

PREDICTING PROXIMITY OF DRIVER HEAD AND THORAX TO THE STEERING WHEEL

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ABSTRACT

The distance between the driver and the steering-wheel airbag module at the time of deployment has been identified as an important factor affecting the frequency and severity of airbag-induced injuries. Pre-crash positioning may influence the clearance at the time of deployment. Data from in-vehicle studies of driving posture were analyzed to determine the clearance between the steering wheel and the driver's head and chest in normal driving postures. Driving postures of over four-hundred men and women were recorded in twenty-two different vehicle conditions representing a wide range of seat heights, steering-wheel-to-pedal distances, and seat cushion angles. The data were used to generate predictive statistical models of the distribution of clearances between the driver's torso and the steering wheel. The findings have implications for vehicle design and airbag-injury countermeasures.

INTRODUCTION

Many airbag-related injuries, including abrasions, fractures, and atlanto-occipital separations occur when the driver interacts with the airbag before it is fully deployed. This occurs when the occupant is out of position, or too close to the airbag module as a result of being unbelted and/or sitting close to the steering wheel when driving. Several studies have indicated that smaller distances between the occupant and airbag at the time of deployment are associated with higher frequency and severity of airbag-induced injuries, and higher loading in human surrogates (1-7).*

Parkin et al. (8) investigated the distances between driver heads and the steering wheel by filming a thousand drivers as they passed a fixed camera. Among other conclusions, female drivers were found to sit closer to the steering wheel than male drivers, and elderly drivers were observed to sit further forward than their younger counterparts. It was also estimated that 25% of the observed population were positioned so that the nasion landmark was within 45.4 cm of the steering wheel center. The occupants' gender and age were deduced from the photos, but no actual anthropometric data were available to distinguish between the effects of stature, gender, and

age. Also, no vehicle package dimensions were included in the analysis.

De Leonardis et al. (9) measured driver position, defined by nasion and xiphoid landmarks, relative to the steering wheel for over 600 drivers and found that 5% of the female population sit closer than 254 mm (10 in) to the steering wheel. Most of the data were collected under static (non-driving) conditions in the subjects' vehicles, and no attempts were made to relate vehicle interior geometry to the response variables, although the paper did suggest a relationship between vehicle wheelbase and driver proximity to the steering wheel. The authors also concluded, through data collected on thirteen short-stature subjects, that many drivers sitting closer than 254 mm could adjust their seats to increase the distance to the steering wheel to over 254 mm of clearance in selected vehicles.

A series of studies at the University of Michigan Transportation Research Institute (UMTRI) have investigated driver posture and position in vehicles (10-12). Although the primary goal of these studies was to determine driver preferred seat position, seatback angle, and eye location, data on driver proximity to the steering wheel were also obtained. These data include the distance from the steering wheel center to the driver's chin and manubrium (top of sternum), and the minimum horizontal distance between the driver and the steering wheel center when seated in a normal driving posture. These data provide information about preferred position of drivers spanning a wide range of stature under normal driving conditions. These distances represent maximum clearances at the time of airbag deployment, since, in a frontal impact, the distance to the steering wheel will decrease during vehicle deceleration.

The driver-to-steering-wheel proximity data from these studies were used along with subject anthropometry and vehicle package measurements to develop predictive equations that describe the distribution of proximities to the steering wheel based on the male and female stature distributions of the driver population, steering-wheel-to-BOF (ball of foot) distance, and seat-cushion angle of the vehicle. This paper describes the analysis procedures and provides the preliminary prediction equations.

* Numbers in parentheses designate references provided at the end of this paper.

METHODS

Subjects*

Anthropometric measures that were considered possible predictors of driver proximity to the steering wheel include: stature, gender, age, weight, and body proportion (ratio of torso length to leg length). Test subjects were selected to span a range of these parameters in order to determine the effect of these factors on proximity to the steering wheel. A stratified sampling strategy was considered optimal where the short and tall drivers are oversampled to assure adequate data at the extremes of the population. The data are later weighted to represent a defined population stature distribution (e.g., U.S. or Japanese population) or to represent different gender mixes of a defined target population.

In each study, subjects were selected to fill twelve gender/stature groups, as described in Table 1. The groups include subjects who are shorter than the 5th-percentile female stature and those who are taller than the 95th-percentile male stature, based on the 1974 U.S. HANES survey (13). An effort was made to sample subjects over a wide range of weight, body proportion, and age, in order to span most of the anthropometric variance present in the population. The subjects were recruited from the southeast Michigan area through newspaper advertisements. All subjects were required to have at least four years of driving experience and a valid driver's license. Data were available for over four-hundred drivers, equally divided among the stature/gender classifications with 60-120 subjects in each study.

Table 1.
Summary of Subject Sampling Plan

Group	Gender	Percentile Stature Range	Stature Range (mm)
0	Female	< 5th	under 1511
1	Female	5-15	1511 - 1549
2	Female	15-40	1549 - 1595
3	Female	40-60	1595 - 1638
4	Female	60-85	1638 - 1681
5	Female	85-95	1681 - 1722
6	Male	5-15	1636 - 1679
7	Male	15-40	1679 - 1727
8	Male	40-60	1727 - 1775
9	Male	60-85	1775 - 1826
10	Male	85-95	1826 - 1869
11	Male	> 95th	over 1869

* 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 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 Begins, Medical School, The University of Michigan.

Test Conditions

Data were collected in twenty-two vehicles that were carefully chosen to span ranges for several variables that have been identified as the primary factors influencing driver selected seat position and driver eye position. These include seat height (H30), horizontal steering-wheel-to-BOF distance (the horizontal distance between the center of the steering-wheel-rim plane and the BOF landmark defined in SAE J1516), transmission type (manual or automatic), seat-track rise angle and seat-cushion angle (10-12). Figure 1 illustrates some of these package factors.

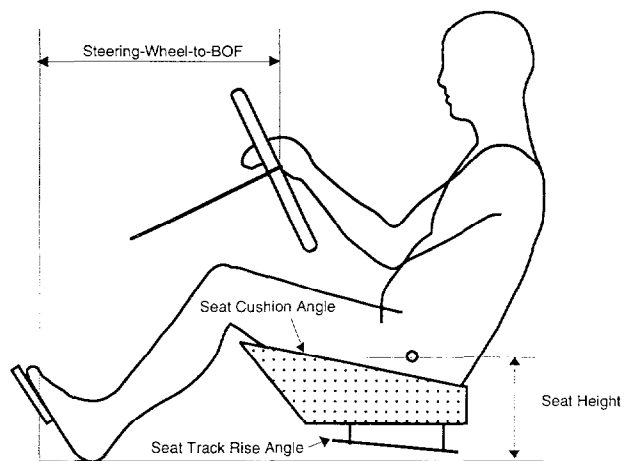


Figure 1. Illustration of relevant vehicle package factors.

Figure 2 shows a scatter plot of seat height versus steering-wheel-to-BOF distance for late-model vehicles. There is a clear trend for decreasing wheel-to-pedal distance with increasing seat height that is necessary for accommodating drivers of a range of body size at all seat heights. The solid circles show the vehicle conditions tested that were specifically chosen to span a wide range of the levels of these variables in the vehicle fleet. Seat-cushion angle is a relatively new measure added to SAE J826 in 1996 that quantifies the angle of the loaded seat cushion under the driver's buttock and thighs (14).

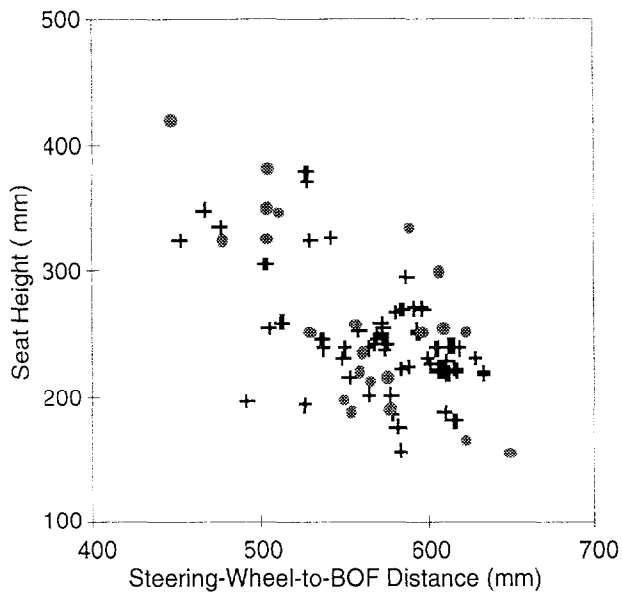


Figure 2. Seat height vs. steering-wheel-to-BOF distance for late-model vehicles. Circles indicate test conditions.

Table 2 summarizes the important package dimensions present in each test vehicle. All dimensions were measured directly from the test vehicles. Many vehicles were modified from the original design specifications for the purposes of the study and do not represent actual production vehicles.

**Table 2
Summary of Relevant Vehicle Characteristics***

Vehicle	Seat Height (mm)	Seat Cushion Angle (deg)	Wheel-to-BOF Distance(mm)
A	154	15.5	650
B	165	14.0	623
C	189	16.6	577
D	188	19.0	555
E	197	11.3	550
F	212	22.5	565
G	216	17.0	576
H	220	17.7	559
I	234	18.0	561
J	250	17.7	597
K	250	16.0	530
L	250	12.0	623
M	254	13.0	610
N	257	12.0	557
O	298	11.3	607
P	326	14.0	504
Q	333	12.5	589
R	346	13.0	512
S	349	13.0	504
T	381	10.0	504
U	324	13.0	478
V	420	9.5	447

Data Collection Procedure

Data collection procedures have previously been described (10-12). The same general procedures were used for all vehicle testing. The subject completed a consent form, health questionnaire, and a survey asking about their current vehicle and driving habits. A set of twenty standard anthropometric measures were taken, including stature, weight, and sitting height. The subject was tested in each of several vehicles in a predetermined random sequence. The initial position of the seat, seatback, and steering wheel in each trial were the same for every subject and were set to mid-range, rather than extreme positions, as the latter has been found to bias the results. The subjects were instructed on the operation of the seat and steering wheel adjustments and were asked to experiment extensively with the adjustments to find a comfortable driving posture and position.

The subject was encouraged to continue to adjust his or her posture while driving over a 15- to 20-minute road route. The subject was asked to find the most comfortable driving position and to notice the posture of their head in straightahead driving. Immediately after the drive, the subject's location and posture were measured while the subject maintained a relaxed, normal driving position. In addition to other posture and position data, three measures related to the steering wheel were collected: chin-to-steering-wheel-center distance, manubrium-to-steering-wheel-center distance, and the minimum horizontal distance between the driver and the steering wheel center, as illustrated in Figure 3. All measures were made to the centerline of the driver's body, compressing clothing when necessary, with the driver in a normal driving position.

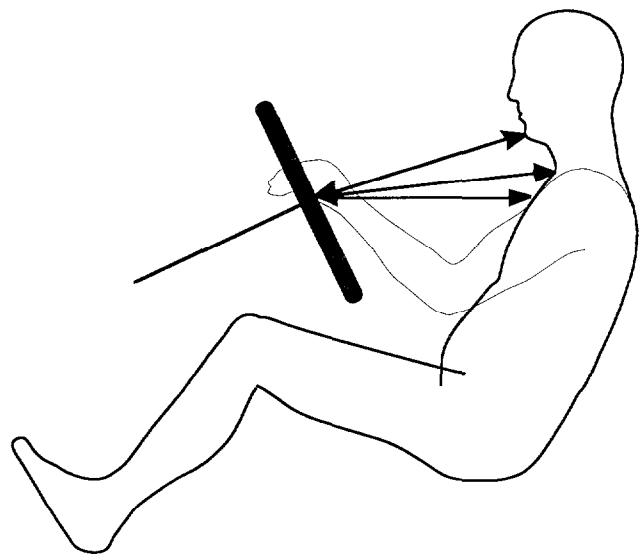


Figure 3. Measures of driver proximity to steering wheel.

The driver proximity measurements were compiled and weighted to represent the U.S. population with a 50:50 gender mix based on the stature distributions in HANES survey data (13). All distances measured were to the center of the plane of the steering wheel rim. Although many steering wheel centers are either dished into or protrude past this rim plane, previous UMTRI studies (10-12) suggest that the tasks of grasping and operating the steering wheel strongly influence driver posture and therefore the relationship between driver torsos and the center of the steering wheel rim will have a relationship that is most amenable to prediction. The distance between the actual center of the wheel hub and the center of the steering wheel rim face can be added or subtracted later to more accurately reflect clearance in a specific vehicle.

RESULTS

Figure 4 shows a histogram of the raw data for driver minimum clearance for one vehicle (N = 120). Table 3 reports the percentage of the U.S. population sitting less than the 200-mm, 250-mm and 300-mm clearance levels for the dynamically tested vehicles. These percentages were calculated by weighting the data according to the percentage of the population represented by each subject.

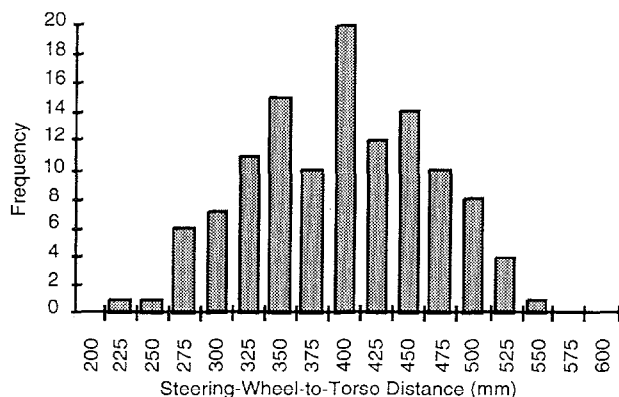


Figure 4. Histogram of minimum clearance to the center of the steering wheel for a typical vehicle.

Because of the variance in the data and past success modeling driving posture and position (10-12), the analysis effort focused on the development of a predictive model. Statistical modeling provides insight into the anthropometric factors that influence driver position and allows differentiation between the effect of stature, gender, and age. Although information on the distribution of proximities could be obtained through subject testing with each new vehicle design, a good predictive model provides this information with less time and cost. Most importantly, a model can provide insight into the vehicle factors and mechanisms that influence driver position, which can be used to design vehicles to better

accommodate the driving population, while potentially increasing the distance between short drivers and the steering wheel airbag module.

**Table 3
Data Summary**

Vehicle	Percent of Population Closer than		
	200 mm	250 mm	300 mm
A	0.00	3.25	25.75
B	3.83	7.12	22.08
C	0.00	0.50	6.50
D	1.39	3.89	10.03
E	0.00	0.00	0.00
F	0.00	0.00	10.00
G	0.50	7.00	18.50
H	0.25	2.50	13.75
I	2.14	4.39	14.41
J	0.25	1.00	9.75
K	3.28	4.79	5.62
L	4.39	7.03	23.22
M	5.50	16.00	34.50
N	0.00	7.25	25.50
O	0.00	0.25	8.67
P	0.00	0.28	3.86
Q	4.00	8.00	22.00
R	0.00	1.50	11.75
S	0.00	3.00	12.00
T	1.39	4.39	13.91
U	1.50	5.79	8.12
V	0.00	0.00	3.75

Model Development

Choice of Dependent Measure - As expected, correlations between the three steering-wheel clearance measures are very high. The correlation between steering-wheel-to-chin and steering-wheel-to-manubrium distances is the highest, at $r=0.96$. The correlations of the minimum horizontal distance between the driver and the steering wheel center with steering-wheel-to-chin and steering-wheel-to-manubrium distance are 0.80 and 0.87, respectively.

The high correlations indicate that predictive models of the three variables will be very similar and that any one measure would be sufficient to identify the effects of vehicle and subject variables on driver-to-steering-wheel proximity. The minimum horizontal distance between the driver and the steering wheel center was selected primarily because it represents a minimum distance, or worst-case measure.

Wheel-Proximity Database - There are 22 production vehicles in the UMTRI wheel-proximity database. Subjects were tested in each vehicle under dynamic conditions. The statistical approach taken is described in detail in Flanagan et al. (11). During the modeling process, inspection of the data indicated that data from

three of the vehicles were outliers, in that they produced steering-wheel-to-driver distances that are greater than expected based on the pattern of results from the other nineteen vehicles. Because these vehicles would cause the model to overestimate distance to the wheel for the majority of vehicles, they were deleted from the modeling process until further understanding of the source of the difference is obtained. Thus, across all vehicles, the model can be considered slightly conservative. On average, however, the model is expected to produce results appropriate to most production vehicles

Checking Basic Assumptions - The first step in developing the model was to check basic assumptions required for the modeling approach to be used. First, population stature is assumed to be normally distributed within gender, based on data from Abraham et al. (13). Second, stature and wheel proximity must be linearly related throughout the range of stature. Data from each vehicle were individually graphed and inspected, and in every case, the relationship was linear throughout the range. Interestingly, even in vehicles with censoring in seat position (i.e., the seat track did not have enough travel fore or aft for some subjects), there was no apparent censoring of minimum horizontal distance between the driver and the steering wheel center. Drivers apparently use seatback angle and other postural changes in the upper body to compensate for restrictions in seat positions (i.e., hip locations).

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 wheel proximity on stature separately for each vehicle, and inspecting the residuals for signs of heteroscedasticity (i.e., unequal variance across stature). In particular, it was hypothesized that people at the extremes of the stature distribution might show less variability in measures of proximity to the steering wheel than people in the middle of the distribution. However, no vehicles showed clear evidence of decreased variance at either tail. Data from the laboratory buck study, in which subjects had ample seat-track travel, showed minimal heteroscedasticity. These analyses demonstrate that the equal-variance assumption is reasonable.

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 wheel proximity. Second, vehicle variables do not affect the variability of wheel proximity. Third, the effect of stature on wheel proximity is the same for males and females. Although age was also shown to influence wheel proximity, the effect of age is so small relative to the effect of stature that the increased complexity of the model was not considered worth the small improvement in predictive power.

These three important results make it possible to separate modeling of the effects of vehicle variables from the effects of stature. Specifically, vehicle variables need only be considered in predicting mean wheel proximity. In addition, the same set of equations can be used to predict parameters of the wheel proximity 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 wheel proximities were calculated for each vehicle. In a 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 should be influenced less by unusual characteristics of the distributions.

Using nineteen vehicles from the database, median wheel proximity (for a 50%-male U.S. stature population) was regressed on seat height, seat-cushion angle, wheel-to-BOF distance, transmission type, and predicted seat position, using the Seating Accommodation Model (11). The resulting equation ($R^2 = 0.72$) is:

$$\hat{\mu} = 464.7 - 0.278w + 3.55p \quad (1.)$$

where,

- $\hat{\mu}$ = predicted mean of driver proximity to wheel distribution,
- w = wheel-to-BOF distance (mm), and
- p = seat-cushion angle (degrees).

Figure 5 shows the observed-versus-predicted median wheel proximities for the vehicles used in dynamic testing. The regression equation predicts median wheel proximity well, at least for a 1:1 male-female U.S. population distribution. It is important to note that, although Equation 1 was generated from medians of the male-female combined distribution, it can be used to predict means for male-only and female-only wheel-proximity distributions because the effects of vehicle variables and stature on wheel proximity are the same for males and females.

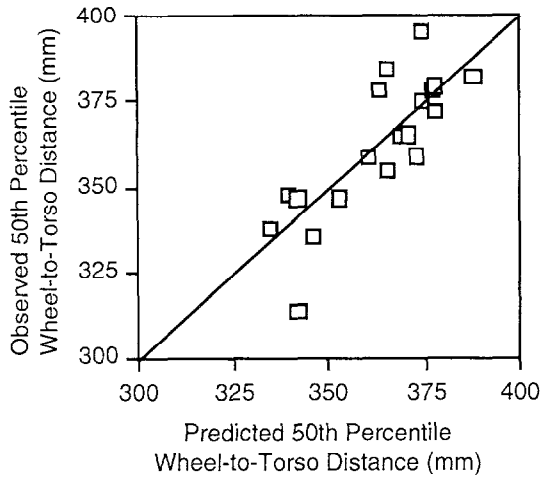


Figure 5. Observed versus predicted 50th-percentile wheel proximity for nineteen vehicles.

Modeling the Effects of Stature - The next step was to determine the relationship between wheel proximity and stature, and to incorporate stature effects into the model. For each vehicle, wheel proximity 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.

The mean of the stature coefficients of the twenty-one vehicles, weighted by the number of subjects in each vehicle after excluding censored observations, is 0.437. This becomes the model coefficient for mean stature. To incorporate the stature component into Equation 1, the intercept was recalculated so that predictions of mean wheel proximity remain the same for 1:1 male-female U.S. stature distribution. The new prediction equation for mean wheel proximity becomes:

$$\hat{\mu} = -271.2 + 0.437\mu_s - 0.278w + 3.55p \quad (2.)$$

where,

μ_s = mean stature of single-gender (male or female) driver population,

$\hat{\mu}$ = predicted mean wheel proximity (mm aft of steering wheel center),

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

p = seat-cushion angle (degrees).

The weighted mean of the mean squared error is 29.75. Using the values for the slope and mean squared error, the prediction equation for the standard deviation of the wheel-proximity distribution becomes:

$$\begin{aligned} \hat{\sigma} &= \sqrt{(.437)^2 \sigma_s^2 + (46.87)^2} \\ &= \sqrt{.191\sigma_s^2 + 2197} \end{aligned} \quad (3.)$$

where,

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

$\hat{\sigma}$ = predicted standard deviation of single-gender wheel-proximity distribution

Combining Male and Female Predicted Wheel Proximity

Equations 2 and 3 define the wheel-proximity model. 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 wheel-proximity distributions need to be combined to estimate population percentiles of wheel proximity.

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

$$\hat{\mu} = k\hat{\mu}_M + (1-k)\hat{\mu}_F \quad (4.)$$

where,

$\hat{\mu}$ = predicted mean of mixed-gender wheel-proximity distribution,

k = proportion of males in the target population,

$\hat{\mu}_M$ = predicted mean of male wheel-proximity distribution, and

$\hat{\mu}_F$ = predicted mean of female wheel-proximity distribution.

For population wheel-proximity 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, the 10th percentile of the female wheel-proximity 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 5 and 6.

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

$$p_f = \frac{p_t}{1-k} \quad (5.)$$

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:

$$p_m = 1 - \frac{1-p_t}{k} \quad (6.)$$

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 wheel-proximity 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 7 and can be solved for x using various numerical methods.

$$p = k\Phi_M(x) + (1-k)\Phi_F(x) \quad (7.)$$

where,

$\Phi(x)$ = the cumulative normal distribution for random variable X with mean, m , and variance, s^2 , and

p = target percentile of the population wheel-proximity distribution.

Model Summary - To use the model to determine driver proximities for a particular vehicle and driver population, follow the following steps:

1) Determine the values for vehicle measures of wheel-to-BOF distance and seat-cushion angle, 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 wheel-proximity distribution by using wheel-to-BOF distance, seat-cushion angle, and the mean of the male stature distribution, and Equation 2:

$$\hat{\mu} = -271.2 + 0.437\mu_s - 0.278w + 3.55p \quad (2.)$$

3) Calculate the standard deviation of the male wheel-proximity distribution using the standard deviation of the male stature distribution and Equation 3:

$$\hat{\sigma} = \sqrt{.191\sigma_s^2 + 2197} \quad (3.)$$

4) Repeat steps 2 and 3 for females.

5) Generate population percentiles of wheel proximity as follows:

1) 50th percentile:

$$\hat{\mu}_{.5} = k\hat{\mu}_M + (1-k)\hat{\mu}_F \quad (4.)$$

2) 5th percentile or less:

$$p_a = \frac{p_t}{1-k} \quad (5.)$$

3) 95th percentile or greater:

$$p_m = 1 - \frac{1-p_t}{k} \quad (6.)$$

4) all other percentiles, solve for x in:

$$p = k\Phi_M(x) + (1-k)\Phi_F(x) \quad (7.)$$

Model Performance - To test the performance of the model, observed 2.5th, 5th, and 50th percentiles of the wheel-proximity distribution were calculated for each of twenty-two vehicles. The observed percentiles were calculated using the same approach embodied in the wheel-proximity model. For each vehicle, wheel proximity was regressed on stature, and the slope, intercept, and mean squared error were recorded.

To calculate observed mean wheel proximity for males for a given vehicle, the slope, intercept, and standard error of the relationship between wheel proximity and stature was determined. Using the mean and standard deviation of U.S.-male stature, the mean and standard deviation of the observed wheel proximity distribution were calculated. The process was repeated for the female mean and standard deviation of stature. Once the mean and standard deviation of the wheel-proximity distributions were calculated, percentiles were determined according to Equation 4, 5, 6, or 7, as appropriate.

For each vehicle, the wheel-proximity model was used to predict percentiles of the wheel-proximity distribution. Figure 6 shows the model performance at the 2.5th percentile across all target populations for all vehicles. On the whole, the model is reasonably accurate at the 2.5th percentile. There are three residuals greater than 25 mm, but for most vehicles the prediction is good at this outer percentile.

Figures 7 and 5 show model performance at the 5th and 50th percentile, respectively. At the 5th percentile, the average residual is -1.8 mm and the largest residual is 39 mm. At the 50th percentile, the largest residual is 28 mm, and the average residual is -1.3 mm. Model performance is good, particularly in the middle of the distribution. Predictions of tail percentiles are off by

more than 25 mm for a few vehicles, but overall the model seems to accurately predict percentile proximities to the steering wheel.

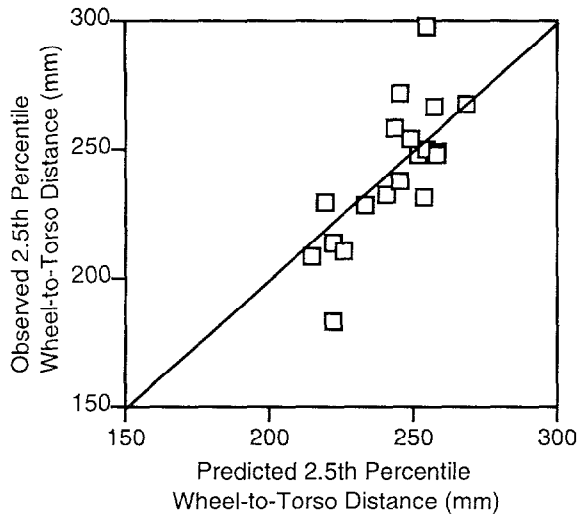


Figure 6. Observed versus predicted 2.5th-percentile wheel proximity.

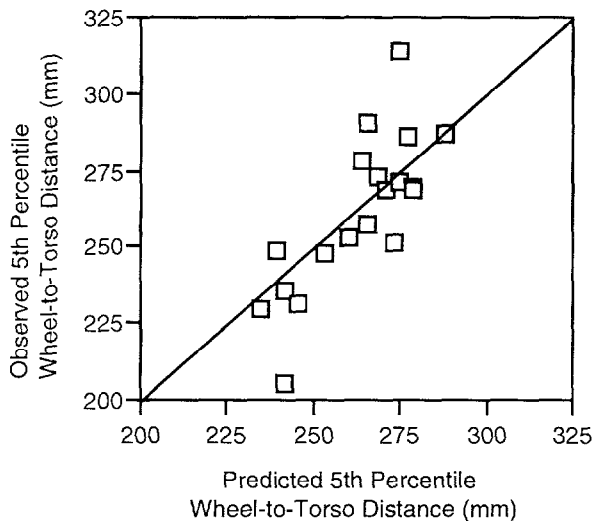


Figure 7. Observed versus predicted 5th-percentile wheel proximity.

DISCUSSION AND CONCLUSIONS

This investigation utilized data on driver proximity to the steering wheel for more than 400 drivers tested in nineteen vehicles to develop a predictive model for driver position relative to the steering wheel. The data show that driver position relative to the steering wheel can be predicted by anthropometric, vehicle, and seat factors. The three primary factors that affect the proximity of the driver to the center of the steering wheel are driver stature, steering-wheel-to-BOF distance, and seat cushion angle. The data suggest a model by which the distribution

of driver proximities to the steering wheel can be predicted for any vehicle if the characteristics of the male and female stature distributions in the target driver population are known.

Driver stature has the most dominate effect on driver proximity to the steering wheel with shorter drivers tending to sit closer to the wheel than taller drivers, as illustrated in Figure 8. The analysis suggests that this effect is independent of driver gender so that male and female drivers of identical height sit, on average, the same distance from the steering wheel. Gender mix of the target population is used in the model only because men and women have distinctly different stature distributions and not because the data support a true gender effect.

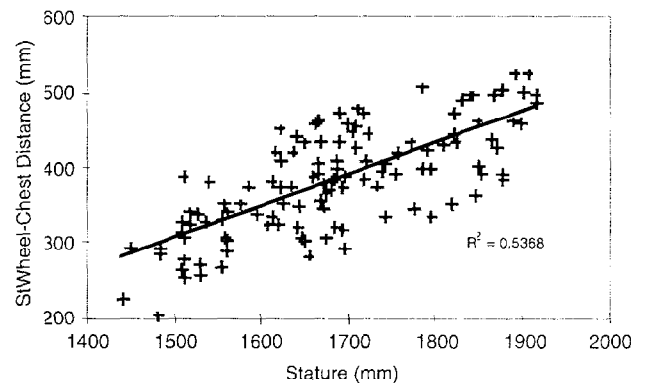


Figure 8. Illustration of the effect of driver stature on proximity to the steering wheel.

One package factor, the horizontal distance between the center of the steering wheel rim plane and the BOF landmark on the accelerator pedal, was found to have an effect on driver proximity to the steering wheel. As steering-wheel-to-BOF distance decreases, the distance between the driver and the wheel increases by 28% of the change in the wheel position. Other package factors that were found not to significantly affect proximity include seat height and transmission type. Although driver's selected seat positions are further forward (closer to the pedals) in vehicles equipped with manual transmissions, the effect of this on driver proximity to the steering wheel is canceled out by more reclined seatback angles (10).

One seat factor, seat-cushion angle, affects driver proximity to the steering wheel. As seat-cushion angle increases, driver-selected seatback angle increases, subsequently increasing the torso-wheel distance. A ten-degree increase in seat cushion angle increases the distance between the driver and the steering wheel by approximately 35 mm. Figure 9 shows the effect of steering-wheel-to-BOF distance and seat-cushion angle on driver proximity to the steering wheel.

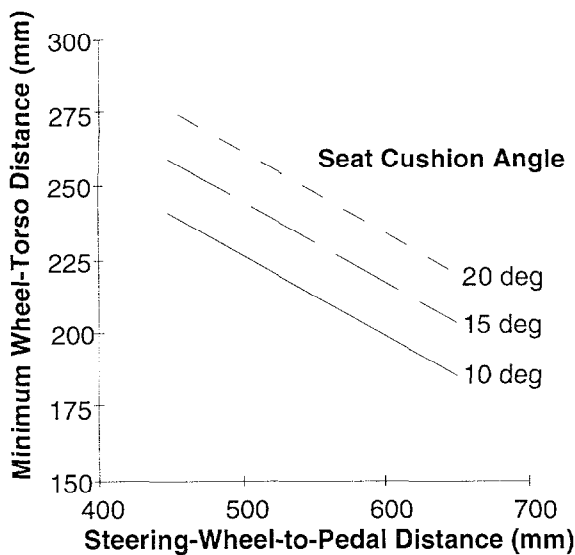


Figure 9. Illustration of the effect of wheel position and seat cushion angle on proximity of drivers' torsos to the steering wheel.

Of the factors found to affect the distance between the driver and the steering wheel, only steering wheel position and seat-cushion angle might be changed in a vehicle to increase the distance for shorter drivers. In the vehicles tested, only a small percentage of the subjects sat closer than 254 mm (10 inches) from the steering wheel. A relatively small increase of 30-40 millimeters in clearance to the wheel would bring most of those above the 254-mm distance suggested to be safe for airbag deployment. The model presented predicts driver position relative to the center of the plane of the steering wheel rim, thus calculations for dished or protruding airbag modules should be offset accordingly.

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