Utilizing Digital Human Modeling to Optimize the Ergonomic Environment of Heavy Earthmoving Equipment Cabins

Nicholas Anton(✉) and Vincent G. Duffy

Purdue University, West Lafayette 47906, USA
anton5@purdue.edu

Abstract. Among heavy earthmoving equipment operators, extended exposure to the cabin environment presents various ergonomic risks. Accordingly, it is necessary to consider methods to model adjustments to cabin environments to reduce ergonomic risks to operators. Digital human modeling approaches, such as the use of RAMSIS, a computer-aided ergonomic design platform, have been used to effectively improve the ergonomics of workers in a variety of disciplines. A bibliometric analysis was performed on relevant literature, which revealed that these techniques have rarely been applied with heavy machine operators. Accordingly, the purpose of the current project was to utilize RAMSIS to model diverse operators in the cabin environment and perform discomfort analyses to identify methods to reduce ergonomic risk. Digital manikins were created based on anthropometric data for a female operator (5th percentage height), and two male operators (50^{th} and 95^{th} percentile height). Several aspects of the cabin environment were adjusted, and several discomfort analyses were performed to identify optimal adjustments that would reduce the ergonomic risk for diverse providers. Modifications made to the seat, steering wheel, armrests/joystick position, touchscreen, and actuating controls led to significantly reduced ergonomic risk and discomfort.

Keywords: Digital human modeling · Ergonomics · Discomfort · Heavy earth moving equipment

1 Introduction and Background

1.1 Ergonomic Risks of Heavy Earthmoving Equipment Operators

Heavy earthmoving equipment (HEME) (e.g., excavators) are vital to major construction projects. Operators of HEME are stationary in the cabin for lengthy periods, so poor environmental design may present significant ergonomic risks. Indeed, previous research involving postural evaluations of HEME operators has shown that operators are required to assume awkward trunk, neck, and shoulder postures while working [1]. Furthermore, researchers have identified HEME cabin ergonomic risk factors such as the height of the seat, which can lead to musculoskeletal disorders [2]. Accordingly, it is necessary to consider methods to optimize HEME cabin environments to reduce ergonomic risks.

V. G. Duffy (Ed.): HCII 2022, LNCS 13319, pp. 16–31, 2022.
https://doi.org/10.1007/978-3-031-05890-5_2

1.2 Digital Human Modeling and Analysis

The field of ergonomics is becoming increasingly reliant on digital human modeling of workers to optimize the physical ergonomics of workstations given this modality's relative inexpensiveness and enhanced efficiency compared to physical ergonomic modeling methods [3]. Computer-aided design software programs, such as RAMSIS (RAMSIS NextGen Ergonomics, Human Solutions, Kaiserslautern, Germany), can allow engineers to make environmental adjustments to workstations and assess their ergonomic impact on human operators. It is unclear, however, if digital human modeling software would be helpful to reduce ergonomic risks for HEME operators.

1.3 Bibliometric Analysis

To determine the existing literature and trends of ergonomics, digital human modeling, and HEME operators, three bibliometric analysis methods were used.

Vicinitas Engagement Search. Twitter has become an important platform for researchers and laypeople to share their opinions on myriad topics. Vicinitas is an analytics platform that allows researchers to assess the engagement (e.g., tweets, retweets, comments, etc.) of posts made on certain topics. This approach can be used to identify current trends in a field for the past 10 days of the search. To assess current trends in the field of ergonomics, the search term "ergonomics" was used. Results of the search are shown in Fig. 1. Based on the resulting word cloud, it appears that "improved design" and "chair" were among the most popular words in recent tweets about ergonomics. Thus, focusing on design improvements to the excavator seat may be an important consideration.

Fig. 1. Vicinitas analytics word cloud from Twitter posts on "ergonomics".

Co-authorship Analysis. To identify the leading authors in the field of digital human modeling, a co-authorship analysis was performed. Using the Scopus database, a search was performed using the keywords “digital human modeling” and “ergonomics”. A total of 579 references were identified and exported to VOS Viewer in .CSV format. VOS viewer is a software tool used to visualize bibliometric connections. Using VOS viewer, a co-authorship analysis was performed using the exported Scopus metadata. A threshold of 5 publications was set as the minimum number of publications needed to be included in the co-authorship analysis (Fig. 2).

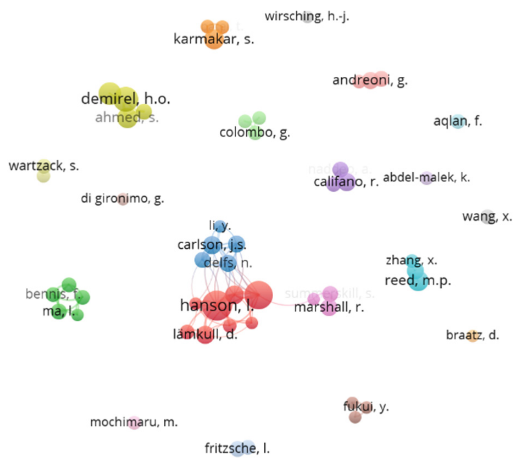

Fig. 2. Co-authorship network visualizing the most published authors on ergonomics and digital human modeling.

Based on this analysis and identification of the most commonly-published authors in the field, a search was performed of these authors’ publications to identify relevant references for the current project. A relevant book chapter on digital human modeling based on anthropometric data was identified [4]. The book chapter details the use of RAMSIS to model variously-sized automobile drivers, and the authors’ identification of needed environment adjustments to accommodate these drivers. This chapter provides evidence that RAMSIS is an appropriate tool to model HEME operators of varying stature based on anthropometric data.

BibExcel Authorship Review. To determine which researchers are leaders in the field of HEME ergonomics, it was necessary to perform an analysis of the researchers commonly publishing in this field. Accordingly, the Harzing Publish or Perish software was used, and a google scholar search was performed on the terms “Ergonomics” and “Earth Moving Equipment” with a specified date range from 2000–2021. This search yielded a total of 302 papers. These citations were exported in Web of Science format to BibExcel, which is freely available software that allows users to convert literature searches to .CSV Microsoft Excel files. Following extraction of author names and citation count into Microsoft Excel, a pivot chart was created to visualize this data (Fig. 3).

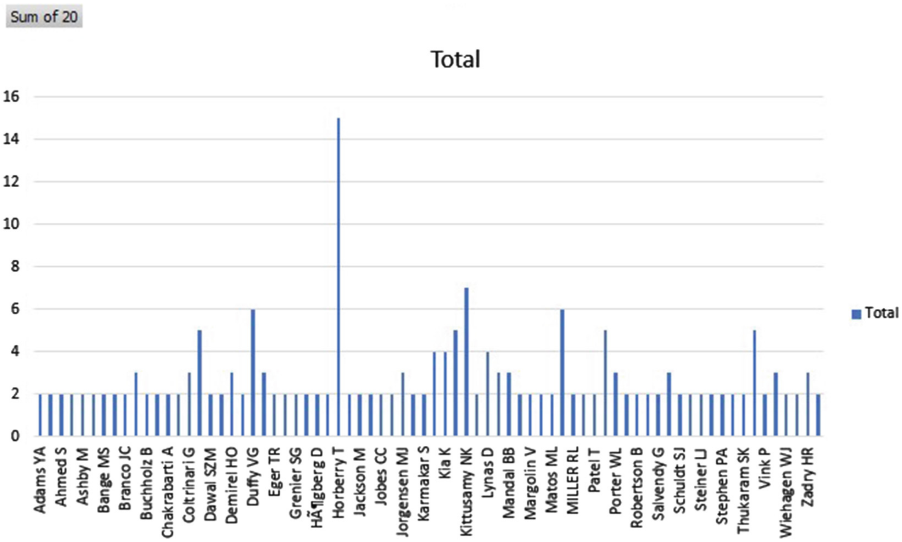

Fig. 3. Pivot chart displaying authors with most citations on ergonomics and digital human modeling.

Following identification of the leading authors in this area, Publish or Perish was again consulted to review the leading authors' publications to determine if relevant insights could be gleaned for this project. A literature review on construction equipment operators' postural stress was identified [5]. The authors of this review found that few studies had attempted to quantify awkward postures among HEME operators. However, those researchers in this area did find that postural stress contributed to the low back pain of operators and lumbar disk herniation. These findings offer further attestation that ergonomic improvements to the HEME cabin environment are needed.

1.4 Problem Statement

Currently, there is a lack of literature on the use of digital human modeling to optimize the HEME cabin environment for human operators of varying statures. Given the ergonomic risks for HEME operators, this project focused on assessing the level of discomfort by diverse operators (i.e., 5^{th} percentile height female, 50^{th} percentile height male, 95^{th} percentile height male), and the adjustment ranges needed for several aspects of the cabin environment to reduce discomfort to an appropriate level for all manikins.

2 Procedure

2.1 Statement of Work

For this project, the following statement of work was requested, which guided the analyses used in this project:

- Create Boundary Manikins for the tasks
- Evaluate the location, adjustment range, and comfort for the overall driving posture including seat adjustment, pedal position, and steering wheel position/adjustment
- Evaluate the location, adjustment range, and comfort for the joystick on the left and right side
- Evaluate the location, adjustment range, and comfort of wrist pads
- Evaluate the location, reach and comfort to touch screen
- Evaluate visibility and comfort while actuating controls.

2.2 Initial Environment Creation and Manipulation

Initial Environment Setup. The initial RAMSIS excavator environment creation and setup has been detailed in my previous project report [6]. All steps were followed to isolate the cabin environment (Fig. 4).

Fig. 4. Isolated excavator cabin environment.

Initial Environment Manipulation. To affix the manikins' hands in the correct locations on the steering wheel, joysticks, touchscreen, and control panel, it was necessary to "group" environment components as needed and create geometry points.

Grouping of Components. For the steering wheel (i.e., base, pedestal, steering wheel), joysticks (i.e., armrests, wrist pads, joysticks), touchscreen (i.e., housing and screen), and controls (i.e., control buttons and jousting), all components of each respective "group" were combined. While holding down the "Ctrl" key, all components of each group were selected using the left mouse button. Then, the right mouse button was used, then the function "Group" was selected.

Placement of Geometry Points. To affix the manikins' hands to positions on the steering wheel at the "9-o'clock" and "3-o'clock" positions and on the control buttons, it was necessary to add geometry points in these positions on the steering wheel. Accordingly, "Geometry" was selected from the top of the software's menu, and "Point" was selected. Then, the drop-down menu was selected and the option "Create on Object" was selected. Finally, using the left mouse button, points were added to the steering wheel as appropriate.

Creation of Geometry Kinematics. The final element of initial environment manipulation involved the creation of object kinematics to be able to manipulate the direction of elements. First, the user selects "Geometry", then "Object Kinematics". Once on this screen, the user selects the starting point (i.e., the surface of the object to be moved) using the left mouse button, then the direction of movement (i.e., x-, y-, or z-axis), and finally the minimum and maximum amount of movement for the object. For the steering wheel, the steering wheel and pedestal were hidden, and two geometry points were added on opposite sides of the top of the base. Then, a point was added in between the two created points to serve as a joint for the steering wheel adjustments (Fig. 5).

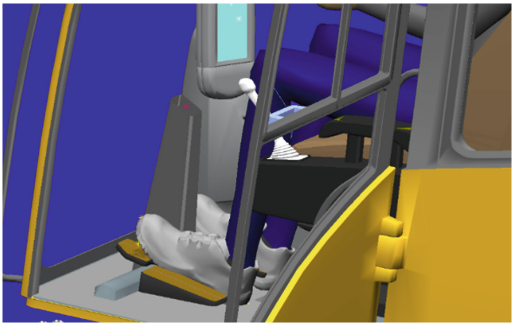

Fig. 5. Joint created at top of steering wheel base.

A degree of freedom was added to this joint to angle the steering wheel -30° (i.e., upward away from the driver) and 30° (i.e., towards the driver). The steering wheel and pedestal were then added back to the scene, and a degree of freedom was added to extend the steering wheel to extend it towards the driver (i.e., at a 45° angle). For the operator's seat, armrests, and touchscreen in the positive x- and z-axes (i.e., positive and negative), and controls in the negative x-axis.

2.3 Boundary Manikin Creation

To create manikins for the present project, NextGen Body Builder was selected, and the "Define Typology" button was selected from the "Anthropometry" menu. The "Germany 2004" anthropometry database was used for the creation of both male and female manikins. Then, under the anthropometry tab, "Control Measurements" was selected to define the unique typology for each manikin. For the first manikin, a male, the age group was defined as 18–70, the reference year was defined as 2034, and the body height, waist circumference, and sitting height were defined by values. Since I wanted the first manikin to represent a 95th percentile male in height, I set the percentile of body height to 95, waist circumference to 35, and sitting height to 44.87. I repeated this process to create a second typology to represent a 50th percentile male in height, so I set the percentile of body height to 50, waist circumference to 50, and sitting height to 50. Finally, I created a third typology to represent a 5th percentile female in height, so I set the percentile of body height to 5, waist circumference to 46.75, and sitting height to 43.74.

Following the creation of these body typologies, a single role of “operator” was created by selecting the item “Role Definition”, which indicates what role is being defined, and indicates the prepositioning point is “PHPT”.

2.4 Evaluate the Location, Adjustment Range, and Comfort for the Overall Driving Posture Including Seat Adjustment, Pedal Position, and Steering Wheel Position/Adjustment

Initial Positioning. All manikins were individually positioned in the seat using the following protocol. The manikins were positioned in the seat by creating “Target” restrictions which position certain skin points of the manikin in specific points in the environment. The following target restrictions were created:

- H-point (the center of the manikin’s buttocks) was affixed to the surface of the seat
- Right heel was affixed on the surface of the floor behind the pedals
- Left heel was affixed on the surface of the floor behind the pedals
- Right ball offset was affixed in the centerline of the right pedal
- Left ball offset was affixed in the centerline of the left pedal
- The points between the index and thumb were placed on geometry points on the steering wheel at 3 and 9-o’ clock.

Following initial positioning, a “Pelvis Rotation” restriction was defined to prevent the manikin from rotating their trunks in the seat. Finally, directional restrictions for line-of-vision were imposed to enable the manikins to focus their eyes forward in a natural plane (Fig. 6).

Fig. 6. Initial positioning of all manikins.

Modifications. Following an iterative process of making modifications and assessing the impact of those changes on the manikins’ comfort for various elements of the body, unique modifications were made to the seat and steering wheel for each manikin. All final modifications are specified for each manikin below (Fig. 7).

Fig. 7. From left to right, final steering wheel position for 5th percentile female, 50th percentile male, and 95th percentile male.

5th Percentile Female. Seat modifications for the 5th percentile female included lowering the seat in the negative z-axis by 50 mm (mm). Steering wheel modifications included tilting the steering wheel forward by 20° and extending the wheel to the operator by 100 mm.

50th Percentile Male. Seat modifications for the 50th percentile male included raising the seat in the positive z-axis by 50 mm. Steering wheel modifications included tilting the steering wheel forward by 9° and extending the wheel to the operator by 110 mm.

95th Percentile Male. Seat modifications for the 95th percentile male include raising the seat in the positive z-axis by 100 mm and moving the seat backward (i.e., in the positive x-axis). Modifications to the steering wheel include tilting the steering wheel forward by 12° and extending towards the operator by 185 mm.

Analysis. In the current project, discomfort analyses were performed to determine the impact of changes to the cabin environment on operators' comfort. The RAMSIS ergonomics manual defines the discomfort analysis as the assessment of manikins' discomfort in various body elements and the body as a whole, and any value above 3.5 is considered uncomfortable [7]. A baseline discomfort analysis was performed for each manikin in the origin position. A second discomfort analysis was performed for each manikin at the final modified position for comparison.

Results. The results of the discomfort analyses are presented in Table 1. At the original position, all manikins experienced discomfort in several body elements. Specifically, the 5th percentile female experienced discomfort in the neck, legs, and overall. The 50th and 95th percentile males experienced discomfort in the neck, shoulders, legs, and overall. After adjustments were made, no manikins experienced discomfort in anybody elements. However, all manikins still experienced discomfort overall, but the reductions in discomfort are still appreciable.

The range of modifications to the seat was – 50 mm–100 mm in the z-axis and 0 mm–100 mm on the x-axis. The range of modifications to the steering wheel includes tilting the wheel down toward the operator from 9–20° and moving toward the operator from 100–185 mm.

Table 1. Differences in discomfort from baseline to post-modifications to the steering wheel and seat.

Body element	5th% female		50th% male		95th% male	
	Origin	Modified	Origin	Modified	Origin	Modified
Neck	4.22*	3.1	4.7*	3.4	4.9*	3.4
Shoulders	3.12	2.5	4.5*	2.8	4.9*	2.8
Back	2.7	2.2	3.4	2.7	3.45	2.6
Buttocks	2.4	1.7	2.8	2.1	3.3	2
Left leg	3.6*	2.4	4.6*	3.1	5.2*	3
Right leg	3.6*	2.4	4.5*	3.1	5.2*	2.9
Left arm	3.45	2.6	3.3	2.8	3.3	2.9
Right arm	3.4	2.5	3.45	2.8	3.4	2.8
Discomfort feeling	5.51*	4.3*	6.5*	4.9*	7*	4.8*

*Indicates a value is above 3.5 and is uncomfortable.

Design Changes. Based on this data, I believe it is necessary to make the seat adjustable to move back up to 100 mm and have the ability to depress downward up to 50 mm and raise to 100 mm. The steering wheel should be made telescopic to allow egress and ingress into and out of the cabin by keeping the steering wheel at its original position and then moving it toward the operator from 100–185 mm. Furthermore, the steering wheel should have the ability to tilt downward to the operator from 9–20°.

2.5 Evaluate the Location, Adjustment Range, and Comfort for Joystick on the Left and Right Side

Initial Positioning. With the manikin in the previously-discussed initial position (see Sect. 2.4), the manikin's hands were placed on the joysticks in points just below the top of the joystick (Fig. 8).

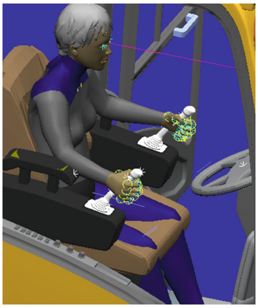

Fig. 8. Operator with hands affixed to joysticks.

Modifications. Following an iterative process of making modifications and assessing the impact of those changes on the manikins' comfort for various elements of the body, unique modifications were made to the armrests for each manikin.

5th Percentile Female. For the 5th percentile female, the armrests were moved up in the z-axis by 200 mm and backward in the x-axis by 150 mm.

50th Percentile Male. For the 50th percentile male, the armrests were moved up in the z-axis by 200 mm and backward in the x-axis by 150 mm.

95th Percentile Male. For the 95th percentile male, the armrests were moved up in the z-axis by 175 mm and backward in the x-axis by 135 mm.

Analysis. A baseline discomfort analysis was performed for each manikin in the origin position. A second discomfort analysis was performed for each manikin at the final modified position for comparison.

Results. The results of the armrest discomfort analyses are presented in Table 2. At the original position, all manikins experienced discomfort in several body elements. The 5th percent female experienced discomfort in the neck, legs, and overall, and the 50th and 95th percentile males experienced discomfort in the neck, shoulders, legs, and overall. All manikins experienced reductions in discomfort in all body elements and overall (i.e., to the point of being unremarkable aside from overall discomfort).

Table 2. Differences in discomfort from baseline to post-modifications to the armrests.

Body element	5th% female		50th% male		95th% male	
	Origin	Modified	Origin	Modified	Origin	Modified
Neck	4.45*	3	4.7*	3	4.7*	3.1
Shoulders	3.32	2.4	4.1*	2.7	4.6*	3
Back	3.8*	2.3	3.8*	3	4.2*	3.2
Buttocks	2.9	1.8	3.4	2.4	3.4	2.2
Left leg	3.8*	2.3	4.1*	3	5.2*	4.4*
Right leg	3.7*	2.3	4*	3	5.2*	4.3*
Left arm	3.4	2.9	3.6*	2.6	3.8*	2.4
Right arm	4*	2.1	3.6*	2.6	3.8*	2.4
Discomfort feeling	6.4*	4.2*	6.9*	5*	7.3*	5.1*

*-Indicates a value is above 3.5 and is uncomfortable.

The range of modifications to the armrests was 175–200 mm on the z-axis and 135–150 mm on the x-axis.

Design Changes. Based on this data, I recommend making the armrests adjustable in the z- and x-axes, by 25 and 15 mm, respectively, and moving them upwards in the z-axis by 175 mm and backward in the x-axis by 135 mm.

2.6 Evaluate the Location, Adjustment Range, and Comfort of Wrist Pads

Initial Positioning. With the manikin in the previously-discussed position (see Sect. 2.5) and the armrests positioned accordingly, the wrist pads were manipulated to determine the optimal position just behind the wrist.

Modifications. Following manipulation of the wrist pads only (i.e., by grouping them, and establishing degrees of freedom in the z- and x-axes), the optimal position for each manikin was determined.

5th Percentile Female. For the 5th percentile female, the wrist pads were moved down in the negative z-axis by 30 mm, and forwards in the negative x-axis by 50 mm.

50th Percentile Male. For the 50th percentile male, the armrests were moved down in the negative z-axis by 15 mm, and forwards in the negative x-axis by 60 mm.

95th Percentile Male. For the 95th percentile male, the armrests were moved down in the z-axis by 10 mm, and forwards in the x-axis by 50 mm.

Design Changes. Based on this data, I recommend making the wrist pads adjustable in the z- and x-axes, by at least 20 and 10 mm, respectively, and moving them downwards in the negative z-axis by 10 mm and forwards in the negative x-axis by 50 mm.

2.7 Evaluate the Location, Reach and Comfort to Touch Screen

Initial Positioning. With the manikin in the previously-discussed initial position (see Sect. 2.4), the manikin's right index finger and line of vision were placed on the center of the touch screen (Fig. 9).

Fig. 9. Position of index and line of vision on the touchscreen.

Modifications. Following an iterative process of making modifications and assessing the impact of those changes on the manikins' comfort for various elements of the body, unique modifications were made to the touchscreen for all manikins. Unlike the previous modifications, a single modification was made to the touchscreen that appropriately reduced discomfort for all manikins. The touchscreen was raised in the z-axis by 200 mm and was moved toward the operator in the x-axis by 210 mm.

Analyses. In addition to the discomfort analysis, a reach analysis was performed for the manikins' right arms, which provides a visual indicator of what aspects of the environment fall within a manikin's reach (Fig. 10) [7].

Fig. 10. Reach analysis of what environmental elements are within the manikin's reach.

Results. The results of the touchscreen discomfort analyses are presented in Table 3. The modifications to the touchscreen location led to remarkable reductions in discomfort for all manikins. The 95th percentile male did retain some neck discomfort, but this was borderline uncomfortable given the threshold for this value.

Table 3. Differences in discomfort from pre- to post-modifications to the touchscreen.

Body element	5th% female		50th% male		95th% male	
	Origin	Modified	Origin	Modified	Origin	Modified
Neck	4*	3.1	4.84*	3.1	4*	3.5*
Shoulders	4.4*	2.8	4.9*	2.8	4.6*	3.2
Back	2.8	2.1	3.5*	2.1	2.5	2.2
Buttocks	3.2	1.3	3.5*	1.4	2.6	1.9
Left leg	3.4	2.6	4.9*	2.8	3.3	2.8
Right leg	3.1	2.4	4.4*	2.7	3	2.6
Left arm	2.9	2.2	3.6*	1.9	2	1.8
Right arm	3.5*	2.2	3.5*	2.5	3.2	3
Discomfort feeling	5.8*	4*	6.8*	4*	5.4*	4.5*

*-Indicates a value is above 3.5 and is uncomfortable.

Regarding the reach analysis, the touch screen was partially within reach at its origin but fell within reach for all manikins following the modifications.

Design Changes. Based on this data, I recommend a fixed position of the touchscreen by increasing it in the z-axis by 200 mm and moving it in the x-axis by 210 mm towards the operator.

2.8 Evaluate Visibility and Comfort While Actuating Controls

Initial Positioning. With the manikin in the previously-discussed initial position (see Sect. 2.4), the manikin's right index finger and line of vision were placed on a point on the actuating controls (Fig. 11).

Fig. 11. Position of index and line of vision on actuating controls.

Modifications. Through several modifications to the actuating controls' location and assessing the impact of those changes on the manikins' comfort for various elements of the body, unique modifications were made to the actuating controls for all manikins. Again, a single modification was made to the actuating controls that appropriately reduced discomfort for all manikins. The controls were moved in the negative x-axis by 150 mm.

Analyses. A discomfort analysis was performed before and following the modifications. Additionally, an analysis of operators' visual field was conducted by selecting the "Analysis" tab on the menu, then selecting "Vision", and finally "Limits of Visual Field". The vision analysis provides visual insights into the limits of sharp (±2.5°), optimum (±15°), and maximum (±50°) sight areas [7]. The purpose of the visual field analysis was to determine whether or not the manikins were able to maintain the touch screen and the front window of the excavator within their optimal and/or maximum visual fields of vision.

Results. The results of the actuating controls discomfort analyses are presented in Table 4. The modifications to the actuating controls' location led to reductions in discomfort for all manikins, yet there was still discomfort in the male operators' legs. However, given the limited amount of time likely needed to operate the actuating controls, this discomfort is likely minimal.

Table 4. Differences in discomfort from pre- to post-modifications to the controls.

Body element	5^{th}% female		50^{th}% male		95^{th}% male	
	Origin	Modified	Origin	Modified	Origin	Modified
Neck	3.6	3.1	4.6*	3.4	4.1*	3.2
Shoulders	2.2	2	2.5	2.2	4.6*	2
Back	3.2	2.9	4*	3.48	3.7*	3.2
Buttocks	1.5	1.7	2.3	1.9	2.1	1.6
Left leg	2.9	2.9	4.4*	3.92*	4*	3.6*
Right leg	3.1	2.8	4.1*	3.7*	3.7*	3.3
Left arm	2.9	2.8	2.9	2.3	2.6	2.1
Right arm	1.6	2.1	4*	3.3	3.9*	3.2
Discomfort feeling	4.6*	4.6*	6.22*	5.3*	5.7*	4.9*

*-Indicates a value is above 3.5 and is uncomfortable.

In regards to the visual field analysis, all manikins were unable to maintain the touchscreen in the optimal field of vision and the front of the excavator in the maximum field of vision when focusing on the actuating controls in their original position (Fig. 12). However, after modifications were made to the actuating controls' location, all manikins were able to maintain the touchscreen in their optimal field of vision and increased their vision of the front of the excavator.

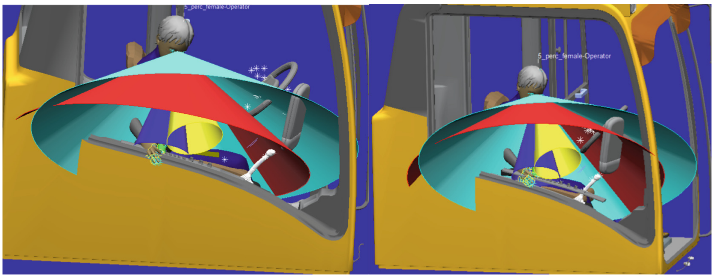

Fig. 12. The difference in optimal (red) and maximum (blue) visual fields of 5^{th} percentage female with controls at original (left) and final positions.

Design Changes. Based on this data, I recommend a fixed position of the actuating controls by moving them in the negative x-axis by 150 mm.

3 Discussion

3.1 Impact of Prior Experience on Assignment Completion

Previously, I have been a teaching assistant in an undergraduate-level ergonomics course, and I taught students to use a digital modeling program to assess the postural impact of various lifts on joints and the workers' spine. Despite the differences between this program and RAMSIS, this experience helped me learn to navigate RAMSIS efficiently. This experience also helped me understand that I need to be mindful of realism when modeling manikins using digital modeling software, as an unrealistic manikin position will impact my ability to provide meaningful suggestions for ergonomic improvements.

3.2 Challenge Overcome During Assignment

One issue I faced during this assignment was making realistic modifications to the environment based on the joint capacity analysis. When using this analysis tool to modify aspects of the environment, I frequently encountered situations where the manikins' backs would be forced through the seatback to attain a more comfortable posture (Fig. 13). Since this approach is unrealistic and limits my ability to meaningfully interpret the data, I elected to utilize the discomfort analysis for the work requested in Andre's statement of work, as I could reliably model realistic manikin positions and make appropriate suggestions for modifications. While not ideal, I felt this was the best way to proceed with this project given the limitations I faced.

Fig. 13. Unrealistic manikin position using joint capacity analysis to modify the environment.

3.3 Future Considerations for RAMSIS Users

Future users of RAMSIS should be provided a comprehensive list of issues faced when using the software (e.g., unrealistic manikin positioning like the problem above), and potential solutions to the problem. Following the completion of an initial demonstration, this information would be helpful to have is addition to a question and answer session with a RAMSIS representative, as users could troubleshoot any unresolved issues with their assistance. Furthermore, further discussion is needed on the various analyses ran, and how to properly interpret the data. Specifically, the visual field analysis was not discussed during the demonstrations for the current study, so my interpretation of this information may be skewed from its intended application.

4 Future Work

4.1 Limitations of RAMSIS

Currently, RAMSIS does not allow for the assessment of machine vibration on operators. For excavator operators, this is an important consideration, as research has shown that vibrations are a major source of ergonomic risk to operators [5]. Perhaps RAMSIS could assess the estimated vibrations experienced by the operator, and display how modifications to the materials surrounding the engine or cabin or modifications to the seat pedestal structure could impact vibrations felt by the operators.

References

1. Kittusamy, N.K.: Assessment of ergonomic risk factors among operators of heavy earthmoving machinery. In: ASSE Professional Development Conference and Exposition. OnePetro (2003)
2. Pałęga, M., Rydz, D.: Work safety and ergonomics at the workplace an excavator operator. Trans. Motauto World **3**(1), 25–29 (2018)
3. Duffy, V.: Human digital modeling in design. In: Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, pp. 1016–1030. John Wiley & Sons, Hoboken (2012)
4. Hanson, L., Högberg, D.: Use of anthropometric measures and digital human modeling tools for product and workplace design. In: Handbook of Anthropometry, pp. 3015–3034. Springer, New York, NY (2012)
5. Kittusamy, N.K, Buchholz, B.: Whole-body vibration and postural stress among operators of construction equipment: a literature review. J. Saf. Res. **35**(3), 255–261 (2004)
6. Anton, N.: Reducing Ergonomic Risk and Discomfort of Excavator Operators Using RAMSIS. IE 578 Project 1 Report (2021)
7. RAMSIS NextGen 1.8 Ergonoics User Guide, pp. 1–243. Human Solutions, Germany (2021)