



Development of seating accommodation models for soldiers in vehicles

Yaser Zerehsaz, Jionghua (Judy) Jin, Sheila M. Ebert & Matthew P. Reed

To cite this article: Yaser Zerehsaz, Jionghua (Judy) Jin, Sheila M. Ebert & Matthew P. Reed (2017) Development of seating accommodation models for soldiers in vehicles, Ergonomics, 60:4, 589-596, DOI: [10.1080/00140139.2016.1184760](https://doi.org/10.1080/00140139.2016.1184760)

To link to this article: <https://doi.org/10.1080/00140139.2016.1184760>



Published online: 16 Jun 2016.



Submit your article to this journal [↗](#)



Article views: 335



View Crossmark data [↗](#)



Citing articles: 4 View citing articles [↗](#)

Development of seating accommodation models for soldiers in vehicles

Yaser Zerehsaz^a, Jionghua (Judy) Jin^a, Sheila M. Ebert^b and Matthew P. Reed^{a,b}

^aIndustrial and Operations Engineering Department, University of Michigan, Ann Arbor, MI, USA; ^bUniversity of Michigan Transportation Research Institute, Ann Arbor, MI, USA

ABSTRACT

Data from a previous study of soldier driving postures and seating positions were analysed to develop statistical models for defining accommodation of driver seating positions in military vehicles. Regression models were created for seating accommodation applicable to driver positions with a fixed heel point and a range of steering wheel locations in typical tactical vehicles. The models predict the driver-selected seat position as a function of population anthropometry and vehicle layout. These models are the first driver accommodation models considering the effects of body armor and body-borne gear. The obtained results can benefit the design of military vehicles, and the methods can also be extended to be utilised in the development of seating accommodation models for other driving environments where protective equipment affects driver seating posture, such as vehicles used by law-enforcement officers and firefighters.

Practitioner Summary: A large-scale laboratory study of soldier driving posture and seating position was designed to focus on tactical vehicle (truck) designs. Regression techniques are utilised to develop accommodation models suitable for tactical vehicles. These are the first seating accommodation models based on soldier data to consider the effects of personal protective equipment and body-borne gear.

ARTICLE HISTORY

Received 13 January 2016
Accepted 25 April 2016

KEYWORDS

Anthropometry; posture;
vehicle occupants;
accommodation

1. Introduction

The design of military vehicles in the United States is guided in part by Military Standard (MILSTD) 1472G, Human Engineering, a design standard that encompasses a broad array of normative data for human needs and performance. A small section of this standard addresses the design of vehicle seats and the layout of the driver workstation. However, this guidance is out of date and incomplete in many respects. For example, the standard neither considers the distributions of soldier body dimensions from modern studies nor specifies appropriate ranges of seat adjustment. In addition, the effects of body armor on driver posture and position are not considered in the designs.

The automobile industry has a long history of using more sophisticated tools for designing and assessing occupant accommodation. During the 1950s, a template-based design approach that represented the human body (usually a midsize male) as a kinematic linkage began to be used (Dempster 1955; Geoffrey 1961). Because the template-based approaches, including modern methods using three-dimensional computer-aided design manikins, cannot provide precise estimates of accommodation,

Meldrum (1965) introduced the eyellipse model which is a geometric representation of the distribution of drivers eye locations based on a multinormal approximation. This eyellipse model is the first of what became known as population accommodation models. The critical insight in the development of the eyellipse model was that it was necessary to combine the effects of vehicle layout and driver anthropometric variability into a single model. The eyellipse model was adopted as an industry standard in Society of Automotive Engineers (SAE) J941, and other related tools followed in the 1970s and 1980s (Hammond and Roe 1972): hand control reach (SAE J287), seating accommodation (SAE J1517), and head clearance (SAE J1052). SAE J941 was completely revised in 2002 using a new model developed at the University of Michigan Transportation Research Institute (UMTRI) (Manary et al. 1998). SAE J1517 was superseded in 2004 by SAE J4004, which incorporates a new seating accommodation model developed at UMTRI (Flannagan et al. 1998).

Although the current generation of automotive accommodation models could be applied to military vehicle design, several problems are still evident. The application range for these models is SAE Class A, which is limited to

seat heights (SAE H30) of 405 mm or lower. Many military trucks have higher seat heights. Most importantly, the models do not take into account the effects of body armor or body-borne gear on soldier driving posture and seating position.

During the 1980s, analogous models were developed for SAE Class B vehicles, i.e. trucks and buses. The tools were all based on the same data-set (Philippart, Kuechenmeister, and Stanick 1985; Sanders and Shaw 1985; Stanick, Philippart, and Kuechenmeister 1987) obtained in a laboratory study of truck drivers. The eyellipse and seating accommodation models were incorporated into SAE J941 and J1517, respectively, with important locating procedures embodied in SAE J1516. Additional models only for Class B were published in separate recommended practices: driver shin/knee contour (SAE J1521) and belly contour (SAE J1522).

In the late 1990s, UMTRI and industry collaborators conducted a laboratory study, in-vehicle study aimed at overcoming the limitations of the Sanders and Shaw study and their resulting design tools (Reed and Flannagan 2000; Reed, Lehto, and Schneider 2000; Jahns, Reed, and Hardee 2001). The testing configurations included height-adjustable seats and a wide range of steering wheel positions, spanning most of the practical Class-B range. The data were used to create posture-prediction models, new eyellipse and seating accommodation models (Reed 2005), and new knee, head and belly clearance models (Reed 2006). These UMTRI Class-B models have been widely used for vehicle design over the past 10 years. However, both the SAE practices and the more recent UMTRI models have critical limitations for military vehicle design. The SAE models do not consider the effects of height-adjustable seats and seats with adjustable back angles. Unlike the new generation of automotive (Class-A) models, the SAE Class-B models do not consider the population body dimensions; hence, they cannot be adjusted to target an Army population. Neither the SAE nor UMTRI Class-B models account for body armor or body-borne gear.

This paper follows the recent UMTRI Class-B models, except that the data are from the Seated Soldier Study (Reed and Ebert 2013) collected from a large-scale laboratory study of soldier driving postures and seating positions. The study was designed to focus on tactical vehicle (truck) designs with fixed driver heel points and H30 values spanning the upper end of the SAE Class-A range and the lower end of the SAE Class-B range. In this way, the data fill the gap between UMTRI's previous automotive models and the commercial vehicle models. This paper presents the methods and results for new driver seating accommodation models taking into account body armor and body-borne gear. The seating accommodation models predict the drivers' preferred fore-aft and vertical seat positions,

given a particular driver population and vehicle layout. These models can also be extended for designing cab layout, and in particular for ensuring a sufficient range of seat adjustment for an appropriate amount of accommodation.

2. Methods

2.1. Data source and applicable ranges

The data used for the current analysis were gathered in the Seated Soldier Study (Reed and Ebert 2013). The data were recorded for male and female enlisted personnel at three Army posts as they sat in a driver mockup (Figure 1).

The current study used data from 145 men and women tested in the driver mockup. A preliminary analysis identified no important gender effects. Consequently, the data from men and women were combined. Table 1 lists the summary statistics of the standard anthropometric variables for the combined male/female population.

Figure 2 shows the garb levels used for measurements in the mockup. At the advanced combat uniform (ACU) level, soldiers wore their own ACU consisting of a jacket, trousers, moisture wicking shirt and brown combat boots. All items were removed from the pockets, extra padding removed from the knees, and any cap or helmet was removed. At the personal protective equipment (PPE) level, soldiers wore an Improved Outer Tactical Vest (IOTV) with Enhanced Small Arms Protective Insert (ESAPI) plates, Enhanced Side Ballistic Inserts (ESBI), and an Advanced Combat Helmet (ACH) over their ACU ensemble. Five sizes of IOTV were available at the study site. The soldiers were given their self-reported sizes of helmet and IOTV with front, back and side plates. The investigator helped the soldier don the PPE and checked the fit. The fit was considered acceptable if (1) the elastic waistband of the IOTV



Figure 1. Driver mockups.

Table 1. Anthropometric characteristics of the driver population (combined men and women).

Variable	Mean	SD	5th%ile	50th%ile	95th%ile
Stature (mm)	1726	74.2	1589	1734	1840
Body weight (kg)	78.7	13.3	58.1	76.5	102.4
Erect sitting height (mm)	902	40.6	831	905	977
Sitting height/stature	0.523	0.0135	0.497	0.523	0.545
BMI (kg/m ²)	26.4	3.9	20.3	26.5	33.2

**Figure 2.** Three levels of military garb worn during measurement: ACU, PPE and ENC.**Table 2.** Condition matrix for driver mockup.

Package [†]	Accelerator heel point relative to steering wheel	Accelerator pedal angle	Initial seat H-point relative to steering wheel	Seat height	
	SAE L11, fore-Aft (mm)	SAE H17, vertical (mm)	Degrees from horizontal	Fore-aft (mm)	SAE H30 (mm)
1	225	785	47	417	473
3	375	785	47	364	473
5*	337.5	735	40	390	423
7	300	685	33	417	373
9	450	685	33	364	373

*Repeated with PPE and ENC.

[†]Conditions 2, 4, 6 and 8 were dropped after the first few sessions due to time constraints. The original condition numbers were retained for consistency with earlier documentation.

was snug with the Velcro closure fully overlapped and (2) the bottom of the IOTV was located below the navel and above the belt. The soldiers wore the smallest size helmet in which the soldier's head was in contact with the padding on the inside of the top of the helmet.

The third level of gear was referred to as encumbered (ENC), which consisted of ACU, PPE, a hydration pack, and a tactical assault panel. Figure 2 shows a soldier in the three levels of gear.

Table 2 shows the driver mockup conditions which were presented in a random order at the ACU level of garb. Condition 5 was repeated at the PPE and ENC (rifleman) levels. In each condition, the seat was initially adjusted to the expected mean position for male soldiers based on previous research, and the seat back angle was set to 17°, a typical design seat back angle for military seats. The soldier entered the mockup and adjusted the seat fore-aft and vertically, along with adjusting the seat back angle, to

obtain a comfortable driving position. The soldier posture and seat adjustments were recorded by digitising body and seat landmarks using a FARO Arm coordinate digitiser. The seat position was expressed as the SAE J826 H-point location relative to the accelerator heel point (AHP). Seat back angle was expressed relative to the SAE J826 manikin torso angle with respect to vertical (SAE A40).

2.2. General modelling approach

The data analysis and model development in this paper are based on the linear regression analysis. In the paper, the selected dimension of interest, such as fore-aft seat position, is expressed as a linear function of potential independent predictors, such as steering wheel position and driver stature that follows a normal distribution. The linear model is generally expressed as the following form

$$y = c_0 + c_1x_1 + c_2x_2 + \dots + c_px_p + \epsilon \quad (1)$$

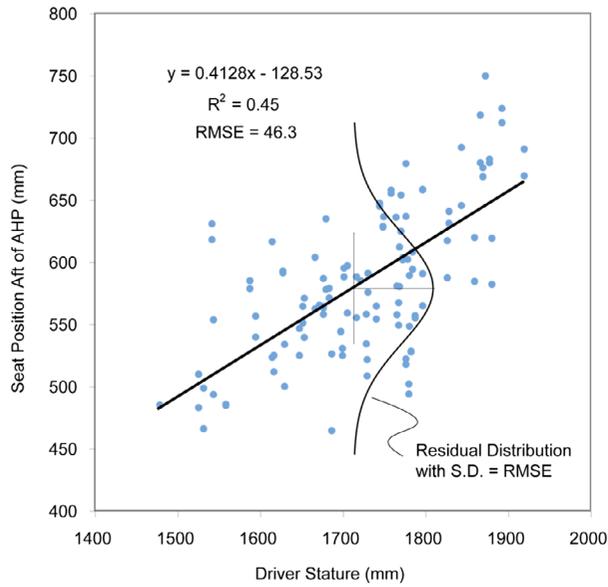


Figure 3. Plot of stature vs. fore-aft seat position to illustrate regression analysis principles.

where y is the dependent measure to be predicted, the c_i 's; $i = 0, 1, \dots, p$, are regression parameters that must be estimated, and x_i 's; $i = 1, \dots, p$, are the predictors (vehicle and driver body dimensions). ε 's are independent random error variables following a normal distribution with mean zero and constant variance σ^2 that can be estimated by mean squared error. It is assumed that the random error variables are independent from the predictors.

The model development procedure in this paper exploits the well-known property of normal distributions that a linear combination of a set of normal random variables has also a normal distribution. Specifically, define y as

$$y = c_1x_1 + c_2x_2 \quad (2)$$

where x_1 and x_2 are normally distributed random variables with means μ_1 and μ_2 respectively and a covariance matrix

$$\Sigma = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}. \text{ In this case, } y \text{ has a normal distribution}$$

with mean $c_1\mu_1 + c_2\mu_2$ and variance $c_1^2\sigma_1^2 + c_2^2\sigma_2^2 + 2c_1c_2\sigma_{12}$, where σ_{12} is the covariance between x_1 and x_2 . This formulation is particularly valuable for modelling driver posture because the relevant human descriptors, such as stature and body mass index, are approximately normally distributed or can be transformed to be. For example, consider

$$HPtX = c_0 + c_1Stature + \varepsilon \quad (3)$$

where $HPtX$ is the fore-aft seat position, c_0 is the intercept and c_1 is the slope coefficient. If stature is modelled as a normally distributed random variable with mean $\mu_{Stature}$ and variance $\sigma_{Stature}^2$, $HPtX$ becomes the sum of two

normally distributed random variables. As a result, $HPtX$ can be modelled as a normal random variable with mean

$$\mu_{HPtX} = c_0 + c_1\mu_{Stature} \quad (4)$$

and variance

$$\sigma_{HPtX}^2 = c_1^2\sigma_{Stature}^2 + \sigma^2 \quad (5)$$

where σ^2 is the variance of random error variable ε . Figure 3 shows a linear regression for fore-aft seat position, using (for purposes of illustration) stature as a single predictor.

The occupant population includes both men and women. The single-gender distribution of many anthropometric variables can be accurately approximated as a normal distribution, so men and women are modelled separately. The level of accommodation for each gender is computed and the respective fractions are combined using the population gender mix. For example, if the fraction of males in the population is m , the total fraction disaccommodated is

$$F_{total} = m(F_m) + (1 - m)F_f \quad (6)$$

where F_m and F_f are the fractions of disaccommodated male and female occupants, respectively.

2.3. Data analysis

The goal of the seating accommodation modelling is to create a predictive statistical model of the driver-selected seat positions given the vehicle configuration and the population descriptors. Linear regression analyses were conducted to express the fore-aft and vertical seat positions with respect to AHP as functions of steering wheel position and subject attributes. The regression results are tabulated in Reed and Ebert (2013) and are provided in this paper in the Results section.

For the purposes of the analysis, the seat track is assumed to provide both vertical and fore-aft adjustment, so that the seat adjustment range can be represented by a rectangle in the side view. In practice, a designer will likely want to accommodate a target percentage of drivers on fore-aft and vertical seat positions simultaneously. Suppose the target is 95% accommodation on both vertical and fore-aft seat positions. The total percentage disaccommodated is the sum of the fractions disaccommodated on the front, back, top and bottom of the adjustment range, minus the double-counted individuals in the corners (see Figure 4). Because the fore-aft and vertical seat positions are uncorrelated in this data-set, the disaccommodated fractions in the corners are simply the product of the adjacent disaccommodated fractions. For example, if 2.5% of drivers are disaccommodated at the top of the

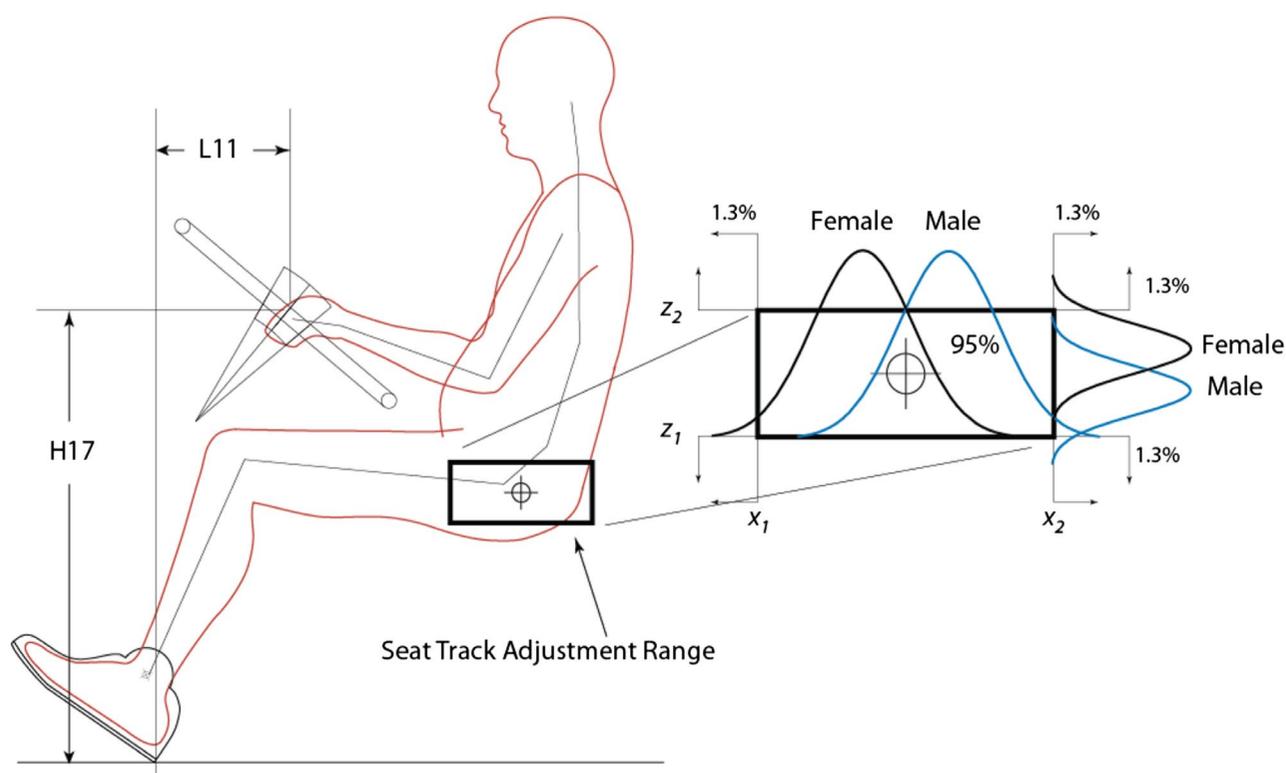


Figure 4. Predicted seat adjustment range and schematic of calculations.

Table 3. Linear regression models for predicting fore-aft and vertical seat positions (ACU).

Mean	Intercept	L11rel*	H17	Stature	Ln(BMI)	Sitting height (SH)/stature (S)	R^2_{adj}	RMSE
$\mu_{seatpositionx}$	1014	0.487	-0.780	0.310	62.2	-923	0.75	30.3
$\mu_{seatpositionz}$	-252	-0.089	0.99	-0.037			0.80	20.8

* $L11_{rel} = L11 - (888.75 - 0.75 H17)$; $L11_{rel}$ takes on values of -75, 0, and 75 mm.

travel and 2.5% at the front of the travel, the percentage of drivers who prefer a seat position both above and forward of the adjustment range is $(0.025)^2 = 0.0006225$. For the current example, symmetrical disaccommodation is assumed, i.e. the disaccommodation fraction is the same for all forward, rearward, upward and downward corners of the seat travel path. With symmetrical disaccommodated fraction $p \ll 1$ in each of the four directions, the total accommodation A is

$$A = 1 - 4p + 4p^2 \quad (7)$$

Solving the quadratic equation for p gives

$$p = 0.5 - 0.5(A)^{1/2} \quad (8)$$

So, to accommodate the central $A = 95\%$ population, the disaccommodation at the top, bottom, front and back of a rectangular seat track must each be not more than approximately 1.3%. The examples in this paper use this symmetrical distribution of disaccommodation, but an alternative distribution could be used. For example, a seat

track adjustment range could be computed such that very few drivers are disaccommodated on vertical travel or at the front of the seat track.

3. Results

Table 3 shows the linear regression equations from Reed and Ebert (2013) for predicting driver-selected fore-aft and vertical seat positions. For demonstration purposes, we use the anthropometric distributions from the Army Anthropometric Survey (ANSUR) (Gordon et al. 2014) shown in Table 4. The natural log transform of BMI was used to obtain a measure that was approximately normally distributed. Fore-aft steering wheel position is represented by the relative L11 value ($L11_{rel}$), which is computed as $L11 - (888.75 - 0.75 H17)$. In the data, $L11_{rel}$ takes on values of -75, 0 and 75 mm, but the resulting models can be used with any $L11_{rel}$ value. The fore-aft and vertical steering wheel positions ($L11$ and $H17$, respectively) are illustrated in Figure 4.

Table 4. Anthropometric data from ANSUR used for example calculations (Gordon et al. 2014).

Dimension (mm)	Men	Women
Stature (S)	1756 (68.6)	1628 (64.2)
Ratio of erect sitting height to stature (SH/S)	0.523 (0.0135)	0.526 (0.0141)
Ln(BMI) [†]	3.31 (0.146)	3.23 (0.135)

[†]Units are *natural log* (kg/m²).

Garb effects are applied to the mean values calculated using the ACU equations in Table 4. The mean seat positions are shifted rearward by 20.8 and 64.7 mm for PPE and ENC conditions, respectively. Using the equations from and values from Table 4 we calculate:

$$\mu_{\text{seatpositionx, male}} = 1278.8 - 0.780H17 + 0.487L11_{\text{rel}} \quad (9)$$

$$\mu_{\text{seatpositionx, female}} = 1231.9 - 0.780H17 + 0.487L11_{\text{re}} \quad (10)$$

$$\sigma_{\text{seatpositionx, male}} = \sqrt{(0.310\sigma_{\text{Stature, male}})^2 + (62.3\sigma_{\text{ln(BMI), male}})^2 + (-923\sigma_{\text{SH/S, male}})^2 + (30.3)^2} = 39.7 \quad (11)$$

$$\sigma_{\text{seatpositionx, female}} = \sqrt{(0.310\sigma_{\text{Stature, female}})^2 + (62.3\sigma_{\text{ln(BMI), female}})^2 + (-923\sigma_{\text{SH/S, female}})^2 + (30.3)^2} = 39.2 \quad (12)$$

The correlations among stature, ln (BMI) and Sitting Height (SH)/Stature (S) is negligible ($r_{\text{Stature, lnBMI}} = 0.00$; $r_{\text{Stature, SH/S}} = -0.12$; $r_{\text{lnBMI, SH/S}} = 0.15$); hence, the last two equations overlook the covariance among these variables in computing the standard deviation of fore-aft seat position.

Now, we are able to determine the fore-aft seat adjustment range that is needed to accommodate a desired percentage of the mixed-gender population. Taking m as the fraction of males in a population, the total disaccommodated fraction of the two-gender population lying forward of x_1 is

$$F_1 = m \left[\Phi \left(\frac{x_1 - \mu_{\text{seatpositionx, male}}}{\sigma_{\text{seatpositionx, male}}} \right) \right] + (1 - m) \left[\Phi \left(\frac{x_1 - \mu_{\text{seatpositionx, female}}}{\sigma_{\text{seatpositionx, female}}} \right) \right] \quad (13)$$

where $\Phi(z)$ is the cumulative standard normal distribution, and x_1 represents the forward boundary of the fore-aft seat track. Analogously, the fraction of the combined male and female population which lies rearward of x_2 can be given by

$$F_2 = m \left[1 - \Phi \left(\frac{x_2 - \mu_{\text{seatpositionx, male}}}{\sigma_{\text{seatpositionx, male}}} \right) \right] + (1 - m) \left[1 - \Phi \left(\frac{x_2 - \mu_{\text{seatpositionx, female}}}{\sigma_{\text{seatpositionx, female}}} \right) \right] \quad (14)$$

with x_2 denoting the rearward boundary of the fore-aft seat track. Since there is no closed-form solution to x_1 and x_2 , a solution is obtained by the iteration of x_1 and x_2 to

obtain the desired accommodation level. The procedure is illustrated schematically in Figure 4, which shows normal distributions for the male and female population, demonstrating the cutoffs at x_1 and x_2 .

A similar procedure is followed in order to obtain the vertical adjustable range. Note that garb level does not affect the seat vertical position. Since stature is a significant predictor in the model, we proceed by calculating the

mean and standard deviation of the vertical seat position for each gender as

$$\mu_{\text{seatpositionz, male}} = -317 + 0.99H17 - 0.089L11_{\text{rel}} \quad (15)$$

$$\mu_{\text{seatpositionz, female}} = -312.3 + 0.99H17 - 0.089L11_{\text{rel}} \quad (16)$$

$$\sigma_{\text{seatpositionz, male}} = \sqrt{(-0.037\sigma_{\text{Stature, male}})^2 + (20.8)^2} \quad (17)$$

$$\begin{aligned} \sigma_{\text{seatpositionz, female}} &= \sigma_{\text{seatpositionz, female}} \\ &= \sqrt{(-0.037\sigma_{\text{Stature, female}})^2 + (20.8)^2} \quad (18) \end{aligned}$$

The male and female distributions are combined in the same manner as for fore-aft seat position to obtain z_1 and z_2 representing the lower and upper boundaries of the vertical seat track, respectively. The required seat track adjustment ranges are shown in Figure 4. Sample computations are presented in Appendix A.

4. Discussion

This paper presents seating accommodation models for soldiers in a driving environment. The modelling methodology follows the state-of-the-art techniques developed for passenger cars and light trucks (Flannagan et al. 1998; Manary et al. 1998) that were previously applied to the development of similar models for commercial truck drivers (Reed 2005, 2006). The models presented in this paper are the first seating accommodation models based on soldier data and the first to incorporate the effects of PPE and body-borne gear.

The most important limitation of the new driver seating accommodation model is the lack of in-vehicle validation. In particular, some effects of vehicle geometry and the nature of the driving task could result in differences in driver posture. Exterior vision obstructions could result in posture differences. However, previous research with passenger car drivers has shown that even substantial vision restrictions have only small effects on posture (Reed, Manary, and Schneider 2000). In research with commercial truck drivers, accommodation models created from laboratory data were accurate in predicting the distribution of driver postures in trucks with widely varying exterior vision restrictions (Reed 2005). However, for military applications, accommodation models for situations with highly constrained eye locations will be needed.

The driver accommodation models in this paper also do not take into account the effects of censoring of posture due to restrictions in cab space or seat adjustment ranges. For example, headroom restrictions could cause drivers to sit lower than predicted. The seating accommodation model assumes that drivers can sit with their preferred seat position and seat back angle. If the seat adjustments are restricted, the postures may be different.

The models are limited by the particular uniform and gear conditions that were used in data collection. The ACU condition included standard-issue boots with an effective heel height of about 25 mm. Boots with thicker heels would be expected to have a small effect on posture, roughly equivalent to the same increase in stature. More importantly, the PPE and ENC conditions were based on particular garb configurations. The IOTV and ACH geometry had a significant effect on soldier posture and space claim. However, the effects of a change in body armor or the configuration of the body-borne gear would need to be investigated through additional posture measurements. One critical limitation of the ENC conditions is that a single hydration pack was used. Soldiers not wearing a hydration pack or sitting on a seat with an opening designed to accommodate the hydration pack would be expected to sit somewhat differently. Although new data would be the best way to account for different seats, using the PPE models for ENC situations with hydration pack relief is a reasonable approach.

The data on which these models are based were gathered from a convenience sample of soldiers at three Army posts in 2012, but this does not impose a substantial limitation. Because the modelling methodology is not strongly dependent on the representativeness of the sample, even relatively large changes in the anthropometric distributions of soldiers would not have important effects on the validity of these models. However, large changes in the nature of the driving task and the associated changes in vehicle design would make these models less useful. For

example, drivers using on-head displays for forward vision might position themselves differently. Similarly, highly adjustable steering wheels and pedals might result in different seat position adjustment behaviour.

Funding

This research was supported by the Automotive Research Center (ARC) at the University of Michigan, under agreement W56H2V-14-2-0001 with the US Army Tank Automotive Research, Development, and Engineering Center (TARDEC) in Warren, MI.

References

- Dempster, W. T. 1955. *Space Requirements of the Seated Operator: Geometrical, Kinematic, and Mechanical Aspects of the Body with Special Reference to the Limbs*. WADC Technical Report No. 55-159. Wright-Patterson Air Force Base, OH: Wright Air Development Center.
- Flannagan, C. A. C., M. A. Manary, L. W. Schneider, and M. P. Reed. 1998. "An Improved Seating Accommodation Model with Application to Different User Populations." *SAE Transactions: Journal of Passenger Cars* 107 (6): 1189–1197.
- Geoffrey, S. P. 1961. *A 2-D Manikin – The Inside Story*. SAE Technical Paper 267A. Warrendale, PA: Society of Automotive Engineers.
- Gordon, C. C., C. L. Blackwell, B. Bradtmiller, B. Bradtmiller, J. L. Parham, P. Barrientos, S. P. Paquette, B. D. Corner, J. M. Carson, J. C. Venezia, B. M. Rockwell, M. Mucher, and S. Kristensen. 2014. *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*. NATICK/TR-15/007. Natick, MA: U.S. Army Natick Soldier Research, Development, and Engineering Center.
- Hammond, D. C., and R. W. Roe. 1972. *SAE Controls Reach Study*. Technical Paper 720199. Warrendale, PA: Society of Automotive Engineers.
- Jahns, S. K., M. P. Reed, and H. L. Hardee. 2001. *Methods for In-vehicle Measurement of Truck Driver Postures*. SAE Technical Paper 2001-01-2821. Warrendale, PA: Society of Automotive Engineers.
- Meldrum, J. F., 1965. *Automobile Driver Eye Position*. Technical Paper 650464. Warrendale, PA: Society of Automotive Engineers.
- Manary, M. A., C. A. C. Flannagan, M. P. Reed, and L. W. Schneider. 1998. "Development of an Improved Driver Eye Position Model." *SAE Transactions: Journal of Passenger Cars* 107 (6): 43–50.
- Philippart, N. L., T. J. Kuechenmeister, and J. M. Stanick. 1985. *Describing the Truck Driver Workspace*. Technical Paper 85217. Warrendale, PA: Society of Automotive Engineers.
- Reed, M. P., M. M. Lehto, and L. W. Schneider. 2000. *Methods for Laboratory Investigation of Truck and Bus Driver Postures*. Technical Paper 2000-01-3405. *SAE Transactions: Journal of Commercial Vehicles*, vol. 109.
- Reed, M. P., M. A. Manary, and L. W. Schneider. 2000. "The Effects of Forward Vision Restriction on Automobile Driver Posture." *Transportation Human Factors* 2 (2): 173–189.
- Reed, M. P., and C. A. C. Flannagan. 2000. *Anthropometric and Postural Variability: Limitation of the Boundary Manikin Approach*. Technical Paper 2000-01-2172. Warrendale, PA: Society of Automotive Engineers.

- Reed, M. P. 2005. *Development of a New Eyellipse and Seating Accommodation Model for Trucks and Buses*. Technical Report UMTRI-2005-30. Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Reed, M. P. 2006. *Accommodation Models for Truck Driver Knee Clearance, Abdomen Clearance, and Shifter Location*. Technical Report UMTRI-2006-30. Ann Arbor, MI: University of Michigan Transportation Research Institute.
- Reed, M. P., and S. M. Ebert. 2013. *The Seated Soldier Study: Posture and Body Shape in Vehicle Seats*. Technical Report

2013-13. Ann Arbor, MI: University of Michigan Transportation Research Institute.

- Sanders, M. S., and B. E. Shaw. 1985. *U.S. Truck Driver Anthropometric and Truck Work Space Data Survey: Sample Selection and Methodology*. Technical Paper 852315. Warrendale, PA: Society of Automotive Engineers.
- Stanick, J. M., N. J. Philippart, and T. J. Kuechenmeister. 1987. *Describing the Truck Driver Eye and Head Accommodation*. Technical Paper 871531. Warrendale, PA: Society of Automotive Engineers.

Appendix A. Example calculations

All dimensions in mm unless otherwise noted.

Dimension	ANSUR II (2013)			
	Men		Women	
	Mean	SD	Mean	SD
Stature (S), mm	1756	68.6	1628	64.2
Erect Sitting Height (SH), mm	918	35.7	857	33.1
Stature minus Sitting Height (SSH), mm	837	46.5	772	44.4
SH/S	0.523	0.0135	0.526	0.0141
Log(BMI)*, log(kg/m ²)	3.31	0.146	3.23	0.135
*Note – this is natural log of BMI.				
<i>Fraction Male</i>	0.9			
Vehicle Geometry				
SWX (L11)	337.5	mm		
SWZ (H17)	735	mm		
L11rel	0			
A40	0	mm		
H30	423	mm		
Ensemble level	PPE	ACU, PPE, ENC		
Hydration pack relief	No	Yes, No		
Calibration tool	J826	J826, SIPT		
		L11	H17	
		(mm)	(mm)	
Steering wheel preference				
Preference line endpoint, min	363.2		700.0	
Preference line endpoint, max	94.8		850.0	
Steering wheel point (SWP)	337.5		735.0	
Seating accommodation				
Centre of travel (X)	721.6		mm	
Centre of travel (Z)	408.7		mm	
Fore-aft travel (X)	190.9		mm	
Vertical travel (Z)	93.9		mm	
	X (mm)		Z (mm)	
Full down, full rear	817.1		361.7	
Full down, full forward	626.2		361.7	
Full up, full forward	626.2		455.6	
Full up, full rear	817.1		455.6	
Full down, full rear	817.1		361.7	