Journal of Engineering and Technology

ISSN 2180-3811 eISSN 2289-814X https://jet.utem.edu.my/jet/index

DOI: https://doi.org/10.54554/jet.2026.17.1.005

APPLICATION OF 3D MODELLING TECHNIQUE FOR ERGONOMIC IMPROVEMENT OF MANUFACTURING ASSEMBLY LINE WORKSTATION

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Article history:
Received Date: 1 September 2025
Revised Date: 22 April 2026
Accepted Date: 1 May 2026

Keywords: Anthropometry, Autodesk Fusion, Digital Human Modelling,

Abstract— An ergonomically workstation design is vital for improving workers' health, safety, and productivity in manufacturing industries where workers are not guided against repetitive tasks, awkward postures, and restricted workspaces. Studies have shown that these conditions often contribute to musculoskeletal disorders, fatigue, and absenteeism, which impact both employee and organization. This study was designed to apply 3D modelling and digital human simulation techniques to evaluate and redesign an assembly line workstation in Nigeria using anthropometric data of the participants. Fifty experienced workers were purposively selected, and data were

Ergonomic, Musculoskeletal Discomforts	collected using structured questionnaires and direct observation. Ergonomic risks were evaluated using the Rapid Upper Limb Assessment (RULA), while Autodesk Fusion 360 and Jack Siemens 8.4 software were used for modelling, simulation, and validation of the redesigned workstation. Findings revealed that 90% participants reported discomfort, mainly back pain (40%) and wrist pain (18%), while 86% reported poor tool accessibility and gave RULA score between 6 and 7. The redesigned workstation improved postures, reduced bending and awkward reaches, and achieved a RULA score of 2, indicating low ergonomic risk. Therefore, integrating modelling and simulation-based ergonomic intervention in workstation design provides a proactive and cost-saving solution for improving workers' well-being and increasing productivity.

I. Introduction

Ergonomics emphases on designing work systems, tools, and environments to conform to human capabilities and boundaries, particularly in human-machine interactions [4]. In industrial environment, an effective ergonomic design is important for safeguarding workers' health and improving performance.

However, many establishments, mostly in developing economies, still lack appropriate ergonomic practices, leading to a high occurrence of Musculoskeletal Disorders (MSDs) and Repetitive Strain Injuries (RSIs) [5]. These conditions diminish productivity but raise healthcare costs. In Nigeria, where economic development is mostly labourintensive, designing an ergonomics fitted workplace is important.

An inadequately designed workstations may force workers into a difficult posture, causing physical strain, fatigue, and prolong injury [17]. Assembly line workstation workers are endangering due to repetitive tasks, time pressure, and restricted movements. Factors like repetitive motion, forceful exertion, inappropriate load handling, and extended standing may increase injury risk [10][18].

Ergonomics design being integrated into workstation may significantly minimise these risks by improving comfort, productivity, and job satisfaction [1][13]. Developments in digital technologies, such as 3D modelling and Digital Human Modelling (DHM), may allow designers to model, simulate an optimize work settings before implementation. 3D modelling and DHM tools support assessment of posture, arm reach, and movement, thereby, reducing costly modifications that may be required [21].

This study aims to improve assembly line workstation design by applying 3D modelling and DHM techniques to optimize ergonomic settings before implementation.

II. Literature Review

Ergonomics has evolved from a direct focus on MSDs prevention to a broader involvement of safety, productivity, and system design [13]. Cognitive ergonomics examines human mental capability involving perception and decision-making, which has contributed to improvement of workplace design [11].

Technological improvements have noticeably transformed ergonomic practice. Digital Human Modelling (DHM) is a vital tool for simulating human interaction in virtual environments. This enables early discovery of ergonomic risks and encourage proactive design improvements [4][7][19]. Software like Jack Siemens, Tecnomatix, DELMIA, and RAMSIS allow for detailed workstation simulations [6][19].

[16] studied musculoskeletal disorders risk in four soap making industries and observed that workers experienced discomfort when performing their jobs, which may have been corrected if the workstation was simulated before implementation. In a physically demanding workplace, studies shows that early ergonomic interventions may reduce fatigue and improve efficiency [24]. Improper workstation design in assembly line has been associated with MSDs due to repetitive movements, awkward postures, and time constraints [8][20].

Although known interventions such as adjustable workstations, improved tool location, and worker training have been shown to enhance comfort and efficiency [3][11][23]. However, recent approaches combining motion capture technologies, ergonomic assessment tools, and computational methods seem to optimize workers' posture and minimize strain [15]. Human Systems Interaction (HSI) emphasize assessing user-workplace environment by simulation [14].

DHM aligns with the approach by allowing thorough analysis of posture, arm reach, and movement while recording for user variability [25]. However, its effectiveness relies on anthropometric and biomechanical data precision, which may not completely capture unwary human behaviour.

This did not invalidate ergonomic design as a critical technique for increasing workers' efficiency, productivity, and to minimize MSDs-related costs [12]. DHM tools such as Jack Siemens 8.4 gives a realistic simulation of unforeseen tasks, making it appropriate tool for optimizing Assembly Line Workstations (ALW) [22].

III. Methods

This research employed purposive sampling to select 50 assembly line workers who were directly involved in ALW. This allowed for selection of participants who had experience in ALW to provide important insights on ergonomic risks.

Data were gathered using both direct observation and structured questionnaires. This is to collect evidence on discomfort levels, fatigue, tool accessibility, and workstation limitations. Oral informed consent was gotten from all the participants, also, confidentiality, anonymity, and right to withdraw from the study were copiously observed. The study followed established ethical rules such as outlined in the Declaration of Helsinki.

Rapid Upper Limb Assessment (RULA) method was used to evaluate ergonomic risk. Classification of scores were into four categories: low (1-2), moderate (3-4), high (5-6), and very high (7 and above).

The redesign procedure was aligned to a 3D parametric model of the assembly line workstation created in Autodesk Fusion 360. The model used anthropometric measurements gotten from participants. This is to ensure that the design reproduced actual worker dimensions. The 2D sketch modelling was performed to define the workstation dimensions. The base worktable, chair, shelf, and tool location areas were sketched on individual files to distinguish them, for easy assemble. The extrude, loft, and revolve feature were used to convert the sketches to 3D solid models to develop the complete workstation layout.

Digital human modelling software (Jack Siemens 8.4) was used to create a virtual redesign using participants anthropometric data, thereby allowing workers posture analysis and ergonomic risk assessments in the virtual environment.

A. Software and Hardware Requirements

The Jack Siemens 8.4 human modelling software was used to evaluate the assembly line workstation workers' postures, while Autodesk Fusion 360 was used as the 3D computer-aided design and workstation modelling. The analyses were performed on an x86-64 Intel Xeon CPU, running Windows 11 or Linux, Ubuntu 22.04 LTS. The system was configured with 8-16 GB of RAM and at least

1GB of storage capacity (or a 32GB SSD Flash memory).

IV. Results and Discussion

The demographic characteristics of the study population is presented in Table 1. The female and male participants were 98, and 2%, respectively. The respondents age shows that 18-25years and 26-35years were 44, and 56%, respectively. The participants' work experience revealed that 70% had more than one year of experience on the assembly line, 22% had between 6 months and 1 year, and 8% had less than 6 months. This suggest that data were gotten largely from experienced workers, which enhance the reliability of this present finding.

Table 1: Demographic Information for Workers

Variables	Frequency	Percentage (%)
	Gender	
Female	49	98
Male	1	2
	Age	
18-25 yo	22	44
26-35 yo	28	56
	Working experience	
6 months - 1 year	11	22
< 6 months	4	8
> 1 year	35	70

Table 2 presents working hours and posture analysis of the participants. The participants who worked 12hours, 8hours, and null (not indicate their working hours) shifts were 80, 16, and 4%, respectively. Respondents postural discomfort assessment revealed participants who always, often, sometimes, rarely, and never experienced discomfort as 12, 8, 62, 10, and 8%, respectively. This suggests that only four (8%) of the participants never felt discomfort with the existing assembly line workstation, which corresponds to workers with less than 6months experience.

The reported comfort levels were felt comfortable (4%), slightly comfortable (20%), uncomfortable (40%) and very uncomfortable (36%). In addition, responses as pertaining to frequent bending revealed that 76% of respondents reported bending frequently, 12% sometimes, and 12% not at all.

The region of the ALW workers body where discomforts were experienced include the back (40%), wrists (18%), hands (10%), arms (8%), feet (8%), shoulders (6%), legs (6%), and neck (4%). These findings implies that the back and wrists are the most discomfort areas of the body. This suggests a significant lack of ergonomic intervention in the existing assembly line workstation.

Table 2: Working Hours and Posture Analysis

Variable	Frequency	Percentage (%)
Hours in Workstation per shift		
4hours	0	0
8hours	8	16
12hours	40	80
Null	2	4
Do you often experience discomfort while working?		
Always	6	12
Often	4	8
Sometimes	31	62
Rarely	5	10
Never	4	8
Comfortability of work posture while performing tasks		
Comfortable	2	4
Slightly comfortable	10	20
Uncomfortable	20	40
Very Uncomfortable	18	36
Do you frequently have to bend while performing the task?		
Sometimes	6	12
Yes	38	76
No	6	12
Sufficient legroom in the workspace		
Yes	6	12
No	38	76
Sometimes	6	12
Body Area of Discomfort		
Neck	2	4
Shoulder	3	6

Arm	4	8
Back	20	40
Wrists	9	18
Hand	5	10
Legs	3	6
Feet	4	8

The responses regarding tool accessibility are presented in Table 3, where 86% of participants indicated lack of easy accessibility to tools, while only 14% reported adequate accessibility.

Table 3: Accessibility to Assembly Tools

Variables	Frequency	Percentage (%)
Are assembly tools easily within reach		
Yes	7	14
No	43	86

The Rapid Upper Limb Assessment (RULA) evaluation of the existing workstation yielded scores range 6-7. This indicates high to very high ergonomic risk, meaning that the working postures require immediate intervention. These high-risk scores are associated with excessive trunk flexion due to frequent bending (76%), awkward wrist postures linked to poor tool accessibility (86%), and insufficient legroom (76%), which collectively forced workers into constrained and non-neutral postures during extended 12-hour shifts.

These findings are consistent with the self-reported discomfort levels, particularly back pain (40%) and wrist discomfort (18%), further confirming poor ergonomic conditions in the existing workstation. Given that most participants were female (98%), the anthropometric data used for digital modelling were primarily based on female body dimensions. Table 4 presents key anthropometric measurements (5th, 50th and 95th percentiles), which were used to derive the dimensions of the redesigned chair, table, and workstation.

Table 4: Female Anthropometric Data

Body dimension	Percentiles (cm)		
	5^{th}	50^{th}	95^{th}
Stature (standing height)	150	160	170
Sitting height	78	83	88
Shoulder height (sitting)	55	59	63
Elbow height (sitting)	25	27	30
Upper arm length	28	30	32
Forearm length	23	25	27
Popliteal height	37	40	43
Buttock-popliteal length	41	45	49
Thigh clearance	12	15	18
Hip breadth (sitting)	33	36	39
Shoulder breadth	34	36	38
Knee height (sitting)	44	47	50
Reach distance	60	67	74

Figures 1 to 3 present the 2D designs and dimensions of the proposed chair, table, and workstation layout, respectively. Figures 4(a) to 4(c) illustrate the 3D renderings (front, back, and side views) of the redesigned workstation, which were used for simulation in Jack Siemens 8.4. The redesigned workstation prioritizes ergonomic compliance, improved tool accessibility, and worker comfort and safety.

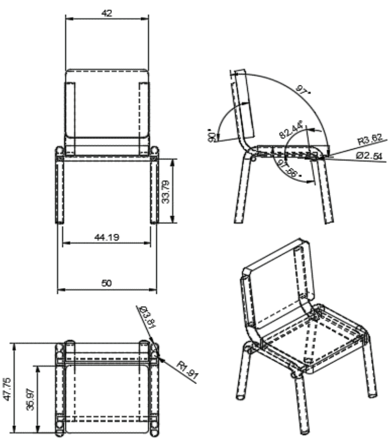

Figure 1: Proposed Ergonomic Improved Chair Design

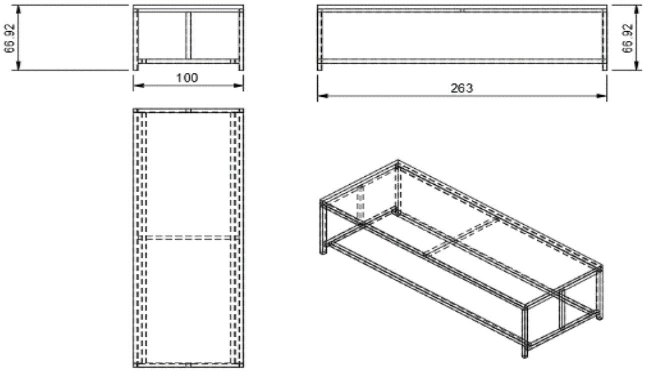

Figure 2: Proposed Table Design

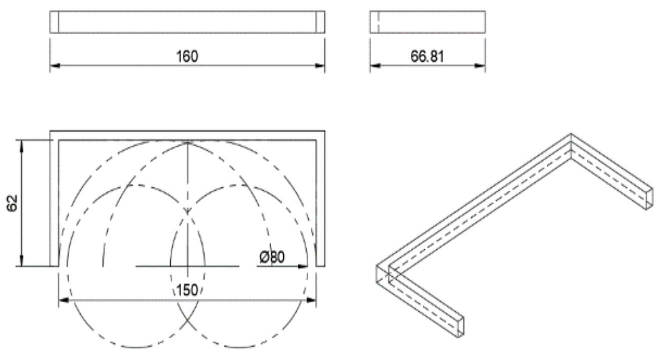

Figure 3: Proposed Workstation Workspace Design

(a) Front View

(b) Back View

(c) Side View

Figure 4: Proposed Workstation for 3D Model Design

The Rapid Upper Limb Assessment (RULA) score was used to evaluate the proposed workstation in digital human modelling using Jack Siemens 8.4. The evaluation assessed worker posture in relation to neutral positions to determine ergonomic suitability. Figure 5 presents the simulation interface, while Figure 6 shows the 3D simulation of the redesigned workstation in Autodesk Fusion 360, representing the use of the chair, table and workstation by workers in a virtual environment of the Jack Siemens 8.4.

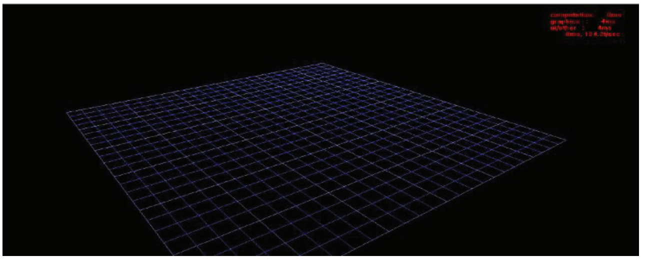

Figure 5: Jack Siemens 8.4. Interface

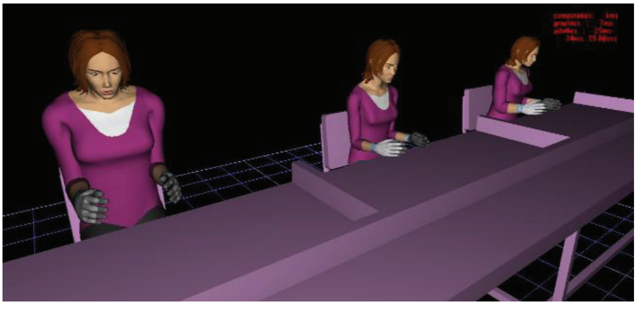

Figure 6: Simulation of the Proposed Assembly Line Workstation

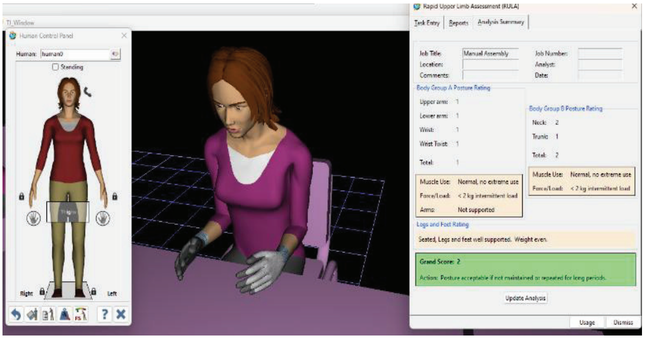

Figure 7: DHM Posture Analysis in Jack Siemens 8.4

The postural analysis of the redesigned workstation in Figure 7 incorporated anthropometric data across 5th, 50th, and 95th percentiles to represent the entire workforce population.

Table 5 presents the RULA analysis results for the redesigned workstation. The body was categorized into Group A (upper arm, lower arm, wrist, and wrist twist) and Group B (neck, trunk, and legs). Group A scores were all rated as 1, with no excessive muscle use and minimal force/load (<2kg). Group B scores were 1 for the trunk and 2 for the neck, indicating acceptable posture. The legs were well supported, ensuring even weight distribution.

The grand total of the postural analysis was 2. This means that in the workstation the workers were able to maintain a stable upright and rest position, therefore, reduced risk of developing musculoskeletal disorders. RULA score for the redesigned workstation was 2, which is within the low-risk category. This implies that assembly line workstation workers may maintain stable, neutral postures with minimal risk of experiencing musculoskeletal disorders, depending on maintaining minimal period of static postures.

The redesigned chair allows posture variation, thereby reduce the likelihood of static positioning and promotes sustained productivity. These findings align with previous studies [9].

Table 5: Jack Siemens 8.4 Rapid Upper Limb Assessment Report

Body Groups	Posture Ratings
Body Group A	
Upper arm	1
Lower arm	1
Wrist	1
Wrist Twist	1
Total	1
Muscle Use	Normal, no extreme use
Force/load:	< 2kg intermittent Load
Arms	Not supported
Body Group B	

Neck	2
Trunk	1
Total	2
Muscle Use	Normal, no extreme use
Force/Load	< 2kg intermittent load
Leg and Feet Rating	Seated, legs and feet well supported, Weight even
Grand Score	2
Action	Posture acceptable if not maintained or repeated for long periods

The outcome of comparison between existing and redesigned workstations is presented in Table 6. This shows a significant reduction in RULA score from 6-7 (high/very high risk) to 2 (low risk). This proves the effectiveness and significant of the ergonomically redesigned workstation.

Therefore, confirming that improper workstation design significantly contributes to musculoskeletal discomforts and postural strain among assembly line workers. This is supported by [8], that reported prevalence of back and wrist pain due to repetitive tasks in constrained postures. Likewise, this present finding that 86% of workers experienced tool inaccessibility supports [15], that emphasize the importance of optimizing reach distances.

Table 6: Comparison of Existing and Redesigned Assembly Line Workstation

Parameters	Existing ALW	Redesign ALW
RULA Score	6-7 (High to Very high risk)	2 (Low risk)
Trunk posture	Frequent forward bending (76%)	Neutral posture with reduced bending
Neck posture	Awkward flexion/extension	Neutral alignment supported
Wrist/arm posture	Awkward wrist angles, poor tool reach (86%)	Improved reach zones, neutral wrist posture
Legroom	Insufficient space (76%)	Adequate legroom and seated support
Reported discomfort	Back (40%), Wrist (18%), Hand (10%), Neck/Shoulder (10%)	Substantial reductions in postural risk indicators were observed in the digital simulation

Action level required	Immediate investigation and corrective action	Posture acceptable if not maintained for long periods

The redesigned workstation revealed significant ergonomic improvements, giving a RULA score of 2, which is in line with previous findings [2][12] that DHM enables proactive detection and mitigation of ergonomic risks. Integrating anthropometric data will ensure neutral posture alignment, tool accessibility improvement, and minimized workers' fatigue.

Apart from the physical benefits, these improvements include economic implications. As suggested by [1], ergonomic interventions minimize absenteeism and enhance productivity. This infers dual advantage of ergonomic redesign workstation, particularly in less technological advancement nations such as Nigeria where such interventions are often limited.

V. Limitation

The present study considered the anthropometric measurement of the female assembly line workstation workers because most of the participants were female (98%), hence there may be need to consider the male workers' anthropometric data for requisite design in the future.

VI. Conclusion

The redesigned assembly line workstation made RULA score of 2, suggesting a low ergonomic risk level. This suggests a significant improvement in tool accessibility, minimized forward bending, and enhanced postural support through the redesigned chair and table. The reduction in RULA score from 6-7 in the existing workstation to 2 in the redesigned model implies the effectiveness of DHM and 3D simulation in discovering and mitigating ergonomic risks in manufacturing settings.

From a practical perception, organizations should prioritize ergonomic interventions (like adjustable seating, optimized reach zones, and improved tool placement). Digital simulation tools support a cost-effective and evidence-based method for appraising workstation designs prior to physical implementation. Area of further research should include collection of anthropometric data from more diverse worker populations to assess prolong health outcomes of ergonomic interventions and explore different emerging technologies such as artificial intelligence and digital twins for real-time ergonomic monitoring and redesign.

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