SAE TECHNICAL PAPER SERIES

2000-01-3405

Methods for Laboratory Investigation of Truck and Bus Driver Postures

Matthew P. Reed, Michelle M. Lehto and Lawrence W. Schneider
University of Michigan Transportation Research Institute

Reprinted From: Ergonomics, Work Station, and Driver Issues (SP-1570)

The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL

Truck and Bus Meeting and Exposition
Portland, Oregon
December 4-6, 2000

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-5760

The appearance of this ISSN code at the bottom of this page indicates SAE's consent that copies of the paper may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay a $7.00 per article copy fee through the Copyright Clearance Center, Inc. Operations Center, 222 Rosewood Drive, Danvers, MA 01923 for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.

GLOBAL MOBILITY DATABASE

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

ISSN 0148-7191
Copyright 2000 Society of Automotive Engineers, Inc.

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions. For permission to publish this paper in full or in part, contact the SAE Publications Group.

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

2000-01-3405

Methods for Laboratory Investigation of Truck and Bus Driver Postures

Matthew P. Reed, Michelle M. Lehto and Lawrence W. Schneider
University of Michigan Transportation Research Institute

Copyright © 2000 Society of Automotive Engineers, Inc.

ABSTRACT

Few studies have systematically examined the effects of truck and bus workstation geometry on driver posture and position. This paper presents methods for determining drivers' postural responses and preferred component locations using a reconfigurable vehicle mockup. Body landmark locations recorded using a three-dimensional digitizer are used to compute a skeletal-linkage representation of the drivers' posture. A sequential adjustment procedure is used to determine the preferred positions and orientations of key components, including the seat, steering wheel, and pedals. Data gathered using these methods will be used to create new design tools for trucks and buses, including models of driver-selected seat position, eye location, and needed component adjustment ranges. The results will also be used to create accurate posture-prediction models for use with human modeling software.

INTRODUCTION

The design of driver workstations in truck and bus cabs is assisted by the use of several design tools embodied in recommended practices adopted by the Society of Automotive Engineers (SAE). These include the driver eyellipse (SAE J941), seat position distributions (SAE J1517 and J1516), and belly contours (J1050). The most recent revisions of these practices, dating from the mid-1980s, were based on the last large-scale U.S. study of truck driver posture. Sanders and Shaw (1985) used stereophotogrammetry to measure the postures of 183 male and 58 female truck drivers as they sat in a reconfigurable vehicle mockup. The data were analyzed, using techniques previously applied to data from passenger cars, to develop eyellipses and seat position curves (Phillipart et al. 1985, Stanick et al. 1987).

The Sanders study was conducted prior to the widespread use of computerized human figure models to assess vehicle designs. These tools are now used to assess driver reach, vision, and clearance in new truck and bus models (Porter et al. 1994, Loczi 2000). Unfortunately, the Sanders data were not presented in a manner appropriate for use with human figure models. The population distributions given in the published reports, and the associated SAE recommended practices, cannot be used to make posture predictions for individual drivers.

In recent years, there have been important advances in posture prediction for drivers of passenger cars and light trucks. As part of the ASPECT program (Schneider et al. 1999), Reed et al. (1999a) developed the Cascade Model, a posture-prediction approach that uses regression models based on measured driver postures, combined with data-guided inverse kinematics, to predict driving posture. The Cascade Model accurately predicts the postures of passenger car drivers (Reed et al. 2000). Seidl (1997) developed an optimization-based approach that is the basis for the posture prediction used in the RAMSIS model. RAMSIS has been used extensively for driver workspace analysis in passenger cars (Loczi et al. 1999) and in heavy trucks (Loczi 2000).

This paper describes the application of methods originally developed for the study of passenger car occupant postures to investigations of heavy vehicle driver postures. The laboratory and data collection facilities are discussed, along with strategies for participant recruitment. The importance of appropriate test conditions and driver-selection procedures is highlighted.

METHODS

Vehicle Mockup

Laboratory studies of driver posture provide the opportunity to observe a driver's posture in many different vehicle configurations in a short amount of time. For the current studies, a reconfigurable truck cab has been constructed that allows recreation of key characteristics of the interior geometry of a wide range of Class B vehicles.

A driver's posture can be viewed as the output of an internal optimization procedure that balances comfort against the physical and perceptual requirements of the task. For example, the driver must be able to operate the pedals, manipulate the steering wheel and shifter, and view the exterior environment, both directly and via mirrors. Table 1 lists some of the physical factors that act as constraints on driver posture.

Table 1
Physical Constraints on Driver Posture

Constraint	Fixed in Current Study	Set at Several Levels in Current Study	Driver Adjusts in Current Study
Steering wheel vertical position with respect to the floor		x	x
Steering wheel fore-aft position with respect to the pedals		x	x
Pedal lateral spacing	x		
Pedal fore-aft spacing		x	
Pedal stroke length and force requirements (particularly clutch)		x	
Shifter location, movement envelope, and force requirements			x
Steering wheel diameter		x	
Steering wheel angle			x
Seat height with respect to floor		x	x
Other seat factors, such as cushion and back angles		x	x
Exterior viewing requirements	x		
Secondary control locations	x		

Studies in passenger cars have shown that seat height and the fore-aft position of the steering wheel are the primary geometric factors affecting driver posture (Flannagan et al. 1998). The typical arrangement of component locations and availability to the driver of component adjustments suggests that additional factors may be important in heavy vehicles. Because steering wheel angles are generally closer to horizontal in heavy vehicles, the steering wheel diameter may affect driver posture to a greater extent than in passenger cars. In passenger cars, the diameter of the steering wheel and the vertical seat adjustment range are considerably constrained by the torso length of short drivers, who must simultaneously be able to see over the top of the steering wheel and fit their thighs beneath it. In a vehicle with a steering wheel angle close to horizontal (most SAE Class B vehicles), even a person with a short torso can choose a wide range of vertical torso positions with respect to the steering wheel while still obtaining adequate vision and clearance. Consequently, both the steering wheel vertical position (with respect to the floor) and steering wheel diameter are important variables for study in heavy vehicles.

If the seat height above the floor is fixed or highly constrained, it becomes an important constraint on driver posture. However, many trucks and buses are now built with seats having a large range of vertical adjustment. In this case, the vertical position of the steering wheel becomes the primary constraint on the vertical position of the driver's torso.

The large number of factors that may affect driver posture necessitates prioritizing the factors when designing a posture-measurement study. For the current study, the steering wheel fore-aft and vertical position with respect to the pedals and floor were identified as the primary factors. Secondary factors include steering wheel diameter, seat height (if fixed), and seat cushion angle.

A mockup of a vehicle cab has been constructed to manipulate these variables independently. Figure 1 shows a schematic of the mockup, and Figure 2 shows several views of the mockup in the laboratory. To preserve a reasonable relationship between the steering wheel and instrument panel, the vertical position of the steering wheel relative to the main cab structure is fixed. The floor of the mockup in the area of the pedals (heel rest surface) is adjustable vertically to provide a range of steering wheel and seat heights. The brake, accelerator, and clutch pedals are mounted to a plate that pivots at the accelerator heel point. This allows the pedal plane angle to be changed without moving the accelerator heel point relative to the floor. The floor/pedal assembly moves fore-aft on a motorized adjuster over a wide range. The steering wheel angle is adjustable around a lateral pivot located 50 mm below the plane of the steering wheel. This pivot point location, which is closer to the wheel plane than in most production systems, minimizes the change in steering wheel height and fore-aft position that result from changes in steering wheel angle.

The seat is mounted to the mockup frame independent of the heel rest surface (floor). The seat fore-aft adjustment is provided by a motorized screw drive that moves the mounting platform over a 400-mm range, ensuring that all drivers will be able to obtain their preferred fore-aft seat positions. Vertical seat position is adjusted by a pneumatic system that provides 200 mm of travel. Seat cushion angle and seat back angle are also adjustable. The cab has electrically adjusted mirrors on both sides.

Controls for the motorized adjusters for each moving mockup component are provided both to the experimenters and to the driver. The experimenter uses the controls to set initial test conditions. Depending on the particular test condition being studied, the driver may subsequently be permitted to adjust component positions (e.g., adjust the fore-aft position of the pedals). The shifter is a primary control that may influence drivers' postures in some vehicles. However, adding the shifter position as an input variable would create an excessively complicated test matrix. Consequently, drivers in the current study adjusted the shifter to their preferred positions, which were recorded as a dependent measure.

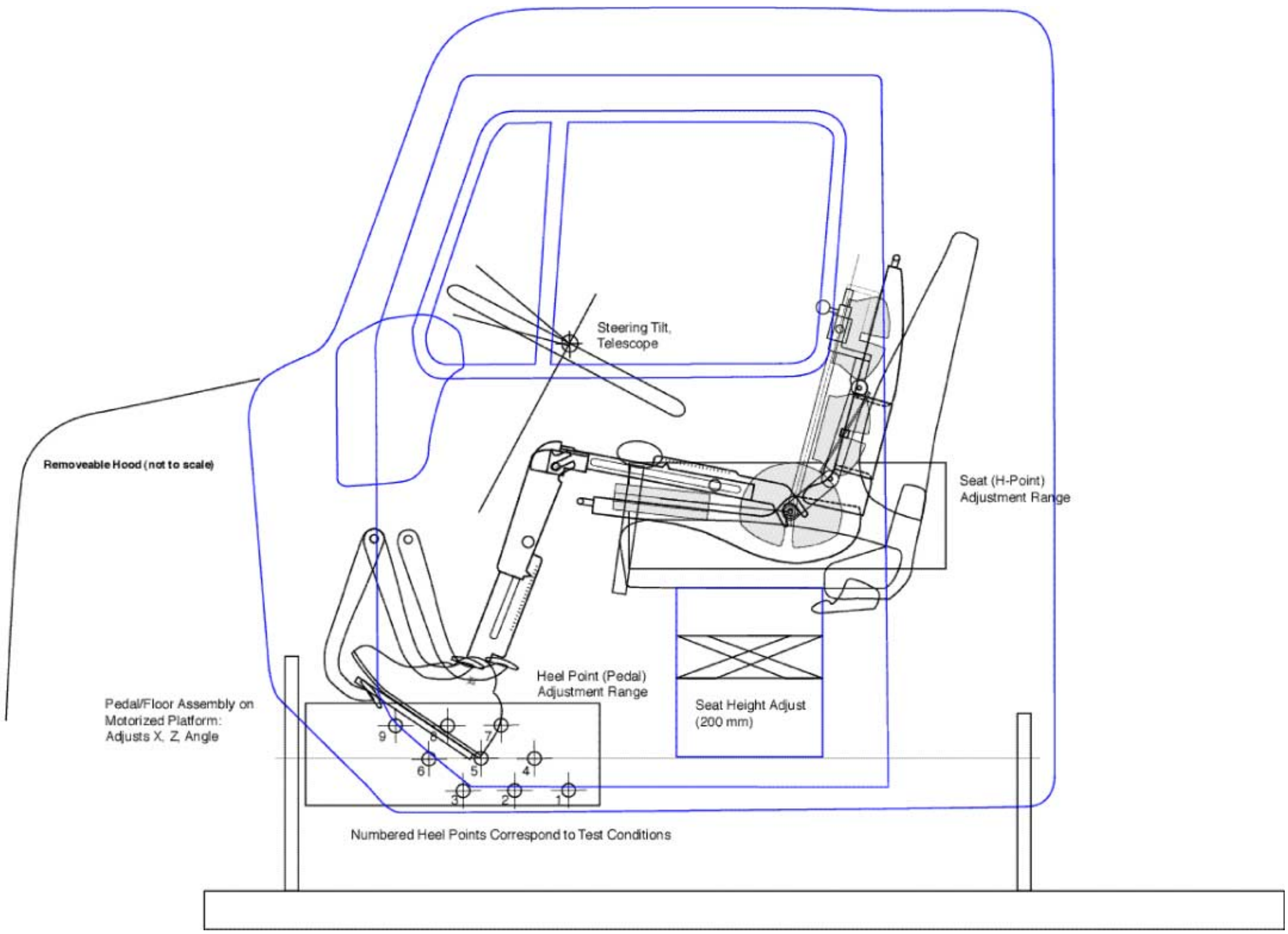

Figure 1. Schematic of cab mockup.

Figure 2. Laboratory cab mockup.

Test Matrix Development

After the identification of the factors of interest (Table 1), the next step in the development of the test matrix is the determination of the factor levels and the select of factor effects and interactions to be studied. There are at least 10 factors in Table 1 that could be manipulated independently, so that a full factorial design using only 2 levels of each factor would have over 100 test conditions. This would clearly be impractical, and is also unnecessary, since prior knowledge and practical considerations can readily yield a much simpler test matrix.

For each of the primary test factors, a good estimate of the main effects should be obtained, with the potential for evaluating nonlinearity. This suggests testing the vertical steering wheel position, fore-aft steering wheel position, and seat height at three levels for each, and manipulating them independently, giving 27 test conditions. However, since seat height and steering wheel height are highly correlated in practice, an effective reduction in the number of conditions can be obtained by fixing the relative height of the steering wheel and seat, so that seat height differ from steering wheel height by a constant. This reduces the matrix to nine conditions, but means that seat height effects cannot be differentiated from steering wheel height effects. This is not a substantial limitation, because steering wheel height effects are primarily of interest when the driver is allowed to adjust the vertical seat position. In that case, the seat height becomes a dependent rather than independent variable and the steering-wheel height effects on driver-selected seat height and other posture outcomes can be determined.

Table 2 shows a test matrix created for the current study. The five conditions (Group A) are a 2 x 2 matrix in steering wheel fore-aft position and steering wheel vertical position, along with a center point. Conditions six through nine (Group B) complete the 3-x-3 matrix. Testing is conducted both with the seat height fixed (a constant vertical distance between seating reference point and the steering wheel center) and with the seat height adjustment under the driver's control.

The remainder of the test matrix is comprised of sub-experiments that test other main effects and interactions of interest. The Group C conditions investigate the effects of seat cushion angle at two levels. The seat cushion angles are presented at both high and low steering wheel positions, providing an opportunity to assess whether seat cushion angle effects are different with different cab configurations. The group D conditions are a repeat of the Group A conditions with a longer clutch travel. This provides an opportunity to assess the effects of clutch travel, along with potential interactions with steering wheel height or fore-aft position. The Group E conditions examine steering wheel diameter effects. Combined with conditions 3, 7, and 8, Group E demonstrate the effects of steering wheel diameter and potential interactions with steering wheel fore-aft position relative to the pedals.

Driver Adjustments

Any test factor can be switched from an independent variable to a dependent variable by allowing the driver to adjust the component location. At the extremes, the driver could be provided with no seat or component adjustments or every component could be adjustable. Fixed component locations provide the opportunity to study how drivers adjust to postural constraints, while driver-adjustable components provide direct information on preferred positions.

In practice, it is useful to conduct trials under both fixed and adjustable conditions. One approach is to begin a trial with most components fixed, and then progressively allow the driver to adjust additional components, until eventually all components have been set by the driver to preferred positions.

In the current testing, the driver is always free to adjust the fore-aft seat position, seat back angle, and steering wheel angle. These component adjustments are provided on virtually all new trucks and buses. Other component locations are initially fixed, then added to the adjustment pool for subsequent measurements (see Procedures).

Table 2
Test Matrix

Condition	Condition Group	Steering Wheel Z re Floor	Steering Wheel X re AHP	Seat Cushion Angle	Steering Wheel Dia.	Clutch Travel
1	A	Low	Short	Mid	Mid	Short
2	A	Low	Long	Mid	Mid	Short
3	A	Mid	Mid	Mid	Mid	Short
4	A	High	Short	Mid	Mid	Short
5	A	High	Long	Mid	Mid	Short
6	B	Low	Mid	Mid	Mid	Short
7	B	Mid	Short	Mid	Mid	Short
8	B	Mid	Long	Mid	Mid	Short
9	B	High	Mid	Mid	Mid	Short
10	C	Low	Mid	Low	Mid	Short
11	C	Low	Mid	High	Mid	Short
12	C	High	Mid	Low	Mid	Short
13	C	High	Mid	High	Mid	Short
14	D	Low	Short	Mid	Mid	Long
15	D	Low	Long	Mid	Mid	Long
16	D	High	Short	Mid	Mid	Long
17	D	High	Long	Mid	Mid	Long
18	E	Mid	Short	Mid	Small	Short
19	E	Mid	Short	Mid	Large	Short
20	E	Mid	Long	Mid	Small	Short
21	E	Mid	Long	Mid	Large	Short

Driver Selection

Driver body dimensions are important determinants of posture and component locations, and should be the primary criteria by which drivers are selected. Extensive studies of driver posture and position in passenger cars and light trucks (Flannagan et al. 1998, Manary et al. 1999, Reed et al. 1999a) have led to several important observations concerning driver sampling which are equally applicable to heavy vehicle studies.

First, the test population should include more people at the anthropometric extremes than are present in the target population. A representative sample is inefficient for determining the effects of anthropometric variables on posture, position, and component location preference. Following testing, the data can be weighted to represent any population of interest. Second, stratified sampling based on stature (standing height) and gender yields a test population that has wide variability on other important dimensions, such as weight and sitting height (Manary et al. 1999). Adding additional stratification variables, such as weight, greatly increases the difficulty in recruiting drivers, without adding substantially to the strength of the study. Note that there may be issues for which certain anthropometric extremes are important and should be included in the driver pool. For example, some large drivers have clearance problems between the steering wheel rim and their abdomens. An adequate sample of drivers with large waist circumferences would be necessary to quantify affects associated with this clearance dimension.

Table 3 shows a typical stratified sampling approach for a driving posture experiment. Driver groups are defined using percentiles of the U.S. civilian population, based on NHANES II, the second National Health and Nutrition Examination Survey (Abraham et al. 1979). Note that the shortest and tallest drivers are sampled at higher rates, relative to their representation in the general population, than are drivers with midrange statures.

A large number of participants will ensure that the study has the statistical power to detect even very small factor effects, but large sample sizes also increase the cost of the experiment. In most driving studies, factor effects large enough to be of practical interest can be detected reliably with only about 30 drivers. If gender differences are of interest, along with potential interactions between, e.g., stature and gender, then about twice that number should be tested. Table 3 shows a sampling strategy for study of 64 drivers, focussing equally on men and women.

Table 3
Typical Driver Sampling Strategy

Group	Gender	Percentile Stature Range by Gender *	Stature Range (mm)	Number of Drivers
0	Female	< 5th	Under 1511	8
1	Female	5-15	1511 - 1549	8
2	Female	15-40	1549 - 1595	4
3	Female	40-60	1595 - 1638	4
4	Female	60-85	1638 - 1681	4
5	Female	85-95	1681 - 1722	4
6	Male	5-15	1636 - 1679	4
7	Male	15-40	1679 - 1727	4
8	Male	40-60	1727 - 1775	4
9	Male	60-85	1775 - 1826	4
10	Male	85-95	1826 - 1869	8
11	Male	> 95th	Over 1869	8
	Total			64

* Abraham et al. 1979. Categories are defined using NHANES II data rather than more recent data to preserve continuity with previous UMTRI studies.

Procedures

The methods by which a laboratory study is conducted are important in determining the validity of the resulting data. The starting positions of components are particularly important. If the components are initially set to extreme positions (e.g., seat full rearward), the resulting data will be biased in the direction of the initial conditions. Instead, components to be adjusted by the driver should be set to initial positions at the expected average position across drivers, which should also be close to the center of the adjustment range. These positions can readily be determined by pilot testing or reference to existing data.

The drivers are asked to select a “normal driving posture” while manipulating the components. It is important that the drivers exercise the full range of motion of the pedals, shifter, and steering wheel as they adjust the components. The experimenter should encourage the driver to readjust each component to ensure that he or she has obtained a stable posture. Some instruction may be necessary to ensure that the drivers know how to operate adjusters with which they may not be familiar.

Studies with passenger car drivers have demonstrated that these instructions produce consistent, repeatable postures. Drivers have a clear conception of “normal driving posture,” although many will volunteer that they sometimes sit with other, generally extreme postures (for example, with one foot on the instrument panel). Since these other postures are not of great interest for design, data concerning them is not recorded.

Test conditions are presented in randomized order, although it is sometimes convenient to block trials (e.g., those with one steering wheel diameter). In this case, the order of presentation of blocks is counterbalanced across the subjects in each anthropometric group. Testing should be held to under two hours in duration, because the driver’s attention often wanes in longer test sessions. Often, it is necessary to schedule the driver for two test sessions. In this case, the assignment of test conditions to test sessions should be counterbalanced within anthropometric groups, and a subset of test conditions should be presented in each session to provide data by which to compare the postures across test sessions.

Posture Measurement and Representation

There are a wide variety of methods of measuring and representing human postures, a number of which have been applied to vehicle occupants. The most common techniques involve video tracking of targets attached to the skin or clothing (Pruett et al. 2000) and manual measurement of body landmark locations (Reed et al. 1999b). The latter technique is used in the UMTRI testing. An articulated coordinate-measurement device, manufactured by FARO Technologies, is used to measure the three-dimensional locations of body landmarks, which are palpated by the experimenter as the measurements are made. This provides more accurate data on skeleton location than is possible using skin- or clothing-mounted targets, but is only applicable to static postures.

Figure 3 shows the landmarks that are recorded. Usually data are taken from only one side of the body, typically the right. The body landmarks are used to estimate the internal locations of skeletal joints that define a kinematic linkage representation of the body, as shown in Figure 4. The locations of the spinous-process landmarks are recorded with respect to anterior landmarks on the pelvis and chest during an initial measurement on a laboratory seat that allows access to the spine. The individual torso geometry is then used with the data measured in vehicle seats to obtain estimates of spine location. Details of the posture measurement and representation techniques are provided in Reed et al. (1999b).

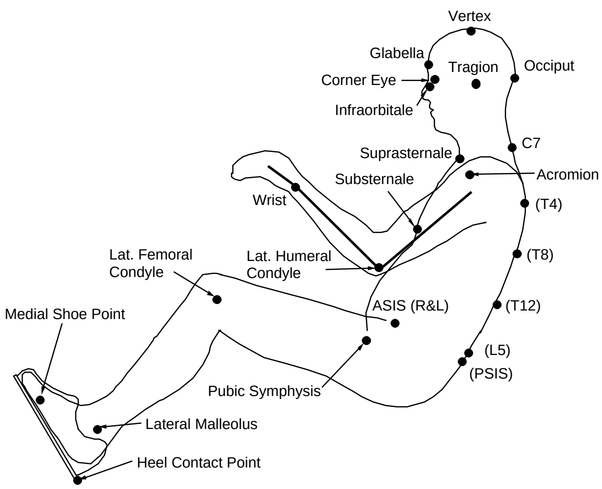

Figure 3. Body landmarks used to calculate internal joint locations and segment orientations. Parentheses indicate landmarks measured only in a specially constructed laboratory seat.

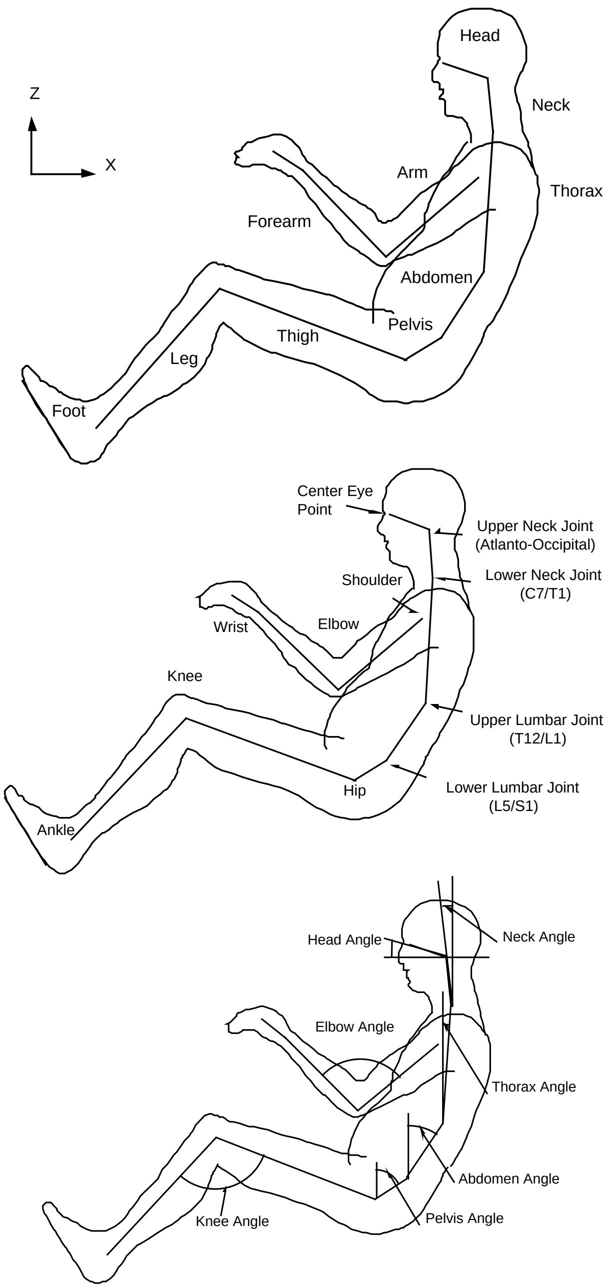

Figure 4. Definitions of kinematic linkage and posture measures. Angles referenced to horizontal or vertical are XZ (sagittal) plane angles. Angles between segments (elbow angle, knee angle, and ankle angle) are measured in the plane formed by the segments (included angles). Note: Neck angle is negative as shown. All other angles are positive as shown.

Subjective Assessments

Although the posture data are the primary dependent measures, subjective information regarding the cab configurations is often useful to compare alternative designs. Three types of data are used to assess driver's preferences. First, the component locations selected by the drivers are measured. These give quantitative information regarding the preferred component locations, which can be compared to those of a proposed design. Second, the driver is asked to provide body-region and overall discomfort ratings. Third, the driver is asked to report on the location or orientation of a component, specifying, for example, whether it is too close or too far away. The questionnaire developed for use in truck-cab testing is reproduced in the appendix. The driver rates the position of the steering wheel as "too close" or "too far", and also specifies using a numerical score how far the wheel is from an optimal position. Disomfort ratings are given on a numerical score. The questionnaire is presented on a clipboard or screen in front of the driver. All responses are verbal, so that the driver can respond without moving out of his or her selected driving posture. There is a potential directionality conflict between the body-area discomfort scales and the overall evaluation. For continuity with previous data, discomfort is rated using zero (left end of scale) to represent no discomfort, and 10 (right end of scale) to represent severe discomfort. However, for overall package evaluations, high numbers are customarily good scores. This potential conflict is resolved by careful instructions to the subjects and monitoring to ensure that the proper directionality is observed.

The subjective data provide the opportunity to evaluate the extent to which a candidate design will accommodate the target population (defined anthropometrically) at the desired subjective level. The shape of the response functions is of particular importance. For example, drivers may be very sensitive to the fore-aft position of the steering wheel, but less sensitive to the height of the wheel. Together with the posture data, this information can be used to evaluate alternative designs.

Posture Analyses

The joint locations and segment orientations obtained from the kinematic model representation of the driver's posture are the primary dependent measures. A variety of variables are calculated for use in analysis. The fore-aft and vertical position of the hips and eyes relative to the heel surface and accelerator pedal (ball of foot) are the most important variables. The angular relationship between the hip and eye locations defines a useful measure of torso recline, and the hip location reflects the driver's seat-position selections.

Analysis of variance (ANOVA) and regression analyses are used to determine if and how the independent variables affect driver posture. Using ANOVA, drivers are included as an independent factor, so that other variables, such as steering wheel position or seat height, are assessed using a within-subjects analysis. This is a sensitive method for determining, for example, whether the fore-aft position of the steering wheel with respect to the pedals affects the fore-aft steering wheel position. However, within-subjects ANOVA does not provide information about the effects of independent variables that differ between drivers, such as stature and weight. Regression analyses, usually using linear models, provide a means of combining both between- and within-subjects variables to predict posture outcomes. The resulting models are directly applicable to posture prediction for use with human figure models, for which the inputs are the figure anthropometry and the workspace geometry.

In-Vehicle Validation

Laboratory studies are useful because a wide range of test conditions can be presented, with various parameters controlled as needed. However, the resulting postures must be compared to those obtained in real vehicles driven on roads.

A typical validation study will involve six to ten vehicles, selected to span the range of intended application of the posture-prediction models. Using procedures similar to those employed in the laboratory, drivers enter each truck, adjust various components, and drive a road route. The posture and selected component locations are recorded after the drive, using procedures essentially identical to those used in the laboratory.

In general, postures measured in the vehicles will be different from those measured in the laboratory, even if the same drivers are used and the on-road package configuration is nominally identical to one used in the laboratory study. The purpose of the data analysis is to determine if the posture prediction models based on the laboratory data are biased, and if the measures of residual variance obtained in the laboratory study are reasonable. Predictions for each in-vehicle condition are made using the individual driver's anthropometry and the package geometry. The results are compared to the measured postures on key variables, typically hip and eye locations. An accurate model will predict average postures that differ only slightly from the actual postures across vehicles. A bias is noted if the models, based on laboratory data, produce errors that are in a consistent direction across vehicles. A small bias can be readily corrected, but a more serious problem is observed if the model predictions differ from the on-road average by different magnitudes and in different directions across vehicles. This suggests that there are important differences between vehicles that are not reflected in the laboratory-based models. For example, if headroom is an important restriction in some trucks, and was not included in the posture-prediction models, then prediction errors will be larger in trucks with restrictive headroom.

Another important assessment to be made in analysis of in-vehicle validation data is whether the laboratory studies accurately predict the residual variance. After accounting for anthropometric and vehicle factors, a considerable amount of postural variance remains. In passenger cars, this residual variance ranges from about 25 percent for seat position to 50 percent or more for eye position (Reed and Flannagan 2000). The residual variance is estimated in the regression analysis, and can be compared using standard ANOVA techniques. Similar variances mean that population distribution estimates based on the laboratory data (e.g., eye location range) are likely to be accurate predictors of actual posture distributions.

DISCUSSION

The trend toward increasing use of computer-aided design tools to conduct human-factors assessments of truck and bus cabs necessitates renewed attention to the underlying database of driver behavior and subjective preference. The methods described in this paper, developed over decades of research into passenger car occupant postures, are now being applied to studies of heavy-vehicle cab layouts. Research of this type is time consuming; however, the time and cost required are minimal compared with the reductions in redesign and prototype fabrication that can be avoided using improved data and models.

At least one systematic study of truck driver posture has been conducted previously (Sanders and Shaw 1985). Unfortunately, the data from that study are no longer available, and the published results do not provide sufficient detail for manikin-based design procedures or revised percentile-accommodation models.

One difficulty in conducting studies of truck drivers is finding participants who have experience in the vehicles of interest (e.g., Class 7 and 8 trucks). Because of their experience driving heavy vehicles, these drivers might choose postures that are different from those that a passenger car driver would choose under the same conditions. In an ongoing study, an anthropometrically similar sample of non-truck-drivers is being compared to a truck driver population with respect to both posture and subjective variables. If the differences between the groups are small, then the pool of potential participants for future studies will be larger.

The distributions of anthropometric variables, such as stature and waist circumference, among truck drivers is slightly different than the general population. This might suggest that only truck drivers have the appropriate anthropometric characteristics. However, truck drivers constitute a subset of the general population, so a general population sample will include people who span the range of truck driver anthropometry. The statistical posture prediction models that result from the laboratory studies include anthropometric variables as inputs. Hence, the results can be adjusted to predict truck driver postures by inputting the appropriate anthropometry.

In small-scale studies of truck drivers, the participants are often chosen approximately proportional to their representation in the current driver population based on some measures (e.g., gender and stature). Hence, many studies have included few or no women. The result, however, is a database that is skewed toward male truck drivers. Cabs designed using these data are likely to fit women poorly, perpetuating a situation in which many women are physically unable to drive trucks because of poor cab layout. Manufacturers of passenger cars and light trucks have made considerable strides in recent decades in improving the anthropometric range of the population that can be accommodated, but heavy truck manufacturers have lagged behind. In the current era, when recruiting and retaining drivers is increasingly difficult, increasing the percentage of potential drivers who can comfortably and safely operate the vehicle makes economic sense.

REFERENCES

Abraham, S., Johnson, C.L., and Najjar, F. (1979). Weight and height of adults 18-74 years: United States, 1971-74, *Vital and Health Statistics, Series 11, Number 208*. DHEW Publications Number 79-1656. Hyattsville, MD: U.S. Department of Health Education and Welfare.

Flannagan, C.A.C., Manary, M.A., Schneider, L.W., and Reed, M.P. (1998). An improved seating accommodation model with applications to different user populations. Technical Paper No. 980651. Warrendale, PA: Society of Automotive Engineers, Inc.

Loczi, J., Dietz, M., and Nielson, G. (1999). Validation and application of the 3-D CAD manikin RAMSIS in automotive design. Technical Paper 1999-01-1270. Warrendale, PA: Society of Automotive Engineers, Inc.

Loczi, J. (2000). Application of the 3-D CAD Manikin RAMSIS to Heavy Duty Truck Design at Freightliner Corporation. Technical Paper 2000-01-2165. Warrendale, PA: Society of Automotive Engineers, Inc.

Manary, M.A., Flannagan, C.A.C., Reed, M.P., and Schneider, L.W. (1999). Human subject testing in support of ASPECT. Technical Paper 990960. Warrendale, PA: Society of Automotive Engineers, Inc.

Phillipart, N.L., Kuechenmeister, T.J., and Stanick, J.M. (1985). Describing the truck driver workspace. Technical Paper 85217. Warrendale, PA: Society of Automotive Engineers, Inc.

Porter, J.M., Case, K., Freer, M.T., and Bonney, M.C. (1993). Computer-aided ergonomics design of automobiles. In *Automotive Ergonomics*, ed. B. Peacock and W. Karwowski, 43-77. London: Taylor and Francis.

Pruett, C.J., Wirsching, H-J., and Logmangino, P. (2000). In-vehicle measurement of human driving behavior. Technical Paper 2000-01-2153. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P., Manary, M.A., and Schneider, L.W. (1999a). Automobile occupant posture prediction for use with human models. Technical Paper 990966. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P., Manary, M.A., and Schneider, L.W. (1999b). Methods for measuring and representing automobile occupant posture. Technical Paper 990959. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. (2000). Comparison of methods for predicting automobile driver posture. Technical Paper 2000-01-2180. Warrendale, PA: Society of Automotive Engineers, Inc.

Reed, M.P. and Flannagan, C.A.C. (2000). Anthropometric and postural variability: limitation of the boundary manikin approach. Technical Paper 2000-01-2172. Warrendale, PA: Society of Automotive Engineers, Inc.

Sanders, M.S. and Shaw, B.E. (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, Inc.

Schneider, L.W., Reed, M.P., Roe, R.W., Manary, M.A., Flannagan, C.A.C., Hubbard, R.P., and Rupp, G.L. (1999). ASPECT: The next-generation H-point machine and related vehicle and seat design and measurement tools. Technical Paper 990962. Warrendale, PA: Society of Automotive Engineers, Inc.

Seidl, A. (1997). RAMSIS - a new CAD-tool for ergonomic analysis of vehicles developed for the German automotive industry. Technical Paper 970088. Warrendale, PA: Society of Automotive Engineers, Inc.

Stanick, J.M., Phillipart, N.J., and Kuechenmeister, T.J. (1987). Describing the truck driver eye and head accommodation. Technical Paper 871531. Warrendale, PA: Society of Automotive Engineers, Inc.

Appendix

TRUCK CAB QUESTIONNAIRE

Arms

No Discomfort	0	1	2	3	4	5	6	7	8	9	10	Severe Discomfort

Legs

No Discomfort	0	1	2	3	4	5	6	7	8	9	10	Severe Discomfort

Torso

No Discomfort	0	1	2	3	4	5	6	7	8	9	10	Severe Discomfort

Overall

No Discomfort	0	1	2	3	4	5	6	7	8	9	10	Severe Discomfort

STEERING WHEEL — **Just Right**

Too Close	5	4	3	2	1	**0**	1	2	3	4	5	Too Far
Too Low	5	4	3	2	1	**0**	1	2	3	4	5	Too High

SEAT HEIGHT — **Just Right**

Too Low	5	4	3	2	1	**0**	1	2	3	4	5	Too High

SEAT CUSHION ANGLE — **Just Right**

Too Flat	5	4	3	2	1	**0**	1	2	3	4	5	Too Angled

ACCEL/BRAKE PEDAL — **Just Right**

Too Close	5	4	3	2	1	**0**	1	2	3	4	5	Too Far
Too Low	5	4	3	2	1	**0**	1	2	3	4	5	Too High

CLUTCH PEDAL — **Just Right**

Too Close	5	4	3	2	1	**0**	1	2	3	4	5	Too Far
Too Low	5	4	3	2	1	**0**	1	2	3	4	5	Too High

OVERALL

Very Bad	0	1	2	3	4	5	6	7	8	9	10	Very Good

OTHER COMMENTS?