Redesigning an Excavator Operator's Seat and Controls Using Digital Human Modelling in RAMSIS

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Abstract. This paper aims to ergonomically analyze and improve an excavator operator's seat design for comfort and reachability. Anthropometric diversity considerations uncover glaring oversights in the seat's initial design and serve as a potential for improvement before actual production begins. Three manikins - 2 males and 1 female - of different sizes were used in all assessments to simulate even demographic spread and identify boundary conditions. The 3D CAD software RAMSIS was used to perform all simulations, dichotomized into operators performing two key actions from their seat – Driving and Digging. The three fundamental analyses that were covered in this report are Comfort Feeling, Joint Capacity, and Reach assessment. Results demonstrate that the neck and shoulder joints face maximum discomfort while performing digging tasks and a simple design change like raising the armrests showed considerable improvement in comfort feeling. Some variation in discomfort was seen when the manikin type was altered. Reachability analysis unveiled another crucial design flaw as a controls shaft near the steering wheel was out of reach of all three manikins. Some of the recommended modifications in seating include height-adjustable armrests (discomfort feeling dropped by 28% for the medium Male) and slide-mounted steering, which can move forward and backward (a translational movement of 100–130 mm along the x-axis was required to get the touchscreen and driving controls within arm's reach of all manikins). Procedure and challenges are discussed, and some operator-specific customizations have been incorporated along with the scope for further design improvement. As a motivation for the problem statement, literature surveys, and bibliometric analyses have been included in this report, which highlights the importance of cultural change in higher-order decision making to push for design improvements that promote employee well-being. Relative movement of repositioned controls has been tabulated at the end, in a table for each case, to access the range of movement needed for each object/control. Findings and studies from this paper can be referenced by design teams to aid in ergonomically optimizing operator seats and controls of excavators or similar construction equipment.

Keywords: RAMSIS · Comfort · Reach · Manikin · Ergonomics

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1 Introduction and Background

1.1 Problem Statement and Objective

Repositioning controls for improved ease of access and minimizing strain to make sensible recommendations considering a broader perspective than the last paper. The same 3 manikins were used to run all simulations, providing a range of values for customizing the positions of the seat and controls. Apart from the usual driving and digging tasks, the manikin is simulated to access the touchscreen and control knobs near the right armrest as well. Foot pedal positions and angles, which were largely ignored in the previous analysis have been taken into consideration. Also, eye and head movements have been introduced to get a holistic sense of vision and barriers to the line of sight. Individual objects for the armrests, foot pedals, touch screen, and steering wheel were defined to identify the best positions for each manikin, and boundary conditions were identified.

1.2 Motivation

Boosting employee health and safety. Jobs like those of an excavator operator require prolonged shifts repeated actions under stressful operating conditions. Cases of employees suffering from Work-related musculoskeletal disorders (WMSDs) are prevalent in a job line like theirs. This issue has ballooned, even in developed countries like the US. Conservative figures estimate that WMSDs cost the US a total of $45 to $54 billion annually [1].

Moreover, a press release by the Bureau of Labor Statistics shows that there were 1000 cases of WMSDs each day on average during 2014, at a rate of 34 cases per 10 000 full-time workers [2]. This can be seriously debilitating for businesses as these are not only lost work hours but seriously crippling cases can also lead to lawsuits and compensation charges. Software like RAMSIS can largely assist in solving this problem by suggesting smarter workplace and job designs through CAD models and simulations.

Another motivating factor was that as of today very few engineers have been trained in human factors and ergonomics, and only a small percentage of human factors and ergonomics specialists have the opportunity to learn about DHM (Digital Human Modeling) as a part of the course curriculum [3]. Increasing awareness and demonstrating the benefits of HMI modeling to inculcate these indispensable aspects of engineering in future generations is a strong motivating factor for corporations and educational institutes.

2 Systematic Review

Change beings from the top. Leaders are often the drivers of positive change that is reflected in safe and employee-friendly workplace practices. Initially, my literature surveys were heavily focused on ergonomics in corporate decision-making and how culture creates a dialog that reflects in design changes. These changes aimed at improving employee health and safety trickle down to the grass-root level to benefit frontline workers. As engineers, our challenge is not only to push for implementing best practices but also to understand if corporations introduce effective policies to improve work conditions and if they really take into account workers' issues [4]. The next steps in my systematic review approach covered finer topics pertinent to this project. 3 out of the 8 conducted analyses have been included below.

2.1 MAXQDA Wordcloud Analysis

I chose 4 random articles across a spread of sources (SpringerLink, ResearchGate, and GoogleScholar) and Chapter 15 from the Handbook of Human Factors to identify buzzwords and popular terms used in publications. The overarching theme of all these papers revolved around Human Machine interface and computer aided-simulation. The wordcloud in Fig. 1 indicates trending hot topics and as expected, some popular terms repeated across multiple publications are – **analysis, model, disability, design,** and **measurement.**

Fig. 1. Literature analysis: Word-cloud to identify main topics of discussion from publications

2.2 Pivot Chart of Authors for Selected Search Terms

A keyword search for the terms "accessibility" and "ergonomics" was performed on Google Scholar to identify key contributing authors whose publications encompass these fields as shown in Fig. 2. The time range was set to 2010–2021 to filter out obsolete trends.

2.3 Cluster Analysis Using WoS Extract on CiteSpace

For the next analysis, I wanted to narrow my search down towards a specific application of ergonomics, that was related to my project work. My search terms on Web

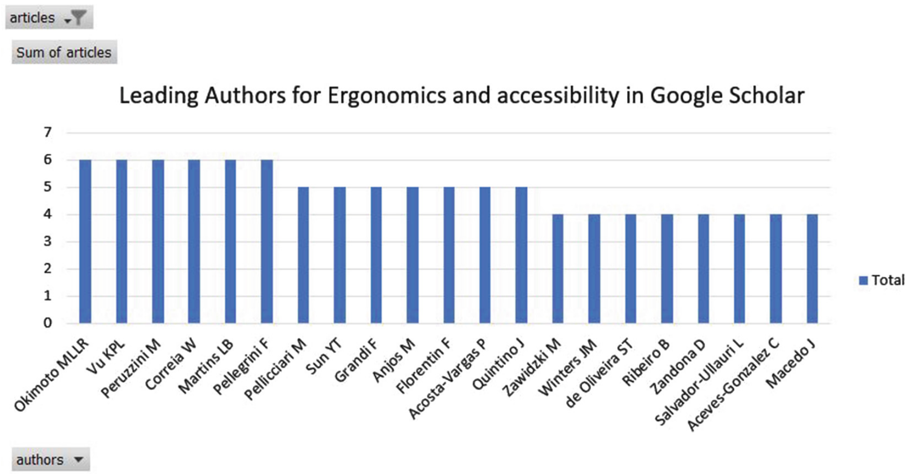

Fig. 2. This chart displays the leading authors who've published articles pertaining to the fields of ergonomics and accessibility. Values above 4 have been retained.

of Science were "driver", "seat" and "ergonomics". Time slicing for the years 2016–2021 was performed in CiteSpace to visualize the attached cluster diagram. As seen in Fig. 3, "Automotive Ergonomics" and "Seat design" are prominent clusters amongst the 6 identified. Some popular authors also came up from this analysis.

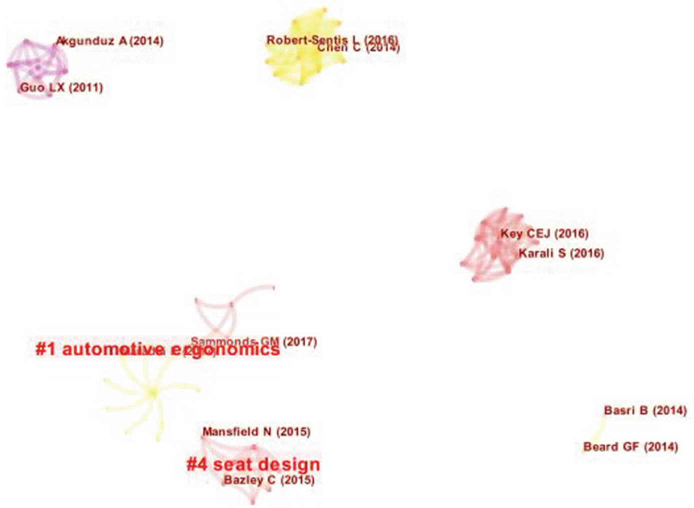

Fig. 3. This image was generated using Citespace and the Metadata was sourced from Web of Science.

3 Statements of Work – RAMSIS Simulations

3.1 Creating Boundary Conditions for the Tasks

Using the Germany2004 dataset available in RAMSIS, I created 3 manikins to simulate all experiments, representative of almost 90% of the entire population. Anthropometric measurements were retained from my last paper [5]. The 95%tile male and 5%tile female were used to determine upper and lower bounds. Initial runs were carried out on the Medium Male and to ascertain upper and lower limits of motion, these were then replicated on the Tall Male and Short Female. The process to group and name objects and define kinematics can be referenced in my previous paper. A walkthrough of those procedures would be repetitive and hence those have purposefully been omitted from this paper.

3.2 Evaluating Location, Adjustment Range, Comfort for the Overall Driving and Digging Posture Including Seat Adjustment, Pedal Position, and Steering Wheel Position/adjustment

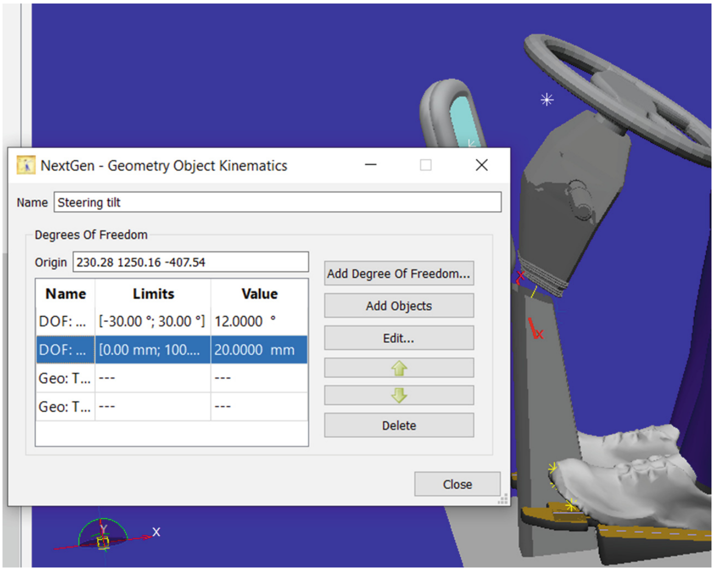

Fig. 4. Creating the steering tilt object and defining Kinematics.

The new Steering wheel geometry splits the steering mount into 2 parts. After the new steering wheel geometry file was copied to the project folder, 2 degrees of freedom were added for the upper part. The first changed the angle of tilt between 0° to 30° as shown in Fig. 4 above. The second translational degree of freedom moves the upper joint up and down for improved reach.

The pedals were grouped into a common object called Pedals. This was then assigned a rotational degree of freedom to adjust angle of tilt and a translation one to move it up and down as seen in Fig. 5.

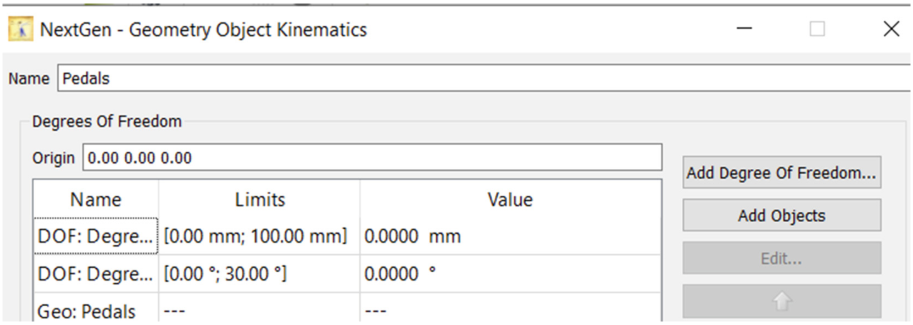

Fig. 5. Creating the Pedals object and defining Kinematics.

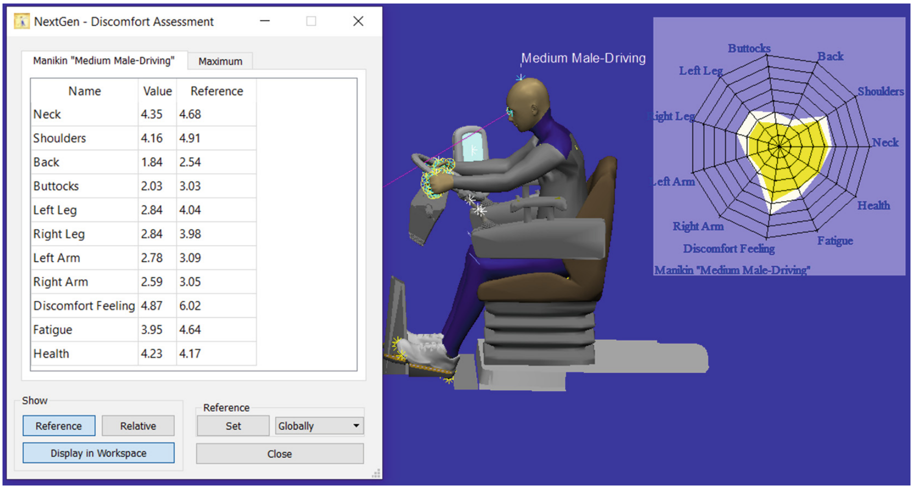

Fig. 6. Comfort feeling assessment for driving task. The white portion of the radar chart indicates discomfort values before repositioning

After repositioning the steering wheel and foot pedals, a comfort feeling analysis was done for the medium male manikin (Fig. 6). The reference values were set before relocating pedals and steering wheel to compare the change in comfort levels. Splitting the steering wheel and lifting the foot pedals has resulted in an improvement of comfort feeling from my previous paper [5].

As an improvement from my last paper [5], The armrests were assigned now assigned an additional translational degree of freedom along the x-axis apart from the pre-existing one for the z-axis (Fig. 7).

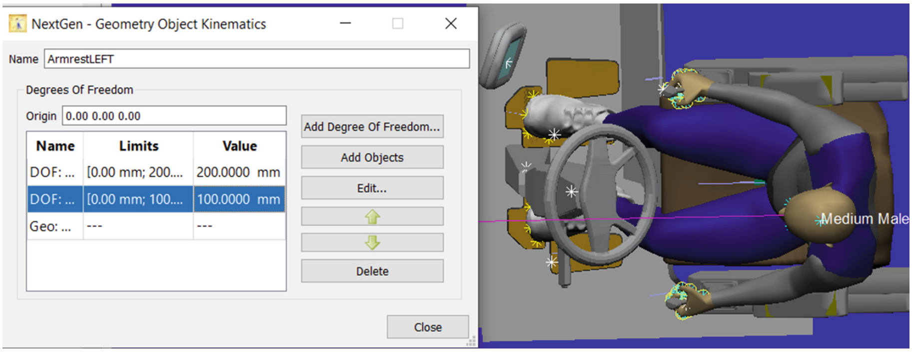

Fig. 7. Creating the ArmrestLEFT object and defining Kinematics. Similarly, ArmrestRIGHT was also created

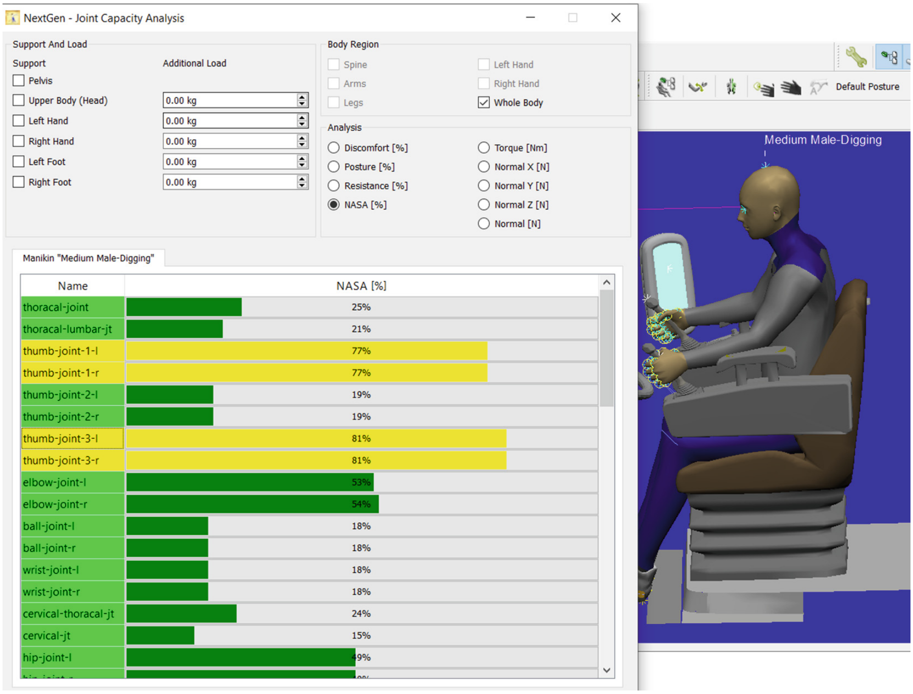

Fig. 8. Joint capacity analysis for digging task performed by the medium male. NASA zero-g posture is used to compute discomfort percentages. Apart from the shoulder joints and fingers, all values were green. (Color figure online)

Both armrests move in unison, so instead of 2 groups, a common object could have been created. This is something future students can consider. Wrist pads are connected to the armrests and do not move independently.

3.3 Evaluating the Location, Adjustment Range, and Comfort of Wrist Pads

This part only applies to the digging task. A driving action would require the manikin to free its elbows while rotating the steering wheel. Resting elbows on wrist pads would show an increase in comfort feeling but restrict hand movements. It is important to consider what the task demands before suggesting ways to minimize strain.

For all experiments, wrist pads have been assumed to be connected to the rest of the armrest. The manikin's elbows have been made to touch the wrist pads to reduce discomfort % as seen in the joint capacity analysis image in Fig. 8 for the medium male manikin.

3.4 Evaluating the Location, Reach, and Comfort of Touchscreen

The touch screen object was created by combining individual parts and the center point and assigned 3 degrees of freedom to enable translation motion along the x-axis, towards the manikin and rotational movement to face the manikin. This is shown in Fig. 9 below. The angle change was added later, following observations from reachability analysis.

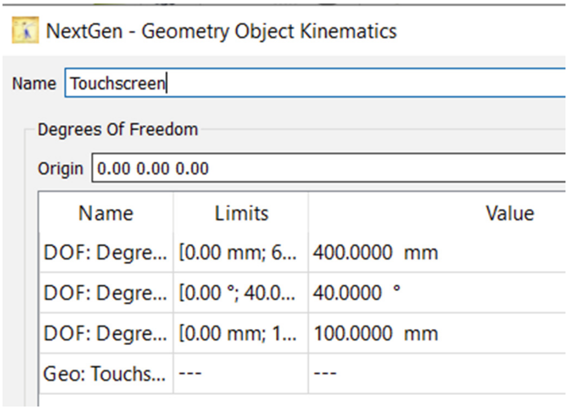

Fig. 9. Creating the touchscreen object and assigning degrees of freedom

Digging. A reachability analysis of the manikin's right arm uncovered some oversights in initial touchscreen placement. For this analysis, the touchscreen object was moved by 200 mm along the z-axis and 500 mm along the x-axis. The inner green sphere in Fig. 10 indicates "comfort reach" which was created under Reach Definitions by using points on the manikin's right shoulder and index finger. This is an improvement from the change of 250 mm suggested for the medium manikin in my mid-term paper [5].

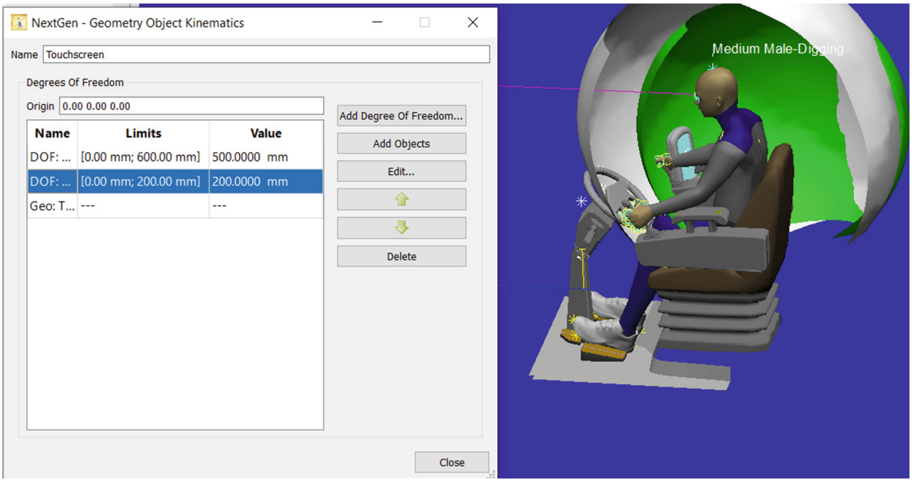

Fig. 10. The green envelope indicates comfort reach of the manikin's right arm. The touchscreen is now within comfortable reach (Color figure online)

Another key observation from this exercise - the touchscreen was not only found to be out of reach of the short female manikin's right arm but also partially blocked, beyond her line of sight (Fig. 11).

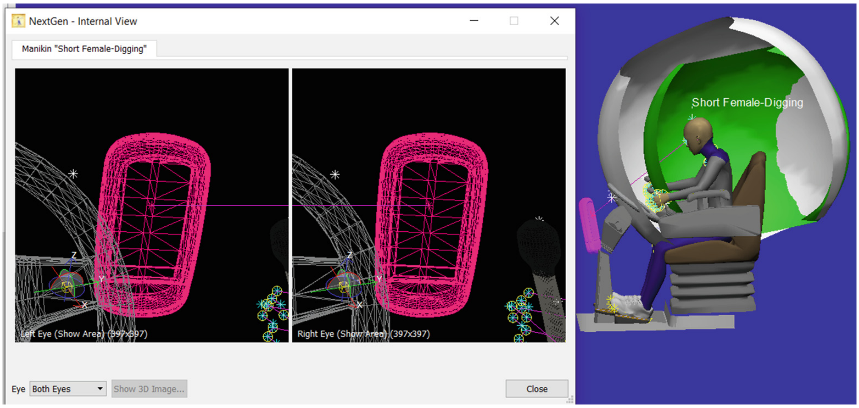

Fig. 11. For the touchscreen's initial position, the short female manikin was simulated to look at that general direction. Her vision is captured in the image on the left

Once the touchscreen position is changed, it is also desirable to alter the viewing angle to ensure that it faces the operator (Fig. 12). Additional head movement, if avoidable would reduce the chances of neck injuries or strain. Hence, 3 degrees of freedom were finally assigned to the touchscreen and the final position is shown below, in reference to the medium male mannikin. The final touchscreen position is shown in Fig. 13.

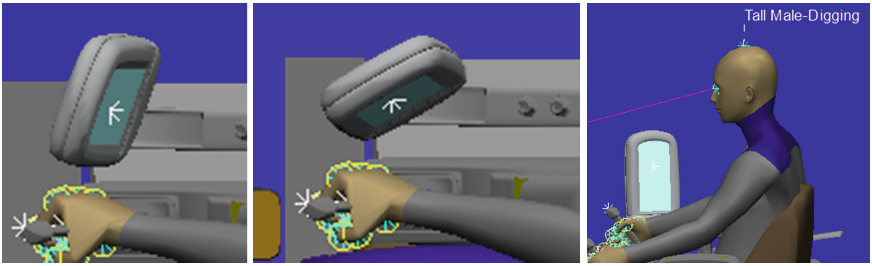

Fig. 12. Touchscreen position post-relocation. In the 2nd image, the screen has been tilted by 40° towards the operator for better viewing. Now, the touchscreen directly faces the manikin.

Fig. 13. Final touchscreen position for the short female manikin. The touchscreen is within comfortable reach of her right arm

Driving. The touchscreen is assumed to require occasional access during the driving task as it would cause distraction. Its main purpose might be as a display, as commonly seen on car dashboards. It is highly unlikely that the operator would need to periodically press buttons on the touchscreen while driving. For the driving task as well, although it isn't shown in Fig. 14 for the sake of brevity, the touchscreen was repositioned following a reachability analysis.

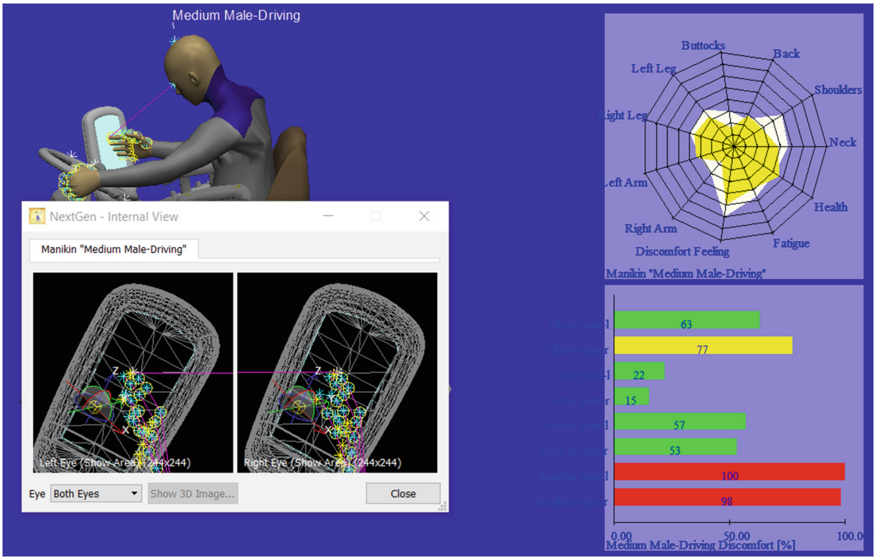

Fig. 14. The manikin is simulated to reach the mid-point on the touchscreen with one hand on the steering. Comfort feeling (radar diagram, joint capacity (color-coded bar plot), and vision are also displayed (Color figure online)

3.5 Evaluating Comfort While Actuating Controls

A key observation from Fig. 15 is that while actuating the control knobs/buttons on its right, the manikin's right shoulder joint is under considerably less stress as opposed to its left shoulder. Outstretched arms exert more load on the shoulder joint and this is directly proportional to the object's proximity.

4 Results and Recommendations

For each of the 3 manikins, unique combinations of repositioning metrics have been calculated from RAMSIS simulations and tabulated in Table 1. For digging, joint capacity analysis was used to compute (NASA) discomfort percentage levels and comfort feeling analysis for driving. The optimum levels of comfort were reached when all objects were moved in unison.

Office-chair-like armrest adjustments that go up-down and slide forward and backward need to be installed on the seat. The steering wheel needs to be angle adjustable as well as movable towards the operator's seating direction. This can be achieved by splitting the steering joint and adding a telescopic arm connecting the 2 parts. This arm would then be placed on a hinge-joint to facilitate angular motion. To accommodate height differences among operators, foot pedals should move up-down but angle adjustment is largely insignificant. Adding an additional movable part on the pedals for a minuscule improvement in comfort wouldn't be prudent. There is a further need to simulate the manikins' feet under flexion while pressing the pedals. Hanging pedals can also

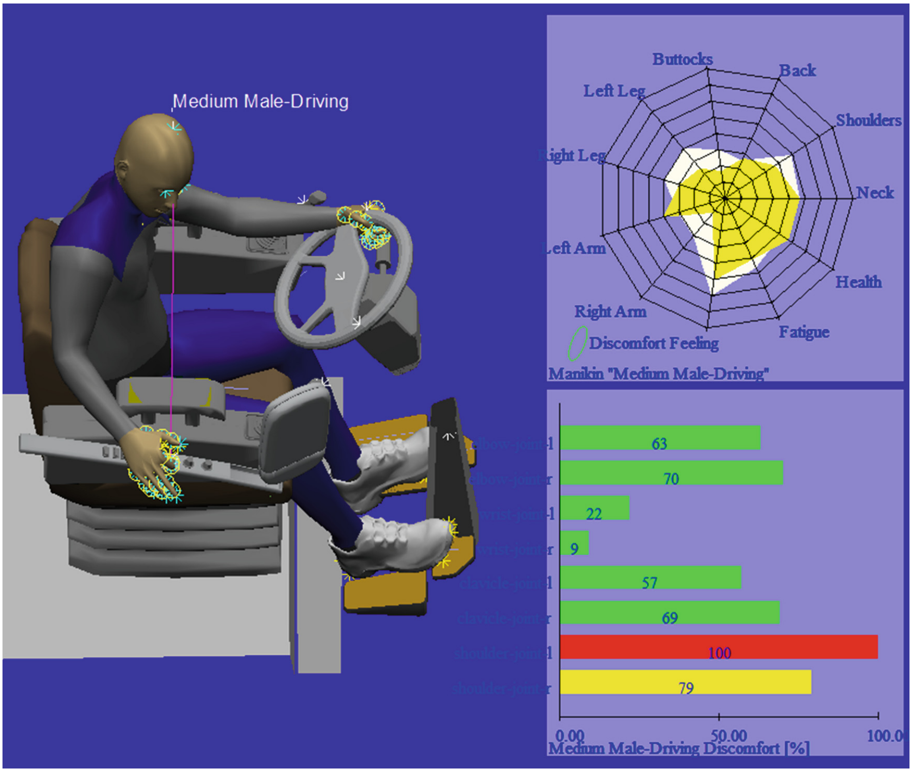

Fig. 15. Comfort feeling and joint capacity analysis while actuating controls

Table 1. Recommended changes in object placement. All non-angle values are in mm.

Object	Direction	Digging			Driving		
		Tall Male	Medium Male	Short Female	Tall Male	Medium Male	Short Female
Armrests	x-axis	100	50	0	NA	NA	NA
	z-axis	250	200	170	NA	NA	NA
Steering	Angle	NA	NA	NA	0°	5°	12°
	Away from mast	NA	NA	NA	200	180	70
Foot pedals	Angle	0°	5°	5°	0	0	0
	x-axis	0	30	40	0	0	0
Touch screen	x-axis	400	500	450	300	400	250
	Away from manikin	100	100	40	100	100	100
	Angle towards manikin	40°	40°	40°	40°	40°	40°

be tested. The touchscreen needs to be mounted on a movable arm with multiple degrees of freedom. It should allow for rotation as well as front-back and side-side translational motion. Ideally, a 2-stage arm connected by ball and socket joints would suffice.

5 Discussion

5.1 Prior Experience

My prior analytics experience came in handy and I could understand concepts pertinent to systematic review quite well. I have worked as a freelance tutor in the past, helping master's and doctorate students with their dissertations and reports. I am well versed with literature review concepts and have performed text mining, bibliometric analyses, natural language processing, and created interactive visuals like word clouds, clusters, and network diagrams using R.

5.2 Overcoming Challenges

I took this course online alongside my full-time co-op which is scheduled to end in January 2022. As my company is still in a relatively nascent stage, my team is putting in the hard yards to get ahead of the curb. For a significant portion of my co-op, I ended up working overtime. Balancing and distributing my time was quite challenging but my multitasking abilities helped me overcome this challenge. I deployed the Agile project management strategy to deliver this project on time - breaking down deliverables into sequential daily tasks to keep myself on track.

At least 6 software were required to perform bibliometric and literature analyses as a pre-requisite for this project. RAMSIS in itself is quite bulky and combined with these, I had to clear out quite some space on my laptop to install all of them. Future students should clear out at least 8 GB of space on their computers beforehand to successfully install and run these without lag. It would help if a consolidated download manual with all links is provided at the very start of the course rather than scattering setup instructions across pdfs on TopHat.

6 Future Work

A bottom-up approach can be tested where students get to reverse engineer ideal seating position by defining restrictions first and then repositioning the manikin on the seat. This approach might give better results in terms of joint stresses and reach.

Amongst several data points that are missing, perhaps the most critical piece is data on resistance to motion. Additional insight on motion resistance of the steering wheel, foot pedals, and joysticks to the force exerted by the operator. The closest approach for simulating this is by adding additional weights on the manikin's joints under joint-capacity analysis.

A myriad of practical considerations come into play when a redesign is discussed in depth. HVAC aspects like the positioning of cooling vents have not been considered in the cab design at all. Accelerated fatigue on hot sunny days needs to be simulated to understand actual field conditions. Ingress-egress and ladder placement were not taken into account in this paper.

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