range of body size. The average knee breadth was 110 mm (s.d. 9 mm). The average offset from the suprapatella landmark to the tibial tuberosity landmark with the leg (shank) vertical was 22.7 (6.7) mm forward and 47.1 (4.8) mm downward. The variance in knee dimensions is small compared with postural variance, and hence the use of the average knee geometry does not significantly alter the results.

To locate the distribution of patella landmarks in package space, a linear regression model was developed for each of four dependent measures:

- PatellaX: Fore-aft location of the suprapatella landmark relative to seat H-point.
- PatellaY: Lateral location of the suprapatella landmark relative to driver centerline.
- PatellaZ: Vertical location of the suprapatella landmark above AHP.
- Leg Angle: Angle of the (lower) leg with respect to vertical, positive rearward of vertical.

Table 1 lists the results of the regression analyses. The fore-aft location of the patella was predicted relative to seat H-point as a function of stature and the natural log of body mass index (BMI). (The log-transformed BMI better approximates a normal distribution than does the untransformed BMI for typical truck-driver populations.) Predicting relative to seat H-point rather than AHP allows the effects of the vehicle package on fore-aft seat position to be taken into account through application of the seating accommodation model. The R^2 value for predicting the patella location forward of seat H-point is only 0.39, indicating a modest level of predictive ability for the model. The residual variance is due primarily to variability in sitter hip location relative to the seat, only a portion of which is accounted for by BMI.

The lateral patella location relative to driver centerline is predicted weakly by stature and BMI. The vertical location is a function of stature as well as steering wheel position. Initially, the analysis focused on predicting vertical location relative to the seat H-point, as was done with fore-aft position. However, the effect of steering wheel position has an effect on knee location in these data beyond the effect on seat position, necessitating the inclusion of steering wheel position in the final model. The values in the root-mean-square error (RMSE) column in Table 1 quantify the residual variance in knee location that is not accounted for by the predictors. This variance is important in estimating the distribution of knee locations for a population of drivers.

Table 1
Regression Results for Patella Location

Dimension	Relative To	Equation	R^2	RMSE
PatellaX	H-point	85 - 0.2347 Stature - 32.3 Ln(BMI)*	0.39	28.3
PatellaY	Driver Centerline	-275+0.0928 Stature + 92.4 Ln(BMI)	0.23	34.8
PatellaZ	AHP	-108 + 0.2529 Stature - 0.154 SWX + 0.328 SWZ	0.74	20.0
Leg Angle	Vertical	59 + 0.059 SWX - 0.061 SWZ †	0.48	5.8

* Stature in mm; Natural log of body mass index, where BMI is calculated as body weight in kg divided by stature in meters squared: $\ln(kg/m^2)$

† Fore-aft (X) and vertical (Z) steering wheel location with respect to accelerator heel point. Steering wheel location is defined as the intersection of the wheel pivot axis with the top plane of the steering wheel.

The knee clearance models are represented by three-dimensional ellipsoids aligned with vehicle grid. The right-knee ellipsoid is identical to the left-knee ellipsoid, except that it is reflected around the driver centerline. As with the seating accommodation model, separate computations are performed for men and women, with the results combined to establish accommodation. The axis lengths and centroid locations for the knee-clearance ellipsoids are computed as follows.

1. Predict the mean fore-aft seat positions (SPX) for men and women using the seating accommodation model (Reed 2005).

2. Predict the mean fore-aft, lateral, and vertical patella locations using the equations in Table 1.

3. Calculate patella ellipsoid axis dimensions for the combined male and female population based on the desired cutoff percentile. This involves computing the variance in patella location on each axis, taking into account the residual variances in Table 1, anthropometric variance in stature and BMI, and the correlation between seat position and fore-aft patella location.

4. Expand the lateral axis by 110 mm to account for knee width.

5. Compute the translation from the patella to the top of the tibia (forward and down). Translate the centroid down and extend the fore-aft and vertical axis lengths to account for this translation.

Ellipsoid Axis Lengths

Axis lengths are computed under the assumption that the location of the patella landmark, or any other landmark on the knee, can be approximated within gender by a multivariate normal distribution aligned with the vehicle grid. The data from both the laboratory and vehicle studies support this assumption. Axis lengths are chosen to achieve the desired cutoff characteristic for the combined male and female distribution. For example, the X (fore-aft) axis length for a 95% cutoff ellipse is chosen such that the knee locations of 5% of the combined male/female distribution will lie forward of the front edge of the ellipsoid.

The first step in calculating axis lengths is to compute the standard deviation on each coordinate. Following the procedures of section 2.3 of Reed (2005), the standard deviation on the X coordinate is given by

$$s^2_{\mathrm{PatellaX}} = (0.2347\ s_{\mathrm{Stature}})^2 + (32.3\ s_{\log(\mathrm{BMI})})^2 + (28.3)^2 \qquad [1]$$

where $s_{\log(\mathrm{BMI})}$ is the standard deviation of the *natural log* of BMI for the population. Note that this equation includes the residual variance for fore-aft patella location with respect to seat H-point from Table 1. Similarly, the standard deviations on the Y and Z coordinates are given by

$$s^2_{\mathrm{PatellaY}} = (0.0928\ s_{\mathrm{Stature}})^2 + (92.4\ s_{\log(\mathrm{BMI})})^2 + (34.8)^2 \qquad [2]$$

$$s^2_{\mathrm{PatellaZ}} = (0.2529\ s_{\mathrm{Stature}})^2 + (20.0)^2 \qquad [3]$$

The initial axis lengths for the patella landmark ellipsoid are then calculated to cut off the desired percentage of the population under the normal assumption. For example, to cut off 5% of the population (95% cutoff ellipse), choose a fore-aft axis length equal to

$$\mathrm{L}_{\mathrm{X},\,0.95} = 2\ (s_{\mathrm{PatellaX}})\ \Phi^{-1}(0.95) \qquad [4]$$

where $\Phi^{-1}(\mathrm{q})$ is the inverse cumulative standard normal distribution, e.g.,

$$\Phi^{-1}(0.95) = 1.64 \qquad [5]$$

$\Phi^{-1}(\mathrm{q})$ can be obtained in Microsoft Excel as *normsinv*(*q*).

Repeating for the other two axes gives $\mathrm{L}_{\mathrm{Y},\ \mathrm{q}}$ and $_{\mathrm{LZ},\ \mathrm{q}}$, where q is the desired cutoff percentage. For the two-gender population, iteration is required to determine the value such that the sum of the cutoff percentages from the male and female distributions is equal to the desired value.

The axis lengths computed for the patella landmark distributions are then adjusted to account for the three-dimensional shape of the knee and shin. As shown in Figure 1, the patella ellipse is translated down and forward to approximate the distribution of the most forward point on the tibia plateau. This is also typically the most forward point on the shin, relative to the leg (ankle-knee) line. The translation vector with the leg oriented vertically is 22.7 mm forward and 47.1 mm downward. This vector is rotated rearward in by the leg angle given by the equation in Table 1, so the {X, Z} translation is {-22.7 cos(a) - 47.1 sin(a), 22.7 sin(a) - 47.1 cos(a)}, where a is the leg angle.

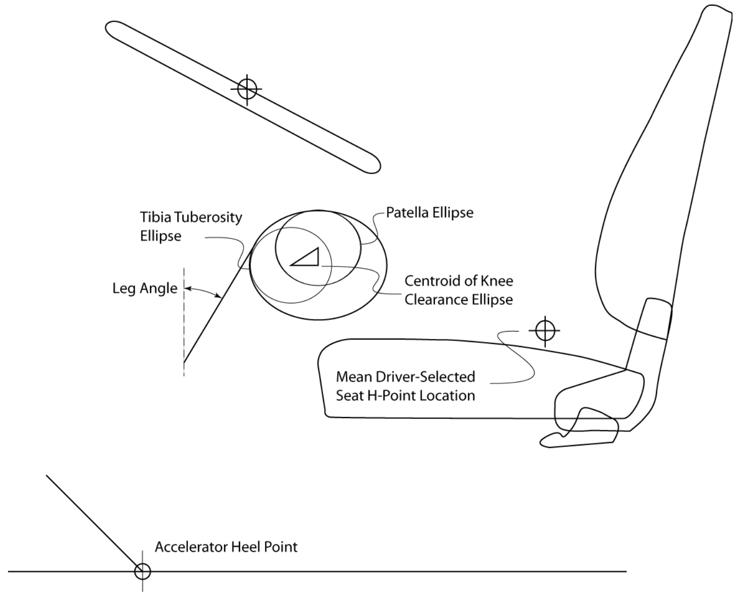


Figure 1. Constructing the knee clearance ellipsoid.

To approximate the boundary of the tibia and patella ellipses with a single ellipse, the origin of the ellipse is translated downward to the same height as the tibial tuberosity ellipsoid centroid and the X and Z axis lengths are extended such that the top and front of the composite ellipsoid are tangent to the top and front of the patella and tibial-tuberosity ellipsoids, respectively (see Figure 1). The lateral axis is extended by 110 mm to account for the knee width. Finally, a downward projection angle for the shin contour is established by computing the leg angle using the equation in Table 1. The shin contour is taken as a side-view tangent to the front of the knee-clearance ellipsoid at the lateral location of the centroid. The line should be extended downward as far as needed.

Accounting for Leg Motions

The knee ellipsoid generated by this approach represents a cutoff contour for normal resting knee locations, based on the right knee locations measured with the driver's right foot on the accelerator pedal. Reflecting this ellipsoid to the left side provides a good indication of the likely resting location of the left knee. Often, however, the primary clearance issue for the left knee concerns clutch operation. Although knee locations associated with clutch operation were recorded during the laboratory study, a unified modeling approach was sought that would not involve a large number of additional calculations. Hence, knee locations during clutch operation or other leg motions are modeled by pivoting the knee ellipsoid around virtual hip pivots located at the mean driver-selected H-point location.

Figure 2 shows the procedure schematically for a clutch. A resting ankle location is estimated. This will typically be estimated using the SAE J826 or J4003 shoe profile with the heel at the AHP and the bottom of the shoe at the design pedal plane angle. The side-view distance from this ankle location to the knee clearance centroid is calculated, as is the distance from the centroid to the mean driver-selected seat position. A second ankle location is estimated with the shoe profile positioned with the ball of foot on the undepressed clutch. The knee clearance ellipsoid is then translated in side view to the "knee" location obtained by maintaining the ankle-to-knee-centroid and knee-centroid-to-mean-H-point distance. The calculations are performed in side view and the ellipsoid is moved in the XZ (vertical longitudinal) plane. When the knee clearance ellipsoid is translated to account for knee movement, the shin angle should be modified to follow the change in angle of the side-view ankle-to-knee-centroid vector.

This procedure is deliberately simplified and does not take into account the potentially complex leg kinematics associated with clutch operation. The simplification is justified by the fact that intersubject variability in segment length, seat position, and clutch behavior is likely to be much larger than any discrepancy between the average behavior and the simple locating procedure.

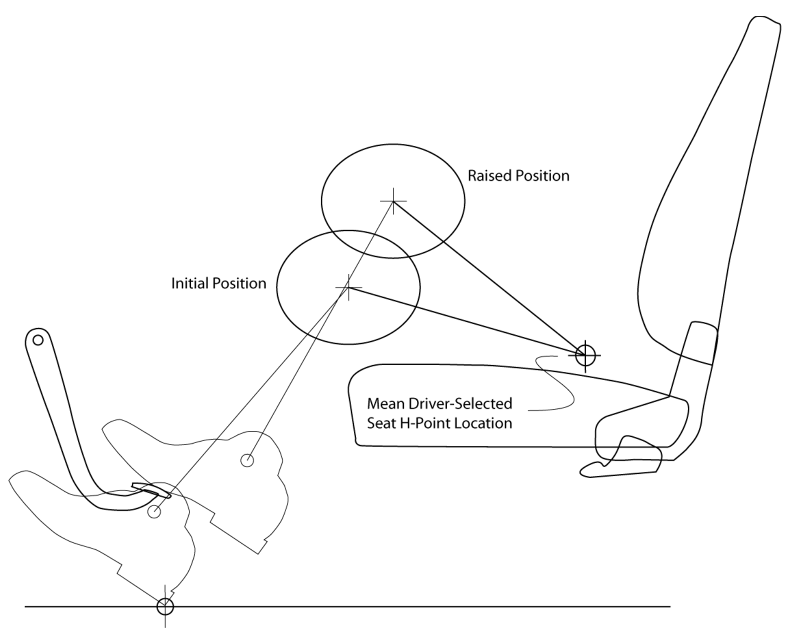


Figure 2. Procedure for locating the knee ellipsoid to estimate the clearance requirements for clutch pedal operation.

3.2 Abdomen Clearance Model

The abdomen model combines the seat-position predictions from the seating accommodation model with a model of abdomen profile with respect to seat H-point. All calculations are performed in side view on the driver centerline.

Abdomen Profile Model

The abdomen profile data, shown in Figure 3, were expressed relative to seat H-point and then resampled at 50-mm vertical increments, using linear interpolation, to facilitate statistical analysis. A regression model was developed that predicts the fore-aft location of the profile as a function of driver attributes (stature and body mass index) and the vertical coordinate. Because the abdomen contour is nonlinearly related to body mass index, the model includes squared and cubed terms. The natural log of BMI is used, rather than BMI, because the log of BMI is approximately normally distributed.

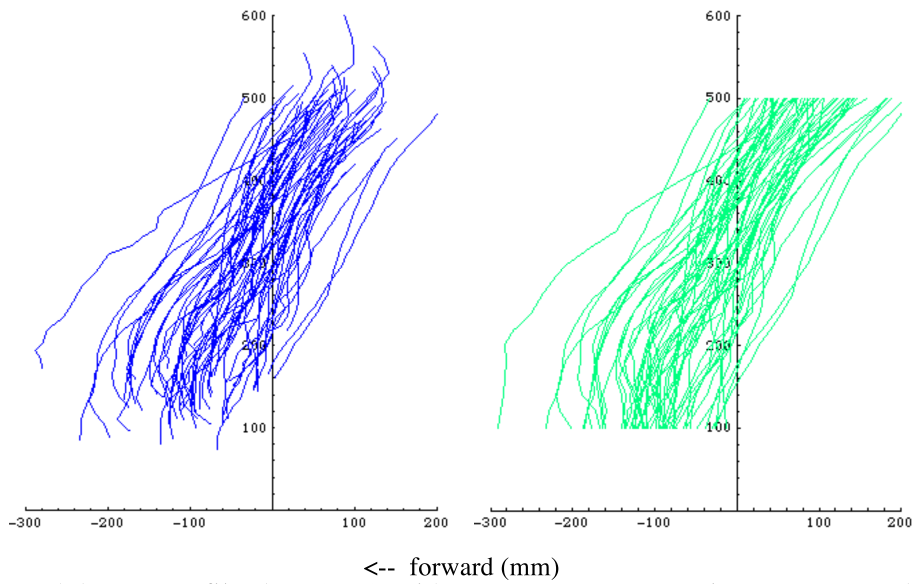


Figure 3. Abdomen profile data (mm) with respect to seat H-point: as measured (left) and resampled (right).

After experimenting with a number of different model formulations, a linear regression model was obtained:

AbdomenXreHPt (mm) = 923 – 0.07279 *Stature* - 2.476 z^3 – 267.5 *ln(BMI)* – 0.1396 z *ln(BMI)* + 0.0008648 z^2 *ln(BMI)*, $R^2 = 0.83$, RMSE = 33.6 [6] where *Stature* is erect standing height without shoes in mm, *ln(BMI)* is the natural log of BMI (kg/m^2) and *z* is the vertical distance above H-point in mm. The interaction terms account for the increase in prominence and curvature of the abdomen with increasing body mass index. The residual variance is approximately normally distributed, which is useful for the modeling approach described below. Importantly, the residual variance is negatively correlated with seat position. That is, individuals whose abdomen protrudes farther than predicted by the model also tend to sit with their seats farther rearward. This correlation is taken into account in the modeling. Figure 4 shows the model-predicted profile for a wide range of body mass index. The model captures the general change in abdomen profile with greater body mass.

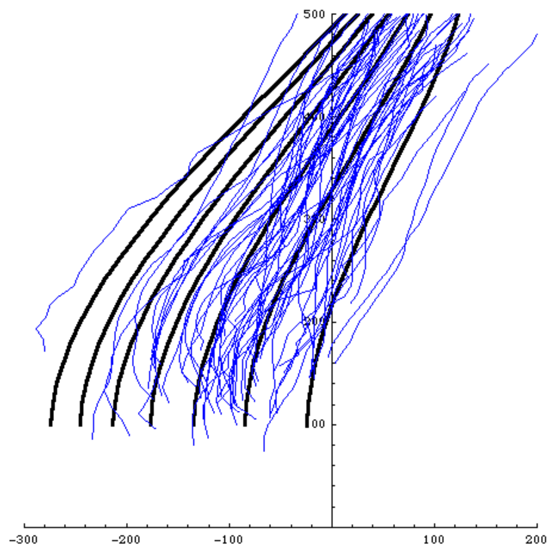


Figure 4. Abdomen contour model relative to seat H-point for drivers with midsize male stature and BMI from 20 to 50 (thick lines) overlaid on the original data.

As with the knee clearance model, calculations for the abdomen model are performed separately for men and women, because within-gender body dimensions distributions (stature and the natural log of BMI) can be readily characterized as normal distributions. At each vertical position (z coordinate value), separate male and female means and standard deviations are computed. An x-axis (fore-aft) value that cuts off the desired percentage of the combined population is then computed using numerical iteration.

The abdomen contour in package space at the desired cutoff fraction is computed using the within-gender mean and standard deviation of seat position predicted by the seating accommodation model. The abdomen profile and seat position distributions are summed to obtain the fore-aft abdomen profile distribution in package space. The mean values of seat position and abdomen location sum at each vertical position to obtain the mean abdomen profile, but the covariance is included when summing the variance. For each gender,

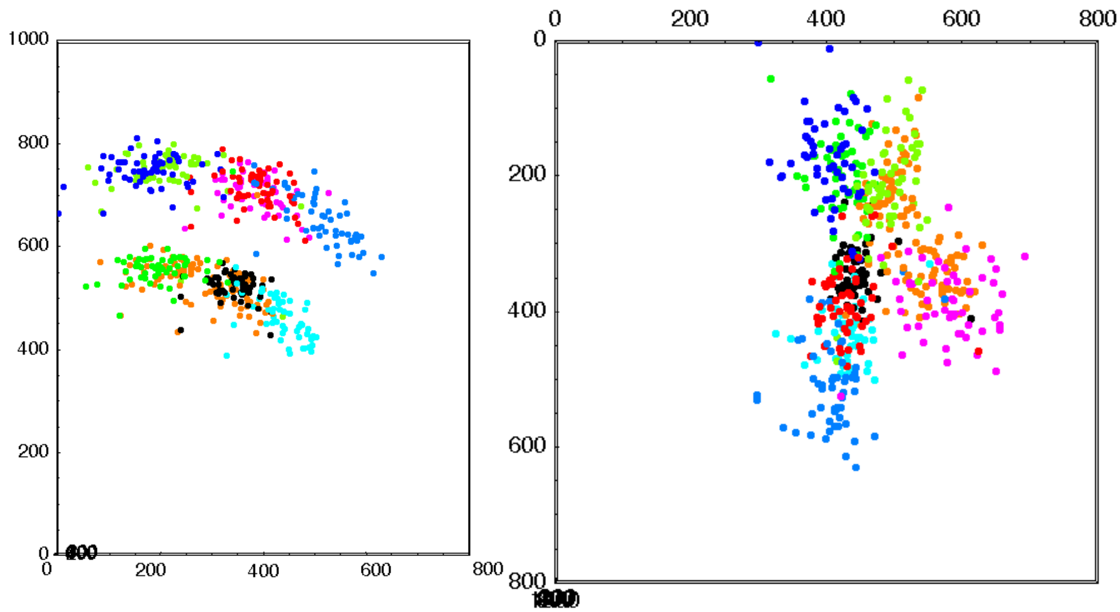
$$s_{\text{abd, AHP}}^2 = s_{\text{sp}}^2 + s_{\text{abd,Hpt}}^2 + 2\, r\, \text{s}_{\text{sp}}\, s_{\text{abd, Hpt}} \qquad [7]$$

where $s_{\text{sp, AHP}}^2$ is the fore-aft variance of the abdomen profile with respect to AHP, s_{sp}^2 is the variance of seat position with respect to AHP, $s_{\text{abd,Hpt}}^2$ is the variance of abdomen position with respect to H-point, and r is the correlation between seat position and abdomen position with respect to H-point (-0.42).

3.3 Shifter Location Model

The shifter location data were analyzed to define two geometric regions for use in assessing candidate designs. The data are interpreted differently than the knee or abdomen data. Whereas the latter are well defined by posture and body dimensions, the shifter data are primarily dependent on drivers' preferences. For example, in all cases, the drivers could have pushed the shifter further to the right or further forward if they desired. The shifter data from each driver therefore represent several points that lie within the zone of preferred shifter locations. The objective of the analysis is to construct a simplified geometric representation of the aggregate of the drivers' preferred shifter zones for use in design.

The locations of the sampled shifter points were analyzed with respect to AHP and driver-selected seat H-point. Figure 5 shows the points relative to package space. The design of the shifter allowed the length of the shifter shaft to be adjusted independent of its position, but the data show a curved contour in side view suggesting that the drivers did not make fine adjustments of height at position, but rather chose "high" and "low" shifter positions (shaft lengths) and then pivoted the shifter to achieve the forward, lateral, and rearward positions.



← Forward

Side View of Shifter Data

Right →

Top View of Shifter Data

Figure 5. Measured shifter locations relative to accelerator heel point (fore-aft and vertical) and driver centerline (lateral). Different colors represent different measured points, e.g., forward and up, rearward and down.

The statistical analysis relative to H-point indicated that the shifter zones preferred by taller drivers extended further forward relative to the seat. The strongest relationship was at the rearward boundary, with the most-rearward edge of the shifter zone being further forward, relative to the seat, for taller drivers. The analysis relative to AHP, however, showed few statistically significant relationships with driver body dimensions. The tendency for taller drivers to sit further rearward approximately offsets their willingness and ability to reach further forward, such that the fore-aft location of the front edge of the shifter envelope is only weakly related to body dimensions (R^2 = 0.06). None of the other boundary points is significantly related to body dimensions.

These observations suggest that the most efficient way to model preferred shifter location is with respect to AHP, because no scaling based on body dimensions will be required. That is, the analysis suggests that the range of preferred shifter locations measured for the study population would be similar to the range that would be obtained with a representative population of drivers. Consequently, the modeling approach is as follows:

1. Model the location, size, and shape of the preferred shifter zone with respect to AHP.

2. Position the shifter-zone model across vehicles by reference to the mean driver-selected fore-aft and vertical seat position provided by the seating accommodation model.

The second step allows the shifter zone to be adjusted for changes in vehicle package, e.g., steering wheel position with respect to AHP.

Two zones, defined by geometric volumes, were created through analysis of the measured boundary points (the center point was neglected for this analysis). For each point (e.g., forward and up), two points were computed. The innermost point was selected such that 95% of the measured points were more extreme (further forward or higher) based on a multivariate-normal approximation to the data. The outermost point was selected so that only 5% of points were more extreme. Repeating the process for all 8 outer sampled points defined a set of inner and outer volumes. (Two inner points, defining the high and low "preferred" positions, were neglected in defining the volumes because those points were enclosed in all cases by the volumes defined by the boundary points.)

The interpretation of the inner and outer volumes is as follows: The fore-aft, vertical, and lateral extremes of a candidate shifter region that lies entirely within the inner volume could be expected to lie within the extremes of the preferred shifter boundaries of 95% of drivers. Note that the accommodation estimate applies to each margin (e.g., the forward boundary) individually. A shift pattern that lies entirely within the outer boundary is less extreme than 5% of drivers at each point.

To create a continuous boundary around the sampled points, simplified geometric representations of the inner and outer volumes were constructed. The front quadrant is a quarter cylinder, which adjoins a rectangular prism. The parameter values defining this geometry were selected manually to provide a reasonable fit to the boundary points identified by the statistical analysis. Figure 6 shows two views of the geometric models. Table 2 summarizes the boundaries of the models relative to the mean driver-selected seat position. The top and bottom surfaces have a side-view slope of –0.3 to match the contour of the data.

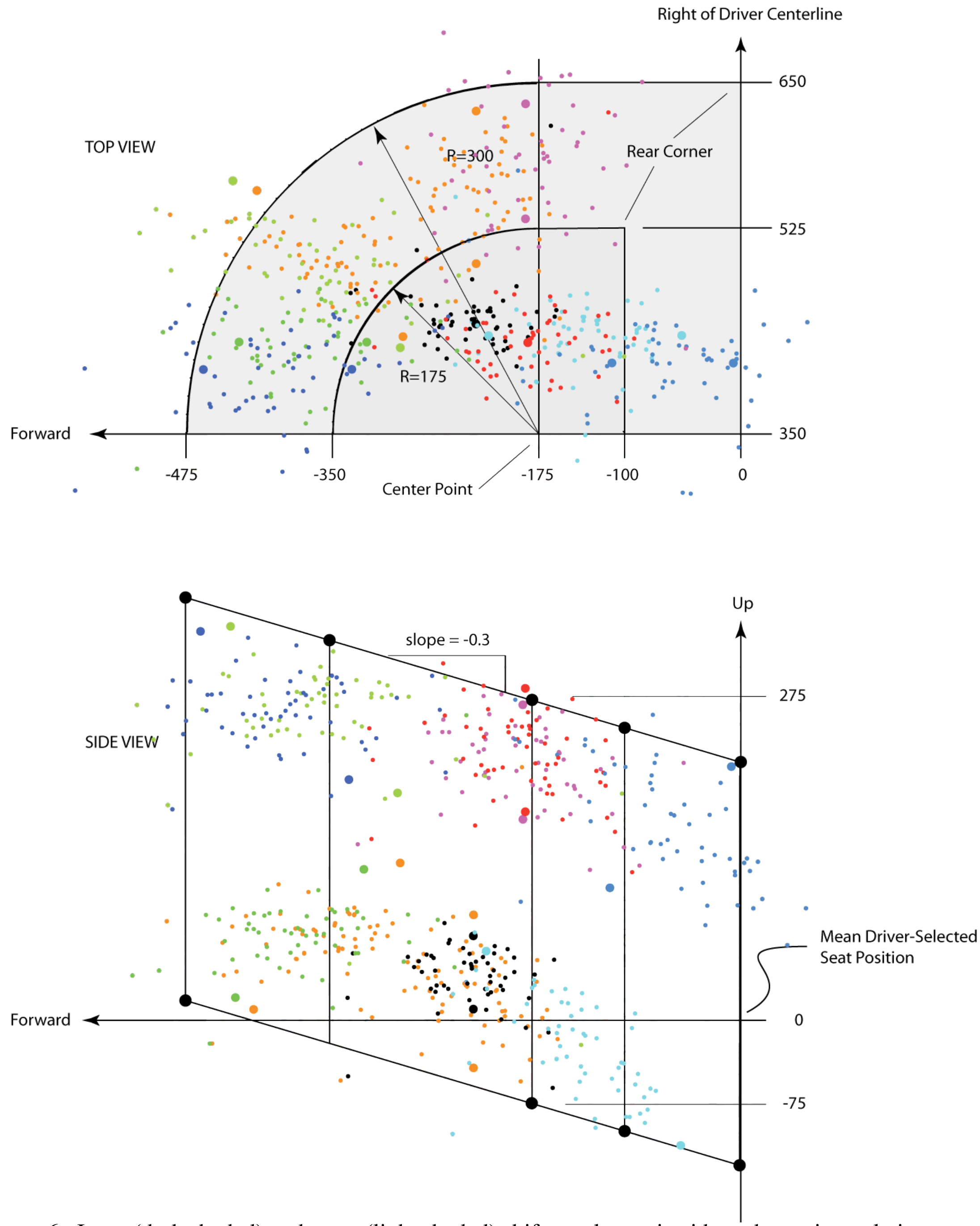


Figure 6. Inner (dark shaded) and outer (light shaded) shifter volumes in side and top view relative to mean driver-selected seat position. The measured shifter locations are shown as dots. Colors represent different measured points, e.g., up and forward, down and rearward. Larger dots represent statistically generated boundary points (see text). The dimensions of the shifter volumes are listed in Table 2 and described in the text.

Table 2
Parameter Values (mm) for Shifter Volumes Relative to
Mean Driver-Selected Seat Position*

Parameter	Outer Volume	Inner Volume
Center Point X†	-175	-175
Center Point Y	350	350
Center Point Z (min)	-75	-75
Center Point Z (max)	275	275
Radius	300	175
Rear Corner X	0	-100
Rear Corner Y	650	525

* See Figure 6.
† X is positive rearward, Y positive to the right of the driver, Z positive up.

Locating the Shifter Volumes

The volumes described in Figure 6 and Table 3 can be constructed as CAD objects and then positioned relative to a design to perform assessments. The fore-aft and vertical reference for the geometry is the mean driver-selected seat position, based on the seating accommodation model described in Reed (2005). The seat position model takes into account the effects of steering wheel position and adjustment range, along with the characteristics of the driver population. The lateral reference for the shifter volumes is the driver centerline. If there is a discrepancy between the lateral center of the steering wheel or the seat, the seat centerline should be used.

Analysis

For the reasons described above, the shifter volumes do not have the statistically derived cutoff character that the other models have. Consequently, design analyses using these tools are more subjective, but the models nonetheless provide some potentially useful design guidance. First, the inside volume provides a good indication of where a shifter pattern should be centered. The rear of this volume is also important, because shift patterns that extend beyond this plane are likely to result in seat/elbow interference for some drivers. Second, shifter patterns that extend beyond the outer volume are likely to extend beyond the preferred movement range of most drivers. Such shift patterns are likely to be uncomfortable for many drivers. Third, shifter handles that are centered vertically on the volumes are likely to be acceptable to most drivers.

4.0 DISCUSSION

The development of the clearance models in this report was in some ways more challenging than the development of the seating accommodation and eyellipse models because robust models for these purposes have not previously been developed. The belly contour model in SAE J1522 was based on modeling of a single point by a multivariate ellipsoid, and was not meaningfully parameterized. For example, the model could not be adjusted to represent populations with a larger percentage of obese drivers. The now-standard methodologies for representing the distributions of individual points using multivariate normal distributions have been applied with considerable success to predicting population distributions of seat positions and eye locations. The knee location model in this report extends this concept in a manner somewhat similar to the construction of the SAE J1052 head contour, which was developed by moving an average head form around a cutoff eyellipse. The current analysis used average knee dimensions to extend an ellipsoid constructed for the patella to cover the perimeter of the three-dimensional knee.

The knee model is limited by the conditions and characteristics of the mockup used for data collection. In particular, the contouring of the seat cushion (side bolsters) may have affected knee location by altering driver leg splay. The seat used was a highly adjustable ISRI model that may have had more bolstering than some truck seats. Higher or narrower seat cushion bolsters would tend to bring the knee locations closer to the driver centerline. The mockup was designed so that knee interference in preferred driving postures was unlikely, but it is possible that some drivers would have sat with their knees further forward in the absence of an instrument panel.

The method for repositioning the knee clearance model to estimate clearance requirements for leg motions (e.g., clutch operation) is designed to be relatively easy to implement. However, some potentially important aspects of this method are left undefined. In particular, the best way to estimate an ankle location on the undepressed clutch has not been determined. This issue should be addressed in future work, along with the critical issue of leg kinematics for both clutch and brake operation.

The new abdomen model applies the cutoff concept uniaxially (fore-aft). That is, the calculated profile represents the target cutoff percentile for abdomen location at a particular vertical location on the driver lateral centerline. This approach was judged to be appropriate because the clearance dimension of interest, to the bottom rim of the steering wheel, can meaningfully be analyzed using a univariate, fore-aft analysis. The utility of the abdomen model is limited primarily by the range of anthropometric variability in the subject population. About half the subjects were obese, which is believed to be typical of some truck driver populations, but the subject pool lacked morbidly obese individuals with BMI greater than 40 kg/m^2. These individuals are most likely to be affected by steering wheel interference. Some other results from the laboratory study are relevant in this regard. Trials were conducted using 14-, 18-, and 22-inch-diameter steering wheels, but the steering wheel diameter was not found to have a significant, systematic effect on driver posture and position. The current model does not include a gender-specific effect of BMI on abdomen profile, because the data lacked a sufficient number of obese women to support such a model. However, systematic gender differences in body shape make it likely that the current model is more accurate for predominantly male populations.

The current models do not explicitly take into account rearward censoring on seat position, which would tend to place drivers closer to the steering wheel and instrument panel when they are prevented by limits to the seat adjustment range or cab dimensions from sitting as far rearward as they would prefer. However, censoring can be taken into account through its effect on mean driver-selected seat position. If censoring on seat position is asymmetric (more censoring on the back than the front, for example) the effect on mean seat position should be computed and then reflected in the positioning of the models in this report. Simulations of the effects of various levels of seat-position censoring on knee locations suggests that adjusting the location of the knee clearance ellipsoid based on shifts in mean seat position are adequate for disaccommodation levels up to about 30%.

The shifter model was the most difficult to develop, for several reasons. First, ten points were gathered from each driver, spanning a volume of preferred shifter locations for each subject. Second, the measured values necessarily were more sensitive to preference in behavior than are abdomen or knee location. For abdomen and knee clearance, it is reasonable to adopt an implicit assumption of a binary cost: either the driver's preferred position is accommodated or it is not. But for the shifter location, it is unclear from the data whether a shifter pattern that extended slightly outside of the volume that the driver demonstrated in the laboratory would represent any meaningful disaccommodation. More generally, we can assume that the cost to individual drivers for deviating by some amount from the perimeter of their preferred volume would vary widely.

As a consequence of these basic differences in the data, the goal of the shifter model development was to capture the overall minimum and maximum size and shape of the shifter volumes, rather than to provide a quantitative accommodation analysis tool, as was the case with the knee and abdomen models. The simplified geometric models that were developed are easy to construct and locate in CAD, and provide a direct representation of the data that were measured in the laboratory.

The knee and abdomen clearance models are based on a contact condition. For most applications, some clearance margin would be desired for comfort. Recommended margins for both the knee and abdomen are 25 mm, but larger margins, particularly at the knees, would provide for greater confidence that the desired percentage of the population would be accommodated. The knee clearance ellipsoids have validity primarily at the front, top, and outside. The tangents on other planes are probably reasonable, but are not directly supported by the data. Restrictions on one plane may affect the others. For example, if a console restricts leg splay, the average knee location is likely to be forward of that predicted by the model. These effects could be estimated by rotating the knee clearance ellipsoids around the mean seat position, as is done to simulate clutch operation.

The appropriate ways to interpret these models for design purposes will need to be developed through benchmarking and further laboratory and in-vehicle studies. In particular, analyses of existing shift patterns relative to these guidelines will help to determine whether the boundaries are unnecessarily restrictive or if the guidelines correspond well to designs that have been judged by drivers to be acceptable. A preliminary comparison of the results from Parkinson and Reed (2006b) shows a good correspondence between shifter locations predicted using a balance criterion and the current models.

Future Work

The models presented in this report represent a substantial advancement in accommodation models for cab design. However, additional validation is needed, using data gathered from drivers in vehicles driven on-road. Another important limitation of the current models is that they do not explicitly take into account censoring of various kinds produced by limits in component adjustment ranges or other sources of postural interference, such as restrictive headroom. Referencing the models to mean seat position provides some flexibility, but calculating mean seat position in the presence of censoring is relatively complicated. A more complete solution to accommodation modeling is to use simulation studies (Parkinson et al. 2005, Parkinson and Reed, 2006a) in which large numbers of virtual drivers are positioned in the design, taking into account restrictions on component adjustment ranges.

Other potential improvements to these models include:

- motion-based clearance contours for the lower extremities, taking into account a variety of resting positions for the limbs as well as clearance requirements for large footwear during both normal and emergency pedal operations;

- three-dimensional torso contours based on a statistical analysis of body scan data; and

- shifter location models that take into account both force requirements and position, including subjective and objective costs appropriate for different driver populations.

As part of additional in-vehicle validation studies, the postural and subjective responses to various types of censoring and disaccommodation should be studied. The results would be valuable for optimizing tradeoffs between cost, adjustability, and accommodation.

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