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Ergonomic Analysis and Redesign of Bus Handgrips Using Rapid Upper Limb Assessment (RULA) and Posture Evaluation Index (PEI)

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ABSTRACT

This study aims to analyze and improve the ergonomic performance of bus handgrips on Metro Jabar Trans using an integrated approach combining Rapid Upper Limb Assessment (RULA) and Posture Evaluation Index (PEI). The research employed a quantitative method involving 30 respondents, with data collected through observation, interviews, joint angle measurements, and anthropometric analysis. A virtual simulation was developed using Jack 8.4 software to evaluate ergonomic conditions based on RULA, Lower Back Analysis (LBA), and Ovako Working Posture Analysis System (OWAS), which were then integrated into the PEI metric. The results indicate that the existing handgrip design produces RULA scores predominantly at levels 5–6, reflecting moderate ergonomic risk, with PEI values ranging from 1.358 to 1.875, indicating suboptimal conditions. A redesigned handgrip was developed by optimizing key dimensions, including width, diameter, and finger clearance, based on anthropometric data. Simulation results demonstrate a consistent reduction in ergonomic risk, with PEI values decreasing to a range of 0.925 to 1.221. The reduction in PEI values, ranging from 0.233 to 0.903, confirms improved postural conditions and reduced risk of musculoskeletal disorders. These findings highlight that integrating posture assessment and quantitative ergonomic indices can effectively support the development of safer and more comfortable public transportation facilities.

Keywords: *Ergonomics, Handgrip Design, RULA, Posture Evaluation Index (PEI), Musculoskeletal Disorders (MSDs), Public Transportation.*

Introduction

Public transportation plays a crucial role in reducing traffic congestion in major Indonesian cities, including Bandung, where high population density and the dominance of private vehicle use contribute significantly to traffic problems [1], [2], [3]. One of the most widely used modes of public transportation is the bus, as it is considered economical and efficient [4]. In Bandung, bus services such as DAMRI, Trans Metro Bandung (TMB), Trans Metro Pasundan (TMP), and Metro Jabar Trans operate to serve public mobility needs [2]. Djawatan Angkutan Motor Republik Indonesia (DAMRI) is one of the dominant public transport providers in Bandung. It offers affordable and relatively modern transportation services that support mobility across various community groups [5]. One of its services, Metro Jabar Trans, is part of the development of an urban bus-based transportation system. This service provides cashless payment options through Tap on Bus (TOB) and Quick Response Code Indonesian Standard (QRIS), with a fare of IDR 4,900 per trip. In terms of facilities, Metro Jabar Trans buses are equipped with 20 passenger seats, two entry and exit doors, and 20 handgrips for standing passengers. These facilities are designed to support passenger comfort and safety during travel [6].

As a service provider, DAMRI is responsible for ensuring passenger safety and comfort are well maintained [7]. Although various service improvements have been implemented, some aspects remain suboptimal, particularly the design of handgrips. Handgrips function as supports for standing passengers, especially when buses are crowded or during peak hours such as commuting times to work or school [8]. Empirical observations indicate that some passengers experience discomfort related to handgrip dimensions, particularly insufficient grip width and limited finger clearance. A customer satisfaction

survey conducted by DAMRI, involving 10 randomly selected respondents, revealed that most reported discomfort, including pain in the shoulders, wrists, palms, and fingers, due to the use of handgrips on Metro Jabar Trans buses.

From an ergonomic perspective, handgrip design is a fundamental aspect of human–product interaction, where improper design may reduce performance and increase discomfort or even injury risk [9], [10], [11]. Grip strength is also strongly influenced by the shape and dimensions of the handle, making anthropometric compatibility a crucial factor in ergonomic product design [12]. These findings suggest that the existing handgrip design does not fully accommodate user anthropometric characteristics, potentially increasing the risk of Musculoskeletal Disorders (MSDs) [13], [14].

These issues are consistent with previous studies highlighting the importance of ergonomic evaluation using quantitative approaches. Previous studies have applied methods such as Rapid Upper Limb Assessment (RULA) to evaluate postural risk and Posture Evaluation Index (PEI) to assess ergonomic performance. Rifano and Kansayulisa [14] analyzed Suroboyo Bus handgrips using the Rapid Upper Limb Assessment (RULA) method and reported risk scores of 4–5, indicating the need for ergonomic improvement. Sundana and Utomo [15] Applied RULA in pallet production activities and obtained a score of 7, reflecting a high level of ergonomic risk. These studies demonstrate that RULA is effective for rapidly identifying postural risks in various contexts, particularly in tasks involving upper limb activity. However, its evaluation is limited to posture-based assessment and does not quantify overall ergonomic performance or user comfort. Meanwhile, Khasianto, Purwantoro, and Wibowo [16] utilized Posture Evaluation Index (PEI)-based virtual modeling to assess driver seat ergonomics, showing improved performance after redesign. In addition, Lawolo and Febrianti [17] found that PEI-based redesign significantly reduced ergonomic risks and musculoskeletal disorder (MSD) complaints in workstation settings. These findings highlight that PEI provides a more comprehensive evaluation by integrating multiple ergonomic parameters into a single index and is particularly useful for simulation-based analysis. Nevertheless, PEI requires more complex data inputs and is less suitable for rapid initial assessments.

Despite these complementary strengths, most previous studies have focused on workstations and driver seats and have typically applied only a single analytical approach. Research on handgrips in public transportation remains limited and generally evaluates only postural risk without integrating quantitative comfort indices or simulation-based methods. Furthermore, studies examining the compatibility between handgrip design and user anthropometry in Indonesian urban bus systems, particularly in the context of Metro Jabar Trans, are still scarce. This indicates the absence of a comprehensive approach that simultaneously evaluates posture, comfort, and design optimization.

To address this gap, this study proposes a comprehensive ergonomic evaluation framework by integrating Rapid Upper Limb Assessment (RULA) and Posture Evaluation Index (PEI) within a virtual human modeling environment. The main contributions of this study are: (1) the integration of postural risk and quantitative comfort assessment into a unified analysis, (2) the application of digital human modeling using Jack 8.4 software for simulation-based evaluation, and (3) the development of a redesigned handgrip based on anthropometric data to improve user comfort and reduce MSD risk. The effectiveness of the proposed design is evaluated by comparing the ergonomic performance of the existing and redesigned handgrips using PEI indicators, providing a more comprehensive basis for ergonomic evaluation and design improvement.

Research Method

This research was conducted at Perum DAMRI Bandung Branch located at Jalan Soekarno Hatta No. 787, Bandung, West Java, Indonesia, selected due to its relevance to the study object, namely bus handgrips used by passengers. The study was carried out over a period of six months from September 2025 to March 2026. The research object in this study is the handgrip used in Metro Jabar Trans buses. The physical characteristics and dimensions of the handgrip were obtained through direct measurement. The handgrip has a width of 100 mm, height of 105 mm, diameter of 12 mm, thickness of 12 mm, and finger clearance of 12 mm. The object of this study is presented in Figure 1, while the detailed dimensional data are summarized separately in Table 1. These dimensions serve as the basis for modeling and ergonomic analysis.

Table 1. Dimensions of the existing bus handgrip

No.	Indicator	Dimension (mm)
1.	Handgrip Width	100 mm
2.	Handgrip Height	105 mm

3.	Handgrip Diameter	12 mm
4.	Handgrip Thickness	12 mm
5.	Finger Clearance Width	12 mm

Figure 1. Object of the study

Data Collection Techniques

This study employed a quantitative research approach, which enables systematic measurement and analysis of ergonomic conditions using numerical data and statistical interpretation [18]. This method was selected because it enables systematic measurement and analysis of ergonomic conditions based on measurable data. The sampling technique used was purposive sampling, where respondents were selected based on specific criteria relevant to the study, namely, active users of Metro Jabar Trans bus services [19], [20]. A total of 30 respondents aged 17–47 years, comprising both male and female participants with varying body weights, were included in this study. The sample size of 30 respondents was considered adequate for ergonomic studies involving human posture and anthropometric evaluation, as it meets the minimum requirement for representing population variability and allows for basic statistical analysis. Similar sample sizes have been widely used in ergonomic research to ensure sufficient representation while maintaining feasibility.

Data collection was conducted using a triangulation approach by combining observation, interviews, direct measurements, and documentation [21], [22]. To ensure data reliability and consistency, several procedures were implemented. Joint angle measurements were performed using a goniometer under standardized posture conditions, and each measurement was repeated to minimize random error. In addition, observations were conducted systematically to maintain consistency in posture assessment. Interview data were used to support the quantitative findings on user discomfort. Primary data were obtained through direct observation of handgrip characteristics, passenger interviews on perceived comfort, measurement of joint angles, and documentation of user postures during handgrip use. Secondary data were collected from official sources, particularly Indonesian anthropometric data, including body height, shoulder height, elbow height, and hand dimensions. These data were used to support the ergonomic analysis and redesign process.

Procedure Analysis

The research procedure was systematically designed and conducted based on a structured research flow to ensure that each stage of analysis was carried out comprehensively and coherently. Each step in this study is interconnected, from identifying ergonomic problems to evaluating and formulating recommendations based on the analysis results. The research stages are described as follows:

1. Identify the ergonomic problems related to the use of handgrips in Metro Jabar Trans buses.
2. Collect research data consisting of primary data (observation, interviews, joint angle measurement, and documentation) and secondary data (Indonesian anthropometric data).
3. Conduct observations on the dimensions and characteristics of the existing handgrip.
4. Document passenger postures during handgrip usage from the lateral view as the basis for posture analysis.
5. Measure joint angles using a goniometer, including the upper arm, lower arm, wrist, neck, and trunk.
6. Process the measured joint angles and input them into the Rapid Upper Limb Assessment (RULA) worksheet to obtain the initial ergonomic risk score.
7. Develop the existing handgrip model using CAD software based on actual dimensions.
8. Develop a virtual environment and human modeling using Jack Software 8.4 based on anthropometric data.
9. Integrate the human model into the virtual environment and simulate handgrip usage activities.
10. Perform analysis using the Task Analysis Toolkit in Jack Software to obtain Rapid Upper Limb Assessment (RULA), Lower Back Analysis (LBA), and Ovako Working Posture Analysis System (OWAS) values.

11. Calculate the Posture Evaluation Index (PEI) to obtain an integrated ergonomic assessment based on RULA, LBA, and OWAS parameters.
12. Evaluate the PEI results to determine the ergonomic level of the handgrip design and compare the existing design with the redesigned model.
13. Draw conclusions and provide recommendations based on the analysis results.

All stages of the research are summarized in the flow diagram shown in Figure 2.

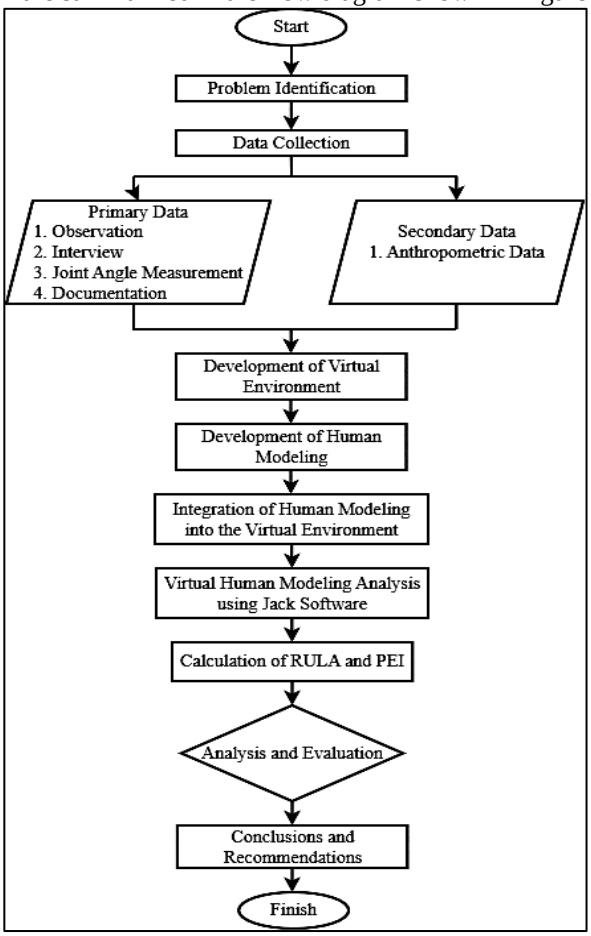

Figure 2. Research flow diagram

Referring to the analysis stage in step 10, the ergonomic parameters obtained from the simulation results, namely Rapid Upper Limb Assessment (RULA) [23], Lower Back Analysis (LBA) [24], and Ovako Working Posture Analysis System (OWAS) [25], were further processed to obtain an integrated evaluation value. This processing was carried out using the Posture Evaluation Index (PEI) method to comprehensively represent the level of postural risk. The PEI value is calculated using the following equation [26]:

$$PEI = I_1 + I_2 + (I_3 \times Mr) \quad (1)$$

Where:

$$I_1 = \frac{LBA}{3400}, I_2 = \frac{OWAS}{3400}, I_3 = \frac{RULA}{7} \quad (2)$$

Description:
LBA = Lower Back Analysis (N)
OWAS = Skor Ovako Working Posture Analysis System
RULA = Skor Rapid Upper Limb Assessment
Mr = Amplification coefficient (1.42)
A lower PEI value indicates a better ergonomic condition and a lower risk of injury.

Results and Discussion

Measurements of The Posture Angle of Metro Jabar Bus Passengers

The measurements were conducted on 30 passengers of Metro Jabar Trans buses while using the handgrip. Data collection was carried out by documenting passenger postures in the lateral view, followed by joint-angle measurements using a goniometer. The measured parameters included the upper arm (UA), lower arm (LA), and wrist (W), complemented by respondent characteristics such as body height (BH) and body weight (BW). The measurement results are presented in Table 2.

Table 2. Results of passenger joint angle measurements using a goniometer in Metro Jabar Trans buses

No.	Nama	Height	Weight	Upper Arm	Lower Arm	Wrist	Neck	Trunk
1.	Lucky	173	86	90°	155°	0°	30°	8°
2.	Caroline	160	65	90°	170°	0°	30°	0°
3.	Kiele	151	53	120°	170°	0°	30°	0°
4.	Nina	155	52	114°	170°	0°	20°	30°
5.	Arsyq	168	68	97°	166°	0°	30°	0°
6.	Salwa	157	48	107°	167°	0°	35°	0°
7.	Filberth	162	52	90°	180°	0°	28°	0°
8.	Fedrick	181	66	70°	180°	0°	30°	10°
9.	Ira	152	48	120°	130°	12°	28°	0°
10.	Fauzan	169	57	90°	150°	0°	29°	0°
11.	Jocelyne	163	57	113°	168°	0°	25°	0°
12.	Anggi	163	60	100°	145°	0°	30°	31°
13.	Assyfa	155	47	111°	180°	0°	45°	29°
14.	Rio	165	56	110°	140°	0°	23°	0°
15.	Devan	178	68	129°	180°	0°	23°	10°
16.	Nadia	147	40	130°	160°	0°	26°	0°
17.	Irma	150	55	120°	160°	0°	30°	20°
18.	Herni	158	63	110°	154°	11°	23°	20°
19.	Remarsya	162	75	100°	150°	11°	25°	0°
20.	Naily	153	57	120°	157°	10°	25°	19°
21.	Vanessa	160	60	92°	149°	9°	25°	0°
22.	Nadya	158	50	118°	172°	0°	50°	0°
23.	Deva	163	78	99°	167°	0°	30°	0°
24.	Nova	158	44	108°	180°	0°	23°	0°
25.	Lili	166	62	95°	163°	15°	21°	11°
26.	Oriza	154	40	125°	154°	15°	26°	10°
27.	Karen	169	75	110°	165°	0°	25°	10°
28.	Isel	156	49	115°	165°	0°	35°	0°
29.	Haffina	152	61	114°	167°	0°	34°	0°
30.	Arsyia	150	44	106°	173°	0°	35°	0°

Development of Virtual Environment and Virtual Human Modeling

Prior to conducting the ergonomic comfort analysis of passengers, the first step was to develop a virtual environment in Jack Software 8.4. The virtual environment was designed to replicate real conditions, particularly the existing handgrip design, whose dimensions were adjusted based on actual measurements. The developed handgrip model was then imported into Jack Software 8.4 using the (.igs) format. Figure 3 presents the implementation of the existing handgrip design in the virtual environment.

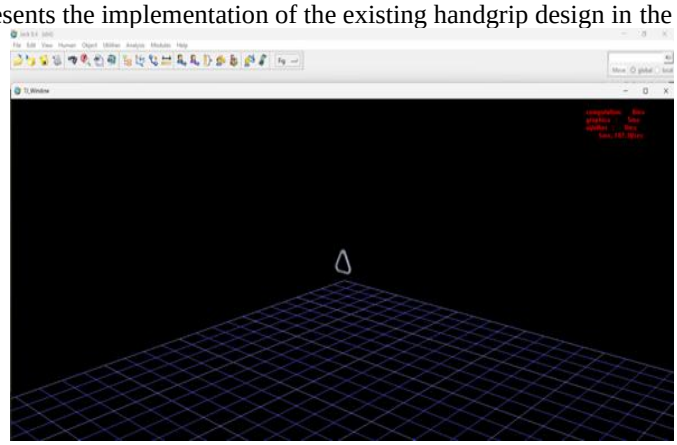

Figure 3. Existing handgrip design within the virtual environment

Subsequently, virtual human modeling was developed using the Human Builder feature. The Asian-Indian anthropometric database was used as a proxy due to the limited availability of comprehensive Indonesian anthropometric data, as it represents populations with relatively similar body characteristics. The 50th percentile was selected to represent average users, providing a balanced reference for general ergonomic evaluation. Anthropometric parameters, such as body height and weight, were adjusted based on respondent data to improve representativeness.

The generated human model was then integrated into the virtual environment. Posture configuration was performed using a predefined posture and further refined by adjusting joint angles, including the upper arm, lower arm, and wrist, to simulate handgrip usage. To ensure consistency, posture settings were standardized across all simulation scenarios. This configuration was used as the basis for ergonomic analysis using Rapid Upper Limb Assessment (RULA), Lower Back Analysis (LBA), and Ovako Working Posture Analysis System (OWAS). The virtual human modeling within the simulation environment is presented in Figure 4.

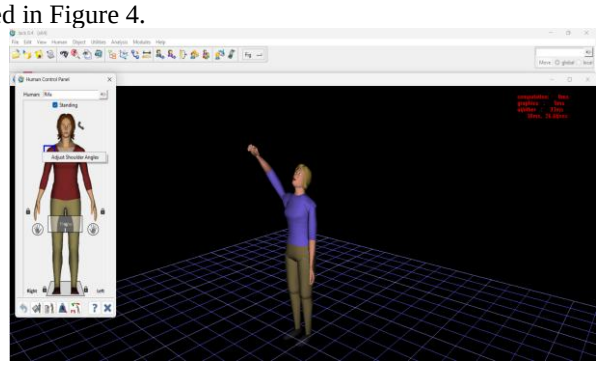

Figure 4. Virtual human modeling of passenger grasping the bus handgrip in jack software 8.4

Posture Evaluation Index (PEI) Analysis of The Existing Handgrip Design

To obtain the ergonomic evaluation using the Posture Evaluation Index (PEI) method, virtual human modeling and a virtual environment were first developed to represent actual conditions when passengers grasp the handgrip in Metro Jabar Trans buses. The posture of the human model was adjusted based on the observed joint angles to ensure that the simulation reflects real usage conditions. Subsequently, ergonomic parameters, including Rapid Upper Limb Assessment (RULA), Ovako Working Posture Analysis System (OWAS), and Lower Back Analysis (LBA), were obtained from the simulation using Jack Software. These parameters were then processed using the PEI method to generate an integrated ergonomic evaluation value. The PEI value was calculated using Equation (1), while the component indices are defined in Equation (2). Furthermore, Table 3 below presents the results of the ergonomic evaluation for 30 passenger samples based on the simulation using the existing handgrip design.

Table 3. Results of passenger joint angle measurements using a goniometer in Metro Jabar Trans buses

No.	Name	Height	Wight	RULA	LBA	OWAS	PEI Before Redesign
1.	Lucky	173	86	5	864	1	1,518
2.	Caroline	160	65	6	417	1	1,59
3.	Kiele	151	53	6	394	1	1,583
4.	Nina	155	52	5	337	2	1,613
5.	Arsyq	168	68	5	548	2	1,675
6.	Salwa	157	48	6	345	1	1,569
7.	Filberth	162	52	6	597	1	1,643
8.	Fedrick	181	66	5	711	1	1,473
9.	Ira	152	48	5	384	1	1,377
10.	Fauzan	169	57	6	606	1	1,645
11.	Jocelyne	163	57	6	420	2	1,841
12.	Anggi	163	60	6	447	1	1,599
13.	Assyfa	155	47	5	398	1	1,381
14.	Rio	165	56	5	506	1	1,413
15.	Devan	178	68	6	536	2	1,875
16.	Nadia	147	40	5	317	1	1,358
17.	Irma	150	55	6	436	2	1,845
18.	Herni	158	63	5	439	1	1,393

19.	Remarsya	162	75	5	615	2	1,695
20.	Naily	153	57	5	441	2	1,644
21.	Vanessa	160	60	5	519	2	1,667
22.	Nadya	158	50	5	418	1	1,387
23.	Deva	163	78	5	701	1	1,47
24.	Nova	158	44	5	324	1	1,36
25.	Lili	166	62	5	618	2	1,696
26.	Oriza	154	40	6	403	1	1,586
27.	Karen	169	75	5	563	1	1,43
28.	Isel	156	49	5	357	2	1,619
29.	Haffina	152	61	5	462	2	1,65
30.	Arsyia	150	44	5	344	1	1,365

Based on the PEI analysis results presented in Table 3, the existing handgrip design has not yet provided optimal ergonomic conditions for passengers. This is indicated by several PEI values exceeding 1, which signifies a higher level of postural risk. PEI values greater than 1 indicate that the posture adopted by passengers while using the handgrip is not ergonomically optimal and may increase the potential risk of musculoskeletal disorders. Conversely, PEI values below 1 represent better ergonomic conditions with lower postural risk. These findings suggest that the current handgrip design requires improvement to reduce the PEI value below the threshold and enhance passenger comfort. Therefore, a redesign of the handgrip is necessary to improve ergonomic performance and minimize injury risk during use.

Handgrip Redesign and PEI Analysis of The Redesigned Handgrip

The redesigned handgrip was developed to improve passenger comfort and reduce the risk of injury during use in Metro Jabar Trans buses. The redesign focuses on optimizing key dimensional parameters, particularly finger clearance, overall width, and handgrip diameter, based on the results of the previous ergonomic analysis. The selection of these dimensions was guided by ergonomic principles and anthropometric data collected from respondents aged 17–47 years who are active bus users. The handgrip diameter was increased to 15 mm to better accommodate users' grip capabilities, as appropriate handle dimensions have been shown to improve grip strength and reduce muscular strain. Similarly, the finger clearance was expanded to 15 mm to provide sufficient space for finger movement and to minimize contact pressure during use. Adjustments to width and height were also made to improve reachability and compatibility with standing posture. The redesign was based on anthropometric characteristics of the sampled population, particularly reflecting average user dimensions (50th percentile), to ensure suitability for the majority of users while maintaining ergonomic balance. The geometry and dimensional configuration of the redesigned handgrip are illustrated in Figure 5, while the detailed dimensions are presented in Table 4.

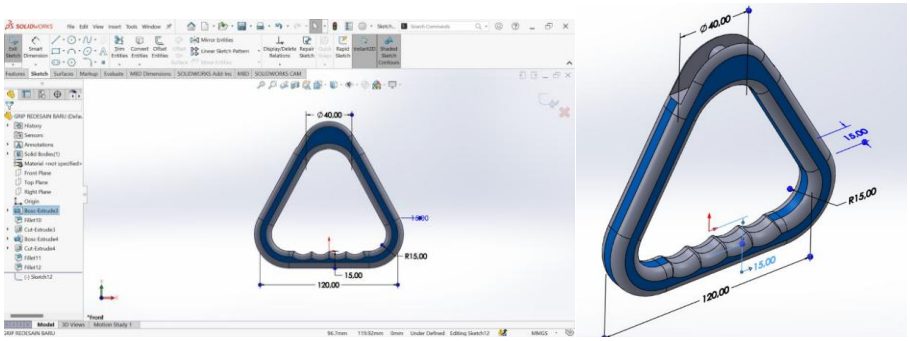

Figure 5. 3D model of the redesigned bus handgrip

Table 4. Dimensions of the redesigned bus handgrip

No.	Indikator	Ukuran (mm)
1.	Handgrip Width	120 mm
2.	Handgrip Height	129 mm
3.	Handgrip Diameter	15 mm
4.	Handgrip Thickness	15 mm
5.	Finger Clearance Width	15 mm

Furthermore, the ergonomic evaluation of the redesigned handgrip was conducted using the Posture Evaluation Index (PEI) method. The analysis results for the redesigned handgrip, based on the simulation

of 30 passenger samples, are presented in Table 5.

Table 5. Posture Evaluation Index (PEI) results for the redesigned handgrip

No.	Name	Height	Wight	RULA	LBA	OWAS	PEI After Redesign
1.	Lucky	173	86	3	613	1	1,039
2.	Caroline	160	65	3	384	1	0,972
3.	Kiele	151	53	3	253	1	0,933
4.	Nina	155	52	3	243	1	0,93
5.	Arsyq	168	68	4	392	1	1,177
6.	Salwa	157	48	4	273	1	1,142
7.	Filberth	162	52	3	481	1	1
8.	Fedrick	181	66	3	567	1	1,025
9.	Ira	152	48	4	254	1	1,136
10.	Fauzan	169	57	3	486	1	1,002
11.	Jocelyne	163	57	3	381	1	0,971
12.	Anggi	163	60	3	337	1	0,958
13.	Assyfa	155	47	3	322	1	0,953
14.	Rio	165	56	3	383	1	0,971
15.	Devan	178	68	3	384	1	0,972
16.	Nadia	147	40	3	227	1	0,925
17.	Irma	150	55	4	318	1	1,155
18.	Herni	158	63	3	384	1	0,972
19.	Remarsya	162	75	3	493	1	1,004
20.	Naily	153	57	3	383	1	0,971
21.	Vanessa	160	60	3	375	1	0,969
22.	Nadya	158	50	3	322	1	0,953
23.	Deva	163	78	4	544	1	1,221
24.	Nova	158	44	3	243	1	0,93
25.	Lili	166	62	4	543	1	1,221
26.	Oriza	154	40	3	340	1	0,959
27.	Karen	169	75	3	387	1	0,972
28.	Isel	156	49	3	279	1	0,941
29.	Haffina	152	61	4	340	1	1,161
30.	Arsyia	150	44	4	240	1	1,132

Based on the PEI results presented in Table 5, the redesigned handgrip consistently yields lower PEI values than the existing design across all 30 passenger samples. This indicates an overall improvement in ergonomic conditions, as lower PEI values correspond to reduced postural risk and enhanced comfort during handgrip usage. To provide a clearer comparison between the existing and redesigned handgrip, the PEI values for both conditions are illustrated in Figure 6. The graph highlights the difference in PEI values before and after the redesign, showing a consistent decrease across all samples.

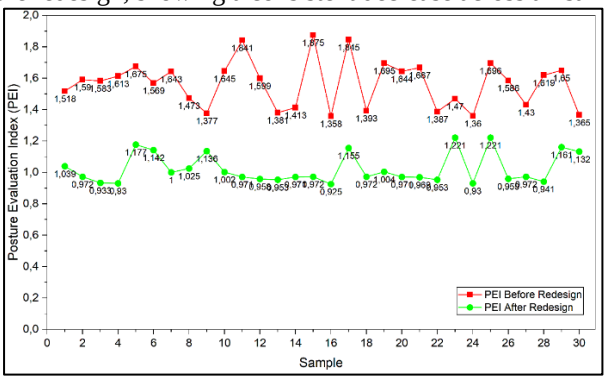

Figure 6. Comparison of Posture Evaluation Index (PEI) values for existing and redesigned handgrip

The reduction in PEI values ranges from 0.233 (minimum) to 0.903 (maximum), indicating that the proposed handgrip redesign effectively reduces postural risk. This improvement can be explained from an ergonomic and biomechanical perspective. The increase in handgrip diameter and finger clearance allows for a more natural grip posture, reducing excessive flexion in the wrist and minimizing localized pressure on the fingers. This condition helps distribute muscular load more evenly across the upper limb. In addition, the adjusted dimensions improve hand–handle compatibility, which is known to enhance

grip stability and reduce the need for compensatory muscle activity in the forearm and shoulder. As a result, muscle strain is reduced, leading to lower PEI values that reflect better overall ergonomic conditions. This finding is consistent with ergonomic principles stating that proper handle design can improve comfort and decrease the risk of musculoskeletal disorders (MSDs). Although the magnitude of reduction varies among individuals, this variation is influenced by differences in anthropometric characteristics and initial posture. Nevertheless, the overall trend confirms that the redesigned handgrip promotes more neutral joint positions and improved biomechanical efficiency during use.

Conclusion

This study demonstrates that the initial handgrip design of Metro Jabar Trans buses does not fully meet ergonomic principles, as indicated by RULA scores in the range of 5–6, which reflect a moderate level of postural risk requiring improvement. The simulation-based evaluation using Jack 8.4, integrating RULA, LBA, and OWAS into the Posture Evaluation Index (PEI), shows that the initial design produces higher PEI values (1.358–1.875) compared to the redesigned handgrip (0.925–1.221). The proposed redesign, which involves increasing the handgrip width, diameter, and finger clearance based on anthropometric considerations, consistently reduces PEI values across all samples, with a maximum reduction of 0.903. This indicates a significant improvement in ergonomic performance, as the redesigned handgrip promotes more comfortable and biomechanically favorable postures, thereby reducing the risk of musculoskeletal disorders (MSDs). These findings provide practical implications for public transportation providers, particularly DAMRI, in enhancing passenger comfort and safety through ergonomically improved facilities. The proposed design can serve as a reference for developing standardized handgrip dimensions based on user anthropometry, contributing to better service quality and reduced physical strain among passengers.

However, this study has several limitations. The analysis is based on virtual simulation, which may not fully represent dynamic movements and real-world conditions. In addition, the sample size is limited to 30 respondents aged 17–47 years, which may not capture the full variability of the passenger population. Furthermore, the redesigned handgrip has not been validated through real-world implementation. Therefore, future research is recommended to conduct experimental validation, incorporate material and structural considerations, and explore more adaptive design solutions to accommodate a wider range of users.

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