SAE International

2013-01-0452
Published 04/08/2013

doi:10.4271/2013-01-0452
saepcmech.saejournals.org

Development of a Methodology for Simulating Seat Back Interaction Using Realistic Body Contours

Jingwen Hu and Matthew Reed
Univ. of Michigan

ABSTRACT

Seat comfort is driven in part by the fit between the sitter and seat. Traditional anthropometric data provide little information about the size and shape of the torso that can be used for backrest design. This study introduces a methodology for using three-dimensional computer models of the human torso based on a statistical analysis of body shapes for conducting automated fit assessments. Surface scan data from 296 men and 417 women in a seated posture were analyzed to create a body shape model that can be adjusted to a range of statures, body shape, and postures spanning those typical of vehicle occupants. Finite-element models of two auto seat surface were created, along with custom software that generates body models and postures them in the seat. A simple simulation technique was developed to rapidly assess the fit of the torso relative to the seat back. The methodology developed in this study will enable automated virtual fitting trails considering a wide range of body sizes and shapes, allowing statistical evaluations of seat fit within a specific sitter population. Further refinement of the method will allow prediction of seat pressure distribution, which may be usefully related to subjective assessment of seat fit.

CITATION: Hu, J. and Reed, M., "Development of a Methodology for Simulating Seat Back Interaction Using Realistic Body Contours," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-0452.

INTRODUCTION

Dimensional mismatch between a seat and sitter can cause discomfort. For example, a backrest that is too narrow can create discomfort at the sides of the body and can also diminish the effectiveness of a lumbar support [5]. Traditional anthropometric data have customarily been gathered using tape measures, calipers, and other simple apparatus to obtain repeatable point-to-point and circumferential measures. These dimensions provide little guidance for seat back design because they are not closely related to seat design parameters. In particular, traditional anthropometric data do not provide guidance on three-dimensional body shape, which can be used for choosing appropriate contours for backrests.

In the past decade, surface-scanning equipment has revolutionized anthropometry by allowing rapid recording of whole-body surface shapes. The Civilian American and European Anthropometry Resource (CAESAR) project was the first large-scale study to scan U.S. civilians [7]. In addition to standard anthropometric measures, scans were recorded in one standing and two seated postures for a convenience sample of 2400 U.S. adults from 18 to 65 years old. Body landmark locations were extracted from the scans.

The application of the CAESAR scan data for seat design has been hampered by difficulties in working with the data and the need to develop new methodologies to apply the data in design. Each set of raw scan data in CAESAR database typically contains over 500,000 unstructured data point and represent a single posture. One approach to using the CAESAR data has been to manually craft manikins based on a small number of selected scans for use in human modeling software packages used for ergonomics, such as Jack and RAMSIS [4]. However, this method takes advantage of only a small fraction of the available information. An alternative approach is to build statistical models of body shape using a large number of subjects. The technical details associated with this approach were first introduced by Allen et al. [1], and have been applied specifically to ergonomic analysis of seating by Reed and Parkinson [6], who developed a statistical model of body size and shape using a combination of principal component analysis and regression analysis (PCAR). For backrest design applications, this model can be exercised to randomly sample the space of body shapes, which will enable automated virtual fitting trails.

The objective of this study was to introduce a methodology for using a statistical body shape model to conduct automated fit assessments for vehicle seat backrest.

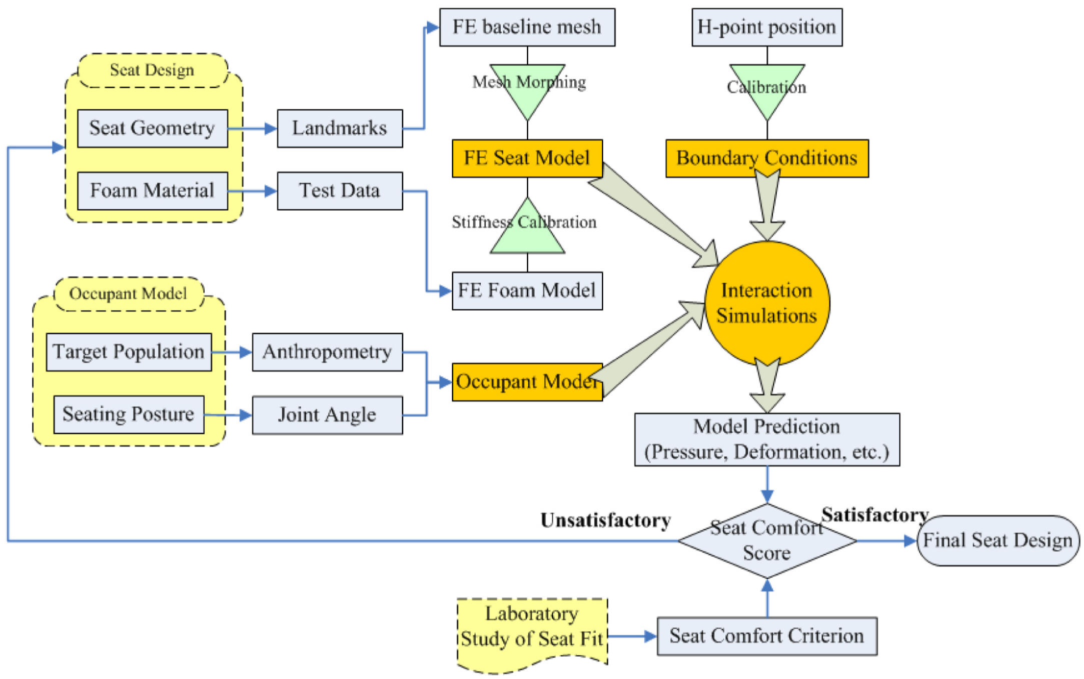

Figure 1. Flowchart of virtual fit methodology.

Specifically, the previously developed torso shape model was augmented to predict body shape as a function of recline, lumbar spine flexion, stature, and BMI for both men and women. Finite-element (FE) models of two seat contours were created. An automated software procedure was developed to simulate the movement of the sitter, defined using the statistical body shape model, into the seat model. The resulting penetration was assessed with respect to seat fit.

METHODS

Framework for Virtual Seat Fit Testing

A framework was developed in this study to conduct virtual fit assessments using a wide range of body sizes and shapes selected to represent the target user population. Each virtual fit predicted the seat surface deformation and pressure for a particular occupant in a seat with a specific posture, and statistical evaluation can be performed with multiple simulations for occupants with different body sizes and shapes.

Figure 1 shows the virtual fit process using FE seat models and human body contour models representing different body sizes and shapes. The core of this process is the interaction simulation using the parametric seat FE model and the body shape model. In this study, a program was written in Scilab, a free, open-source computing environment (www.scilab.org), to automatically generate the occupant FE body contour models with specific body size, shape, and posture; integrate the seat FE model into the simulation; and setup the boundary conditions of virtual fit simulations. To make this method useful, validation of the seat model, boundary condition setup, and the seat comfort evaluation are necessary. However, in the current study, we only focused on setting up the framework for virtual seat fit testing.

Posturable Torso Model

Figure 2 shows the methodology of generating a posturable torso model in the current study. Torso data from relaxed seated scans for 296 men and 417 women, including all of the obese subjects in the U.S. CAESAR sample, were extracted for analysis. Surface data for the arms and legs were removed to isolate the parts of the body that normally interact with seats. A uniform mesh was fit to the data (60 slices × 60 points per slice), exploiting the fact that the data were sampled in horizontal slices. A statistical analysis was then conducted on the vertices of the mesh, along with the associated body landmarks and internal joint locations estimated from the surface landmark locations. The analysis method (PCAR) uses principal component analysis to obtain a simpler representation of the data, followed by a regression analysis to predict the body shape from subject covariates such as stature and body weight [6].

The previously developed statistical model of torso shape represented only the scanned posture, which is not typical of vehicle occupant postures. For the current study, the original data were reanalyzed using a novel methodology. Each subject's scan model (a set of 3600 vertices representing the surface and associated landmarks) was articulated to a set of postures relative to the scanned posture, defined by two variables.

The entire model (thighs through head) was tipped rearward from zero to 30 degrees. The lumbar spine was flexed, relative to the measurement posture, by −15 to 30 degrees, with the lumbar motion evenly distributed between

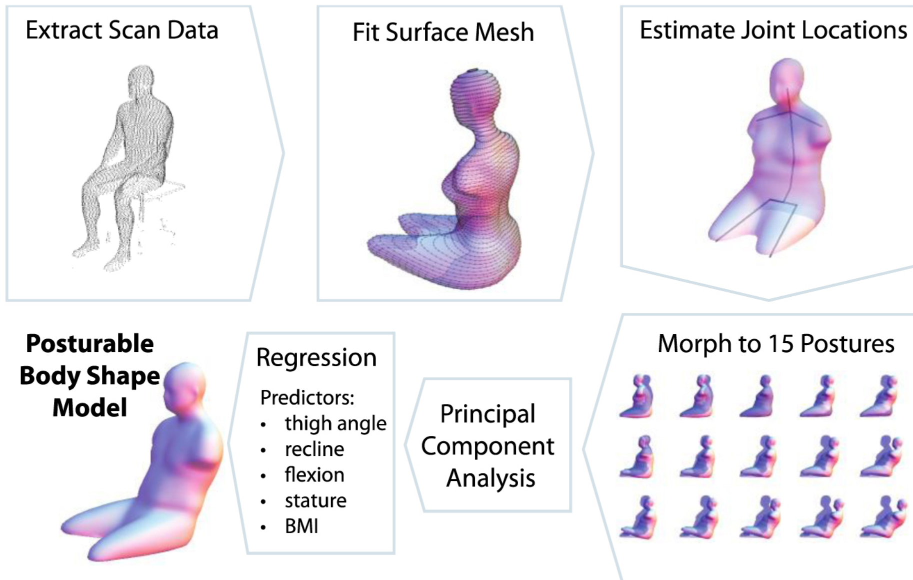

Figure 2. Schematic of process for creating a posturable body shape model from scan data.

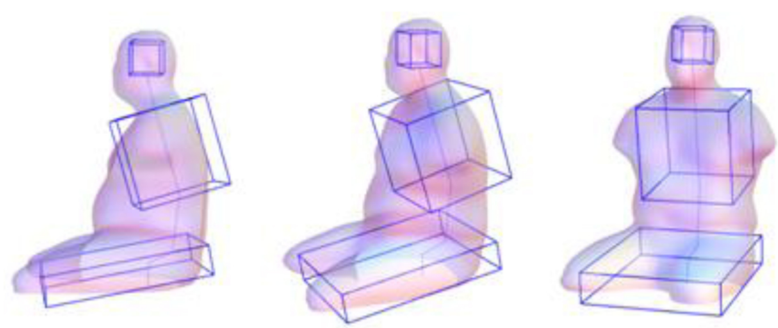

Figure 3. Head, thorax, and pelvis/thigh reference point boxes used to morph postures.

the estimated T12/L1 and L5/S1 joint locations. In all postures, the head was maintained at the measured global orientation by flexion or extension of the cervical spine, with motion evenly distributed between the estimated C7/T1 and L5/S1 joint locations.

Flexion of the lumbar and cervical spine areas was accomplished using a radial-basis-function (RBF) morphing method [2]. A "box" of eight reference nodes was constructed around each of the head, thorax, and pelvis/thighs, as shown in Figure 3. These reference nodes were articulated with the underlying skeletal linkage to each new posture. The change in locations of the nodes relative to the original positions was used to construct a 3D vector interpolation function using multiquadric basis functions [2]. This morphing function was applied to all of the surface nodes and landmarks in the original model to obtain a repostured model. The resulting models (15 per subject, including the scan posture) were analyzed using the PCAR method. For prediction, three posture variables were included. Thigh angle is the mean thigh angle with respect to horizontal. Lumbar flexion is estimated as two times the angle between the estimated lumbar (L5/S1 to T12/L1) and thorax (T12/L1 to C7/T1) skeletal segments. Torso recline is the angle with respect to vertical of a vector from the midpoint between the estimated hip locations to C7/T1. These variables were calculated for each of the morphed scan models and used as covariates in the regression analysis. Separate models were created for men and women. An example of the body shape models at different postures are shown in Figure 4.

Seat Model

To shorten the calculation time, two simplified seat FE models were generated based on the surface geometry of two seat models provided by Faurecia. The new seat (Figure 5) is a modified version of the old seat with relatively flatter seat back contour around the lumbar region and better comfort performance based on customer evaluations. A layer of shell elements was used to represent the seat surface geometry. Two components, rigid base and elastic layer, were used for seat back as shown in Figure 5. The elastic layer was assigned a 3-mm thickness and an elastic material with 140 MPa Young's modulus. Note that since the purpose of this

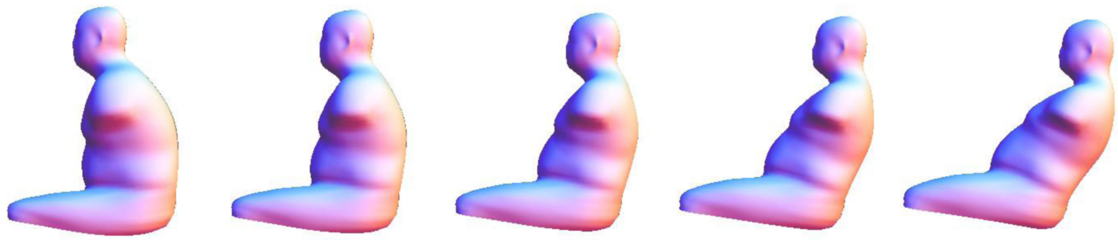

Figure 4. Example of exercising the male model over a range of postures with stature of 1755 mm and BMI of 40 kg/m^2.

study is to setup the framework and provide a demonstration of virtual fit, the stiffness of the seat model may not be accurate. Further improvement can be made on the seat model, and a more complicated seat model can be easily implemented into the whole virtual fit process.

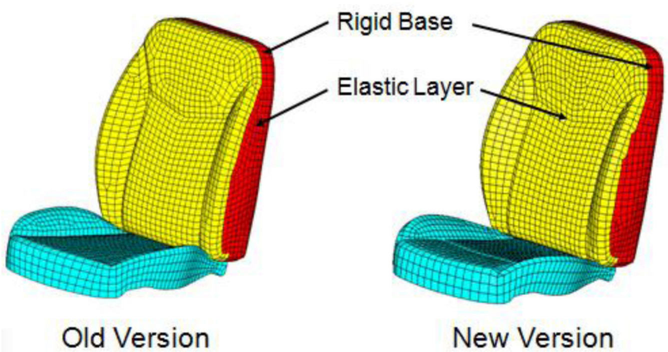

Figure 5. Simplified seat FE models with two seat geometries.

Virtual Fit Simulation Setup

Hypermesh 10.0 was used as the FE pre-processor to perform the meshing and generate a template, which was modified by the Scilab program to setup each simulation. LS-DYNA 971 was used as the solver for all FE simulations. In the Scilab program, FE node coordinates for a group of occupants with different body sizes, shapes, and postures can be generated based on different sets of input parameters, including the height, BMI, thigh angle, lumbar flexion, and torso recline.

For each simulation, the setup is shown in Figure 6, in which the H-point of the occupant model was initially positioned 40 mm higher and 100 mm more forward compared to the seat H-point. Motion at about 0.1 m/s was prescribed onto the occupant model, moving the occupant H-point (hip joint center location) toward the seat H-point. Surface-to-surface contact with friction coefficient of 0.1 was defined between the occupant model and the elastic layer of the seat back model. The rigid base of the seat back model was fixed throughout the simulation. By using the Scilab program, a group of simulations with different body sizes, shapes, and postures can be set up automatically and copied into different folders, and the simulations can be run in batch mode.

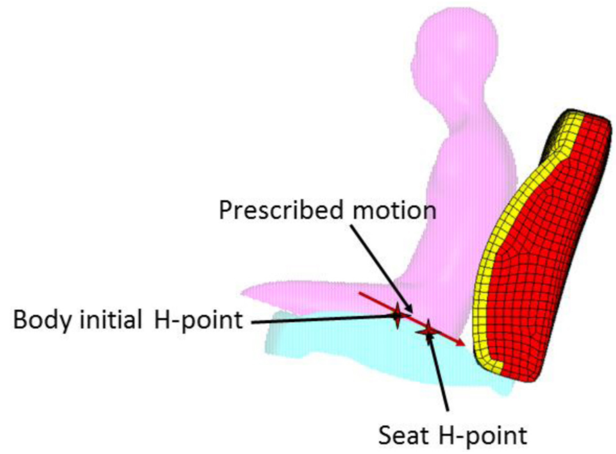

Figure 6. Virtual fit simulation schematic.

Parametric Study

To demonstrate the feasibility of this virtual fit program, a parametric study of 24 simulations was conducted. The parameters controlled in the parametric study are shown in Table 1. The distribution contours of the seat back deformation on the elastic layer were output from each of 24 simulations. Each simulation took less than one minute to run. Further improvement of the seat model may increase the calculation time significantly.

Table 1. Parameters for the Parametric Study

Parameters	Levels
Stature	165cm, 175cm, and 185cm
BMI	20 and 35
Torso recline	Same as the cushion angle
Lumbar spine flexion angle	5 and 15 deg
Seat model	Old seat and new seat

RESULTS

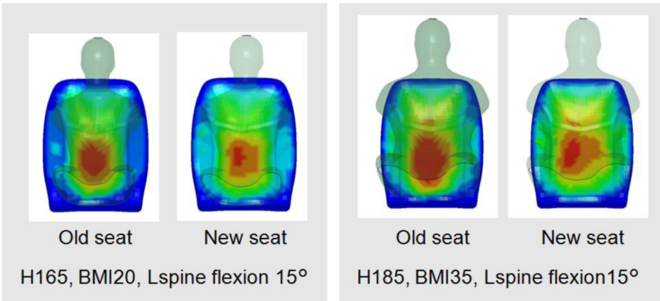

Figure 7. Simulated seat back deformation results for old seat vs. new seat

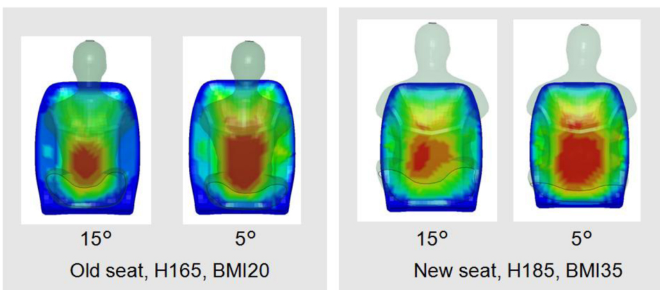

Figure 8. Simulated seat back deformation results for different lumbar spine flexion angles

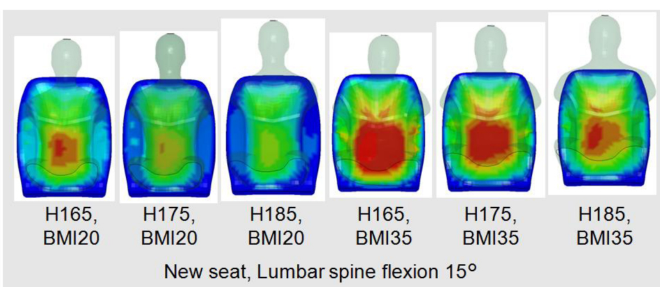

Figure 9. Simulated seat back deformation results for different torso shapes

Figures 7, 8, 9 show some of the simulation results. Figure 7 shows that the new seat provides a different deformation distribution with the range of body sizes investigated. In particular, the new seat resulted in lower deformation values across the seat back than those from the old seat. Because all the simulations were conducted under the same prescribed motion, a lower deformation distribution would indicate a better contour fit. This is consistent to the results from customer evaluations. Figure 8 indicates that higher lumbar spine flexion angle reduces the seat back deformation under the prescribed loading regime, and Figure 9 demonstrates that the occupant with a higher BMI generates higher deformation on the seat back for this loading scenario. All results from the parametric study demonstrated that the virtual fit process developed in this study is sensitive to body size and shape.

DISCUSSION

Accomplishments

This project demonstrated the feasibility of conducting virtual fit trials using a parametric human figure model and a simplified FE simulation of occupant to seatback interaction. The work had several innovative elements:

- A method was developed and implemented to include posturing capability in a statistical model of torso shape.
- Automated methods for rapidly assembling a simulation with a large number of human body models and seat back models were developed using an open-source software system.
- A simple prescriptive method for defining seatback interaction showed sensitivity for differentiating seat fit among seats and body shapes.

Although computational models have played increasingly important role in the design process of auto seats, previous studies usually only used one or a few sizes of human models, namely small-female, mid-size male, and large-male, to evaluate the seat comfort [3, 8], neglecting the variability of body shape among the population. The method developed in the current study would enable automated virtual fitting trails considering a wide range of body sizes and shapes, allowing statistical evaluations of seat fit within a specific sitter population.

Limitations

This pilot work is limited by the small number of simulations performed. In particular, only two seats were examined for a small number of body shapes and postures, since the goal was to establish the feasibility of the method rather than to make judgments about the seats. The human body contour model is based on a fairly small sample (296 men and 417 women). Using a larger number of subjects (a total of 2400 are available in the U.S. CAESAR sample) could improve the fidelity of the body models. The posturing methodology is as yet unvalidated, both with respect to the body shape morphing and the effects of the seat on the posture; work ongoing in our research group will provide validation for this approach.

The most important limitation of the current work is that the simulated pattern of deflection on the seatback, which is the primary outcome measure, has not been validated. More detailed human body FE model with proper hard/soft tissue properties and refined seat FE models with proper material assignments for the foam/padding and supporting structures would be necessary to achieve a high accuracy. The joint characteristics of the human body model may also plays an important role to simulate the interaction between the sitter and the seat, which needs further investigation. Data are needed to link the posture and body shape of sitters with a wide range of body shapes to physical measurements of seat back interaction. Moreover, the ultimate success of the method is dependent on the development of a quantitative, reliable method to predict subjective responses from the (predicted) physical interaction between the sitter and seatback.

Future Work

The current study was envisioned as the first phase in a multi-stage research program leading to a fully developed virtual seat evaluation methodology. Four tasks are suggested for the next phase of the research:

1. Improve the human body shape model by adding more subjects and both improving and validating the posturing functionality.

2. Refine the human body FE model by including more hard/soft tissues and proper joint characteristics.

3. Conduct a laboratory study with human volunteers to quantify the relationships between subjective fit and objective measures of seatback interaction, in the process generating data that can be used to validate simulations.

4. Validated the FE method for simulating seatback interaction based on the framework developed in the current study.

CONCLUSIONS

In this study, an automated virtual fit framework was developed to evaluate the comfort of auto seats. This framework included a statistical human contour model that predicts body shape as a function of recline, lumbar spine flexion, stature, and BMI for both men and women, simplified FE seat models representing the surface geometry of the seats, and an automated software procedure to simulate the occupant to seat back interaction. Preliminary results have shown sensitivity for differentiating seat fit among seats and body shapes. This methodology will enable automated virtual fitting trails considering a wide range of body sizes and shapes, allowing statistical evaluations of seat fit within a specific sitter population. Further refinement of the method will allow prediction of seat surface pressure distribution, which may be usefully related to subjective assessment of seat fit.

REFERENCES

1. Allen, B., Curless, B., and Popovic, Z., "The space of human body shapes: reconstruction and parameterization from range scans," presented at 2003 International Conference on Computer Graphics and Interactive Techniques (SIGGRAPH). San Diego, CA, USA. 2003.
2. Bennink, H.E., Korbeeck, J.M., Janssen, B.J., and Romenij, B.M., "Warping a neuro-anatomy atlas on 3D MRI data with radial basis functions," *IFMBE Proceedings*. 15(2): 28-32, 2007.
3. Grujicic, M., Pandurangan, B., Xie, X., Gramopadhye, A.K., et al., "Musculoskeletal computational analysis of the influence of car-seat design/adjustments on long-distance driving fatigue," *International Journal of Industrial Ergonomics*. 40(3): 345-355, 2010.
4. Nilsson, G., "Validity of Comfort Assessment in RAMSIS," SAE Technical Paper 1999-01-1900, 1999, doi: 10.4271/1999-01-1900.
5. Reed, M.P., "Survey of Auto Seat Design Recommendations for Improved Comfort," *Technical Report*. University of Michigan Transportation Research Institute, Ann Arbor, MI. 2000.
6. Reed, M.P. and Parkinson, M.B., "Modeling Variability in Torso Shape for Chair and Seat Design," presented at ASME 2008 IDETC/CIE. Brooklyn, NY, USA. 2008.
7. Robinette, K., Blackwell, S., Daanen, H., and Boehmer, M., "Civilian american and european surface anthropometry resource (CAESAR)," *Final report*, Volume 1. United States Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio, USA, 2002.
8. Siefert, A., Pankoke, S., and Wolfel, H.P., "Virtual optimisation of car passenger seats: Simulation of static and dynamic effects on drivers' seating comfort," *International Journal of Industrial Ergonomics*. 38(5-6): 410-424, 2008.

CONTACT INFORMATION

Jingwen Hu, PhD
jwhu@umich.edu
University of Michigan Transportation Research Institute
2901 Baxter Rd, Ann Arbor, MI 48109, USA

Matthew Reed, PhD
mreed@umich.edu
University of Michigan Transportation Research Institute
2901 Baxter Rd, Ann Arbor, MI 48109, USA

ACKNOWLEDGMENTS

This research was funded by Faurecia. The authors thank Samuel Baudu, Yang Cao, Michael Kellar, and Dana Lowell for their contributions to the project.