

TITLE: NIOSH Pilot Study of Truck Driver Anthropometric and Workspace Dimensions

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1. Introduction

1.1 Objective and Specific Aims

The objective of this pilot study is to establish procedures for measuring anthropometric and workspace dimensions as well as taking 3D scans for U.S. truck drivers. The specific aims of this project are as follows:

- a. Complete the design and construction of an experimental truck cab buck;
- b. Determine anthropometric and workspace measurements critical to truck cab design;
- c. Establish test procedures for data collection and analysis;
- d. Complete data collection for 60 truck drivers.

1.2 Occupational Safety and Health Problems

An estimated 1,594,980 workers were employed as heavy and tractor-trailer truck drivers in 2004 [Bureau of Labor Statistics 2006a]. Trucking is the most hazardous occupation in the U.S. Truck drivers were 6.5 times more likely to be killed in job-related incidents than the average worker [Suarez 1999]. Fatal traffic crashes led all other work-related fatal events among truck drivers, claiming 6,884 lives during 1992-2000. Semi-trucks, in particular, have been identified as the leading vehicle source of work-related fatalities. In the same 1992-2000 period, 3,378 semi-truck drivers died in work-related highway incidents, accounting for 28.3 percent of all work-related highway fatalities [Pratt 2003]. In 2004, the Survey of Occupational Injuries and Illnesses estimated 63,570 non-fatal injuries among heavy and tractor-trailer drivers – the second highest number among all occupations. The most common events causing these nonfatal injuries were overexertion, contact with object/equipment, and transportation events [Bureau of Labor Statistics 2006b].

Problems in human-cab interaction may contribute to fatal and non-fatal incidents. For example, it is generally accepted that good visibility is essential for safe operation of a motor vehicle [Henderson et al. 1983]. To design a safe truck with good visibility, up-to-date driver anthropometric and workspace data is required. In addition, anthropometry plays an important role in post-crash survivability. To prevent ejection

and entanglement, designers need to know drivers' body size and workspace information in order to design effective restraint systems and to maintain sufficient survival space.

Up-to-date information on U.S. truck driver anthropometry is not available. The SAE released its landmark truck driver anthropometric and workspace data in the early 1980s [Sanders and Shaw 1983; Shaw and Sanders 1984], but the data has largely become outdated due to demographic changes (e.g., gender, age, and race/ethnicity) that have taken place in the past 20 years. A new anthropometry survey of U.S. truck drivers is needed. This pilot study is to establish test procedures needed for possible new anthropometric survey of U.S. truck drivers.

2. Method

2.1 Participants

Sixty professional truck drivers will be asked to participate in this study. They will be recruited from trucking fleets and driving schools in the tri-state area of West Virginia, Western Pennsylvania, and Eastern Ohio. The study will include 10% female drivers in its sample. Subjects will be compensated for their participation in this study.

2.2 Apparatus

2.2.1 Cab Buck. NIOSH is the process of building a truck cab buck specifically for this project. This buck will consist of windshield, hood, door (driver's side), floor, seat, seat belt, steering wheel, accelerator (floor-mounted and suspended), brake (floor-mounted and suspended), and clutch (suspended). There will be two cab styles: conventional and cabover. For the conventional style, the hood is attached to the front of the cab and the engine cover is removed from the cab. In contrast, for the cabover style, the hood is removed and the engine cover is installed in the cab. The adjustable parts of the cab are the driver's seat (up-down, fore-aft, recline), steering wheel (telescoping, translating and tilting), and clutch pedal (fore-aft). The adjustment values of this cab buck are listed in Table 1. The unique features of the cab are that its dimensions are generic, non-specific to a certain model of truck cab, and the seat and steering wheel are adjustable over a wide range so that the cab is capable of accommodating all participants.

Table 1. Cab Buck Adjustment Values

	Min	Max	Range
Seat			
Back Angle, Degrees	13.5	18.0	4.5
H point – AHP (fore-aft), mm	450	810	356
H point – Floor (up-down), mm	250	885	635
Steering Wheel			
Size (diameter), mm	457	559	102
Steering column angle, degrees	50	75	25
Telescope, mm	*	*	405
Longitudinal Transverse, mm	68	-494	562
Clutch -AHP (fore-aft), mm	-25.4	-323.4	298

* Min and Max values are meaningless because reference point is arbitrary.

- Negative values indicate forward of AHP

2.2.2 *Devices for Traditional Anthropometric Measurement.* A set of anthropometry survey devices will be used to measure truck drivers. These devices are an anthropometer (GPM, Switzerland), a beam caliper (rearranged pieces of the anthropometer), a Lufkin tape measure (Cooper Tool, Apex, North Carolina), a Toledo scale (Mettler-Toledo Inc., Worthington, Ohio), and a Burton pupillometer.

2.2.3 *Whole Body Scanner.* The Cyberware WB4 3-D whole body scanner (Cyberware Inc., Monterey, California; Figure 1a) will be used to scan subjects. The scanner uses four scan heads to capture the contours of the human body in 17 seconds. The scanner heads start above the head level and move downward at a constant rate. The scan heads contain safe low power visible and invisible (infrared) lasers that are swept across the human body to record dimensions and brightness. After the scanning, the four 2-D images from four scan heads are merged into a 3-D image in a few seconds. The scanner will be used to scan subjects in three postures: standing, sitting, and seated driving. These scans will be used to digitally extract truck driver anthropometry as well as for applications in computer modeling. The accuracy of the scanning system is an average error of 2.9 mm, ranging from +6 mm to -6 mm.

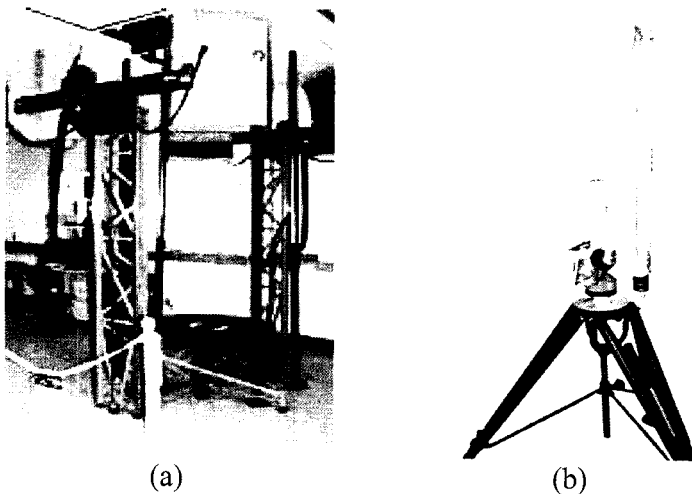


Figure 1. (a) Cyberware whole body laser scanner (WB4) is to be used in this Project. This equipment is currently located in the DSR/PTB Anthropometry Lab, Morgantown, West Virginia; (b) a FaroArm, Bronze Series.

2.2.4 *FaroArm.* A 10-foot Bronze Series FaroArm (FaroArm Technologies, Lake Mary, Florida) will be used to measure cab accommodation values for individual subjects. The FaroArm is a six-axis articulating measurement device and is capable of measuring an area of a 150 cm in radius (See Figure 1b).

2.2 *Workspace Measurement Matrix*

The cab workspace measurement matrix is presented in Table 2. Of all cab adjustment parameters, only the seat height will be controlled. The remaining parameters will be adjustable by the subjects. It is worth noting that the 508-mm and 559-mm diameter steering wheels are in parentheses because they will only be used in limited cab measurements (seat fore-aft travel, hand position on the wheel, and stomach-steering wheel distance). The 457-mm diameter wheel will be used in all cab measurements because this wheel size is most commonly used in modern truck cabs.

Table 2: Workspace Measurement Matrix

Parameter	Conventional			Cabover		
	1	2	3	1	2	3
Seat						
Fore-Aft, mm	v	v	v	v	v	v
Height, mm	400	460	520	400	460	520
Back Angle, deg	v	v	v	v	v	v
Steering Wheel						
Size (diameter), mm	457 (508) (559)	457 (508) (559)	457 (508) (559)	457 (508) (559)	457 (508) (559)	457 (508) (559)
Fore-Aft, mm	v	v	v	v	v	v
Height, mm	v	v	v	v	v	v
Angle, deg	v	v	v	v	v	v

Note: “v” indicates parameters adjustable by subjects

2.3 Landmarks and Measurements

2.3.1 Body Landmarks. The following 25 body landmarks will be used to define anthropometric measurements in the study. An investigator will identify these body landmarks on the subject’s skin, by gently feeling for some bones and joints. Then, the landmarks will be marked with a non-permanent cosmetic marker. Definitions of these dimensions are available in Appendix A. Other sources include Blackwell et al. 2001; Gordon et al. 1989.

(1) acromion, right and left; (2) buttock point, posterior; (3) cervicale; (4) deltroid point, right and left; (5) dorsal juncture of the calf and thigh; (6) ecotocanthus; (7) first metatarsophalangeal protrusion; (8) fifth metatarsophalangeal protrusion; (9) glabella; (10) knee point, anterior (11) metacarpale, II; (12) metacarpale V; (13) midshoulder; (14) olecronon, bottom and rear; (15) radial styloid; (16) suprapatella; (17) thigh point, top; (18) trapezius point, right and left; (19) trochanter; (20) thigh point, top; (21) top of the head (vertex); (22) trapezius point, right and left; (23) trochanterion; (24) ulna styliion; (25) waist (omphalion) right and left, anterior and posterior.

2.3.2 Driver Anthropometric measures

The following 50 measures will be taken on each subject by traditional anthropometry. Definitions of these dimensions are available in Appendix B. Other sources include Blackwell et al. 2001; Gordon et al. 1989; Roebuck et al. 1975; Sanders and Shaw 1985.

- **Standing posture:** (1) body height with feet together (stature); (2) body height with feet apart; (3) crotch height; (4) shoulder-elbow length; (5) spine-shoulder length; (6) spine-wrist length; (7) trochanterion height; (8) waist breadth, standing; (9) waist circumference, standing; (10) waist depth, standing; (11) thigh circumference.
- **Sitting posture:** (12) acromial height; (13) bi-acromial breadth; (14) bi-deltroid breadth; (15) buttock-foot length; (16) buttock-knee length; (17) buttock-popliteal length; (18) cervical height,

sitting; (19) elbow rest height; (20) eye height, sitting; (21) forearm-forearm breadth; (22) forearm-hand length; (23) hip breadth sitting; (24) knee height, sitting; (25) mid-shoulder height, sitting; (26) popliteal height; (27) sitting height; (28) thigh clearance; (29) waist breadth, sitting; (30) waist depth, sitting; (31) waist circumference, sitting; (32) waist height, sitting.

- *Others:* (33) foot breadth (ball); (34) foot circumference (ball); (35) foot length; (36) functional leg length; (37) hand breadth; (38) hand circumference; (39) hand length; (40) head breadth; (41) head circumference; (42) head length; (43) overhead fingertip reach, sitting; (44) overhead fingertip reach, standing; (45) overhead fingertip reach, extended; (46) thumb-tip reach; (47) wrist-wall length; (48) wrist-wall length, extended; (49) interpupillary distance; (50) weight

2.3.3 Cab Workspace Values. The following 17 sets of cab buck accommodation values will be collected with a FaroArm. Explanation of these values are provided in Appendix C. Other sources include Sanders and Shaw 1985.

- *Body segment position values:* (1) eye position, right and left; (2) foot reach on clutch (unblocked); (3) forward grip reach positions, left and right; (4) hand position on the steering wheel, left and right; (5) head position, top; (6) knee position, left foot on clutch (blocked); (7) knee position, right foot on accelerator (floor-mounted and suspended); (8) knee position, right foot on brake (floor-mounted and suspended); and (9) trochanter, left and right.
- *Other cab accommodation values:* (10) preferred brake depressing depth; (11) seat fore-aft position for the small, medium, and large diameter wheels; (12) seat height; (13) seat back angle; (14) steering wheel center position; (15) steering column angle; (16) safety belt length; and (17) stomach-steering wheel clearance for the small, medium and large diameter wheels.

2.4 Procedures

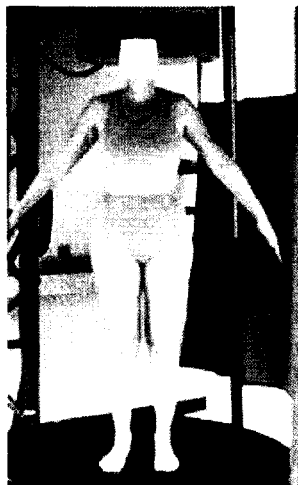
Upon arriving at the mobile laboratory, the subject will view a PowerPoint™ presentation, which describes the study and the tasks the subject is to perform. If he/she agrees to participate, the subject will sign a consent form and fill out a short biographical sketch form. The subject will then be taken to a dressing room, where he/she changes clothing – bike shorts for men and bike shorts with halter top for women. A form-fitting cap will also be placed on the head to cover the hair. For traditional anthropometry, the subject will first assume a standing posture and then a sitting posture. For the standing posture, the subject will stand erect with heels either together or lined up with pre-marked footprints on the floor and hands resting naturally by each side. He/she will be told to face forward with equal weight on both feet. For the sitting posture, the subject will sit erect on a specially designed bench with the head facing forward. The shoulders and upper arms are relaxed, and the forearms and hands are extended forward horizontally with the palms facing each other. The thighs are parallel and the knees are flexed 90 degrees with the feet in line with the thighs. Between the two postures, the investigator will locate 25 landmarks and mark them with a marker (Appendix A). Markers will be placed on the clothing overlying the actual landmarks if landmarks are covered by the clothing. After landmarking, the investigator will measure 50 body dimensions between the standing and sitting postures.

Following the data collection using traditional anthropometry, the subject will be taken to the truck buck for workspace measurement. He/she will be randomly assigned to either the conventional style cab or the

cabover style cab group and to one of the three conditions (1, 2, 3). A hood will be attached to the front of the cab to simulate a conventional cab style or will be removed to simulate the cabover style.

Before the subject enters the cab buck, the investigator will make sure that all the adjustable parts of the buck are set at the values described in Table 2. Then, the subject will sit in the driver's seat. The investigator will make adjustments in seat position (fore-aft and back angle) and steering wheel position (fore-aft travel, height, and tilting) based on the verbal feedback from the subject. The sequence of the adjustment will be seat angle, seat fore-aft travel, steering wheel fore-aft travel, height, and tilting. During these adjustments, the investigator will record the value of each adjustment. After he/she is satisfied with all adjustments, the subject will be told to fasten the seat belt. The seat belt length will be recorded. Then, the subject will be told to sit in a comfortable driving posture, with both hands holding the steering wheel, left foot resting on the clutch (mechanically blocked), and right foot resting on the accelerator (mechanically blocked). The investigator will take workspace measurements using the FaroArm. For top of the head (vertex) and eye position measurements, a head clamp will be used to fix head position. The head clamp will be loosen and moved out of the way for other cab measurements. For the right knee position measurement while the foot is on the accelerator or brake, two types of accelerator and brake pedals (floor-mounted and suspended) will be used. For foot reach measurement, the investigator will unblock the clutch so that it can move in the fore-aft direction. The subject will be instructed to place the ball of his/her left foot on the clutch and fully extend the leg forward without pointing the toes. The position of the clutch will be recorded with the FaroArm. For hand grip reach measurement, the subject will be instructed to reach for the knobs located to the front of the cab buck using three-finger grip hand posture. The subject will be asked to reach for two knobs with the left hand and two knobs with the right hand. The subject will be instructed to lean slightly forward and reach toward the knob, stopping at a comfortable position. The position of the thumb tip will be recorded. After these measurements are taken, two different diameter steering wheels will be installed sequentially and relevant work-space dimensions (i.e., stomach-steering wheel clearance, hand position on the steering wheel, and seat fore-aft travel) in the seated driving posture will be measured.

After the cab workspace data collection is completed, the landmarks will be covered with adhesive dots for 3D laser scanning. The subject will be scanned in three postures: standing, sitting, and seated driving (Figure 2a, 2b, 2c).



(a)



(b)



(c)

Figure 2. (a) standing posture; (b) sitting posture; (c) seated driving posture. Reflective markers are not shown in these demonstrative photos.

Standing posture. For this scan, the subject will line up the feet with the pre-marked footprints on the scanner platform. The subject's arms will be 20 cm away from the torso with palms facing forward, and the two legs will be about 10 cm apart at heels with toes about 30 degrees away from the sagittal plane. The subject will be told to hold his/her breath while the 17-second scanning is completed.

Sitting Posture. For this scan, a specially made stool, adjustable in height, will be placed on the scanning platform. The subject will be seated on the stool, torso kept erect, eye looking straight ahead, knee kept at 90 degrees, elbows kept at 90 degrees, palms facing each other, and fingers extended and pointing forward. The subject will be told to stay still and hold his/her breath while the 17-second scanning is completed.

Seated Driving Posture. For this scan, a truck seat will be placed on the platform. The spatial layout of the seat, clutch, accelerator, and steering wheel will closely follow those obtained during the subject's cab workspace measurement. Physical objects (accelerator, clutch, and steering wheel) will be used to make sure that the posture closely mimics his/her posture during the cab workspace measurement. For this scan, the subject will be seated comfortably, with hands holding to a small-size steering wheel, eyes looking straight ahead, the left foot (ball) resting on the clutch pedal (blocked), and the right foot resting on an accelerator pedal (blocked). It is worth noting that physical objects (except the accelerator) will be removed before the scan is taken. The subject will be instructed to sit still and hold his/her breath while the 17-second scanning is completed. After the scanning is completed, the subject will change back into street clothes, will be compensated for his/her time, and will be dismissed.

2.5 Data Analysis

All 50 driver anthropometric and 17 sets of workspace measurements will be summarized and tabulated. All the scans, collected in luminance for superior accuracy, will be stored in the polygon file format (PLY), accompanied by corresponding landmark files. These scans will be used for computer simulation studies.

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Appendix A

Landmarks and Definitions (Adapted from Blackwell et al., 2001; Gordon et al., 1988):

1. Abdominal point, anterior: The most protruding point of the relaxed abdomen of a seated subject.
2. Acromion, right and left: The point of the intersection of the lateral border of the acromial process a line running down the middle of the shoulder from the neck to the tip of the shoulder.
3. Buttock point, posterior: Point of maximum protrusion of the right buttock of a standing subject.
4. Cervicale: The superior palpable point of the spine of the seventh cervical vertebra.
5. Deltoid point, right and left: The lateral point of the right deltoid muscle, and the margin of the left deltoid muscle at the level of the right deltoid point.
6. Dorsal juncture of the calf and thigh: The juncture between the right calf and thigh behind the knee of a subject sitting with the knee flexed 90 degrees.
7. Ecotocanthus: The outside corner of the right eye formed by the meeting of the upper and lower eyelids.
8. First metatarsophalangeal protrusion: The medial protrusion of the right foot in the region of the first metatarsophalangeal joint.
9. Fifth metatarsophalangeal protrusion: The lateral protrusion of the right foot in the region of the fifth metatarsophalangeal joint.
10. Glabella: The anterior point on the frontal bone midway between the bony brow ridges.
11. Knee point, anterior: The most protruding point of the kneecap of a seated subject.
12. Metacarpale II: The lateral point of the right metacarpophalangeal joint II (at the base of the index finger on the outer edge of the hand).
13. Metacarpale V: The medial point of the right metacarpophalangeal joint V (at the base of the little finger on the outer edge of the hand).
14. Midshoulder: The point on top of the left shoulder midway between the neck (left trapezius point) and tip of the shoulder (acromion, left)
15. Olecranon, bottom and rear: The lowest and rearmost points of the right elbow with the elbow flexed 90 degrees.
16. Radial Styloid: The highest point on the outside edge of the right radius.

17. Suprapatella: Top of the right kneecap; the superior point on the patella of a standing person.
18. Thigh point, top: The highest point of the top of the right thigh of a seated subject.
19. Trapezius point, right and left: The point at which the anterior border of the trapezius muscle crosses the lateral neck landmark.
20. Trochanter: A point at the center of the lateral surface of the greater Trochanter of the right femur of a sitting subject.
21. Top of the head (Vertex): The highest point on the head when the head is in the Frankfort plane.
22. Trapezius point, right and left: The point at which the anterior border of the trapezius muscle crosses the lateral neck landmark.
23. Trochanterion: The superior point of the greater Trochanter of the right femur of a standing subject.
24. Ulna Styliion: The lowest point of the bottom of the right radius.
25. Waist (omphalion) right and left; anterior and posterior: The level of the center of the navel.

Appendix B

Description of Traditional Measurements (Adapted from Blackwell et al., 2001; Gordon et al., 1989)

1. Body height with feet together (Stature): Vertical distance from the standing surface to the highest point of the head (vertex). Subject stands erect with heels together.
2. Body height with feet apart: Vertical distance from the standing surface to the highest point of the head (vertex). Subject stands erect with feet placed on pre-marked footprints with approximately ten centimeters apart at the inside of the heel and 33 degrees rotation at the toes.
3. Crotch height: Vertical distance from the standing surface to the crotch. The anthropometer bar is placed between the thighs and raised by the subject to the point where it comfortably touches the highest point of the crotch. Subject stands erect with feet placed on pre-marked footprints with approximately ten centimeters apart at the inside of the heel and 33 degrees rotation at the toes.
4. Shoulder-elbow length (arm length): Surface distance measured from acromion to wrist at the ulna styloid landmark. Subject stands erect with the arm bent and fist placed on the hip.
5. Spine-shoulder length: Surface distance measured from cervicale to acromion. Subject stands erect with arms hanging freely.
6. Spine-wrist length (arm length): Surface distance measured from cervicale through acromion to the wrist at the ulna styloid landmark. Subject stands erect with the arm bent and fist placed on the hip.
7. Trochanterion height: Vertical distance between a standing surface and the trochanterion landmark. Subject stands erect with heels together.
8. Waist breadth, standing: Horizontal breadth of the waist at the level of the omphalion. Subject stands erect with heels together.
9. Waist circumference, standing: Horizontal circumference of the waist at the level of the center of the navel (omphalion). The subject stands erect with heels together.
10. Waist depth, standing: Horizontal distance between the front and back of the waist at the level of the center of the navel (omphalion). Subject stands erect with heels together.
11. Thigh circumference: Circumference of the right thigh at its juncture with the buttock. The subject stands erect with legs spread apart just enough so that the thighs do not touch.
12. Acromion height, sitting: Vertical distance between a sitting surface and the acromion landmark on the tip of the right shoulder. Subject sits erect with shoulder and upper arms relaxed, the fore-arms and hands extended forward horizontally, and the palms facing each other.

13. Bi-acromial breadth, sitting: Distance between the right and left acromion landmarks. Subject sits erect with shoulder and upper arms relaxed, the forearms and hands extended forward horizontally, and the palms facing each other.
14. Bi-deltoid breadth: Distance across the maximum protrusions of the right and left deltoid muscles. Subject sits erect with shoulder and upper arms relaxed, the forearms and hands extended forward horizontally, and the palms facing each other.
15. Buttock foot length: Horizontal distance between a buttock plate at the posterior point on either buttock and the tip of longest toe of the right foot. The subject sits erect with thighs parallel and knees flexed 90 degrees with feet in line with the thighs.
16. Buttock knee length: Horizontal distance between a buttock plate at the posterior point on either buttock and the anterior point of the right knee. The subject sits erect with thighs parallel and knees flexed 90 degrees.
17. Buttock-popliteal length: horizontal distance between a buttock plate placed at the most posterior point on either buttock and the back of the right knee (the popliteal fossa at the dorsal juncture of the calf and thigh). The subject sits erect with thighs parallel and knees flexed 90 degrees.
18. Cervical height, sitting: Vertical distance between a sitting surface and the cervicale landmark on the spine at the base of the neck. Subject sits erect with shoulders and upper arms relaxed and the forearms and hands extended forward horizontally and the palms facing each other.
19. Elbow rest height: Vertical distance between a sitting surface and the olecranon landmark on the bottom of the flexed right elbow. Subject sits erect with shoulders and upper arms relaxed and the forearms and hands extended forward horizontally and the palms facing each other.
20. Eye height, sitting: Vertical distance between a sitting surface and the ectocanthus landmark on the outer corner of the right eye. The subject sits erect with the head in the Frankfort plane. The shoulders and upper arms are relaxed, the forearms and hands are extended forward horizontally, and the palms facing each other. The thighs are parallel and the knees are flexed 90 degrees with the feet in line with the thighs.
21. Forearm-forearm breadth: Maximum horizontal distance across the upper body between the outer sides of the forearms. Subject sits erect with shoulders and upper arms relaxed and the forearms and hands extended forward horizontally and the palms facing each other.
22. Forearm-hand length: Horizontal distance between the back of the tip of the right elbow to the tip of the right middle finger. The subject sits erect with the upper arms hanging at the sides and the right elbow flexed 90 degrees. The hand is held out straight with the palm facing inward.
23. Hip breadth, sitting: Distance between the lateral points of the hips or thighs (whichever are broader). Subject sits erect with the feet and knees together.
24. Interpupillary Breadth: The distance of the two pupils is measured with a pupillometer.

25. Knee height, sitting: Vertical distance between a footrest surface and the suprapatella landmark at the top of the right knee. Subject sits with the thighs in parallel, the knees flexed 90 degrees, and the feet in line with the thighs.
26. Mid-shoulder height, sitting: Vertical distance between a sitting surface and the mid-shoulder landmark at the top of the right shoulder. Subject sits erect with shoulders and upper arms relaxed and the forearms and hands extended forward horizontally and the palms facing each other.
27. Popliteal height: Vertical distance from a footrest surface to the back of the right knee (the popliteal fossa at the dorsal juncture of the right calf and thigh). Subject sits with the thighs parallel, the feet in line with the thighs, and the knees flexed 90 degrees.
28. Sitting height: Vertical distance between a sitting surface and the top of the head. The subject sits erect with the head in the Frankfort plane. The shoulders and upper arms are relaxed, the forearms and hands are extended forward horizontally, and the palms facing each other. The thighs are parallel and the knees are flexed 90 degrees with the feet in line with the thighs.
29. Thigh clearance: Vertical distance between a sitting surface and the highest point on the top of the right thigh. Subject sits with the thighs in parallel, knees flexed 90 degrees, and the feet in line with the thighs.
30. Waist breadth, sitting: Horizontal breadth of the waist at the level of omphalion. Subject sits erect with shoulders and upper arms relaxed and the forearms and hands extended forward horizontally and the palms facing each other.
31. Waist depth, sitting: horizontal distance between the anterior point of the abdomen at the point of omphalion and the back at the side level. Subject sits erect with right hand resting on the left shoulder.
32. Waist circumference, sitting: Horizontal circumference of the waist at the level of omphalion. Subject sits erect with knees flexed at 90 degrees.
33. Waist height, sitting: Vertical distance from a sitting surface to the omphalion. Subject sits erect with knees flexed at 90 degrees.
34. Foot breadth (ball): Maximum breadth of the right foot. Subject stands with each foot in a foot-box. The heel of the right foot lightly touches the back of the box, and the side of the foot at the fifth-metatarsophalangeal-protrusion landmark lightly touches the side of the box. The medial side of the foot is parallel to the long axis of the box. A block is placed against the landmark at the first metatarsophalangeal protrusion to establish the measurement on the scale.
35. Foot circumference (ball): Circumference of the foot at the first and fifth metatarsophalangeal landmarks on the ball of the right foot. Subject stands with the feet about 10 cm apart.
36. Foot length: Maximum length of the right foot. Subject stands with each foot in a foot-box. The heel of the right foot lightly touches the back of the box, and the side of the foot at the fifth-

metatarsophalangeal protrusion landmark lightly touches the side of the box. The medial side of the foot is parallel to the long axis of the box. A block is placed against the tip of the longest toe to establish the measurement on the scale.

37. Functional leg length: Straight-line distance between the plane of the bottom on the right foot with the leg extended and the back of the body of a seated subject. Subject sits erect on a stool 40.8 cm high. The right leg is extended and the foot is on the base plate resting on the floor.
38. Hand breadth: Breadth of the right hand between the landmarks at metacarpale II and metacarpale V. Subject places the palm on a table with the fingers together and thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table.
39. Hand circumference: Circumference of the right hand at metacarpale II and metacarpale V. Subject places the palm on a table with the fingers together and thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table.
40. Hand length: Length of the right hand between the stylium landmark on the wrist and the tip of the middle finger. Subject places the palm on a table with the fingers together and thumb abducted. The middle finger is parallel to the long axis of the forearm. The two distal phalanges of the fingers lie on a flat surface 8 mm higher than the table.
41. Head breadth: Maximum horizontal breadth of the head above the attachment of the ears.
42. Head circumference: Maximum circumference of the head above the attachment of the ears to the head, just above the ridges of the eyebrows, and around the back of the head.
43. Head length: Distance from the glabella landmark between the brow ridges to the posterior point on the back of the head.
44. Overhead fingertip reach, sitting: Vertical distance between a sitting surface and the tip of the right middle finger of a seated subject whose arm is extended overhead.
45. Overhead fingertip reach, standing: Vertical distance between a standing surface and the tip of the right middle finger when the arm is extended overhead on a wall scale.
46. Overhead fingertip reach, extended: Vertical distance between a standing surface and the tip of the right middle finger when the arm is extended overhead as high as possible on a wall scale.
47. Thumb tip reach: Horizontal distance from a back wall to the tip of the right thumb on a wall scale.
48. Wrist-wall length: Horizontal distance between a back wall and the stylium landmark on the right wrist of the outstretched arm on a wall scale.

49. Wrist-wall length, extended: Horizontal distance between a back wall and the styliion landmark on the right wrist of the maximally outstretched arm on a wall scale.
50. Weight: Weight of the subject. Subject stands on the scale fully erect with weight distributed equally on both feet.

Appendix C

Description of Cab Workspace Values (Developed with reference from Sanders and Shaw, 1985)

1. Eye position, right and left: The subject is instructed to sit up and look forward. A head clamp is used to fix the head position. The ecotocanthus landmark of the right and left eyes is recorded by the FaroArm, respectively. Then right and left eye positions are estimated based on these two landmarks and the interpupil distance measured in traditional anthropometry.
2. Foot reach on clutch (unblocked): For this measurement, the clutch pedal is unlocked to permit fore-aft travel. The subject is instructed to put the ball of his/her left foot on the clutch pedal and fully but naturally extend the leg forward without pointing the toes. The clutch position is recorded by the FaroArm.
3. Forward grip reach position: The subject uses the three-finger grasp to grip one of the four knobs located on a front panel. There are four knobs. The two knobs on the subject's right are reached by the right hand and the two knobs on the subject's left are reached by the left hand. The non-involved hand remains on the steering wheel while the other hand reaches forward. The subject is instructed to extend the arm, lean comfortably forward and stop at the maximum reach that is comfortable for him or her. The thumbtip position is recorded by the FaroArm.
4. Hand position on the steering wheel, right and left: The subject is instructed to hold the steering wheel as if he/she is driving. The metacarpale II and V landmarks of the right and left hand are recorded by the FaroArm.
5. Head position, top: The subject is instructed to sit up and look forward. A head clamp is used to fix the head position. The vertex landmark is recorded by the FaroArm.
6. Knee position, left foot on clutch (blocked): The subject is instructed to place the ball of his/her left foot on the clutch pedal which is blocked for this measurement. The anterior knee point is recorded by the FaroArm.
7. Knee position, right foot on accelerator (floor-mounted and suspended): The subject is instructed to place the ball of his/her right foot on the accelerator pedal which is blocked for this measurement. The anterior knee point is recorded by the FaroArm.
8. Knee position, right foot on brake (floor-mounted and suspended): The subject is instructed to place the ball of his/her right foot on the brake pedal which is blocked for this measurement. The anterior knee point is recorded by the FaroArm.
9. Trochanter, right: The subject is instructed to assume a normal driving posture. The right trochanter point is recorded by the FaroArm.
10. Preferred brake depressing depth (floor-mounted): The floor-mounted brake is unblocked. The subject is instructed to place the ball of his/her right foot on the pedal and depress the pedal to an extent that is comfortable to him or her and stop. Two points on the right edge of the pedal are

recorded by the FaroArm. The angle between the line formed by the two points relative to the floor plane is calculated.

11. Seat fore-aft travel: The screw on the right front end of the seat (beneath the seat cushion) is recorded by the FaroArm.
12. Seat height: The screw on the right front end of the seat (beneath the seat cushion) is recorded by the FaroArm.
13. Seat back angle: The screw (seat back pivot) and another pre-determined point above the screw (right side view) of the seat will be recorded by the FaroArm. Then, the seat back angle relative to the seat base plane or the floor plane is calculated
14. Steering wheel center position: The steering wheel center position is recorded by the FaroArm.
15. Steering wheel angle: Three points on the upper perimeter of the steering wheel are recorded by the FaroArm. Then, the angle formed by the steering wheel plane and the floor plane is calculated.
16. Safety belt length: Safety belt length consisted of a lap belt component and a chest belt component. The length of both components will be determined by a pre-marked scale on the belt.
17. Stomach-steering wheel clearance: The position of the stomach point landmark and one point on the steering wheel observed to closest to the stomach point is recorded by the FaroArm and calculated as a straight distance.