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ABSTRACT

A new approach to driver seat-position modeling is presented. The equations of the Seating Accommodation Model (SAM) separately predict parameters of the distributions of male and female fore/aft seat position in a given vehicle. These distributions are used together to predict specific percentiles of the combined male-and-female seat-position distribution. The effects of vehicle parameters—seat height, steering-wheel-to-accelerator pedal distance, seat-cushion angle, and transmission type—are reflected in the prediction of mean seat position. The mean and standard deviation of driver population stature are included in the prediction for the mean and standard deviation of the seat-position distribution, respectively. SAM represents a new, more flexible approach to predicting fore/aft seat-position distributions for any driver population in passenger vehicles. Model performance is good, even at percentiles in the tails of the distribution.

INTRODUCTION

Prediction of drivers' seat-positions is important for many aspects of vehicle design, including comfort and safety. The current recommended practice for predicting population percentiles of driver-selected seat position is given in SAE J1517 (1).

Seat-position models have evolved over a period of more than ten years. Philippart et al. (2) used regression equations to predict each of seven percentiles of the seat-position distribution for a 1:1 male-female U.S. driver population. Each percentile was predicted using a second-order function of seat height (H30), obtained from empirical percentile values calculated for each of the vehicles in their database.

This approach directly fits the data at each percentile, thereby avoiding any assumptions about the form of the distribution. However, its use is restricted to the seven percentiles for which equations are available (though these are a good set), and a 50%-male, U.S.-driver population.

By adding the assumption that seat-position is normally distributed, a more flexible seat-position model was created by Flannagan et al. (3). Flannagan et al. also conducted studies to determine how certain vehicle factors influence seat position. They found that across many vehicles, the relationship between H30 and seat position is adequately represented by a linear, rather than a quadratic function. In addition, they found that horizontal steering-wheel-to-pedal distance (measured to the ball-of-foot reference point), seat-cushion angle, and transmission type all influence seat position independently.

Flannagan et al. (3) started with the assumption that the seat-position distribution for a typical driver population can be reasonably described as a normal distribution, and generated equations to predict the two parameters of the normal distribution, the mean and standard deviation. Means and standard deviations of seat position were calculated for each of a number of vehicles. The means were regressed on driver population stature, H30, wheel-to-BOF distance, seat-cushion angle, and transmission type. The standard deviations were regressed on the percentage of males in the driver population (fit with a quadratic function). To calculate predicted percentiles of the seat-position distribution, the user entered the vehicle factors and population factors, and generated predicted mean and standard deviation of the seat-position distribution. Either a normal distribution table or a computer could be used to predict any percentile of the seat-position distribution.

This approach represented an important advancement in modeling seat position because it included population mean stature and gender mix, so that seat position could be predicted for any target driver population.

Since the 1996 paper, an extensive modeling effort has shown that the assumption that the seat-position distribution can be described as a single normal distribution with two parameters leads to systematic errors in predicting tail percentiles. The effort to improve prediction accuracy in the tails of the distribution led to a new, fundamentally different approach to prediction of seat position. This new approach is the topic of the present paper.

MODEL DEVELOPMENT

GENERAL APPROACH – Modeling seat position presents interesting problems whose solutions could be applied in a wide variety of contexts. Two features of the modeling context are particularly challenging. First, because each within-gender stature distribution is approximately normal and because stature and seat position are strongly related, the seat-position distribution is best described as a mixture of two normal distributions. Second, the tail percentiles of the distribution are of greatest interest because these determine the level of accommodation provided by different seat track locations and lengths. However, the tails of any distribution are difficult to estimate because, by definition, there are fewer observations to be made there.

As described above, Flannagan et al. (3) proposed a model of seat position in which a single normal distribution was used to approximate the normal mixture. Although such an approach works well for estimating the mean of the distribution, the errors are larger and biased in the tails. Figureþ1 illustrates a single-normal approximation to a normal mixture typical of a seat-position or stature distribution. The approximating distribution is close to the normal mixture, but the greatest deviation is in the tails.

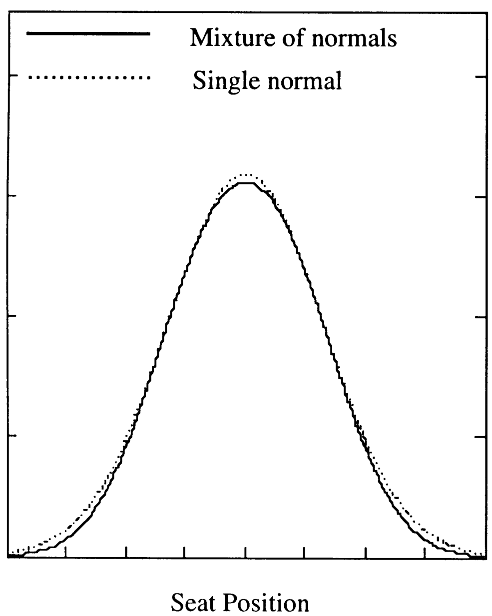

Figure 1. Hypothetical normal-mixture distribution (solid line) and single-normal approximation (dotted line).

Although it might be possible to choose a normal approximation that fits better at the tails at the expense of the center, a model that maintains separate predicted seat-position distributions for males and females was chosen instead. The two predicted distributions are then combined at the end of the prediction process. There are several advantages to this approach. First, the model form matches the form of the presumed true distribution, making artifactual errors of the sort shown in Figure 1 less likely. Second, population means and standard deviations of stature from anthropometric surveys are generally reported separately for males and females. Thus, the seat-position model can make use of these numbers directly. Third, asymmetrical seat-position distributions for populations with male-female ratios other than 1:1 can be better predicted than with a symmetrical single normal distribution. Finally, using separate normal distributions for males and females allows for a new approach to modeling the effect of population stature on seat position.

The new approach is based on certain basic properties of the normal distribution. First, the convolution of a normal distribution with any linear function results in another normal distribution with new parameters. In other words, a set of normally distributed inputs to a linear function will produce a normally distributed output. Second, the sum of two normal distributions is also normal, with mean and variance equal to the sums of the two original means and variances (4). These properties are described mathematically in Equations 1-6.

Suppose that X in Equation 1 represents the distribution of male stature in the driver population. Male stature is distributed normally with mean, μ_X, and variance, ^2_x. The variable, *y′*, in Equation 2, represents idealized seat position, perfectly linearly related to stature. Equation 3 gives the distribution of *y′*, which is the convolution of the normal distribution (stature) and the linear relationship between stature and seat position. Note that the mean of the new distribution is simply equal to the linear function of the input mean, while the variance has been multiplied by the square of the slope. If the relationship were perfect, this would be sufficient for modeling. However, there is variance in seat position that is not explained by stature, and that variance is represented by ε, or error. Under the standard regression model, error is assumed to be normally distributed with mean zero and some variance, ^{2} (Equation 4). Equation 5 shows the relationship between (non-idealized) seat position, *y*, and stature and error. Finally, Equation 6 gives the distribution of seat position as the sum of the two normal distributions from Equations 3 and 4, obtained by adding the error distribution to the idealized seat position distribution.

$$X \sim N(\mu_x, \sigma_x^2) \quad \text{(Eq. 1)}$$

$$y' = mx + b \quad \text{(Eq. 2)}$$

$$Y' \sim N(m\mu_x + b, m^2\sigma_x^2) \quad \text{(Eq. 3)}$$

$$\varepsilon \sim N(0, \sigma_\varepsilon^2) \quad \text{(Eq. 4)}$$

$$y = mx + b + \varepsilon \quad \text{(Eq. 5)}$$

$$Y \sim N(m\mu_x + b, m^2\sigma_x^2 + \sigma_\varepsilon^2) \quad \text{(Eq. 6)}$$

Figures 2 and 3 illustrate this transformation with hypothetical relationships between stature and seat-position. In both figures, the normal distribution shown along the horizontal axis represents the stature distribution for one gender, e.g., males. The normal distribution shown along the vertical axis represents the predicted seat-position distribution based on convolution of the stature distribution with the linear relationship. Note that in Figure 2, the slope is relatively shallow, and in Figure 3, it is relatively steep. Ignoring the unexplained error in either relationship, the steeper slope leads to a seat-position distribution with greater variance than does the shallow slope.

The two elements described above, 1) separating prediction for males and females, and 2) using the seat-position/stature relationship to incorporate the effect of population stature in the model, form the basic approach embodied in the new Seating Accommodation Model (SAM). This modeling approach was used with an expanded seat-position database.

SEAT-POSITION DATABASE – Flannagan et al. (3) described the original UMTRI database of seat positions in 11 vehicles, a laboratory buck study involving 18 conditions, and a study of four pairs of vehicles matched on key interior dimensions but differing in transmission type. Since then, subject-selected seat positions have been measured in seventeen additional vehicles using the same basic methodology described in Flannagan et al.(3).[1]

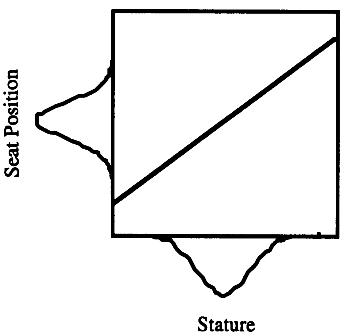

Figure 2. Hypothetical distributions of stature and seat position resulting from a linear relationship with shallow slope.

Each subject sample was stratified by stature as indicated in Table 1 which shows the composition of subject groups. In nine of the vehicles, groups 0 and 11 were not used. For each vehicle, the same number of subjects was selected from each stature group, though that number was different for different vehicles. For example, 60 subjects were tested in a Neon, 5 from each group, while 120 subjects were tested in an Acclaim, 10 from each group. Subjects at the tails of the stature distribution were oversampled in each vehicle to ensure that the extremes were represented by more than one or two subjects. Each subject's stature was measured before driving the vehicle. Subjects drove each vehicle over a specified route for at least 15 minutes and seat position was recorded upon the subject's return. A number of other measures of driver position and posture were taken, but they are not relevant to the modeling of seat position.

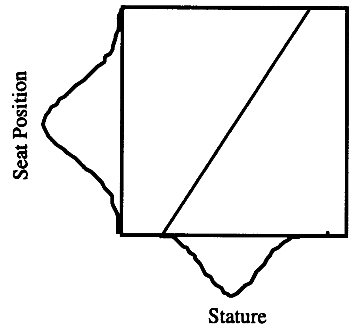

Figure 3. Hypothetical distributions of stature and seat position resulting from a linear relationship with a steep slope.

Table 1. Composition of Subject Groups

Subject Group	Gender	Stature Range	
		mm	Percentile*
Group 0	Female	< 1511	< 5
Group 1	Female	1511-1549	5-15
Group 2	Female	1549-1595	15-40
Group 3	Female	1595-1638	40-60
Group 4	Female	1638-1681	60-85
Group 5	Female	1681-1722	85-95
Group 6	Male	1636-1679	5-15
Group 7	Male	1679-1727	15-40
Group 8	Male	1727-1775	40-60
Group 9	Male	1775-1826	60-85
Group 10	Male	1826-1880	85-95
Group 11	Male	> 1880	> 95

*by gender from Abraham et al. (5)

The UMTRI database now contains seat positions for 36 to 120 subjects of varying statures in each of 36 vehicles and 18 buck conditions. The vehicles, along with key dimensions and number of subjects tested, are listed in Table 2.

CHECKING BASIC ASSUMPTIONS – The first step was to check the basic assumptions in Equations 1 through 6. Population stature is assumed to be normally distributed within gender, based on data from Abraham et al. (5). Stature and seat position are assumed to be linearly related as reported previously by Flannagan et al. (3) for a laboratory buck study, and there is no evidence of a nonlinear relationship between stature and seat position in any of the vehicles.

1. The rights, welfare, and informed consent of the volunteer subjects who participated in this study were observed under guidelines established by the U.S. Department of Health, Education, and Welfare (now Health and Human Services) on Protection of Human Subjects and accomplished under medical research design protocol standards approved by the Committee to Review Grants for Clinical Research and Investigation Involving Human Beings, Medical School, The University of Michigan.

Table 2. Vehicles, Dimensions, Seat Conditions and Sample Sizes in UMTRI Database

Vehicle	Number of Subjects	Seat Height (mm)	Wheel-BOF (mm)	Seat-Cushion Angle (degrees)	Transmission Type
Camaro	55	177	616	13	Automatic
Blazer	55	288	591	7.5	Automatic
Cadillac	55	240	590	8	Automatic
Oldsmobile	55	250	564	18	Automatic
Monte Carlo	55	231	597	11	Automatic
Pontiac 6000	55	266	583	16	Automatic
APV	55	381	518	12	Automatic
CK Truck	55	303	570	12.5	Automatic
Econoline	120	420	447	9.5	Manual
Firebird	120	154	650	15.5	Manual
Camry	50	240	567	13	Automatic
Civic	50	232	547	18	Automatic
Grand Am	50	230	588	15	Automatic
Grand Am	50	234	587	17	Manual
Celica auto	36	215	587	13	Automatic
Celica man	36	215	587	13	Manual
Taurus L	120	257	557	12	Automatic
Taurus SHO	120	257	557	12	Manual
C/K Pickup	50	327	551	10.5	Automatic
Yukon	50	327	551	10.5	Manual
Trans Am	100	165	623	14	Manual
Mazda 626	100	234	561	18	Manual
Grand Prix	100	250	623	12	Automatic
Transport	100	250	530	16	Manual
Tercel	100	324	478	13	Automatic
Previa	100	381	504	10	Automatic
Laser	100	188	555	19	Automatic
Voyager	120	326	504	14	Automatic
Acclaim	120	220	559	18	Automatic
LHS	120	250	597	18	Automatic
Avenger	120	189	577	17	Automatic
Cherokee	120	298	607	12	Automatic
Laser B	120	197	550	11	Automatic
Dakota	60	298	600	12	Manual
Ram Pickup	60	346	512	13	Manual
Neon	60	212	565	23	Manual
Lab. buck 1	100	180	650	11	Automatic
Lab. buck 2	100	180	600	11	Automatic
Lab. buck 3	100	180	550	11	Automatic
Lab. buck 4	100	180	650	18	Automatic
Lab. buck 5	100	180	600	18	Automatic
Lab. buck 6	100	180	550	18	Automatic
Lab. buck 7	100	270	600	11	Automatic
Lab. buck 8	100	270	550	11	Automatic

Table 2. Vehicles, Dimensions, Seat Conditions and Sample Sizes in UMTRI Database

Vehicle	Number of Subjects	Seat Height (mm)	Wheel-BOF (mm)	Seat-Cushion Angle (degrees)	Transmission Type
Lab. buck 9	100	270	500	11	Automatic
Lab. buck 10	100	270	600	18	Automatic
Lab. buck 11	100	270	550	18	Automatic
Lab. buck 12	100	270	500	18	Automatic
Lab. buck 13	100	360	550	11	Automatic
Lab. buck 14	100	360	500	11	Automatic
Lab. buck 15	100	360	450	11	Automatic
Lab. buck 16	100	360	550	18	Automatic
Lab. buck 17	100	360	500	18	Automatic
Lab. buck 18	100	360	450	18	Automatic

The third assumption is that the distribution of unexplained error is the same across all values of the independent variable, stature. This assumption was checked by regressing seat position on stature separately for each vehicle, and inspecting the residuals for signs of heteroscedasticity. In particular, it was hypothesized that people at the extremes of the stature distribution might be less variable in their selection of seat position than people in the middle of the distribution. However, only six vehicles showed any evidence of decreased variance at either tail. Furthermore, data from the laboratory buck study, in which subjects had ample seat track travel, showed no signs of heteroscedasticity. It was concluded that equal variance is a reasonable assumption to make for modeling purposes.

In addition to these basic assumptions, the data support additional simplifying assumptions that make both the modeling process and the end result more straightforward. First, stature does not interact with vehicle variables, such as seat height or steering-wheel position, in its effects on seat position. Second, vehicle variables do not affect the variability of seat position. Third, the effect of stature on seat position is the same for males and females.

These three important results make it possible to separate the modeling of the effects of vehicle variables from the effects of stature. Specifically, vehicle variables need only be considered in predicting mean seat position. In addition, the same pair of equations can be used to predict parameters of the seat position distribution for both males and females.

MODELING THE EFFECTS OF VEHICLE VARIABLES – Because the sample of drivers in each vehicle was stratified by stature, it is necessary to weight each observation according to its likelihood of occurrence in the population. Once weighted, median observed seat positions were calculated for each vehicle. In the normal distribution, the mean and median are the same. Although a weighted mean could have been used as the empirical measure of central tendency, the median was chosen, since it was felt that it would be less influenced by the effects of seat-track detents or other unusual characteristics of the distributions.

Using the expanded database, median seat position (for a 50%-male U.S. stature population) was regressed on H30, seat-cushion angle, wheel-to-BOF distance, and transmission type. Care was taken to identify any effects that differed between static and dynamic test conditions. In particular, seat-cushion angle had previously been found to have an accentuated effect on seat position in the laboratory buck as compared to dynamic test conditions. In addition, manual transmission testing was done only under dynamic conditions on the assumption that driving is necessary to adjust seat position in response to the clutch pedal. In such cases, only dynamically tested vehicles were used.

The resulting equation (R^2 = 0.90) is:

$$\hat{\mu} = 16.83 + 0.433\mu_s - 0.24h - 2.19p + 0.41w - 18.2t \quad \text{(Eq. 7)}$$

where,
ˆ = predicted mean seat position (mm aft of BOF)
h = H30 (mm)
p = seat-cushion angle (degrees)
w = wheel-to-BOF distance (mm), and
t = transmission type (0 if automatic; 1 if manual).

Figure 4 shows the observed versus predicted median seat positions for the vehicles tested dynamically. The regression equation predicts median seat position well, at least for a 1:1 male-female U.S. population distribution.

It is important to note that, although Equation 7 was generated from medians of the male-female combined distribution, it can be used to predict means for male-only and female-only seat-position distributions because the effects of vehicle variables and stature on seat-position are the same for males and females.

MODELING THE EFFECTS OF STATURE – The next step was to determine the relationship between seat position and stature, and to incorporate stature effects into the model. A subset of seat-position data from twenty one vehicles was chosen for this analysis. Fifteen vehicles were excluded because the sample size was too small after censored observations were excluded. Censored data result from too little rearward or forward seat-track travel to accommodate the tallest or shortest subjects, such that there is a "piling up" of subjects at the forward and rearward track positions. In such cases, all observations falling at the front (when forward censoring occurred) or rear (when rearward censoring occurred) of the track were eliminated from the analysis, even though some of those subjects may have been accommodated at the front or rear position.

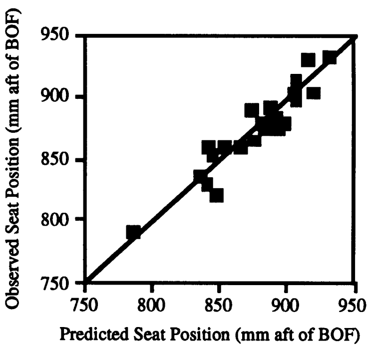

Figure 4. Observed versus SAM-predicted 50th-percentile seat position.

For each vehicle, seat position was regressed on stature, and the slope, intercept, R^2, and mean squared error of the linear fit were recorded. The mean squared error is the estimate of the unexplained variance in the data, corresponding to σ_ε^2 in Equation 4.

The mean of the stature coefficients of the 21 vehicles, weighted by the number of subjects in each vehicle after excluding censored observations, is 0.433. This becomes the model coefficient for mean stature. To incorporate the stature component into Equation 7, the intercept was recalculated so that predictions of mean seat position remain the same for 1:1 male-female U.S. stature distribution. The new prediction equation for mean seat position becomes:

$$\hat{\mu} = 16.83 + 0.433\mu_s - 0.24h - 2.19p + 0.41w - 18.2t \quad \text{(Eq. 8)}$$

where,

$_S$= mean stature of single-gender (male or female) driver population

ˆ = predicted mean seat position (mm aft of BOF)

h = H30 (mm)

p = seat-cushion angle (degrees)

w = wheel-to-BOF distance (mm), and

t = transmission type (0 if automatic; 1 if manual).

The weighted mean of the mean squared error is 29.75. Inserting values for the slope and mean squared error into Equation 6, the prediction equation for the standard deviation of the seat-position distribution becomes:

$$\hat{\sigma} = \sqrt{(.433)^2\sigma_s^2 + (29.75)^2} = \sqrt{.187\sigma_s^2 + 885} \quad \text{(Eq. 9)}$$

where,

σ_S= standard deviation of stature distribution of male or female driver population

ˆ = predicted standard deviation of single-gender seat-position distribution

COMBINING MALE AND FEMALE PREDICTED SEAT POSITION – Equations 8 and 9 define SAM. However, these equations are designed to be used on male and female driver population distributions separately. For most vehicles, the target population will be some mixture of males and females, so the two predicted seat-position distributions need to be combined to estimate population percentiles of seat position.

In most cases, using the two distributions to generate percentiles is simple. For the median seat position, the two predicted means can simply be averaged in proportion to the gender mix. That is:

$$\hat{\mu} = k\hat{\mu}_M + (1-k)\hat{\mu}_F \quad \text{(Eq. 10)}$$

where,

ˆ = predicted mean of mixed-gender seat-position distribution

k = proportion of males in the target population

ˆ $_M$= predicted mean of male seat-position distribution

ˆ $_F$= predicted mean of female seat-position distribution

For population seat-position percentiles at or below the 5th, or at or above the 95th, the overlap between the single-gender distributions is so small that the appropriate tail percentile of either the male or female distribution alone is sufficiently accurate. For example, Table 3 gives the percent of females and the corresponding percent of males under the left tail of a hypothetical (but typical) seat-position distribution. As indicated, less than one-half percent of males are seated forward of the 10th-percentile female seat position. Therefore, the 10th percentile of the female seat-position distribution is a reasonable approximation of the 5th percentile of a 1:1 mixture of males and females. The general formula is given in Equations 10 and 11.

Table 3. Proportion of Females and Males under the Left Tail for a Seat-Position Distribution in a Typical Vehicle

Percent females in left tail	Percent males in same tail	Ratio Male/ Female
2.5%	0.06%	0.024
5.0%	0.16%	0.032
10.0%	0.47%	0.047
25.0%	2.14%	0.086
40.0%	5.18%	0.130
50.0%	8.26%	0.165

To find the appropriate percentile at the lower tail, use:

$$p_f = \frac{p_t}{1-k} \qquad \text{(Eq. 11)}$$

where,
p_t= target population percentile,
k = proportion of males in the target population, and
p_f= percentile of the female-only distribution that corresponds to the target percentile of the combined distribution.

At the upper tail, use:

$$p_m = 1 - \frac{1-p_t}{k} \qquad \text{(Eq. 12)}$$

where,
p_t= target population percentile,
k = proportion of males in the target population, and
p_m= percentile of the male-only distribution that corresponds to the target percentile of the combined distribution.

For cases in which target seat-position percentiles are between 5% and 95% but not 50%, or the male-female ratio is very different from 1:1, the normal mixture function must be solved for the desired value. The function is given in Equation 13 and can be solved for *x* using various numerical methods.

$$p = k\Phi_M(x) + (1-k)\Phi_F(x) \qquad \text{(Eq. 13)}$$

where,
$\Phi(x)$is the cumulative normal distribution for random variable X with mean, μ, and variance, σ^2, and
p is the target percentile of the population seat-position distribution.

MODEL SUMMARY – To summarize the model from the user's point of view:

1. Determine the values for vehicle measures of H30, wheel-to-BOF distance, seat-cushion angle, and transmission type, and also the values for mean and standard deviation of male stature, mean and standard deviation of female stature, and the proportion of males in the driver target population.
2. Estimate the mean of the male seat-position distribution by using H30, wheel-to-BOF distance, seat-cushion angle, transmission type, the mean of the male stature distribution, and Equation 8:

$$\hat{\mu} = 16.83 + 0.433\mu_s - 0.24h - 2.19p + 0.41w - 18.2t \qquad (8)$$

3. Calculate the standard deviation of the male seat-position distribution using the standard deviation of the male stature distribution and Equation 9:

$$\hat{\sigma} = \sqrt{.187\sigma_s^2 + 885} \qquad (9)$$

4. Repeat steps 2 and 3 for females.
5. Generate population percentiles of seat position as follows:
   1) 50th percentile:

   $$\hat{\mu}_{.5} = k\hat{\mu}_M + (1-k)\hat{\mu}_F \qquad (10)$$

   2) 5th percentile or less:

   $$p_a = \frac{p_t}{1-k} \qquad (11)$$

   3) 95th percentile or greater:

   $$p_m = 1 - \frac{1-p_t}{k} \qquad (12)$$

   4) all other percentiles, solve for x in:

   $$p = k\Phi_M(x) + (1-k)\Phi_F(x) \qquad (13)$$

MODEL PERFORMANCE – To test the performance of the model, observed 2.5th, 50th, and 97.5th percentiles of the seat-position distribution were calculated for each of 26 vehicles. All of these vehicles were included in some part of the model development, but several had been excluded from the modeling of the effect of stature. In addition, the three seat-position percentiles were calculated for a 1:1 U.S. stature population, a 1:1 Japanese stature population, and a 1:1 Central European stature population (4,5).

The observed percentiles were calculated using the same approach embodied in SAM. For each vehicle, seat position was regressed on stature, and the slope, intercept, and mean squared error were recorded.

Three target distributions were defined for the purpose of testing the model. These were nominally Japanese stature distribution, U.S. stature distribution, and Central European stature distribution. The source for parameters of the U.S. stature distribution is Abraham et al. (4), and the source for Japanese and Central European stature distributions is Jurgens et al. (5). Table 4 gives the mean and standard deviation of male and female statures used.

The subjects in the samples were all U.S. drivers of different statures. To the extent that stature is the primary subject factor influencing seat position, non-U.S. seat-position distributions can be estimated from these data by using the appropriate parameters of the stature distributions as described below. It is possible that other factors common to drivers of a particular nationality could influence seat position. Such factors will not be reflected in these estimates, but they are unlikely to have a large effect on seat position when compared to the effect of population stature.

To calculate observed mean seat position for males, the mean male stature of the target stature distribution, and the slope and intercept of the seat-position/stature regression were entered into the formula for the seat-position-distribution mean in Equation 8. Similarly, male standard deviation of the target stature distribution, and the slope and mean squared error from the regression were entered into the formula for the seat-position-distribution variance in Equation 9. The process was repeated for the female mean and standard deviation of stature. Once the mean and standard deviation of the seat-position distributions were calculated for the target population, percentiles were calculated according to Equation 10, 11, 12, or 13, as appropriate.

Table 4. Means and Standard Deviations of Stature Distributions for Different Populations

	Male		Female	
	Mean (mm)	**Std Dev (mm)**	**Mean (mm)**	**Std Dev (mm)**
US	1753	71	1615	64
Japan	1720	58	1590	61
Central Europe	1770	58	1660	49

For each vehicle, SAM was used to predict percentiles of the seat-position distribution for each of the three target populations. Figure 5 shows the model performance at the 2.5th percentile across all target populations for all vehicles. On the whole, the model does very well at the 2.5th percentile, with an average residual of -2.4 mm. The largest residual was -34 mm, and 86% of residuals were less than 25 mm in absolute magnitude.

Figures 6 and 7 show model performance at the 50th and 97.5th percentile, respectively. At the 50th percentile, the average residual is -0.1 mm, and no prediction was in error by more than 25 mm. At the 97.5th percentile, the largest residual was 33 mm, and 78% of residuals were less than 25 mm in absolute magnitude.

Clearly, the model performance is quite good, particularly across vehicles. This is to be expected at the 50th percentile of the U.S. population, given that all of these vehicles were included in the modeling of the prediction of the mean seat position for U.S. population. However, not all of these vehicles contributed to the modeling of the effect of stature on mean or standard deviation of seat position, which influences both the estimates of outer percentiles and estimates of all percentiles of non-U.S. populations. At the 50th percentile, the average residual for the Japanese population is -0.92 mm, and -0.54 mm for the Central European population Even at the outer percentiles, which are more difficult to predict accurately, the average residual for any population is less than 3 mm.

SUMMARY AND CONCLUSIONS

Early efforts to model seat position used a regression approach to produce separate models of seat position at seven fixed percentiles for a U.S. stature distribution (1). Flannagan et al. (3) improved on the earlier approach by incorporating effects of other vehicle variables and proposing a more flexible modeling approach that can be used for different stature distributions and gender proportions.

In the present paper, an innovative approach to modeling seat position is presented. The new approach predicts seat-position distributions for males and females separately. In addition, it makes use of basic properties of the normal distribution to model the effect of stature on seat position.

The new Seating Accommodation Model or SAM allows the user to adjust the prediction for driver populations of any composition. As an added benefit, the prediction equation for mean seat position, can be used to predict the mean seat position of individuals with a specified stature. In previous models of seat position (including J1517 and earlier versions of SAM), the model produced only the *n*th percentile of the seat-position distribution, which is generally not the same as the seat position of the *n*th percentile person (in stature).

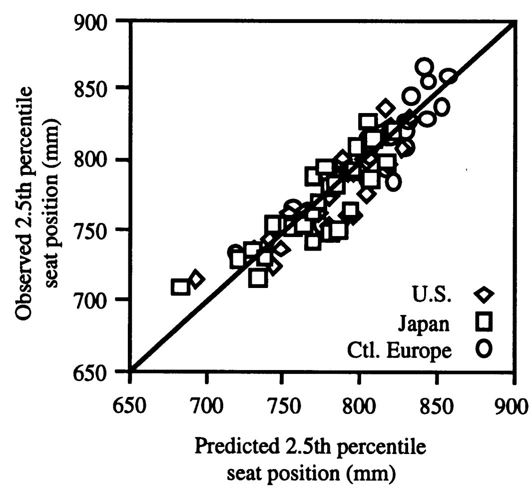

Figure 5. Observed versus SAM-predicted 2.5th percentile seat position.

The effect of vehicle factors on mean seat position has been demonstrated extensively under both laboratory and dynamic testing conditions. The addition of a model component reflecting population composition is an important advancement in seat-position modeling. At this time, the validity of the population stature component relies on the validity of the assumption that stature influences seat position in the same way, regardless of the nationality of the driver. It is likely that stature is far more influential than any other variable. However, testing with other populations is an important future step in validating SAM.

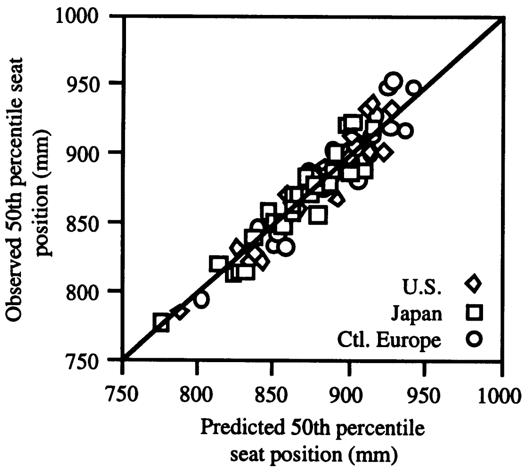

Figure 6. Observed versus SAM-predicted 50th percentile seat position.

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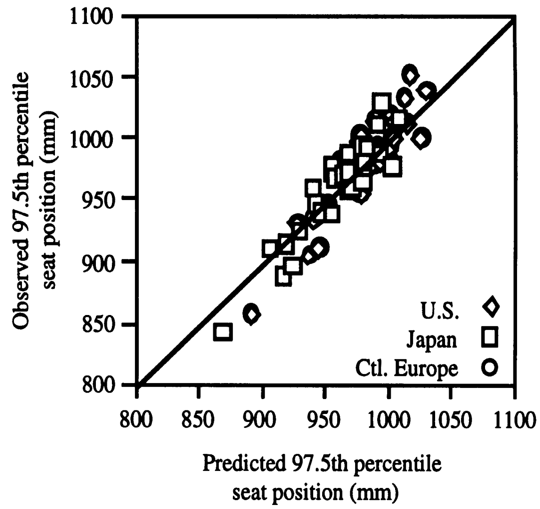

Figure 7. Observed versus SAM-predicted 97.5th percentile seat position.

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