SAE TECHNICAL PAPER SERIES

2006-01-2360

Considering Driver Balance Capability in Truck Shifter Design

Matthew B. Parkinson
The Pennsylvania State University

Matthew P. Reed
University of Michigan Transportation Research Institute

Digital Human Modeling for Design and Engineering Conference
Lyon, France
July 4-6, 2006

SAE International™

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (724) 776-4841 Fax: (724) 776-0790 Web: www.sae.org

ISSN 0148-7191

Printed in USA

2006-01-2360

Considering Driver Balance Capability in Truck Shifter Design

Matthew B. Parkinson
The Pennsylvania State University

Matthew P. Reed
University of Michigan Transportation Research Institute

ABSTRACT

A person's ability to perform a task is often limited by their ability to maintain balance. This is particularly true in lateral work performed in seated environments. For a truck driver operating the shift lever of a manual transmission, excessive shift forces can necessitate pulling on the steering wheel with the other hand to maintain balance, creating a potentially unsafe condition. An analysis of posture and balance in truck shifter operation was conducted using balance limits to define the acceptable range of shifter locations. The results are dependent on initial driver position, reach postures, and shoulder strength. The effects of shifter force direction and magnitude were explored to demonstrate the application of the analysis method. This methodology can readily be applied to other problems involving hand-force exertions in seated environments.

INTRODUCTION

Seated balance maintenance capability has been used to quantify the capabilities of people with spinal cord injury (Seelen et al., 1998) and clinically to assess patient progress (Campbell et al., 2001). An additional use is as a constraint in the design of tasks and environments. Analysis of the forces involved in a particular task can be used to determine if a particular posture is “in” or “out” of balance. Based on these results, the task can be altered or the environment changed so that the worker can provide any necessary counterbalancing force and perform the task successfully. There are situations, however, where the designer needs to be confident that some segment of the population can perform the required task without resorting to counterbalancing maneuvers.

For example, the forces required to shift gears in an SAE Class B truck can be high enough that strength and balance maintenance become issues for drivers. If the forces are too high, or the shifter is placed inappropriately, the driver could resort to using the steering wheel to provide stability—a potentially hazardous condition. Consequently, the placement of the shifter and the magnitude and direction of the forces required to change gears are important aspects of cab design.

A typical approach to solving this problem is to analyze the task with a few drivers of different sizes, perhaps selected to represent the statistical range across the body dimensions or anthropometry of interest. This approach does not work well for this particular problem, however, because in addition to anthropometric variability the postural and strength variability must be taken into account. Consequently a new approach, outlined below and explained more fully in Parkinson et al. (2005) and Parkinson and Reed (2006) is used.

The postural variability describes the distribution of preferred driving postures exhibited by a population of drivers. Relying on a mean driving posture for a person of a particular size could provide misleading results since the location of the Center of Pressure (CoP), a key measure in balance assessment, is highly dependent on posture (Figure 1). Parkinson et al. (2005) gives a regression equation predicting mean balance maintenance capability (as measured by CoP excursion capability) based on stature, age, and hip breadth. But the residual variance from that prediction must be included to get an accurate estimate of a package performance, so that drivers with capabilities below the mean are not mistakenly counted as accommodated.

METHODS

Geometry from a typical SAE Class B truck was utilized for this study. The seat has 200 mm of fore-aft and 150 mm of vertical adjustability. The steering wheel adjustment

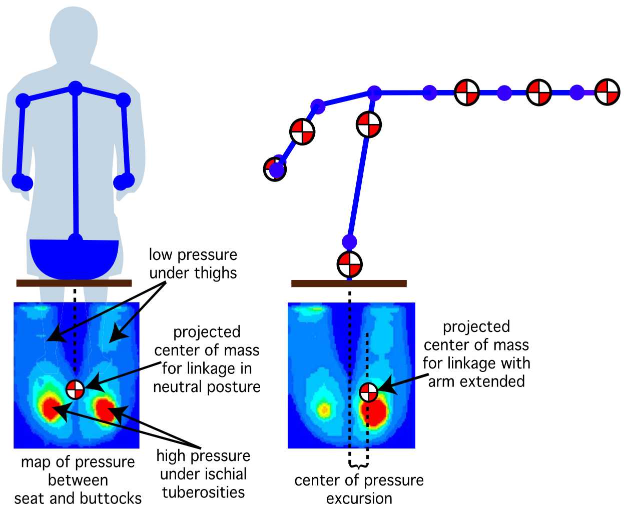

Figure 1: The maximum center of pressure excursion occurs when drivers have their arms extended and are shifting laterally, through neutral, against the spring return.

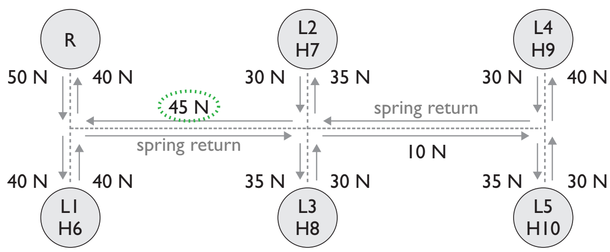

Figure 2: A typical shift pattern and associated forces. The drawing is not to scale. The force that is of primary interest, the 45N required to shift through neutral to R-L1/H6, is circled.

range is 20-60 degrees of pivot and 75 mm of telescope. A variety of shifter locations are considered throughout the paper, but all of them are to the right and forward of the driver H-point travel range. A typical manual-transmission shift pattern is shown in Figure 2 along with typical forces required to change gears. For the balance-limited case examined here, the lateral force required to down-shift (45 N) is the force vector of interest.

A virtual population of 1000 drivers was generated by random sampling from a multivariate normal distribution. The driver descriptors were selected to fulfill the requirements of the posturing, CoP capability, and predicted CoP excursion models. The posturing algorithm requires stature, sitting height, and BMI for each driver (Parkinson et al. 2005). Predicted CoP excursion capability is a function of stature, hip breadth, and age (Parkinson et al. 2006). In addition to those metrics already listed, upper arm length and ratio of upper arm to lower arm lengths are required to predict the location of each driver's CoP during the shifting task. The combinations of these anthropometric measures were generated such that the distributions and covariance of the relevant measures are the same as in the ANSUR population (Gordon et al., 1989). Age was distributed uniformly between 20 and 60 years.

Normal driving posture for each of the drivers in the population was predicted using a modified version of the Cascade Model posture-prediction approach outlined in Reed et al. (2002). The posture models for the current study are based on truck driver posture data from laboratory and in-vehicle studies (Reed et al. 2000, Jahns et al. 2001). The posturing algorithm predicts drivers' seat, steering wheel, and eye locations, including random variance not associated with the predictors, which allows drivers with similar anthropometry to be postured differently. Because of the large number of drivers in the virtual population, the range of preferred initial postures is statistically similar to that observed in real populations.

To determine the terminal posture for shifter operation, the right hand was placed at shifter location to be analyzed. If the shifter is within arm's length of the individual driver, the torso and right shoulder are left in their initial positions and the angle of the elbow is adjusted so that the distance between the shoulder and hand is consistent with the upper-extremity segment lengths. When the shifter is not within arm's length, the arm is assumed to be near full-extension and the torso moves towards the reach target by rotating about a point just below the right hip (Reed et al., 2004). The left hand grips the steering wheel at 9 o'clock and the elbow passively follows the torso as necessary.

The terminal posture was used to calculate the CoP at the buttocks / seat interface. Segment masses and locations of the centers of mass were determined using ratios from de Leva (1996). The shifting force was assumed to be operating at a single point in the right hand. The magnitude of the force varied from 35 N to 55 N, nominal values for an SAE Class B truck. The direction was always lateral since that is a worst-case balance scenario and matches the greatest force requirements in a typical shifter box (Figure 2). The location of the force was varied by changing the location of the center of the shifter box.

An excursion capability is calculated for each driver using the CoP capability model from Parkinson et al. (2006),

$$\begin{aligned} CoP_{cap} \quad = \quad & HipBreadth[0.56 + 1.69 \times 10^{-4} Stature - \\ & 2.55 \times 10^{-3} Age - 9.18 \times 10^{-4} HipBreadth \\ & + N(0, 0.063)] \end{aligned} \qquad (1)$$

where the final term represents the residual error from the regression. This is done for each member of the sampled population so that the range of capabilities across age and anthropometric variability is represented.

For a given shift force magnitude and location, each of the drivers in the population is postured and the location of the CoP in the terminal posture is calculated. The CoP is compared against the CoP excursion capability for that particular driver. If the predicted CoP location exceeds the capability, that driver is disaccommodated for that condi-

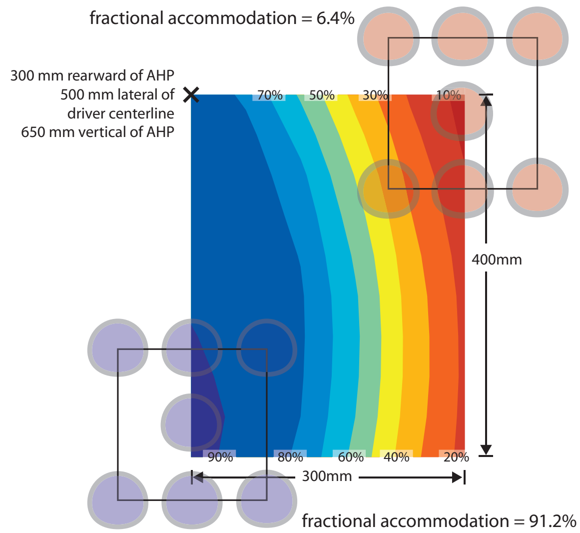

Figure 3: Standard shift patterns, shown to scale, superimposed on a contour plot of levels of fractional accommodation.

tion. That driver would be unable to shift through neutral to R-L1/H6 without exerting some counterbalancing force on the steering wheel or left side of the cab. The accommodation level is then the percentage of drivers whose predicted CoP location is within their capability.

To determine the effect of the force vector on balance-limited accommodation levels, the force magnitude and location were then systematically varied throughout a region of the right-hand reach envelope. Accommodation levels were calculated at each of these locations.

RESULTS

The procedure outlined above was followed for a 45 N force at an elevation of 650 mm above AHP. The shifter location was varied from 500 to 800 mm lateral of the driver centerline and from 300 to 700 mm rearward of AHP. Figure 3 is a contour plot of the accommodation levels in that space. A typical shift pattern is superimposed on the results for scale. The maximum accommodation level in that space is 91.2%, meaning that 912 of the 1000 drivers were able to perform the task without the need for counterbalancing support. Moving the shifter box to the other end of the design space reduces the accommodation level to a mere 6.4%.

The same procedure was repeated for multiple elevations, ranging from 500 mm to 800 mm (in 50 mm increments) above the AHP. The horizontal space was expanded to 300 to 800 mm lateral (in 25 mm increments) and 300 to 700 mm fore-aft (in 40 mm increments). Consequently, accommodation levels were calculated for the 1000 drivers at each of 1617 nodes throughout the three-dimensional space. These calculations were performed for force levels of 35 N and 55 N. The elevation contour plots were then interpolated to create the iso-accommodation surfaces in Figure 4. The surfaces show the boundaries within which the center of the shift pattern can be placed to achieve a particular level of accommodation (90%, 70%, 50%, and 30%). The gap between the surfaces varies with elevation and accommodation level, indicating some nonlinearity in the design space.

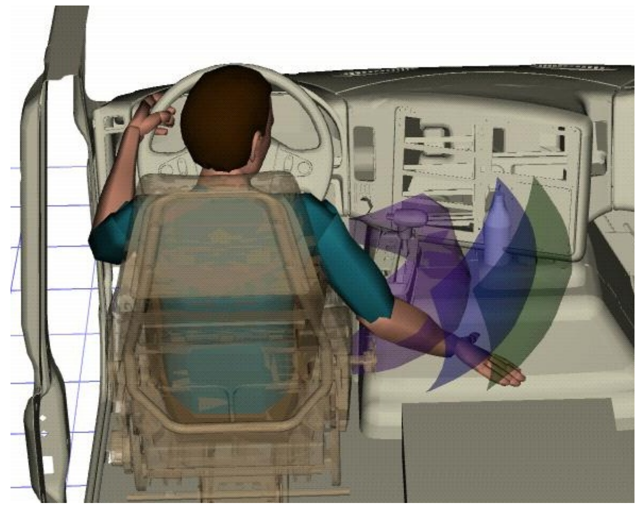

Figure 5: Shells showing three accommodation levels (90%, 60%, and 30%) for a spring force of -45N.

The nonlinearity of the design space is well illustrated by the “fold” exhibited in the 90% accommodation level in the 55 N case of Figure 4. This is due to the magnitude of the force in question. With all other variables and factors fixed, as the elevation of the location of the force increases, the lateral excursion of the CoP in the terminal posture increases. This effect increases linearly with the magnitude of the force. When the magnitude of the force is large, even relatively moderate elevations cause balance maintenance conditions that exceed the capability of some of the more limited drivers, creating the observed fold in the 90% iso-accommodation surface.

To aid in the interpretation and application of these results, iso-accommodation surfaces were placed within a virtual SAE Class B vehicle interior also containing a manikin prepresenting a midsize male driver. Figure 5 shows 90%, 60%, and 30% accommodation levels for the 45 N force. Figure 6 shows 50% accommodation levels for the 35 N, 45 N, and 55 N cases along with the vehicle centerline.

DISCUSSION

This work makes two primary contributions. First, the use of seated balance as a constraint in the design of seated environments is illustrated. Second, the technical approach demonstrates the use of population models and the inclusion of the residual variance associated with the behavioral and capability models to obtain estimates of accommodation that are more comprehensive than those that can be obtained using a small number of manikins.

The location of the CoP is a function of the forces and moments at the buttocks / seat interface. Most of the

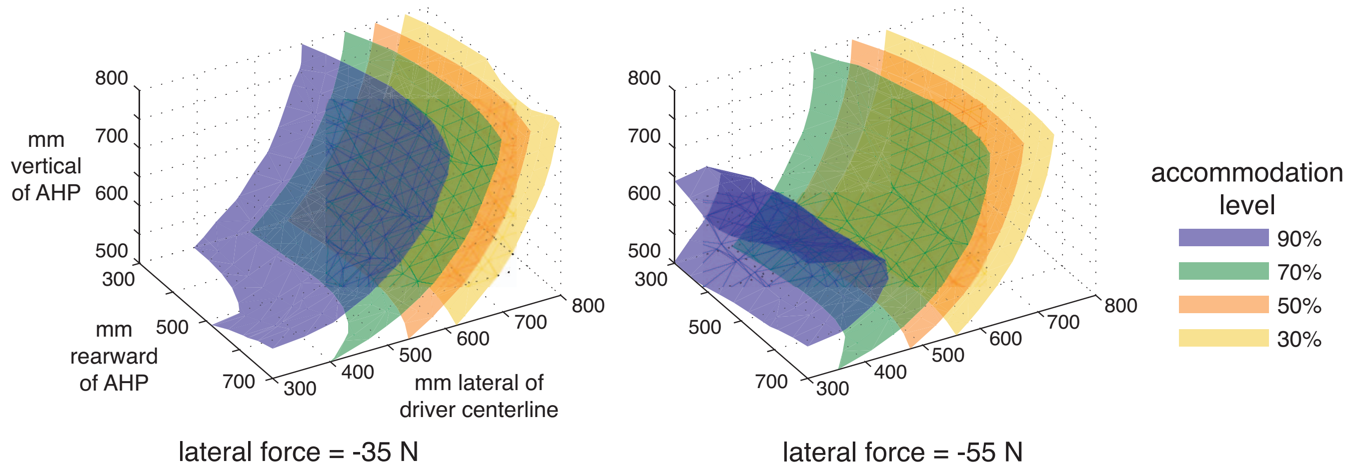

Figure 4: Iso-accommodation level shells for two force conditions (spring force = -35N and -55N).

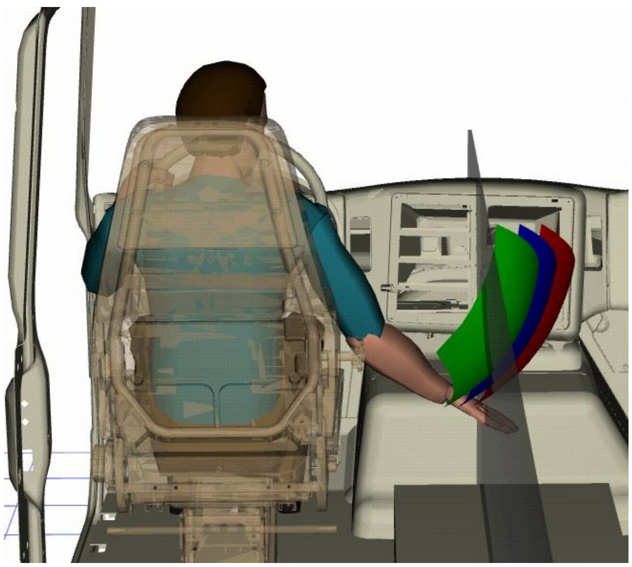

Figure 6: Shells showing 50% accommodation level for three spring force conditions (-35N, -45N, and -55N). The vehicle centerline is also shown.

change in the CoP location is due to changes in the moments. In one scenario, the location of the shifter is within arm's length. The torso is not recruited for the reach so the magnitude of the moment is determined by the magnitude and elevation of the force. Alternatively, the location of the shifter is greater than arm's length away, and the torso must lean towards the shifter. The weight of the torso is approximately half that of the driver, so even small lateral torso angles result in large moments, quickly surpassing those generated by the force at the hand. This paper does not examine a third scenario, where accommodation is limited by strength rather than balance. It is easy to conceive of reaches within arm's length that, due to the location or magnitude of the shifter force, require shoulder strength exertions beyond the capability of some drivers.

The iso-accommodation surfaces depicted in Figures 4, 5, and 6 exhibit a general tendency to move away from the driver laterally as the elevation increases. This is due to the aforementioned effect of the torso on the location of the CoP. The surfaces reflect the effect of arm's length (centered at the shoulder) on their shape. Another interesting result from the example is that the levels of accommodation are sensitive to relatively small changes in the vehicle shifter location. Analysis based on the force magnitude of 45 N, which is typical for an SAE Class B truck, shows that moving the shifter just 10 cm laterally can reduce accommodation level from 80% to 40%.

This paper has addressed one aspect of this problem: given shift forces, geometry, and a population, what are the acommodation levels at various locations throughout the design space? The problem may be posed in a variety of ways, however. For example, given a population, shift forces, and desired capability level, where do I put the shifter? Or, given a population, shifter location, and desired capability level, what does the locus of acceptable force vectors look like? It can also be posed as an optimization problem: given a population, geometry, and force levels, what location maximizes accommodation?

The models used in this paper have some limitations that will be addressed in future work. Notably, the posture prediction does not take into account changes in behavior that drivers might use to compensate for high shifter forces or an incipient loss of balance. From a design perspective, the resulting analyses are conservative, because some fraction of those who are predicted to require a counterbalancing force from the contralateral hand could in fact operate the shifter without it by changing their posturing tactics. However, a more complete design tool for analysis of hand forces will require data on the posture changes associated with high hand forces and type of task (e.g., pushing a button vs. shifting gears). Such data will also permit the modeling of the effects of distributions of shoulder strength on the accommodation surfaces.

ACKNOWLEDGMENTS

The authors thank International Truck and Engine Corporation for their support of this research. The driver-posture research incorporated into this new packaging methodology was conducted over the past 15 years at the University of Michigan Transportation Research Institute with sponsorship from many companies and organizations, including the Motor Vehicle Manufacturers Association, the Association of Automobile Manufacturers, the Alliance of Automobile Manufacturers, BMW, Chrysler, Ford, General Motors, Johnson Controls, Lear Corporation, Mazda, Peugeot-Citroen, and Toyota. Research specific to commercial vehicles has been supported by PACCAR, International Truck and Engine, Transom Technologies, and the Great Lakes Center for Truck and Transit Research. The initial investigation of a driver posture implementation in an optimization framework was supported by the Automotive Research Center at the University of Michigan. Subsequent work has also been supported by The Pennsylvania State University.

REFERENCES

Campbell, F., Ashburn, A., Pickering, R., Burnett, M., 2001. Head and pelvic movements during a dynamic reaching task in sitting: implications for physical therapists. Archives of Physical Medicine and Rehabilitation 82 (12), 16551660.

de Leva, P., 1996. Adjustments to zatsiorsky-seluyanovs segment inertia parameters. Journal of Biomechanics 29 (9), 12231230.

Gordon, C., Churchill, T., Clauser, C., Bradtmiller, B., McConville, J., Tebbetts, I., and Walker, R., 1989. 1988 anthropometric survey of U.S. Army personnel: Methods and summary statistics. final report. (NATICK/TR-89/027).

Jahns, S., Reed, M., and Hardee, H., 2001. Methods for in-vehicle measurement of truck driver postures. SAE Technical Paper 2001-01-2821.

Parkinson, M.B., Chaffin, D.B., and Reed, M.P. (2006). Center of pressure excursion capability in performance of seated lateral-reaching tasks. Clinical Biomechanics, Vol. 21:26-32.

Parkinson, M.B. and Reed, M.P. (2006). Optimizing vehicle occupant packaging. Technical Paper 2006-01-0961. To be presented at SAE World Congress and Exposition. Detroit, MI. Society of Automotive Engineers, Warrendale, PA.

Parkinson, M.B., Reed, M.P., Kokkolaras, M., and Papalambros, P.Y. (2005). Robust truck cabin layout optimization using advanced driver variance models. Proceedings of the ASME International Design Engineering Technical Conferences. Long Beach, CA.

Reed, M., Lehto, M., and Schneider, L., 2000. Methods for laboratory investigation of truck and bus driver postures. Technical Paper 2000-01-3405. SAE Transactions: Journal of Commercial Vehicles., 109.

Reed, M.P., Manary, M.A., Flannagan, C.A.C., and Schneider, L.W. (2002). A statistical method for predicting automobile driving posture. Human Factors. 44 (4): 557-568.

Reed, M.P., Parkinson, M.B., and Wagner, D. (2004). Torso kinematics in seated reaches. Technical Paper 2004-01-2176. SAE Transactions: Journal of Aerospace, Vol. 113.

Seelen, H.A.M., Potten, Y.J.M., Drukker, J., Reulen, J.P.H., and Pons, C. (1998). Development of new muscle synergies in postural control in spinal cord injured subjects. Journal of Electromyography and Kinesiology, 8, 23-34.