SURFACE VEHICLE RECOMMENDED PRACTICE

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Driver Seating Accommodation and Steering Wheel Location Models

RATIONALE

This practice presents methods for establishing the driver workspace. Methods are presented for:

- Establishing accelerator reference points, including the equation for calculating the shoe plane angle.
- Locating the seating reference point (SgRP) as a function of seat height (H30).
- Establishing seat track dimensions using the seating accommodation model.
- Establishing a steering wheel position.

Some of the information in this practice was previously published in SAE J4002, SAE J4003, and SAE J4004.

INTRODUCTION

This document describes recommended methods for laying out important dimensions of the driver workstation. These design tools assume that a design seat height value (H30) is available, along with pedal and floor geometry.

The seating reference point (SgRP) is defined in SAE J1100 as "the rearmost normal design driving or riding position of each designated seating position in a vehicle." For a driver seating position with an adjustable seat, the SgRP is one H-point location within the H-point travel path. This document describes the industry practice for locating SgRP using the SgRP curve referenced to the Ball of Foot Reference Point (BOFRP) and Accelerator Heel Point (AHP). The SgRP curve is the 95% accommodation curve from SAE J1517, which contained the original SAE seating accommodation model. SAE J1517 is no longer applicable to Class-A vehicles, and the seating accommodation model in SAE J1517 has been completely superseded by the seating accommodation model in the current practice. However, to maintain compatibility with decades of practice, the SgRP equation is retained.

Similarly, an updated version of an equation presented in SAE J1516 has been retained to define the Shoe Plane Angle (SPA) as a function of H30. During the development of SAE J1516 and SAE J1517, an equation for an accelerator "pedal plane angle" (denoted by theta) was derived by moving the H-point of the SAE J826 2D template along the SgRP locator curve while holding the ankle angle at 87 degrees, maintaining the ball of foot at a constant X-location and maintaining the template heel at a constant Z-location. To maintain compatibility with previous practice, the SPA is defined using an updated version of the equation that more accurately replicates the kinematics of the template. Note that SAE J1516 and SAE J1517 are no longer applicable to Class-A vehicles.

After computing SPA, the profile of the shoe of the SAE J826 template is placed at the appropriate angle against the profile of the undepressed accelerator pedal with the heel resting on the floor. When the shoe profile is appropriately positioned, BOFRP and AHP are established.

Prediction of the distribution of driver-selected seat position on the seat adjuster path is important to ensure that a large percentage of drivers can comfortably reach and operate vehicle hand and foot controls. This document provides a method for determining driver seat track length and for positioning the seat track in the vehicle package to achieve the desired level of accommodation. This seating accommodation model (SAM) is based on statistical models developed at the University of Michigan Transportation Research Institute (UMTRI) based on data from hundreds of drivers in dozens of vehicles. This new method completely supersedes the model presented in SAE J1517. The recommended position of the driver seat track in the vehicle is based on H30, L6, and the presence or absence of a clutch pedal. The seat track length is independent of vehicle seat or package variables. Background details of the new method are given in Appendix A. Historical information about the prior procedure is given in Appendix B.

This practice also introduces a recommended procedure for establishing a design steering wheel position. The steering wheel preference model is based on driver preference data gathered and analyzed at UMTRI and confirmed by reference to benchmarking data.

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This practice presents methods for establishing the driver workspace. Methods are presented for:

- Establishing accelerator reference points, including the equation for calculating the shoe plane angle.
- Locating the SgRP as a function of seat height (H30).
- Establishing seat track dimensions using the seating accommodation model.
- Establishing a steering wheel position.

Application of this document is limited to Class-A Vehicles (Passenger Cars, Multipurpose Passenger Vehicles, and Light Trucks) as defined in SAE J1100.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J826 Devices for Use in Defining and Measuring Vehicle Seating Accommodation

SAE J826/2 2-D CAD Template for SAE J826 H-point Machine

SAE J1100 Motor Vehicle Dimensions

SAE J1516 Accommodation Tool Reference Point for Class B Vehicles

SAE J1517 Driver Selected Seat Position for Class B Vehicles - Seat Track Length and SgRP

SAE J4002 H-Point Machine (HPM-II) Specifications and Procedure for H-Point Determination - Auditing Vehicle Seats

Philippart, N., Roe, R., Arnold, A., and Kuechenmeister, T., "Driver Selected Seat Position Model," SAE Technical Paper 840508, 1984, https://doi.org/10.4271/840508.

Reed, M., "Driver Preference for Fore-Aft Steering Wheel Location," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):629-635, 2013, https://doi.org/10.4271/2013-01-0453.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

Flannagan, C., Schneider, L., and Manary, M., "Development of a New Seating Accommodation Model," SAE Technical Paper 960479, 1996, https://doi.org/10.4271/960479.

Flannagan, C., Manary, M., Schneider, L., and Reed, M., "An Improved Seating Accommodation Model with Application to Different User Populations," SAE Technical Paper 980651, 1998, https://doi.org/10.4271/980651.

2.2.2 Other Publications

Abraham, S., Johnson, C.L., and Najjar, M.F. (1979). Weight and height of adults 18-74 years of age. *Vital and Health Statistics*, Series 11, No. 211.

U.S. National Health and Nutrition Examination Survey (NHANES III), Height for males and females 20 years and older, 1988-1994.

3. DEFINITIONS

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4. DRIVER LAYOUT REFERENCES

The SAE Recommended Practice for establishing the driver layout is based on the three key reference points: Seating Reference Point (SgRP), Ball of Foot Reference Point (BOFRP), and the Accelerator Heel Point (AHP). The position of these points relative to one another determines critical measurements defined in J1100 within the Driver's space, specifically:

- Seat Height (H30) - vertical distance from SgRP to AHP
- Shoe plane - plane normal to the Y-axis that passes through the BOFRP and the AHP
- L99 - longitudinal distance from the driver's BOFRP and SgRP

The manufacturer positions any one of these reference points within the Driver's space and uses a defined relationship between the reference points combined with an 87-degree ankle angle requirement to complete the layout of the HPD 2D template. This relationship is set by the SAE SgRPx Curve and defined below:

4.1 $SgRP_x$ Curve

The $SgRP_x$ curve expresses the driver seat H-point position aft of the ball of foot reference (L99) as a function of Seat Height (H30). See Equation 1.

$$SgRP_X = 913.7 + 0.672316(H30) - 0.0019553(H30)^2 = \text{Distance (in mm) rearward of BOFRP} \quad \text{(Eq. 1)}$$

If HPM-II (SAE J4002) is used, the $SgRP_x$ value needs to be adjusted to account for the difference in length of the AHP to BOFRP between the HPM-I and HPM-II - 203 to 200 mm accordingly. See Equation 2.

$$SgRP_{X(HPM\text{-}II)} = SgRP_X - 3\,COS(SPA) \quad \text{(Eq.2)}$$

The result of applying this equation to the HPD 2D Template is a bounding box that constraints the position of the remaining key reference points. See Figure 1.

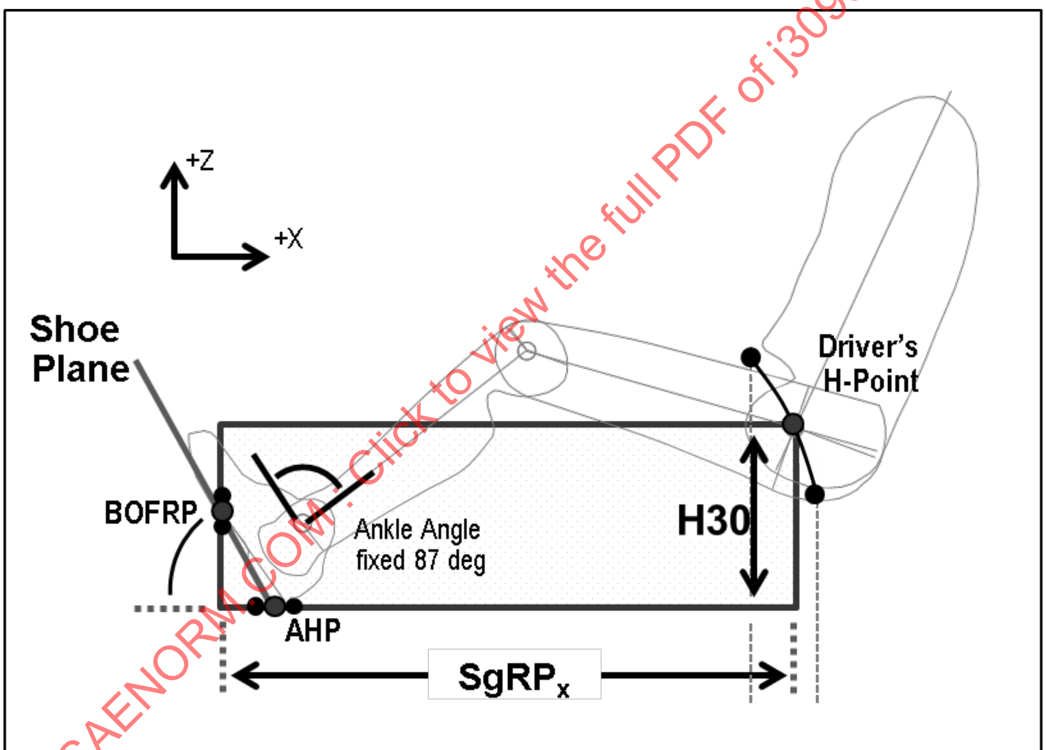

Figure 1 - Driver's SgRP curve and reference point constraints

4.2 Driver's SPA Equation

In some design practices, it is beneficial to only work with the pedal and shoe geometry. The Driver's SPA equation provides a simple method for directly estimating the angle of the Driver's shoe plane as a function of seat height (H30) without the need to determine the complete HPD layout using the $SgRP_x$ equation (see Equation 2).

$$SPA_{driver} = 2.522(10^{-7})(H30^3) - 3.961(10^{-4})(H30^2) + 4.644(10^{-2})(H30) + 74.374 \text{ degrees from horizontal} \quad \text{(Eq. 3)}$$

The resulting output of the equation is within 0.007 degree of the solution determined by the kinematics of the SAE J826 2D template when applying the $SgRP_x$ methodology for defined Class-A vehicle packages.

4.2.1 Driver Shoe Plane Location Derived from Accelerator Pedal Geometry

If the accelerator pedal has already been designed, driver shoe plane may be located using the existing accelerator pedal geometry per the following:

- Non-pivoting, suspended pedal - Position the driver shoe so that the bottom of the shoe contacts the lateral centerline of the pedal surface with the heel on the depressed floor covering.
- Flat, suspended pedal with a pivoting pedal pad - Position the driver shoe so that the bottom of the shoe contacts the lateral centerline of the pedal pad surface with the heel on the depressed floor covering. The pedal pad should be pivoting within its range of motion as needed to allow the shoe plane to be moved as far forward as possible without depressing the pedal.
- Treadle (pivot at floor) pedal - Position the driver shoe so that the bottom of the shoe contacts the lateral centerline of the pedal pad surface with the heel on the depressed floor covering. Three types of contact can occur with a treadle pedal: at the heel of the shoe with the pedal at a flatter angle than the bottom of the shoe, tangent to the bottom of the shoe, or contact at the upper portion of the shoe with the heel of the shoe rearward of the bottom of the pedal.

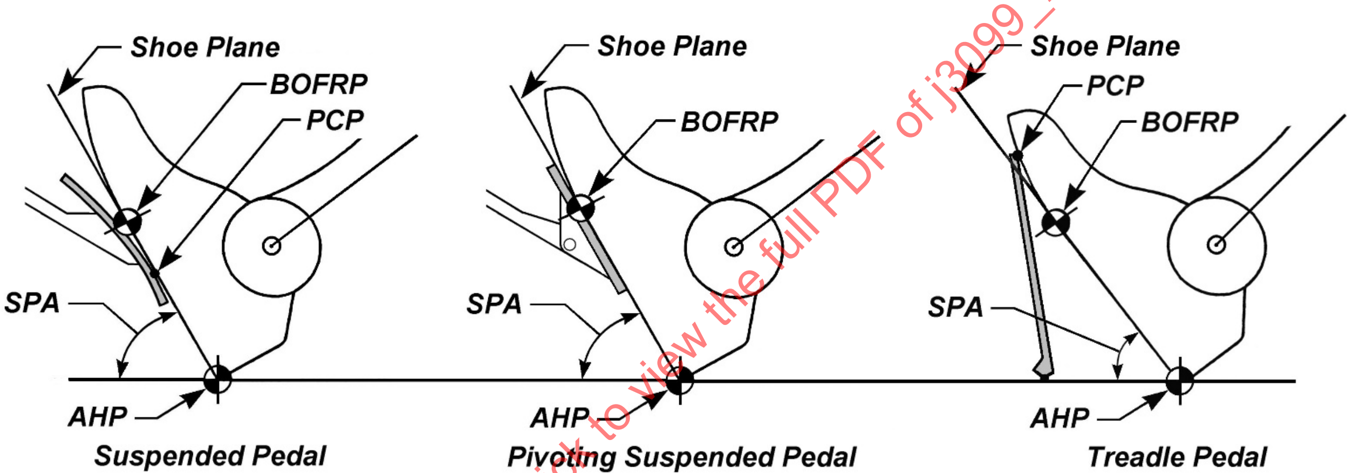

Figure 2 - Examples of the HPD-II driver's shoe plane used with different accelerator pedal geometry

5. DRIVER SEAT TRACK ACCOMMODATION FOR A U.S. DRIVER POPULATION

The Driver Seat Track Accommodation Model provides recommendations for accommodating a preferred fore/aft seat track position of a 50/50 male/female driver population within the seat track travel path.

5.1 H-Point Reference X

The H-point Reference X expresses the position of the Driver Seat Track Accommodation X-reference aft of the BOFRP as a function of seated height (H30), BOFRP to steering wheel center (L6), and transmission type. Determine the X-distance of the H-point reference position aft of the BOFRP based on Equation 4.

$$\text{H-point reference position, } X_{ref} = 718 - 0.24(H30) + 0.41(L6) - 18.2t \quad \text{(Eq. 4)}$$

where:

H30 = vertical distance from the SgRP on the design H-point travel path to the AHP

L6 = horizontal distance from BOFRP-to-steering wheel center (calculation is provided in 6.1)

t = transmission type (1 if clutch pedal and 0 if no clutch pedal)

The Y- and Z-coordinates, W20 and H30, of the H-point reference position are determined by the manufacturer.

5.2 Seat Track Length

Population Accommodation is determined by selecting the available seat track length forward and rearward of the H-point Reference X-position. SAE recommends a minimum seat track length of 240 mm as described in Table 1, which accommodates 95% of the driving population.

Table 1 provides seat track length values for symmetrical accommodation about the X-reference, i.e., the same percentage of the driving population is excluded at the front and the rear of the seat track travel.

Table 1 - Seat track length (mm)

Desired Accommodation (%)	Front of H-point travel path from H-point X-reference (mm)	Rear of H-point travel path from H-point X-reference (mm)	Total Seat Track Length (mm)
98% (1-99)	-135	145	280
97.5% (1.3-98.8)	-131	140	271
95% (2.5-97.5)	-116	124	240
90% (5-95)	-100	106	206
80% (10-90)	-79	83	162

Manufacturers may desire asymmetrical accommodation to target specific populations. Table 2 provides the accommodation values in a format that users can easily select specific Percent Accommodation values forward and rearward of the X-reference.

Table 2 - Accommodation points

Percent Accommodation	Forward of X-Reference					Rearward of X-Reference				
	1	1.25	2.5	5	10	90	95	97.5	98.75	99
Distance from seat track X-reference (mm)	-135	-131	-116	-100	-79	83	106	124	140	145

5.3 Position Fore-Aft H-Point Travel Path in Vehicle

5.3.1 Construct a horizontal line through SgRP.

5.3.2 Set the H-point X-reference point on this line based on calculated horizontal distance from BOFRP in Equation 3.

5.3.3 Set the endpoints on this line based on the selected accommodation values for the forward and rearward travel from the X-reference point. For the recommended 240-mm seat track length, the endpoints will be 116 mm forward, and 124 mm rear of the H-point X-reference calculated in Equation 4.

5.4 Seat Track Angle

5.4.1 Select a design seat track angle (A19).

5.4.2 Rotate the H-point travel path and the accommodation points about the SgRP to the design track angle. This line represents the design fore-aft H-point travel path (see Figure 3).

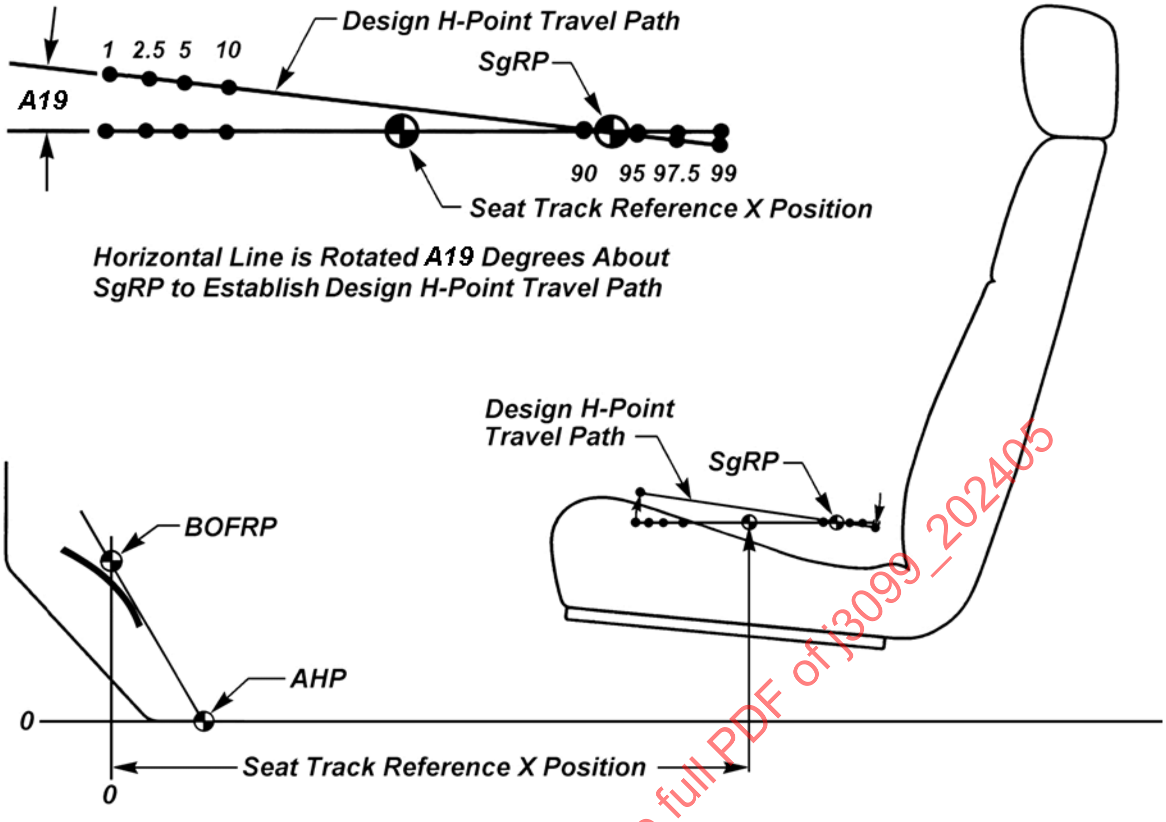

Figure 3 - Example of driver seat position accommodation points on the design H-point travel path

5.5 Vertical Seat Track Travel

Manufacturers may provide additional vertical seat track travel with a seat lift function, lift and tilt function, or similar mechanisms. For seats with vertical adjustment, it is recommended that the design H-point travel path be set at the middle of the vertical adjustment to allow user selection both above and below design intent.

The final H-point travel path will be determined by the movement of the selected mechanism.

6. STEERING WHEEL POSITION

The Steering Wheel Position model provides a recommended longitudinal distance from the BOFRP to the steering wheel center (L6) based on the design Seat Height. L6 is a required input to the SAM described in 5.1.

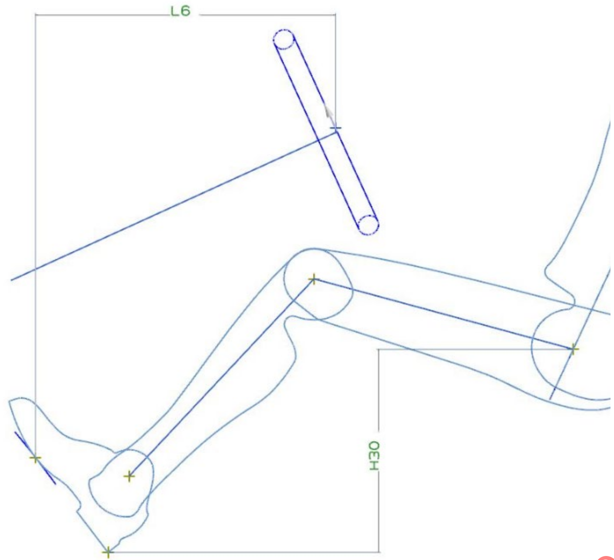

Figure 4 - Definition of H30 and L6

6.1 $L6_x$ Equation

Equation 5 provides the recommended value for L6 as a function of H30.

$$L6_x = -0.0023\ H30^2 + 0.8756\ H30 + 482.9 \qquad \text{(Eq. 5)}$$

Equation 5 is valid for Class-A H30 values above 190 mm. For values below 190 mm, a constant L6 value of 566 mm should be used. This equation applies to a 50/50 male/female U.S. adult driver population. For other populations, see Appendix A.

The equation(s) does not represent an ideal SW position. Many interior package design features and performance targets may impact the final desired placement of the SW (L6). The equation is provided as initial guidance ONLY.

7. NOTES

7.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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APPENDIX A - MODEL DESCRIPTION AND APPLICATIONS FOR OTHER DRIVER POPULATIONS

A.1 BACKGROUND

In this appendix, a more detailed description of the seat position prediction model is described. The complete model provides a method for determining driver seat track length for special cases where seat track lengths are needed for different driver populations (a different stature distribution, gender mix, or percentile accommodation).

SAE J1517 incorporated a driver seat position prediction model that is briefly described in Appendix B. This model was only valid for a 50/50 male/female U.S. driver population. It could not be readily adapted to predict seat position for other driver populations and gender mixes.

The model embodied in SAE J4004 represents a completely different approach to predicting seat position. This model predicts seat position (measured aft of BOFRP) for an individual driver in a specific vehicle, based on his/her stature and various vehicle parameters. The distribution of seat positions for a particular driver population is then built by applying a population stature distribution to the seat position prediction model.

The data used to develop the present model were collected over several years (see 2.2.3 and 2.2.6). Preferred seat position was measured for 50 to 120 subjects in 36 vehicles and 18 laboratory buck conditions. In each vehicle, subjects were stratified by stature so that small and large statures were overrepresented for greater accuracy in measuring seat position preference among drivers near the tails of the seat position distribution. Vehicles were selected to span a wide range of vehicle dimensions.

Within each vehicle, seat position was regressed on stature. Across vehicles, seat position was shown to be linearly related to stature, independent of gender and independent of vehicle variables. Thus, an overall slope, intercept, and error estimate (MSE, the mean squared error) were calculated by averaging the values for individual vehicles.

A.2 MODEL DESCRIPTION

The seat position prediction model in SAE J4004 represents each single-gender seat position distribution using a normal distribution. Data analysis shows that individual seat position is best predicted by stature, regardless of gender. Thus, the relationship between seat position and stature within a vehicle is the same for males and females, so one prediction equation is sufficient. Across vehicles, seat position depends only on vehicle variables, so a single equation can be used to predict the seat position of any individual (male or female) in any vehicle. Equation A1 shows this predictive relationship.

$$X = 16.8 + 0.433\,(\text{stature in mm}) - 0.24(H30) - 2.19(A27) + 0.41(L6) - 18.2t \qquad \text{(Eq. A1)}$$

Because population stature is normally distributed (within gender), and because Equation A1 is linear in stature, the same equation predicts the mean male seat position as a function of the mean male population stature. Similarly, predicted mean female seat position is given by Equation A1 when mean female population stature is entered.

The predicted standard deviations of the male and female seat position distributions can be estimated using Equation A2.

$$s_x = \sqrt{0.433^2 s_h^2 + 29.7^2} \qquad \text{(Eq. A2)}$$

where:

s_x = standard deviation of the male or female seat position distribution

s_h = standard deviation of the male or female stature distribution

Equation A2 represents the basic relationship between the standard deviation of a normally distributed variable and the standard deviation of a linear transformation of that variable. The variance, s_x^2, of the linear combination (seat position) is equal to the sum of two components of variance. The first is the “explained variance,” which is the slope of the relationship squared (0.433^2) multiplied by the variance of the original distribution (single-gender stature). The second component is the “unexplained variance,” which was obtained from the regression of seat position on stature. That value was estimated to be 29.7.

By substituting the standard deviation of male stature or female stature of the driver population for s_h, Equation A2 provides an estimate of standard deviation of male or female seat position. With mean and standard deviation of seat position, distributions of male and female seat position can be fully described for each vehicle. Figure A1 illustrates these distributions.

Figure A1 also illustrates the way in which driver seat position accommodations are determined from these distributions. The horizontal axis represents seat position aft of BOFRP. Although males have a more rearward average seat position, the two distributions overlap. As a result, both distributions must be considered when determining the location of fore and aft cutoff points. In Figure A1, the vertical line represents a candidate forward seat position cutoff. The area with vertical hatch marks represents the males who would be unable to sit in their preferred seat position if the front end of the seat track were located at the cutoff. The area with diagonal hatch marks represents the females who would sit forward of the cutoff. The sum of these areas as a proportion of the whole is the total percent of drivers who would be “disaccommodated” by a seat track with its front end located at the vertical cutoff.

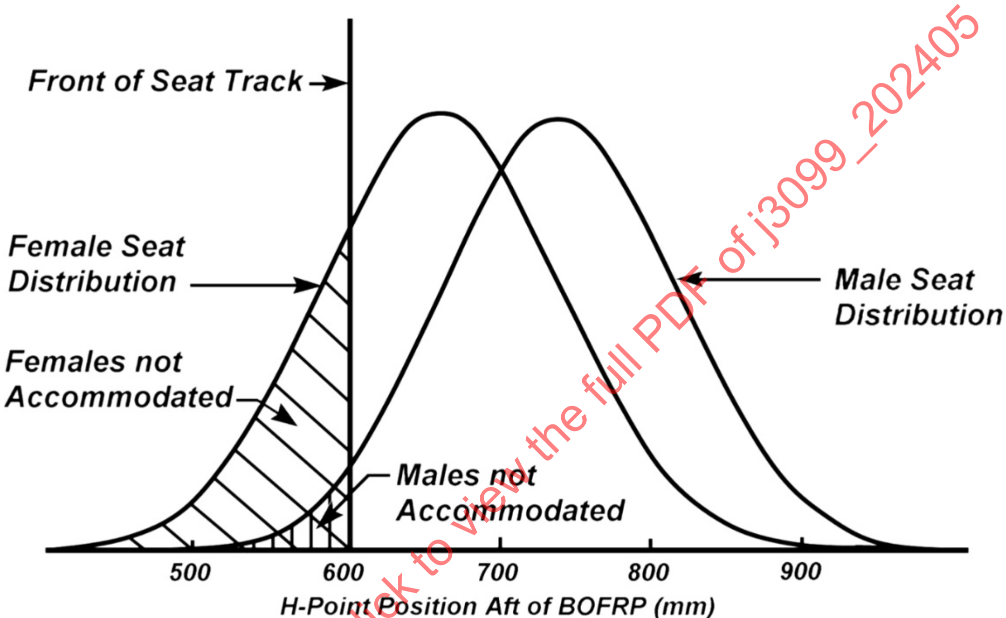

Figure A1 - Illustration of male and female seat position distributions relative to BOFRP X-coordinate

For this application, the desired result is not the percent accommodation for each cutoff, but the cutoff value that corresponds to a given percent accommodation. However, because the cumulative normal distribution is not represented by a closed-form equation, the percent accommodation must be calculated for each cutoff value, and then the results must be searched for the desired accommodation level.

A.3 TOLERANCE

The seat position prediction model described represents the best estimate of the location and spread of the seat position distribution for a given vehicle, on average. For a 50/50 male/female U.S. driver population, the seat track that accommodates 95% of drivers would be 203-mm long. However, the true distribution will differ from the predicted distribution by some amount in each vehicle. Because the key result of this model is to predict the tails of the distribution, deviations from predicted mean and standard deviation of seat position have asymmetrical impact on accommodation at each tail of the distribution. Figure A2 illustrates the case where the predicted mean seat position is shifted rearward of the true underlying distribution.

In Figure A2, the right distribution represents the predicted distribution, on which seat track placement is based. The left distribution represents the true underlying seat position distribution, which, in this case, is forward of predicted. The tall vertical bars show the front and rear seat track limits, selected on the basis of the predicted seat position distribution. The light gray shading indicates the portion of the population that would have been accommodated if the mean prediction had been perfectly accurate but that is disaccommodated by the seat track placement based on the model. The dark gray shading indicates the portion of the population that would have been disaccommodated by a model with perfectly accurate prediction of the mean but that is accommodated by the seat track placement based on the model. From this graph, it is clear that the unintentionally disaccommodated group (light shading) is larger than the unintentionally accommodated group (dark shading). A similar effect occurs with misprediction of standard deviation of seat position, but the effect shows up across vehicles, rather than within a single vehicle.

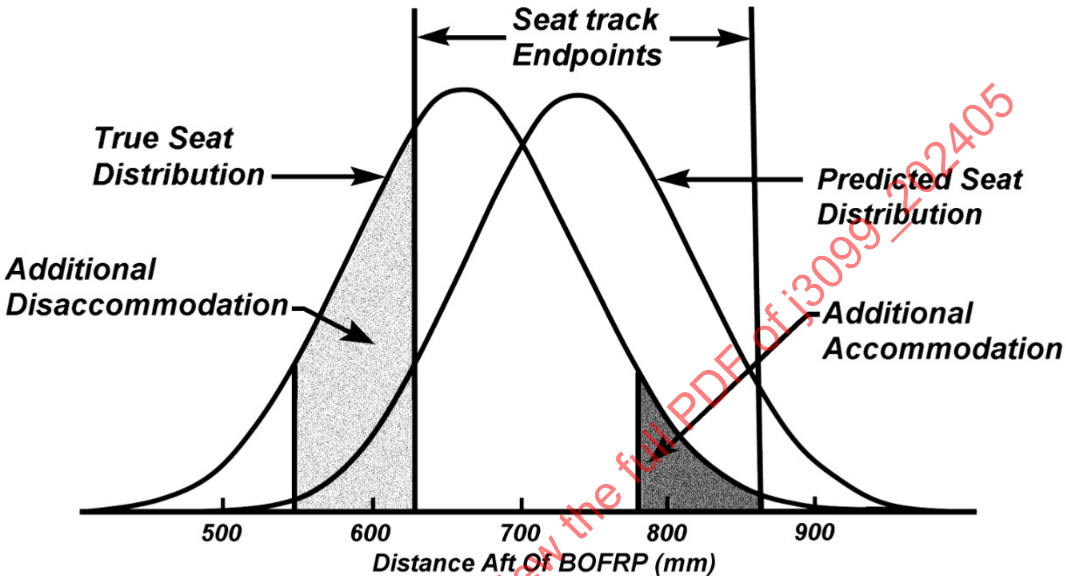

Figure A2 - Illustration of consequences of misprediction in mean seat position

"Tolerance" is a statistical concept in which limits are determined such that X percent of drivers are accommodated with Y percent certainty. Accommodation is represented by X and tolerance by Y. The model as stated above has less than 50% tolerance because of the asymmetrical disaccommodation effect. To reach higher levels of tolerance, the most straightforward approach is to increase the estimate of random error in the standard deviation. Details are given in the next section.

A.4 PROCEDURE

A.4.1 Define Distributions

The distributions in Figure A1 represent seat position distributions for males and females. Defining these distributions is the first step in determining the seat track length and position that will accommodate the desired percentage of the whole driver population.

The seat position distributions for males and females are normal distributions. Each distribution is defined by its parameters, the mean and standard deviation. Because the effect of stature on seat position is the same for males and females, Equation A1, repeated below, is sufficient to determine the mean of both male and female distributions for a given vehicle. The only difference is the value of mean stature used in solving the equation. Use mean female stature to determine mean female seat position, and use mean male stature to determine mean male seat position.

$$X = 16.8 + 0.433(\text{stature in mm}) - 0.24(H30) - 2.19(A27) + 0.41(L6) - 18.2t \quad \text{(Eq. A1)}$$

Similarly, Equation A2 can be used to predict the standard deviation of male and female seat position distributions. Again, the only difference is that the standard deviation of the female stature distribution is used to determine the standard deviation of the female seat position distribution, and the standard deviation of the male stature distribution is used to determine the standard deviation of the male seat position distribution.

$$s_x = \sqrt{0.433^2 s_h^2 + 29.7^2} \qquad \text{(Eq. A2)}$$

A.4.2 Compute Percent Accommodation

Once the two seat position distributions are defined according to A.4.1, the percent of the distribution that lies to the left of each possible cutoff value must be tabulated. The relative proportion of males and females becomes relevant in this step. Equation A3 gives the equation necessary for this step.

$$P(k) = p_m \Phi((k - X_m)/s_m) + (1 - p_f)\Phi((k - X_f)/s_f) \qquad \text{(Eq. A3)}$$

where:

P(k) = proportion of the combined male and female population that lies to the left of cutoff *k*

p_m = proportion of males in the driver population

p_f = proportion of females in the driver population

X and s = mean and standard deviation of seat position

Φ = cumulative normal distribution

Conceptually, Equation A3 translates seat position cutoff (*k*) into a z-score and determines the proportion of the normal distribution that lies to the left of that z-score for males and females separately. The male and female proportions are then weighted by their relative driving population proportions. The result *P(k)* is the proportion of drivers who sit forward of the cutoff location. When the cutoff represents the forward endpoint of the seat track, these drivers are not accommodated. In other words, their preferred seat position would lie forward of the available track travel. When the cutoff represents the rearward endpoint of the seat track, these drivers are accommodated (at least in rearward travel), because their preferred seat position lies forward of the rearmost point on the seat track.

A.4.3 Select Cutoff with Desired Accommodation Level

The procedure described in A.4.1 and A.4.2 is repeated for a wide range of possible cutoff values. To select the appropriate value, the desired percentiles must be defined for both forward and rearward travel. For typical applications, the user will have a target accommodation level such as 95%, and the drivers who are not accommodated will be evenly split between those who sit too far forward and those who sit too far rearward. Thus, the target percentile at the forward end would be 2.5 and the target percentile at the rearward end would be 97.5. However, target accommodation does not have to be symmetrical. A 95% accommodation level could also be achieved with a 1st percentile forward cutoff and a 96th percentile rearward cutoff.

To determine the cutoff for forward travel, the table of possible cutoff values must be searched for the percentile closest to the target for forward travel. The cutoff value that corresponds to the target percentile is the value for the driver population and gender mix for forward travel. The same search procedure is applied to the rear-travel target percentile. The difference between these values is the total seat track travel necessary for the chosen accommodation level.