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# U.S. Truck Driver Anthropometric Study and Multivariate Anthropometric Models for Cab Designs

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**Objective:** This study presents data from a large-scale anthropometric study of U.S. truck drivers and the multivariate anthropometric models developed for the design of next-generation truck cabs.

**Background:** Up-to-date anthropometric information of the U.S. truck driver population is needed for the design of safe and ergonomically efficient truck cabs.

**Method:** We collected 35 anthropometric dimensions for 1,950 truck drivers (1,779 males and 171 females) across the continental United States using a sampling plan designed to capture the appropriate ethnic, gender, and age distributions of the truck driver population.

**Results:** Truck drivers are heavier than the U.S. general population, with a difference in mean body weight of 13.5 kg for males and 15.4 kg for females. They are also different in physique from the U.S. general population. In addition, the current truck drivers are heavier and different in physique compared to their counterparts of 25 to 30 years ago.

**Conclusion:** The data obtained in this study provide more accurate anthropometric information for cab designs than do the current U.S. general population data or truck driver data collected 25 to 30 years ago. Multivariate anthropometric models, spanning 95% of the current truck driver population on the basis of a set of 12 anthropometric measurements, have been developed to facilitate future cab designs.

**Application:** The up-to-date truck driver anthropometric data and multivariate anthropometric models will benefit the design of future truck cabs which, in turn, will help promote the safety and health of the U.S. truck drivers.

**Keywords:** truck driver, human body size, cab design models

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## INTRODUCTION

Trucking is one of the most hazardous occupations in the United States. An estimated 1.5 million workers are employed as drivers of heavy trucks and tractor-trailers in the United States (Bureau of Labor Statistics [BLS], 2010). In 2009, truck drivers experienced 16.8% (303 out of 1,795 cases) of all transportation-related fatalities (BLS, 2009b) and 2.0% of the nonfatal injuries requiring days away from work (BLS, 2009d), even though they only made up 1.0% of the U.S. workforce.

Truck drivers spend long hours behind the wheel, working an average of 41.5 hr per week (BLS, 2009a). A well-designed truck cab not only makes a significant difference in the working conditions for a truck driver but also affects the safety of truck drivers and other road users. If the design of the truck cab is poorly fitted to the size and dimensions of the driver, the road may be less visible, driving controls may be more difficult to reach, and seat belts may be less comfortable and less likely to be used—all of which increase the risk of injury to the driver and other road users.

There is a pressing need to enhance ergonomic cab designs for safe and efficient over-the-road operation. Up-to-date anthropometric data play a key role in the design. Unfortunately, anthropometric data on the U.S. truck driver population have not been collected for several decades. Truck drivers were last systematically measured in the United States in the late 1970s (Sanders, 1977) and early 1980s (Sanders, 1983; Shaw & Sanders, 1984). Demographic evidence suggests that the population is changing, with a greater representation of racial and ethnic minorities, especially the Hispanic ethnic group. In 1983, the combined category of truck drivers (heavy and light) and driver-sales

workers included 11.7% African Americans, 5.6% Hispanics, and 3.5% females (BLS, 1983). In 2009, the category of driver-sales workers and truck drivers included 13.4% African Americans, 18.7% Hispanics, and 5.2% females (BLS, 2009c). This new demographic reality necessitates an updating of the anthropometric data used for the design of truck cabs because anthropometric data are related to various demographic characteristics (Bradtmiller, Ratnaparkhi, & Tebbetts, 1985; Gordon, Bradtmiller, & Ratnaparkhi, 1986; International Organization for Standardization [ISO], 2006).

In recent years, major truck manufacturers in the United States and other countries have begun a transition from the traditional percentile approach toward the multivariate accommodation model (MAM) approach in cab design. The 5th-to-95th-percentile approach has been criticized for the decrease in accommodation when two or more dimensions are involved in a design (Zehner, Meindl, & Hudson, 1993) and for its inability to generate biofidelic models (Robinette & McConville, 1981). The MAM approach offers a superior solution to the workstation design because of its ability to circumvent both problems.

With the MAM, one uses a principal component analysis (PCA) to reduce a large number of body dimensions to a smaller number (e.g., two or three) of variables or principal components (PCs). These PCs approximate an ellipse or ellipsoid in distribution, which enables designers to select the desired level (e.g., 95%) of accommodation for the user population. Then, a small set of body models can be identified on the boundary of the ellipse or on the surface of the ellipsoid. This cadre of body models is composed of not only the overall large or small individuals but also individuals of different body configurations (Zehner et al., 1993). Designers may rely on these more realistic multivariate body models, instead of the traditional percentile values, in cab design.

In 2006, the National Institute for Occupational Safety and Health (NIOSH) initiated a 4-year nationwide anthropometric study of the U.S. truck driver population. In this report, we present the study results and examine the differences in key anthropometric dimensions between the

current U.S. truck driver population and the U.S. general population and between the current truck drivers and their counterparts of 25 to 30 years ago. In addition, MAMs capable of accommodating 95% of the truck driver population were developed to facilitate the next-generation truck cab design.

## METHOD

### Participants

This study sample consists of 1,779 male and 171 female truck drivers measured from January 2008 to March 2009. Data were collected in 15 states across the continental United States. A sampling strategy that took into account age, sex, and race categories was used. The original sampling plan and the final sample are presented in Table 1. Other relevant information (data collection sites and location types) is provided in Table 2. Only those with a valid Class A Commercial Vehicle Driver's License (CDL) were measured. The sample size of this study has exceeded the requirement of ISO 15535 standard on minimum sample size for 95% confidence and 1% relative accuracy (ISO, 2006).

### Apparatus

Standard anthropometric instruments, used in this study, were an anthropometer, beam caliper (rearranged pieces of the anthropometer), sliding calipers, and a Lufkin steel tape. Other instruments included a weight scale and a stool for seated measurement.

### Procedure

The measuring team traveled to each data collection site, where a measuring station was set up. When a participant arrived, an investigator checked his or her CDL to establish eligibility before giving him or her a consent form, on which the purpose of the study and the measurement procedures were explained. If he or she agreed to participate, the participant would sign the form. The participant remained in street clothes during the measurement and was measured on two postures: standing with heels together and sitting (Figure 1). Detailed specifications on the measurement postures can be found in Gordon and associates (1989). The

TABLE 1: Original Study Sampling Plan and Final Sample

Original Sampling Plan	Non-Hispanic White	Hispanic	Non-Hispanic Black and Others	Total
<b>Males</b>				
Ages 20–24	129	30	24	183
25–29	149	38	28	215
30–34	139	38	26	203
35–39	151	40	26	217
40–44	157	39	26	222
45–49	164	37	25	226
50–54	146	32	21	199
55+	241	47	27	315
Total	1,276	301	201	1,780
<b>Females</b>				
All ages, all races				100
Grand total				1,880
<b>Final Sample</b>				
<b>Males</b>				
Age <25 <sup>a</sup>	33	10	8	51
25–29	65	31	21	117
30–34	124	42	27	193
35–39	155	41	42	238
40–44	186	49	33	268
45–49	216	45	38	299
50–54	214	32	30	276
55+	290	25	22	337
Total	1,283	275	221	1,779
<b>Females</b>				
<25	2	2	0	4
25–29	3	2	0	5
30–34	9	2	0	11
35–39	18	2	2	22
40–44	20	5	2	27
45–49	32	2	3	37
50–54	26	3	1	30
55+	31	1	3	35
Total	141	19	11	171
Grand total				1,995

<sup>a</sup>Two drivers, ages 18 and 19, were added to the youngest age category, so it is not exactly equivalent to the youngest Bureau of Labor Studies category (which ranged from 21 to 25).

investigator located body landmarks by palpating the bones and placing small stickers on the clothes overlying those points or marking those points with an eyeliner pencil if they were on

the skin. After the marks were properly placed on the participant's body, 33 anthropometric measurements, plus shoe length and width, were taken with the anthropometric devices.

**TABLE 2:** Data Collection Sites and Location Type

Variable	n	Percentage
Region (states)		
South (Texas, Florida, Tennessee)	509	26
Midwest (Kentucky, Ohio, Missouri, Indiana)	541	28
Northeast (Pennsylvania, New York, New Jersey, West Virginia)	353	18
West (Nevada, California, Arizona, Oregon)	547	28
Total	1,950	100
Location type		
Fleet	795	41
Truck stop	566	29
Truck show	589	30
Total	1,950	100

*Figure 1.* Illustration of sitting height measurement.

After the measurement was completed, the participant was reimbursed and dismissed.

### **Anthropometric Measurements**

The 33 anthropometric dimensions, plus shoe length and shoe width, were chosen on the basis of their utility in facilitating truck cab

design (Appendix A). Five measurements (abdominal breadth, sitting; arm length; thumbtip reach; shoe length; and shoe width) were specifically defined for this study. Further information about the remaining variables can be found in Gordon and associates (1989) and Speyer (2007). Shoe length and width were measured only if the individual was wearing shoes that were typically worn while driving.

To ensure data quality, we trained five measurers prior to data collection; only four of them performed subsequent data collection. During the training session, 9 participants were measured. Since it was a training session, dimensions that are more difficult (e.g., chest width) were measured more often than dimensions that are less difficult (e.g., shoe length). The measuring team repeated the measurements on practice participants until the interobserver differences were at or below the levels specified in ISO 20685 (ISO, 2005). In addition, specifically designed software was employed in data entry. The software signals the operator when an unexpected value is entered. Any values flagged by the system were verified on-site by remeasuring the driver.

### **Data Analysis**

*Sample weighting.* Before data were analyzed, a weighting procedure was applied to the

male and female samples, respectively, to ensure that the current samples represent the current truck driver population in age, race, and ethnicity. The weights are calculated as the relative frequency of a given cell in the truck driver population, divided by the relative frequency of the same cell in the study sample. This approach is standard in anthropometric studies (Gordon, 2000; Harrison & Robinette, 2002; ISO, 2007, 2008).

Information on the racial ethnic distribution of truck drivers came from the BLS (2006). Age distribution was selected from an American Trucking Association–sponsored report (Global Insight, 2005) for lack of official government data. Samples were weighted across six age groups (<25, 25–29, 30–34, 35–44, 45–54, and 55+) and three racial ethnic groups (Non-Hispanic White, Hispanic, and Non-Hispanic Black and Others) for males and females, respectively. Note that this approach treats Hispanic as an ethnic, rather than a racial, group.

*Current truck drivers compared with the U. S. general population.* Measurements from the current study were compared with relevant measurements from the U.S. general population according to the National Health and Nutrition Examination Survey (NHANES). For this analysis, a male sample and a female sample between 20 and 65 years of age were taken from a combined 4-year (2003–2006) NHANES data set (McDowell, Fryar, Ogden, & Flegal, 2008). This age range consists of the majority of the U.S. working population. Before the two samples are compared, the same 20-to-65 age range criterion was applied to the NIOSH truck driver sample, resulting in a male sample of 1,749 participants and a female sample of 171 participants.

Bonferroni  $t$  was used to compare the relevant measurements from both studies. Most measurements in NHANES were not comparable to those taken in this study. As a result, only four comparable measurements (stature, weight, waist circumference, and thigh circumferences) were selected for comparison. With four comparisons, each  $t$  value was evaluated at  $\alpha = .05/4 = .0125$  level.

*Current truck drivers compared to those of 25 to 30 years ago.* The female samples were

not involved in this analysis because the number of female participants in the earlier two studies was very small (Sanders, 1977, 1983; Shaw & Sanders, 1984). As a result, this analysis compared only the male samples. There are 10 dimensions comparably measured between the current study and the two earlier studies, and these 10 dimensions were submitted to statistical analysis by Bonferroni  $t$ . With 10 comparisons, each  $t$  value was evaluated at  $\alpha = .05/10 = .005$  level.

*Multivariate anthropometric accommodation.* The MAM method started with a PCA procedure run by SAS (Version 9; SAS Institute, Cary, NC) on the male and female samples, respectively. This procedure reduced a set of 12 dimensions, chosen on the basis of their utility in cab design, to a smaller number of variables or PCs. In the present study, a decision was made to use the first three PCs (PC1, PC2, and PC3) to define body models on the basis of a scree plot. These three PCs were found to account for 87% to 88% of the total variance.

To ensure the accuracy of body model selection, the multivariate normality of the samples was checked by inspecting Q-Q plots along with a Kolmogorov-Smirnov test for males (large sample) and a Shapiro-Wilk test for females (small sample). The Kolmogorov-Smirnov test showed that PC2 and PC3 for the male sample did not meet the normality assumption ( $p < .01$ ). As a result, The 12 original variables were first transformed by natural log, and 1 participant (No. 488) was removed as an outlier before the PCA procedure was applied. On the other hand, the Shapiro-Wilk test showed that the female sample was able to meet the normality assumption without any transformation after just 4 participants (Nos. 408, 750, 1172, and 1529) were removed from the data set.

The PCs, which are orthogonal to one another, can be described as approximating an ellipsoid. Then, one can select the desired level of accommodation (e.g., 95%) by determining the appropriate confidence level in the ellipsoid (Zehner et al., 1993). In this study, we used the Bonferroni method to determine the 95% enclosure (Johnson & Wichern, 2007). Since the three PCs were standardized to  $z$  scores, we were able to use a single radius value ( $r = 2.40$

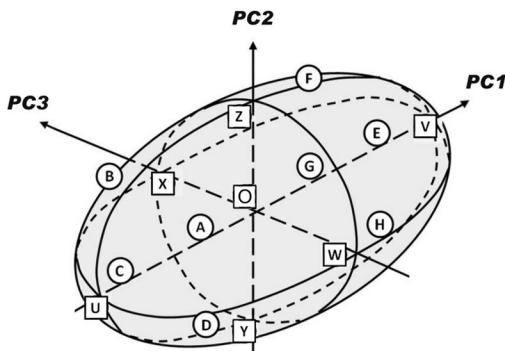


Figure 2. The centroid, intercept points (square) and octant midpoints (circle) of a 95% enclosure ellipsoid.

for males and  $r = 2.42$  for females) as the 95% enclosure criterion.

After the 95% enclosure criterion was determined, the next step was to identify the 14 models (six intercepts, eight octant midpoints) on the surface of the ellipsoid. The six intercept points were obtained on the ellipsoid surface where the three axes intercept. In addition, each of the eight octant midpoints was located at the surface center of each of eight sections (octants) divided by the three axes of this ellipsoid. These 14 points (8 octant points and 6 intercept points), along with the centroid of ellipsoid, were the basis for the selection of the anthropometric models (Figure 2).

We calculated the corresponding 12 anthropometric values of these 14 models first by linearly transforming the coordinates of the models scaled by the Bonferroni factor and making use of the reduced matrices of the eigenvalues and eigenvectors. Then, these calculated values were multiplied by the weighted standard deviations before being added to the weighted means to obtain the final values. These 14 participants, along with the average individual, represented 15 body models, each of which had a set of 12 derived anthropometric dimensions. To determine the closest-neighbor participants for these models, we computed the Euclidean distance from each participant to each model point. One closest-neighbor participant for each model was chosen.

Since truck cab workspace is designed for both male and female drivers, a recombined set of male and female models, after those have been derived separately, is useful for the design process (Hudson & Zehner, 2010). To obtain these recombined male and female models, the models of each gender were put into the other gender's 95% enclosure space, and those who are identified to be within the enclosure space of the opposite gender were considered redundant and discarded. For example, to identify a redundant female model, we first converted the 12 derived body dimensions of that female model into  $z$  scores using the means and standard deviations of the corresponding variables in the male sample. Then, we derived the three PCs by multiplying the set of  $z$  scores with the matrix of component score coefficients. Then, we determined the Euclidean distance of this female model to the centroid of the 95% male enclosure by using the three PCs. If the distance was smaller than the  $r = 2.40$  enclosure criterion, this female model was considered redundant and discarded. Otherwise, this model was retained for the joint male and female space. After all the female models have been evaluated in this way, the male models were placed into the female 95% enclosure ( $r = 2.42$ ) and evaluated for possible redundancy.

## RESULTS

### Measurement Error

Data on measurement errors (minimum and maximum absolute difference between any two measurers and the mean and standard deviation of absolute differences among all measurers) on each measurement are presented in Appendix B. The mean of the absolute differences ranged from 2 mm to 18 mm, except for weight.

### Summary Statistics

Summary statistics on all body measurements are presented in Appendix C. The weighted and unweighted means for each body dimension were very close to each other, as were the weighted and unweighted standard deviations for each body dimension. Since these values were very similar, subsequent analyses were based on the weighted samples

**TABLE 3:** Independent *t* Tests (Bonferroni) on Four Dimensions: Truck Drivers in NIOSH Study (i) versus U.S. General Population (j)

Dimension	NIOSH (i)		NHANES (j)		$M_i - M_j$	<i>t</i>
	<i>n</i>	<i>M</i> ( <i>SD</i> )	<i>n</i>	<i>M</i> ( <i>SD</i> )		
<b>Males</b>						
Stature	1,779	1757 (69.58)	3,335	1,769 (98.15)	-12	-6.53*
Waist circumference	1,779	1,089 (154.31)	3,333	1,002 (266.91)	87	18.55*
Thigh circumference	1,779	635 (69.91)	3,225	545 (90.41)	90	53.59*
Weight (kg)	1,779	102.6 (23.93)	3,193	89.1 (31.18)	13.5	23.61*
<b>Females</b>						
Stature	171	1,626 (69.19)	3,206	1,629 (96.26)	-3	-1.09
Waist circumference	171	1,020 (147.68)	3,121	936 (290.50)	84	11.93*
Thigh circumference	171	671 (78.66)	3,067	536 (138.45)	135	39.90*
Weight (kg)	171	91.0 (21.14)	3,207	75.6 (35.68)	15.4	18.03*

Note. All values are in millimeters except for weight. NIOSH = National Institute for Occupational Safety and Health; NHANES = National Health and Nutrition Examination Survey.

\* $p < .05/4 = .0125$ , two-tailed test; equivalently  $t_{0.05}(4, >120) = \pm 2.50$ .

alone. The similarity between the weighted and unweighted data suggests that this study sample was reasonably representative of the truck driver population in anthropometric dimensions.

### Current Truck Drivers Versus the U.S. General Population

Table 3 shows the results of Bonferroni *t* comparisons for the means of four body dimensions between the current data and the U.S. general population. For the males, differences in the means of all four dimensions were found to be statistically significant. Although the male truck drivers were on average shorter than males in the U.S. general population, they were nonetheless heavier. The truck drivers were, on average, 13.5 kg heavier than those in the U.S. general population, and their thigh and waist circumferences were larger than those of men in the U.S. general population. For the females, the mean stature was not statistically different. However, the female truck drivers were significantly heavier than those in the general population, by 15.4 kg on average. Besides, their thigh and waist circumferences were larger than those of women in the U.S. general population. These results showed that the size and physique

of the truck driving population are not well represented by the U.S. general population.

### Current Truck Drivers Versus Truck Drivers of 25 to 30 Years Ago

As Table 4 shows, the current male truck drivers were larger in abdominal depth, sitting; forearm-forearm breadth; hip breadth, sitting; waist circumference; and body weight as compared with the previously available male truck driver data (Sanders, 1977, 1983). The sitting height in the present study was shorter than that in earlier studies, although the stature was the same. This finding suggests that the current male drivers were different in physique from their counterparts of 25 to 30 years ago. They were heavier by 12.0 kg on average and larger in body width and girth, even though they were not taller.

### Multivariate Anthropometric Models

We used the MAM approach to identify representative truck driver body models for truck cab design. Table 5 presents the PC score coefficient matrix involving 12 anthropometric dimensions for the male and female truck drivers, respectively. The PCA output for the males

**TABLE 4:** Independent *t* Test (Bonferroni) on 10 Dimensions for Male Truck Drivers: NIOSH Study (i) Versus Sanders Studies (j)

Dimension	NIOSH (i)		Sanders (j)		$M_i - M_j$	<i>t</i>
	<i>n</i>	<i>M (SD)</i>	<i>n</i>	<i>M (SD)</i>		
Stature (no shoes)	1,779	1,757 (69.58)	183 <sup>b</sup>	1,756 (62)	1	0.48
Sitting height	1,779	919 (36.14)	267 <sup>a</sup>	927 (35)	-8	-7.51*
Buttock-knee length	1,779	632 (35.04)	183 <sup>b</sup>	636 (32)	-4	-3.98*
Hand breadth	1,779	90 (4.82)	183 <sup>b</sup>	89 (5)	1	6.08*
Hand length	1,779	196 (10.10)	183 <sup>b</sup>	189 (10)	7	22.84*
Abdominal depth, sitting	1,779	331 (66.03)	183 <sup>b</sup>	299 (45)	32	15.44*
Forearm-forearm breadth	1,779	617 (66.17)	183 <sup>b</sup>	502 (48)	115	55.85*
Hip breadth, sitting	1,779	428 (46.04)	267 <sup>a</sup>	353 (35)	75	53.39*
Waist circumference, natural indentation	1,779	1089 (154.31)	183 <sup>b</sup>	1,027 (124)	62	12.76*
Weight (kg)	1,779	102.6 (23.93)	183 <sup>b</sup>	90.6 (17.11)	12.0	16.07*

Note. All values are in millimeters except for weight. NIOSH = National Institute for Occupational Safety and Health.

<sup>a</sup>Sanders (1977).

<sup>b</sup>Sanders (1983).

\* $p < .05/10 = .005$ , two-tailed test; equivalently  $t_{0.05}(10, >120) = \pm 3.29$ .

consisted of three PCs, the combination of which accounted for 88% of the total variation. PC1, which accounted for 53% of the total variation, predicted the overall body size. PC2, accounting for 20% of the variation, showed a contrast between dimensions correlated with body heights and those correlated with body width and depth. PC3, accounting for 15% of the variation, contrasted the measurements of stature and torso height with the remaining 7 body dimensions. The PCA output for females also consisted of three PCs, the combination of which accounted for 87% of the total variation. The three PCs, which followed the same patterns as in the male sample in revealing the relationships among body dimensions, accounted for 53%, 21%, and 13% of the total variation, respectively.

Table 6 describes the 15 representative body models and their corresponding closest-neighbor human participants for the male truck drivers. A graphical representation of these 15 male body models in both standing and sitting

positions can be found in Figure 3. Model O, which was at the center of the ellipsoid, represented an average person in all body dimensions. Model U represented a small-size individual, whereas Model V represented a large-size individual. Model W had a relatively long stature but a short torso. In contrast, Model X was relatively short in stature and torso length but large in abdominal depth and hip breadth. Model C was characterized by a relatively short stature and short limbs but a long torso, whereas Model E was characterized by a relatively long stature and long limbs but a short torso (Figure 4). These 15 body models represented all body sizes and types for the male truck driver population. Table 7 describes the 15 female representative body models and their corresponding closest-neighbor human participants. Similar patterns in body dimensions found among the male representative models apply to the female representative models.

To recombine the male and female body models, we first projected the 14 female body

**TABLE 5:** Component Score Coefficient Matrix, Eigenvalues, and Total Variance Explained for Male and Female Truck Drivers

Variable	Principal Component (PC)		
	PC 1	PC 2	PC 3
<b>Males</b>			
Stature, no shoes	0.137	-0.180	-0.055
Shoulder-elbow length	0.103	-0.229	0.081
Elbow-fingertip length	0.112	-0.209	0.131
Bideltoid breadth	0.099	0.240	0.205
Abdominal depth, sitting	0.084	0.259	0.254
Hip breadth, sitting	0.106	0.222	0.211
Sitting height	0.129	-0.017	-0.287
Knee height, sitting	0.134	-0.137	0.127
Buttock-knee length	0.126	-0.078	0.229
Elbow rest height	0.077	0.272	-0.273
Eye height, sitting	0.123	-0.013	-0.305
Acromial height, sitting	0.128	0.106	-0.236
Eigenvalue	6.333	2.417	1.813
Percentage of variation	53	20	15
Total percentage of variation	88		
<b>Females</b>			
Stature, no shoes	0.134	-0.178	-0.041
Shoulder-elbow length	0.099	-0.215	0.229
Elbow-fingertip length	0.109	-0.174	0.228
Bideltoid breadth	0.094	0.269	0.153
Abdominal depth, sitting	0.066	0.301	0.214
Hip breadth, sitting	0.092	0.235	0.159
Sitting height	0.133	-0.065	-0.279
Knee height, sitting	0.134	-0.086	0.184
Buttock-knee length	0.128	0.028	0.240
Elbow rest height	0.082	0.227	-0.362
Eye height, sitting	0.130	-0.067	-0.292
Acromial height, sitting	0.136	0.029	-0.262
Eigenvalue	6.426	2.531	1.526
Percentage of variation	53	21	13
Total percentage of variation	87		

models (excluding the female Model O) into the 95% male enclosure space. Four female models (E, H, V, and W) were found to coincide with the male space because their respective Euclidian distance to the centroid of the 95% male enclosure was smaller than the  $r = 2.40$

criterion. These four female body models were considered redundant and were, therefore, excluded from the final set of recombined male and female body models. The remaining female models were retained. Then the 14 male body models (excluding the male Model O) were

**TABLE 6:** Multivariate Anthropometric Models and Closest-Neighbor Participants for Male Truck Drivers

Model	Abd Dp, Sit	Acro Ht, Sit	Bidelt Brth	Butt- Knee Lgth	Ebw- Fngrtip Lgth	Ebw Rest Ht	Eye Ht, Sit	Hip Brth, Sit	Shldr- Ebw Lgth	Stature No Shoes
Model O participant	324 323	614 606	535 534	631 633	486 473	252 253	798 797	425 435	568 562	918 923
Model A participant	288 289	552 533	497 500	630 628	490 498	189 176	737 743	392 391	562 553	855 352
Model B participant	387 371	570 588	563 542	614 627	462 477	232 228	734 740	447 461	540 545	851 355
Model C participant	285 277	616 621	503 498	568 581	445 460	289 279	797 783	391 373	519 528	913 331
Model D participant	212 215	596 594	445 466	582 599	471 472	235 260	800 794	342 354	540 531	916 340
Model E participant	370 412	612 618	569 573	700 693	532 529	220 234	800 799	463 449	622 617	923 386
Model F participant	497 486	632 630	644 647	683 692	502 518	270 248	797 797	528 538	598 601	919 405
Model G participant	365 375	682 666	576 562	631 637	482 472	337 304	865 869	462 462	575 580	986 356
Model H participant	272 282	661 641	508 492	647 649	511 511	274 264	868 858	404 417	598 603	989 385
Model U participant	252 261	554 567	468 458	567 560	448 460	216 236	736 751	360 360	513 518	850 333
Model V participant	417 442	680 663	612 597	701 717	528 522	294 277	866 861	502 500	629 625	991 385
Model W participant	241 257	594 622	473 488	646 645	515 518	205 232	801 799	372 373	592 594	921 386
Model X participant	436 419	634 631	606 569	615 620	459 457	310 313	796 778	486 498	546 542	914 345
Model Y participant	261 248	648 652	494 489	597 599	473 482	294 283	846 852	387 366	553 544	964 365
Model Z participant	403 409	581 585	579 565	666 665	500 500	216 215	753 728	468 463	584 578	874 373
										1,727

Note. All values are in millimeters. Abd = abdominal; Dp = depth; Acro = acromial; Ht = height; Bidelt = bideltoid; Brth = breadth; Butt = buttock; Lgth = length; Ebw = elbow; Fngrtip = fingertip; Sit = sitting; Shldr = shoulder.

projected into the 95% female enclosure space. The Euclidian distance of four male models (B, C, U, and X) to the centroid of the 95% female enclosure was smaller than the  $r = 2.42$  criterion. These four models were excluded from the final set of recombined male and female body

models, and the remaining male models were retained. Finally, the recombination procedure resulted in a joint male and female enclosure space that included Models A, D, E, F, G, H, V, W, Y, and Z for the males and Models A, B, C, D, F, G, U, X, Y, and Z for the females.

**TABLE 7:** Multivariate Anthropometric Models and Closest-Neighbor Participants for Female Truck Drivers

Model	Abd Dp, Sit	Acro Ht, Sit	Bidelt Brth	Butt- Knee Lgth	Ebw- Fngrtip Lgth	Ebw Rest Ht	Hip Eye Ht, Brth, Sit	Shldr- Ebw Lgth	Stature No Shoes
Model O participant	325 317	580 597	499 512	606 619	440 445	251 280	753 772	460 467	526 527
Model A participant	271 252	525 515	442 428	591 589	446 448	183 167	697 705	407 410	518 526
Model B participant	386 375	531 550	523 528	597 573	423 419	224 238	682 700	481 468	504 517
Model C participant	316 318	571 561	484 460	556 567	397 383	281 272	737 735	438 430	479 486
Model D participant	201 210	566 546	402 439	551 576	420 422	239 216	751 747	364 407	493 503
Model E participant	335 353	588 585	514 506	655 655	483 471	221 225	769 776	481 476	572 551
Model F participant	449 415	593 608	596 602	660 667	460 461	262 269	754 784	555 574	558 565
Model G participant	380 381	634 649	557 555	620 604	434 457	319 313	809 809	512 458	533 544
Model H participant	265 271	628 620	475 454	615 615	457 459	277 280	823 802	438 403	547 548
Model U participant	262 258	517 528	426 417	542 538	403 392	213 226	681 708	386 388	472 478
Model V participant	389 405	642 623	572 614	669 647	477 472	289 293	825 817	534 534	580 577
Model W participant	211 261	574 577	417 435	600 593	463 454	209 220	767 753	385 388	539 532
Model X participant	440 446	585 583	581 552	611 592	417 431	292 275	738 740	534 547	512 519
Model Y participant	276 269	608 594	471 456	577 572	421 432	291 282	791 762	429 402	508 510
Model Z participant	375 384	551 573	527 528	634 610	458 473	211 232	714 724	490 484	543 553
									349 347
									828 835
									1,621 1,621

Note. All values are in millimeters. Abd = abdominal; Dp = depth; Acro = acromial; Ht = height; Bidelt = bideltoid; Brth = breadth; Butt = buttock; Lgth = length; Ebw = elbow; Fngrtip = fingertip; Sit = sitting; Shldr = shoulder.

## DISCUSSION

### Anthropometric Characteristics of the Current U.S. Truck Driver Population

Table 3 shows that the current U.S. truck driver population is significantly heavier than the U.S. general population of working age. The body width and circumference measurements

are also larger among truck drivers than among those in the U.S. general population. The results are consistent with Hsiao, Long, and Snyder's (2002) findings that different occupational groups have distinctive anthropometric characteristics from the general population.

A comparison between this and earlier truck driver anthropometric studies (Sanders, 1977,

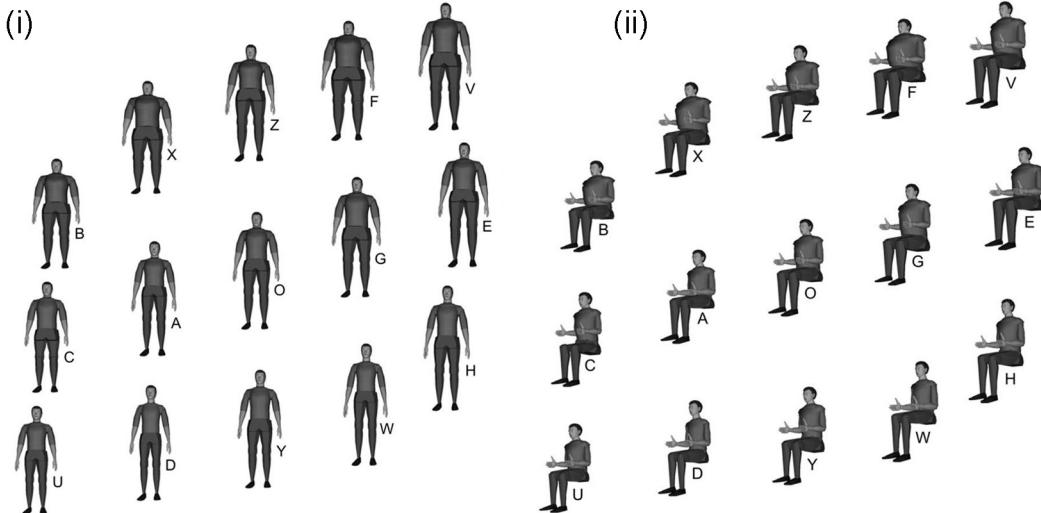


Figure 3. The 15 male representative body models in both standing (i) and sitting postures (ii).

1983) reveals a significant change in the anthropometric profile of truck drivers across a quarter century. The current male truck drivers are, on average, 12 kg heavier than their earlier counterparts, and they are also larger in abdominal depth, sitting; forearm-forearm breadth; hip breadth, sitting; and waist circumference. This change in body width and circumference may reflect the sedentary nature of the trucking occupation and the ongoing obesity epidemic in the United States.

There is also a discrepancy between what this study and the Sanders study found on truck drivers' stature. Sanders (1983) found that both male and female truck drivers are taller than the U.S. general population. On the contrary, this study reported that male truck drivers are shorter than the general population and that female truck drivers are not significantly different from the general population in stature. The difference can be explained by the fact that this study included a more representative Hispanic subsample (14% of the total sample) whereas the Sanders study did not include any Hispanic participants. As an ethnic group, Hispanics have a shorter stature than non-Hispanic Whites. For example, for those 20 years and older, Hispanic males and females were reported to be, on average, 72 mm and 53 mm shorter than their non-Hispanic White counterparts (McDowell et al., 2008). In this study,

we found that the male Hispanic truck drivers are, on average, 56 mm shorter than the male non-Hispanic White drivers ( $t = 12.93, p < .01$ , two-tailed test). The female Hispanic drivers are, on average, 44 mm shorter than the female non-Hispanic White drivers ( $t = 7.0, p < .01$ , two-tailed test). The inclusion of a representative Hispanic sample has enabled this study to yield a more accurate estimate of the true stature in the truck driver population.

The issue of female truck driver sample deserves special attention. Despite various anecdotes that more and more females are entering the trucking occupation, the BLS data consistently show that the percentage (i.e., about 4% to 5%) of female drivers has remained stable for decades in the driver-and-sales worker category. This study includes 171 female truck drivers, or about 8.8% of the total study sample. This percentage is higher than that of the actual female truck driver population. This oversampling is needed for meaningful statistical analysis and desirable for design purposes.

### Percentile Models Versus MAM Approach

Zehner and associates (1993) argued that the use of percentile models leads to a decrease in the accommodation level when two or more

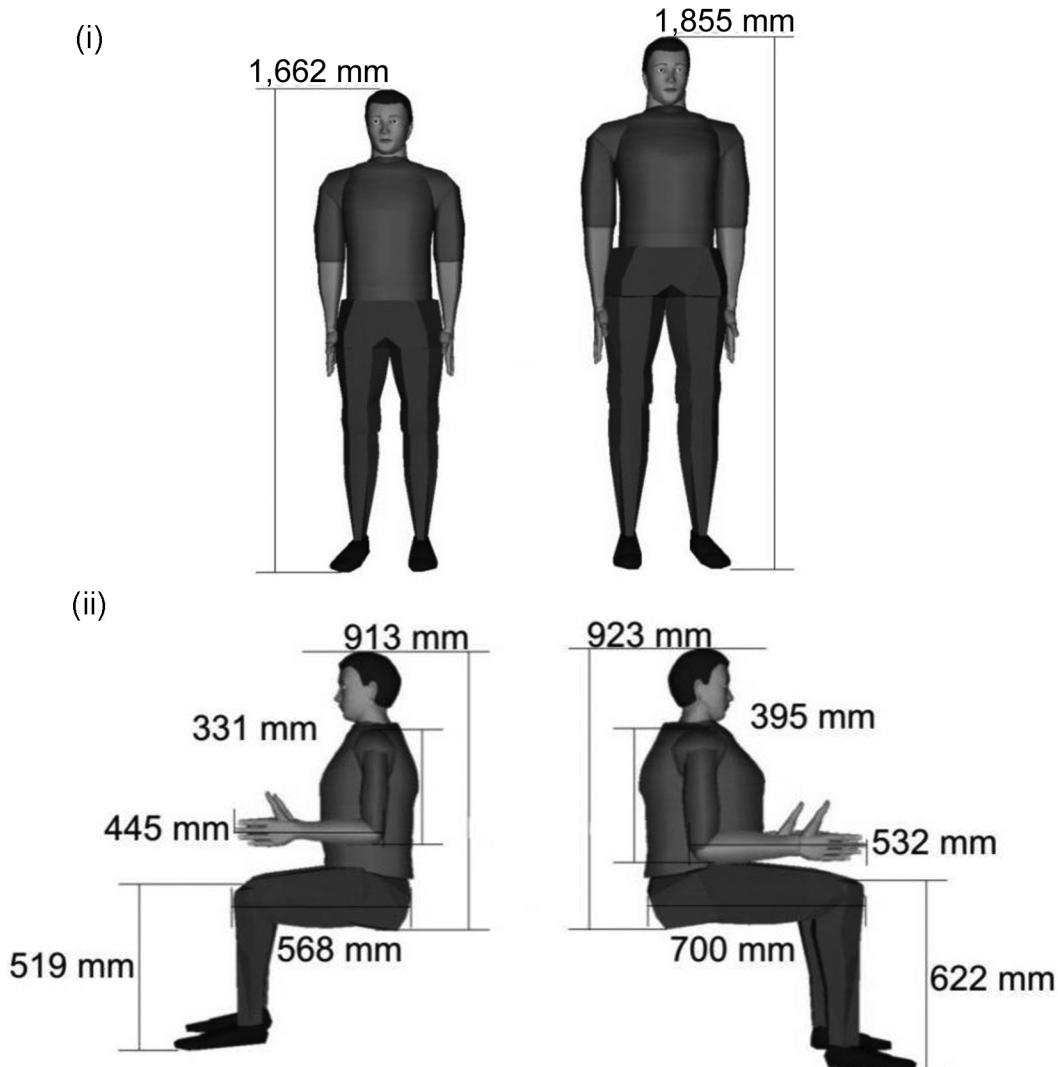


Figure 4. Contrasting Models C, left in (i) and (ii), and E, right in (i) and (ii). Model C has a relatively short stature (1,662 mm [9th percentile]), short arm length (shoulder-elbow length = 331 mm [5th percentile]; elbow-fingertip length = 445 mm [3rd percentile]), and short leg length (buttock-knee length = 568 mm [3rd percentile]; knee height = 519 mm [3rd percentile]) but a large sitting height (913 mm [44th percentile]). In contrast, Model E has a relatively tall stature (1,885 mm [92nd percentile]), long arm length (shoulder-elbow length = 395 mm [97th percentile]; elbow-fingertip length = 532 mm [97th percentile]), and long leg length (buttock-knee length = 700 mm [97th percentile]; knee height = 622 mm [97th percentile]) but a short sitting height (923 mm [55th percentile]).

dimensions are involved in a design. The percentile values are univariate variables. The 5th to 95th percentiles would exclude 10% of the user population on the first dimension. With each additional dimension added, the exclusion

rate would increase and the level of accommodation would decrease. The MAM approach circumvents this problem by taking a multivariate approach. In our example, instead of focusing on each of 12 individual dimensions, the

MAM relies on three PCs, generated by the PCA, that are linear combinations of the 12 original variables. These PCs, which are orthogonal to each other, can approximate an ellipsoid in distribution. Then, a 95% accommodation level was chosen to exclude only 5% of the user population.

Another problem facing the percentile approach is that the percentile values are not additive (Robinette & McConvile, 1981). For example, a 95th-percentile stature cannot be reassembled by adding up all the 95th-percentile body segments that make up the stature. Any attempt to reassemble a whole body based on the 95th-percentile segments would result in mathematically and anatomically incorrect models. In contrast, the MAM approach enables the generation of body models that are representative not only of the size variance but also of proportional body variance in a user population (Zehner et al., 1993). The cadre of MAM models generated in this study includes not only overall large and small persons but also individuals of different body configurations. For example, as shown in Figure 4, male Model C has a short stature (9th percentile) but a relatively tall sitting height (44th percentile). In contrast, male Model E has a tall stature (92th percentile) but relatively short sitting height (55th percentile). This variability in body sizes and configurations will help improve the biofidelity of manikins in cab workspace design.

### Application to Cab Design

In this study, we used the MAM approach to select 15 body models for male and female truck drivers, respectively. Each of the 15 body models represents a unique combination of body size and physique. These models, together with the anthropometric values of their closest-neighbor participants, should benefit the design of the next-generation truck cabs. If a combined set of the male and female models are more desirable, the 20 male and female models

selected in this study may be used for the same purposes. These models can be applied to truck cab design in a number of ways. Developers of ergonomic software may apply these models toward generating biofidelic digital manikins to improve the cab simulation environment. Likewise, cab designers may use these models to create cadres of manikins to evaluate or visualize different "fit" issues in truck designs. For example, a short manikin with short legs but a relatively long sitting and eye height (Model C) and a tall manikin with long legs but a relatively short sitting and eye height (Model E) may be selected to evaluate the cab and mirror design. With the manikins properly seated and their right heels placed on the accelerator heel point, the effects of cab and mirror design on drivers' direct and indirect visibility can be assessed. These manikins provide the level of anthropometric variability that cannot be provided by the percentile models.

### CONCLUSION

An anthropometric study of 1,950 male and female U.S. truck drivers was conducted to provide key human body dimension data for the design of truck cabs. In this study, we found that truck drivers are, on average, heavier in body weight and larger in body width and girth than the U.S. general population. However, the male truck drivers are shorter in stature and the female truck drivers are not different from the U.S. general population. A comparison of the male truck drivers in this and earlier studies showed important anthropometric changes, primarily related to increased width and girth, across a quarter century. Given the substantial differences in key dimensions between the truck drivers and the U.S. general population, and between the current truck drivers and those of 25 to 30 years ago, the current data will be an important resource for future truck cab designs. The PCA-based representative body models were developed to facilitate truck cab designs.

## APPENDIX A

### Definition of Anthropometric Measurements and Shoe Measurements

Dimension	Posture	Definition	Compatible Sources
Abdominal breadth	Sitting	Maximum distance between the lateral points of the abdomen (abdominal point, lateral, left, right) measured in a seated posture	Defined for this study
Abdominal depth	Sitting	Horizontal distance between the most anterior point of the abdomen (abdominal point, anterior, sitting) and the back at the same level measured in a seated posture	ANSUR
Acromial height	Standing	Vertical distance between the standing surface and the acromion landmark on the tip of the right shoulder measured in a standing posture	ANSUR
Acromial height	Sitting	Vertical distance between the sitting surface and the acromion landmark on the tip of the right shoulder measured in a seated posture	ANSUR
Ankle height	Standing	Vertical distance between the standing surface and the lateral malleolus landmark on the outside of the ankle	ANSUR (lateral malleolus height)/RAMSIS (foot height: lateral ankle)
Arm length	Standing	Distance between the acromion landmark on the tip of the right shoulder and the dactylion III landmark at the tip of the middle finger measured in a standing posture	Defined in this study
Biacromial breadth	Sitting	Distance between the right and left acromion landmarks at the tips of the shoulders measured in seated posture	ANSUR
Bideltoid breadth	Sitting	Maximum horizontal distance between the lateral margins of the upper arms on the deltoid muscles measured in a seated posture	ANSUR
Buttock-knee length	Sitting	Horizontal distance between the buttock plate and the anterior point of the right knee (knee point, anterior)	ANSUR/RAMSIS
Buttock-popliteal length	Sitting	Horizontal distance from the buttock plate to the back of the knee	ANSUR
Calf circumference	Standing	Maximum horizontal circumference of the lower leg	ANSUR/RAMSIS

(continued)

**APPENDIX A. (continued)**

Dimension	Posture	Definition	Compatible Sources
Chest depth	Standing	Horizontal distance between the xiphoidale landmark on the lower edge of the body of the sternum and the dorsally most prominent point in the midline of the back at the same level	RAMSIS
Chest width	Standing	Maximum horizontal distance between the two laterally most prominent points of the rib cage at the level of the xiphoidale landmark on the lower edge of the bony part of the sternum	RAMSIS
Elbow-fingertip length	Standing	Horizontal distance between the back of the tip of the right elbow (olecranon, rear) and the tip of the right middle finger (dactylion III) when the right elbow is flexed 90°	ANSUR
Elbow rest height	Sitting	Vertical distance between the sitting surface and the bottom of the right elbow (olecranon, bottom)	ANSUR
Eye height	Sitting	Vertical distance between the sitting surface and the outer corner of the right eye (ectocanthus)	ANSUR
Forearm circumference	Standing	Horizontal circumference of the right forearm at the point of maximum prominence slightly distal to the elbow joint	RAMSIS
Forearm-forearm breadth	Sitting	Maximum horizontal distance across the upper body between the lateral margins of the forearms	ANSUR
Hand breadth	Palm on table	Breadth of the hand between the landmarks at metacarpale II and metacarpale V	ANSUR
Hand length	Palm on table	Length of the right hand between the styilon landmark on the wrist and the tip of the middle finger (dactylion III)	ANSUR
Hip breadth	Sitting	Maximum distance between the lateral points of the hips	ANSUR
Knee height	Sitting	Vertical distance between the footrest surface and the top of the right knee at the center of the widest part of the calf	ANSUR/RAMSIS
Popliteal height	Sitting	Vertical distance between the footrest surface and the back of the right knee (the popliteal fossa at the dorsal juncture of the right calf and thigh)	ANSUR
Shoulder-elbow length	Standing	Distance between the acromion landmark on the tip of the right shoulder and the bottom of the right elbow (olecranon, bottom) with the elbows flexed 90°	ANSUR

(continued)

## APPENDIX A. (continued)

Dimension	Posture	Definition	Compatible Sources
Sitting height	Sitting	Vertical distance between the sitting surface and the top of the head	ANSUR/RAMSI
Stature with and without shoes	Standing	Vertical distance between the standing surface and the top of the head	ANSUR/RAMSI
Thigh circumference	Standing	Maximum circumference of the thigh with the tape perpendicular to the long axis of the leg	ANSUR/RAMSI
Thigh clearance	Sitting	Vertical distance between the sitting surface and the highest point on the top of the right thigh (thigh point, top)	ANSUR
Thumb-tip reach	Sitting	Distance between the surface of the back and the tip of the right thumb when the subject raises both arms horizontally forward with the elbows straight, the thumbs on top, and the fingers curled out of the way.	Defined for this study
Upper arm circumference	Standing	Circumference of the right arm at the biceps point, relaxed, located one-half the distance between acromion and the elbow crease	RAMSI
Waist circumference, natural indentation	Standing	Horizontal circumference at the level of greatest indentation of the torso	ANSUR/RAMSI
Shoe width	Standing	Breadth of the right shoe perpendicular to its long axis	Defined for this study
Shoe length	Standing	Length of the right shoe parallel to its long axis	Defined for this study

Note. ANSUR = 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics (Gordon et al., 1989); RAMSI = RAMSIS Anthropometric Databases (Speyer, 2007).

**APPENDIX B**  
**Mean Absolute Differences of Interobserver Errors in Team Training**

Dimension	n <sup>a</sup>	Min (Absolute Difference)	Max (Absolute Difference)	M (Absolute Difference)	SD (Absolute Difference)
Abdominal breadth, sitting	32	0	36	12	9.35
Acromial height	32	0	19	5	3.91
Acromial height, sitting	32	0	38	9	9.03
Abdominal depth, sitting	32	0	39	11	10.49
Ankle height	35	0	10	3	2.41
Arm length	35	0	30	5	6.78
Biacromial breadth	31	0	19	6	4.23
Bideltoid breadth	33	0	34	1	8.10
Buttock-knee length	32	2	21	10	5.00
Buttock-popliteal length	32	2	39	17	11.74
Calf circumference	36	1	23	6	5.38
Chest depth	38	0	29	8	6.48
Chest width	42	1	36	15	10.60
Elbow rest height	32	0	45	12	10.98
Elbow-fingertip length	36	0	20	6	4.99
Eye height, sitting	32	0	23	7	6.20
Forearm circumference	36	0	9	3	2.14
Forearm-forearm breadth	32	0	37	10	9.03
Hand breadth	32	0	6	2	1.52
Hand length	32	0	11	4	2.86
Hip breadth, sitting	31	0	23	8	6.47
Knee height, sitting	33	0	55	8	9.65
Popliteal height	32	0	35	8	7.032
Shoulder-elbow length	35	0	30	7	6.54
Sitting height	32	0	13	5	3.64
Stature with shoes	26	0	19	4	3.74
Stature (no shoes)	31	0	16	4	3.10
Thigh circumference	39	0	50	13	11.00
Thigh clearance	32	0	15	5	4.59
Thumb-tip reach	33	1	23	8	5.68
Upper arm circumference	38	0	24	10	7.22
Waist circumference, natural indentation	33	0	85	18	21.43
Weight (kg)	10	0	3.5	0.7	1.47
Shoe length	29	0	13	3	3.56
Shoe width	29	0	11	3	2.47

Note. Values are in millimeters except for weight.

<sup>a</sup>n indicates the number of interobserver comparisons.

**APPENDIX C**  
**Summary Statistics for Measured Dimensions in NIOSH Truck Driver Study**

Dimension	M (SD), Un-weighted	M (SD), Weighted	5th Percentile, Weighted	95th Percentile, Weighted	SE 5th and 95th Percentile, Weighted <sup>a</sup>	n
<b>Males</b>						
Abdominal breadth, sitting	372 (55.07)	371 (55.46)	292	471	2.02	1,779
Abdominal depth, sitting	333 (65.93)	331 (66.03)	232	452	2.40	1,779
Acromial height	1,449 (63.75)	1,449 (63.81)	1,345	1,554	2.32	1,779
Acromial height, sitting	615 (32.52)	615 (32.43)	561	669	1.18	1,779
Ankle height	74 (6.19)	74 (6.21)	64	85	0.23	1,779
Arm length	777 (37.81)	776 (37.45)	715	838	1.36	1,777
Biacromial breadth	426 (21.45)	426 (21.53)	392	462	0.78	1,779
Bideltoid breadth	537 (48.62)	537 (48.91)	469	624	1.78	1,779
Buttock-knee length	632 (35.02)	632 (35.04)	577	693	1.27	1,779
Buttock-popliteal length	520 (30.82)	520 (30.66)	473	572	1.12	1,779
Calf circumference	417 (40.97)	417 (41.42)	356	488	1.51	1,779
Chest depth	264 (41.35)	263 (41.56)	199	335	1.51	1,779
Chest width	356 (42.46)	356 (42.82)	299	435	1.56	1,779
Elbow-fingertip length	487 (23.72)	487 (23.48)	449	525	0.85	1,777
Elbow rest height	254 (33.20)	254 (33.13)	202	312	1.20	1,779
Eye height, sitting	799 (34.68)	799 (34.86)	742	858	1.27	1,779
Forearm circumference	309 (25.92)	309 (25.92)	271	353	0.94	1,779
Forearm-forearm breadth	617 (66.12)	617 (66.17)	516	730	2.41	1,779
Hand breadth	90 (4.80)	90 (4.82)	82	98	0.18	1,779
Hand length	197 (10.18)	196 (10.10)	180	214	0.37	1,779
Hip breadth, sitting	428 (45.96)	428 (46.04)	366	513	1.67	1,779
Knee height, sitting	569 (28.29)	569 (28.40)	523	615	1.03	1,779
Popliteal height	439 (25.84)	439 (25.89)	397	483	0.94	1,779

(continued)

## APPENDIX C. (continued)

Dimension	M (SD), Un-weighted	M (SD), Weighted	5th Percentile, Weighted	95th Percentile, Weighted	SE 5th and 95th Percentile, Weighted <sup>a</sup>	n
Shoulder-elbow length	362 (19.01)	362 (18.81)	331	393	0.68	1,777
Sitting height	918 (35.93)	919 (36.14)	858	978	1.31	1,779
Stature with shoes	1,785 (69.28)	1,785 (69.85)	1,672	1,900	2.74	1,522
Stature (no shoes)	1,757 (69.11)	1,757 (69.58)	1,645	1,869	2.53	1,779
Thigh circumference	634 (69.25)	635 (69.91)	535	764	2.54	1,779
Thigh clearance	181 (19.60)	181 (19.71)	152	216	0.72	1,779
Thumb-tip reach	834 (39.51)	833 (39.37)	771	902	1.43	1,778
Upper arm circumference	365 (41.05)	365 (40.98)	305	436	1.49	1,779
Waist circumference, NI	1,093 (153.37)	1,089 (154.31)	856	1,371	5.61	1,779
Weight (kg)	102.8 (23.83)	102.6 (23.93)	72.1	146.4	0.87	1,779
Shoe width	116 (6.33)	116 (6.31)	106	126	0.25	1,521
Shoe length	309 (14.46)	309 (14.50)	285	334	0.57	1,521
Females						
Abdominal breadth, sitting	372 (55.41)	374 (55.43)	283	463	1.36	171
Abdominal depth, sitting	322 (61.00)	325 (61.89)	225	430	1.52	171
Acromial height	1,338 (61.32)	1,337 (61.20)	1,236	1,450	1.50	171
Acromial height, sitting	578 (31.00)	579 (30.66)	524	630	0.75	171
Ankle height	68 (5.66)	68 (5.66)	58	78	0.14	171
Arm length	706 (36.62)	704 (35.20)	650	756	0.87	170
Biacromial breadth	385 (21.37)	385 (21.94)	344	425	0.54	171
Bideltoid breadth	498 (48.96)	499 (49.25)	421	587	1.21	171
Buttock-knee length	607 (33.82)	607 (32.56)	563	667	0.80	171
Buttock-popliteal length	502 (29.56)	502 (28.43)	458	551	0.70	171
Calf circumference	408 (47.77)	411 (47.91)	343	491	1.18	171
Chest depth	242 (37.85)	243 (38.03)	186	316	0.93	171
Chest width	328 (36.78)	328 (36.81)	274	399	0.90	171

(continued)

## APPENDIX C. (continued)

Dimension	M (SD), Un-weighted	M (SD), Weighted	5th Percentile, Weighted	95th Percentile, Weighted	SE 5th and 95th Percentile, Weighted <sup>a</sup>	n
Elbow-fingertip length	441 (22.11)	440 (21.86)	404	477	0.54	170
Elbow rest height	248 (32.16)	249 (31.55)	197	296	0.77	171
Eye height, sitting	751 (35.86)	752 (36.32)	691	813	0.89	171
Forearm circumference	276 (26.96)	276 (26.66)	240	323	0.65	171
Forearm-forearm breadth	570 (65.09)	574 (64.70)	475	684	1.59	171
Hand breadth	79 (3.89)	79 (3.90)	74	87	0.10	171
Hand length	177 (8.83)	177 (8.48)	163	190	0.21	171
Hip breadth, sitting	459 (51.06)	460 (51.19)	388	559	1.26	171
Knee height, sitting	525 (26.47)	526 (25.69)	487	571	0.63	171
Popliteal height	396 (25.29)	396 (25.17)	360	443	0.62	171
Shoulder-elbow length	333 (19.33)	333 (18.46)	304	364	0.45	170
Sitting height	863 (35.18)	863 (35.49)	804	922	0.87	171
Stature with shoes	1,648 (69.81)	1,647 (69.95)	1,530	1,789	1.72	130
Stature (no shoes)	1,627 (68.54)	1,626 (69.19)	1,510	1,763	1.94	171
Thigh circumference	670 (80.51)	671 (78.66)	560	798	1.93	171
Thigh clearance	174 (22.77)	174 (22.31)	143	212	0.55	171
Thumb-tip reach	770 (37.14)	771 (35.91)	716	845	0.88	171
Upper arm circumference	352 (50.78)	353 (51.14)	278	453	1.26	171
Waist circumference, natural indentation	1,014 (147.26)	1,020 (147.68)	787	1,249	3.62	171
Weight (kg)	90.3 (21.26)	91.0 (21.14)	62.6	126.1	0.52	171
Shoe width	106 (6.85)	106 (6.87)	95	118	0.19	130
Shoe length	274 (15.27)	275 (15.60)	250	303	0.44	130

Note. All values are in millimeters except for weight. NIOSH = National Institute for Occupational Safety and Health.

<sup>a</sup>Since the samples were weighted, the standard error of the 5th and 95th percentiles were calculated on the basis of the sum of weights, instead of n, for each body dimension.

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## KEY POINTS

- Truck drivers are heavier than the U.S. general population, with a difference in mean body weight of 13.5 kg for males and 15.4 kg for females.
- The current truck drivers have a different anthropometric profile from their counterparts of 25 to 30 years ago, exemplified by a heavier mean body weight (by 13 kg) and larger width and girth dimensions.
- A set of multivariate anthropometric models, spanning 95% of the current truck driver population, has been developed to facilitate future cab designs.

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