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Driver Oriented Ergonomic Design for Long Distance Heavy Truck Cabins

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Research Article

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Abstract

Ergonomic design of Long Haulage Commercial truck cabin is a critical determinant of driver safety and occupational health, particularly given the increased severity of accidents involving Long Haulage Commercial trucks in long-haul transportation. Despite this, cabin ergonomics have historically been suboptimal, contributing to elevated road risk and driver musculoskeletal disorders. This study evaluates the ergonomic deficiencies of key Long Haulage Commercial truck cabin components through a comprehensive analysis of driver-reported experiences, demographic characteristics, and operational behaviours. Data were collected via structured interviews and standardized questionnaires administered to professional Long Haulage Commercial truck operators. Statistical analyses, including hypothesis testing, were employed to quantify the significance of ergonomic inadequacies across components such as seating systems, restraint mechanisms, steering assemblies, pedal interfaces (accelerator, brake, clutch), and gear shift controls. Results indicate pervasive ergonomic shortcomings that compromise driver comfort and control efficacy. These findings inform targeted design modifications aimed at mitigating injury risk and enhancing driving performance, thereby contributing to improved Long Haulage Commercial truck cabin ergonomics.

1. Introduction

Long-haul commercial trucks constitute a critical vector for freight conveyance over extensive road networks, underpinning the logistics infrastructure on a global scale. The ergonomic architecture of the driver’s cab is a pivotal determinant of operator biomechanical comfort, physiological health, and vehicular operational safety. Empirical evidence substantiates that optimized human-machine interface (HMI) configurations within the cab environment significantly attenuate operator fatigue, reduce cognitive load and distraction susceptibility, and enhance vehicular control precision [1, 2]. Consequently, ergonomic parameters have emerged as foundational design constraints in the heavy truck cab engineering process.Inter-individual variability in driver anthropometry and biomechanical dynamics, coupled with heterogeneous behavioral driving patterns, impose stringent requirements on the spatial ergonomics, dimensional tolerance, and actuation force thresholds of cab control interfaces and ancillary components [3]. Ergonomic optimization must therefore integrate anthropometric data and kinematic profiles to mitigate cumulative musculoskeletal loading, prevent occupational musculoskeletal disorders (MSDs), and sustain optimal control fidelity [4]. These deficits exacerbate physical strain, degrade situational awareness, and amplify operational risk exposure [5].Despite heightened recognition of ergonomic imperatives, the systematic integration of anthropometric databases and driver behavior analytics into cab design workflows remains nascent. Extant international and regional ergonomic standards promulgate rigorous criteria for evaluating operator workstation design, predicated on validated anthropometric datasets and biomechanical posture assessments [6, 7]. This underscores a critical exigency for comprehensive ergonomic audits and iterative redesign of heavy truck cabs to accommodate driver heterogeneity and dynamic operational contingencies. The present investigation aims to delineate ergonomic inadequacies within extant cab configurations by scrutinizing control interface design parameters and driver usage metrics, thereby facilitating evidence-based ergonomic

interventions to optimize driver safety and physiological welfare. The epidemiological data from the Traffic Management Bureau of the Ministry of Public Security of China reported the incidence rate of truck-related collisions significantly surpasses that of other vehicular categories, with heavy truck accidents yielding disproportionately severe outcomes. The fatality and injury incidence per heavy truck vehicle markedly exceed the aggregated mean rates across all vehicle classifications [8].Driver fatigue is recognized as a principal etiological factor exacerbating the severity of traffic collisions within the Chinese context [9]. Empirical assessments indicate a rapid onset of fatigue symptoms and lumbar musculoskeletal discomfort among truck operators [10], with exacerbated effects observed in operators of heavy-duty vehicles engaged in prolonged, long-haul operations. This discomfort has been correlated with diminished neuromuscular control and impaired psychomotor response, thereby increasing the propensity for vehicular control errors and subsequent accident risk.Beyond acute traffic safety concerns, occupational musculoskeletal disorders (MSDs) constitute a prevalent health issue among professional truck drivers. Elevated prevalence of spinal pathologies, notably cervical and lumbar region pain syndromes, have been consistently documented within this occupational cohort [11–13]. Additional reports indicate frequent musculoskeletal fatigue localized in the lower extremities, including plantar discomfort [10]. The pathophysiological basis of these disorders is inherently multifactorial, involving prolonged isometric muscular activation, aberrant joint kinematics due to sustained non-neutral postures, inadequately optimized anthropometric-seat interface parameters, chronic exposure to low-frequency whole-body vibrational stimuli, and repetitive cyclic biomechanical loading that cumulatively exceed tissue adaptation thresholds [14]. In particular, deficient seat design parameters amplify lumbar paraspinal muscle fatigue and discomfort, which, when persistent, may precipitate chronic degenerative musculoskeletal conditions, adversely impacting driver health outcomes and operational performance metrics. Ergonomic optimization of Long Haulage Commercial Truck cabin is a critical determinant in reducing driver fatigue, enhancing operational safety, and mitigating long-term occupational health risks —particularly in the context of Long Haulage transportation. The Long Haulage Commercial Truck cabin functions as the primary human-machine interface (HMI), where prolonged exposure to suboptimal postures, constrained movement, and poorly configured control systems can elevate biomechanical and cognitive stress [15, 16]. Numerous studies have linked inadequate cab ergonomics to driver discomfort, reduced alertness, and increased accident risk, especially during long-haul operations [17, 18]. Effective ergonomic design of Truck cabin systems—encompassing seating, steering, pedal actuation, and instrument layouts—has been shown to improve driver postural alignment, reduce musculoskeletal loading, and lower perceived fatigue levels [19, 20]. In particular, Truck Cabin seat configuration and its interaction with body support, vibration exposure, and anthropometric variability play a dominant role in mitigating lumbar strain and lower extremity discomfort [21]. Despite advances in automotive ergonomics, Long Haul Commercial Truck cabin frequently exhibit design deficiencies that fail to accommodate the physical and operational needs of a diverse driver population, especially within domestic markets where standardized anthropometric data may be lacking or underutilized [22]. To address these challenges, user-cantered design approaches—grounded in empirical data—are increasingly advocated for identifying ergonomic mismatches and informing design interventions [23]. This study applies structured interviews and questionnaire-based surveys to assess the ergonomic

adequacy of current Long Haul Commercial truck cabin in India. The analysis focuses on professional driver experiences, anthropometric fit, and task-specific HMI limitations. Findings from this investigation provide foundational data for improving cab design standards, aligning them with human factors principles, and enhancing safety and comfort in commercial freight transport.

2. Method

This empirical investigation employed a mixed-methods approach, beginning with semi-structured interviews conducted with 21 professional heavy-duty truck drivers to explore behavioural patterns and ergonomic challenges associated with long-haul freight operations. Insights derived from these qualitative interviews, combined with an analysis of operational driving logs, were utilized to design a standardized questionnaire for quantitative assessment of driver ergonomics, operational habits, and environmental factors influencing driver performance and safety. The questionnaire was administered via face-to-face, on-site surveys at two strategically 2 selected locations in Pune District and Solapur District. This method facilitated immediate clarification of questionnaire items, improving data quality and respondent engagement. A total of 50 valid responses were collected, yielding a statistically adequate sample for subsequent quantitative analyses. Inclusion criteria required participants to be professional long-haul truck drivers with at least two to three years of continuous driving experience on heavy trucks. Prior to participation, study objectives, data confidentiality protocols, and voluntary participation were clearly communicated to all participants, and informed consent was obtained in accordance with ethical standards. Data underwent preliminary validation and screening before being subjected to descriptive and inferential statistical analyses. Correlation analyses and significance testing (e.g., t-tests, chi-square tests) were applied to identify prevalent ergonomic deficiencies, characterize driving behaviours, and examine associations between ergonomic variables and self-reported fatigue and discomfort metrics. The outcomes provide empirical evidence supporting targeted ergonomic interventions aimed at optimizing truck cab design and enhancing driver health and traffic safety.

The principal domains investigated in this study encompassed the following:

1. Demographic and Operational Characteristics of Heavy Truck Operators:

This component involved a comprehensive characterization of the driver population, including demographic variables such as gender and age, alongside detailed anthropometric data (e.g., stature and body mass) [24, 25]. Operational parameters were also examined, including typical cargo load profiles, driving frequency, and cumulative driving mileage [26]. These metrics provide essential context for ergonomic evaluation by correlating physical and usage characteristics with ergonomic needs and constraints [27].

2. Ergonomic Assessment of Cab Controls and Driver Interaction:

A systematic, component-level analysis of the heavy truck cab interior was conducted to evaluate ergonomic adequacy and driver interface quality [28]. Key control systems and cabin elements were scrutinized as follows:

1. **Seat Belts**: Evaluation focused on fitment efficacy, retention tension, and positional stability during dynamic operation, critical factors influencing occupant restraint effectiveness and comfort [29].
2. **Seats**: Comprehensive analysis of seat ergonomics included quantification of multi-axis adjustment ranges—vertical (height), longitudinal (fore-aft displacement), and angular inclination. Morphometric seat dimensions (seat pan depth and width) were measured alongside backrest contouring, headrest positioning, lumbar support geometry, and cushion firmness. These parameters critically affect pressure distribution, spinal alignment, and driver fatigue mitigation [30, 31].
3. **Pedals**: Detailed examination of pedal ergonomics involved measurement of pedal tilt angles, maximum depression depths, actuation forces required for operational control, and the inter-pedal spatial arrangement. Optimizing these parameters is vital for minimizing lower limb musculoskeletal strain and enhancing vehicle control precision [32].
4. **Control Handles**: The biomechanical demands imposed by hand-operated controls—specifically the handbrake and gear shift lever—were assessed by quantifying the forces required for actuation and analyzing dimensional characteristics of the shift lever handle. These influence grip comfort, control accuracy, and operator fatigue [33].
5. **Steering Wheel**: The steering interface was evaluated on several ergonomic dimensions, including outer diameter, grip circumference, vertical height adjustment range, tilt angularity, and the feedback force necessary for precise maneuvering. Additionally, assessment included the degree to which the steering wheel obstructs the driver's line of sight to the instrument cluster, impacting situational awareness [34].
6. **Additional Cabin Features**: Supplementary ergonomic factors were reviewed, such as the adjustability and field coverage of side and rear-view mirrors (addressing blind spot reduction), ergonomic placement and operational accessibility of in-cabin controls for entertainment and climate systems, illumination control interfaces, glove compartment usability, as well as the dimensions and heights associated with ingress/egress steps—parameters directly impacting driver comfort, safety, and ease of vehicle operation [35, 36].

3. Results

3.1. Demographic and Anthropometric Characteristics

The sample consisted of 50 professional male long-haul truck drivers, with a mean age of 28 ± 8 years, predominantly representing young adults. The distribution of age suggests a workforce concentrated within the optimal physical performance range, characterized by peak neuromuscular response and endurance capabilities. Anthropometric measurements revealed an average height of 167 ± 6 cm, consistent with the Indian adult male 50th percentile 167, and below the 90th percentile height of 176

cm. The mean body weight was approximately 65 kg, aligning with national norms for this demographic (see Table 1).

Table 1
Anthropometric Characteristics of Sampled Drivers

Parameter	Mean ± SD	Reference Percentile (Indian Adult Males)
Height (cm)	167 ± 6	P50 = 167 cm; P90 = 176 cm
Weight (kg)	65 ± 8	P50 ≈ 65 kg (approximate)
Age (years)	28 ± 8	—

3.2. Driving Frequency and Duration

A majority of drivers (90%) reported driving daily as shown in Fig. 1, with the remainder operating several times per week. The average daily driving duration was between 11 to 12 hours, covering approximately 400 to 425 kilometers per shift (Fig. 1). Significantly, 53% of drivers exceeded 12 hours of driving per day, frequently continuing despite fatigue symptoms. This extended duration highlights a high-risk profile for fatigue-induced performance degradation.

3.3. Implications for Ergonomics and Fatigue

The extended driving hours, combined with demographic and anthropometric profiles, underscore the importance of ergonomically optimized cabin designs that accommodate the average physical dimensions and minimize fatigue risks. The predominance of prolonged shifts exceeding 12 hours increases vulnerability to musculoskeletal strain and decreased alertness, suggesting urgent need for intervention in cab layout, seat design, and control interfaces.

3.4. Devices that Might Cause Fatigue or Discomfort

Based on quantitative feedback from respondents, the primary cab components contributing to driver fatigue and discomfort were systematically identified and their prevalence quantified. Seating assemblies and associated ergonomic accessories accounted for approximately 65% of reported ergonomic deficiencies as shown in Fig. 2, emphasizing their critical role in driver comfort as outlined by ISO 7250-1 standards on anthropometric design [6]. Inadequacies in cabin dashboard layout and control interface ergonomics were cited by 30% of participants, indicating challenges in operational reach and visual accessibility consistent with prior ergonomic assessments [37]. Shift lever ergonomics, including excessive actuation force and suboptimal handle design, were reported by 30%, corroborating literature on manual control-induced musculoskeletal fatigue [38]. Steering wheel dimension constraints and adjustment limitations affected 25% of drivers, with associated risks of upper limb strain as delineated by ISO 15079 guidelines [39]. Accelerator and brake pedal configurations were implicated by 25% of respondents, aligning with research on pedal placement and required exertion influencing lower limb fatigue [40]. Seat belt discomfort, attributed to improper fit and excessive tension, was noted by 10%,

highlighting critical safety-related ergonomic concerns [41]. Additional cab components collectively accounted for 10% of discomfort reports, suggesting further opportunities for auxiliary ergonomic enhancements.

1. Ergonomic Evaluation of Seating Systems

Respondents identified significant ergonomic deficiencies in heavy truck seating assemblies, especially regarding alignment with Indian drivers' anthropometry and sustained comfort. Key seat attributes evaluated included seat depth, width, backrest geometry, headrest configuration, lumbar support, and cushion softness.

1. Lumbar Support (50%): The principal source of discomfort. Common complaints included absence of lumbar contours, excessive concavity, non-adjustable lumbar elements, and lack of simultaneous thoraco-lumbar support. These deficiencies prevented proper spinal alignment and precipitated lower back pain during prolonged driving.
2. Seat Hardness (25%): Excessive firmness in the cushion, seatback, and headrest was frequently reported. These rigid surfaces generated pressure hotspots and contributed to postural fatigue and discomfort during long-haul operations.
3. Headrest Geometry (15%): Many drivers found the headrest placement suboptimal—positioned too far rearward, lacking curvature, and unable to support the cervical spine effectively. This posture mismatch often induced neck strain and instability.
4. Backrest Morphology (5%): Concerns included over-concavity, insufficient rear curvature height, and overly rearward base plate design, prohibiting shoulder support when the lumbar region was engaged.
5. Seat Depth/Width (5%): An inappropriate seat pan length—either undersized or excessive—prevented thigh support up to the posterior seat edge, while narrow seat pans restricted lateral containment, both contributing to discomfort during extended seating periods.
6. Additional Complaints: Additional ergonomic issues included insufficient lateral containment ("surround feel"), excessive seat elevation following airbag deployment, poor thermal comfort, and inadequate vibration isolation due to suboptimal cabin suspension.
7. Fore-a-ft Adjustability (30%): Approximately one-third of respondents reported that the fore–aft adjustment range did not accommodate body size or pedal-reach variability, limiting proper seating posture calibration.

These discrepancies were observed across multiple driver-truck pairings, highlighting a systemic mismatch between seat geometry and the anthropometric diversity of Indian long-haul drivers as shown in Table 2.

Table 2
Summary of Major Seating Component Dissatisfaction among Respondents

Component	%Reporting Discomfort	Key Issues Identified
Lumbar Support	50%	No contour, non-adjustable, lack of dual support
Fore–aft Adjustment Range	30%	Limited travel range for posture customization
Seat Cushion/Back Hardness	25%	Excess rigidity, discomfort over time
Headrest Design	15%	Poor positioning, inadequate cervical support
Seat Back Morphology	5%	Excess convexity, insufficient shoulder support
Seat Depth/Width	5%	Improper length or narrow width

Design Implications

To mitigate these ergonomic gaps, truck seat design must integrate Indian anthropometric data—specifically 5th to 95th percentile distributions for stature and limb length—and include multi-axis adjustability, contoured lumbar support, adaptive cushioning (e.g., variable-density foam), and refined headrest geometry. Expanded seat width, optimized seat pan depth, and enhanced adjustability are essential for reducing musculoskeletal strain and supporting driver comfort throughout long-haul operations.

2. Cabin Dashboard Ergonomic Assessment for Indian Truck Drivers

The ergonomic evaluation of the cabin dashboard focused on assessing the spatial layout, control accessibility, visual clarity, and interface intuitiveness as experienced by Indian long-haul truck drivers. The dashboard serves as a critical human-machine interface, mediating driver interaction with essential vehicle controls and information systems. Poor dashboard ergonomics can increase cognitive workload, delay response times, and contribute to driver fatigue and error.

Survey results indicated that approximately 55% of respondents reported suboptimal ergonomic conditions related to the dashboard's overall spatial organization. Key issues as shown in Tables 3 & 4 included poor reachability of frequently used controls and indicators, leading to extended hand movements and awkward postures during operation. This aligns with anthropometric constraints of Indian drivers, whose upper limb reach and torso dimensions generally fall within a specific percentile range (e.g., median arm reach approximately 70–75 cm, torso depth around 25–30 cm) as per Indian anthropometric datasets (IS 9161: 1992).

Table 3
Summary of Major Dashboard Component Dissatisfaction among Respondents

Dashboard Component	%Respondents Dissatisfied	Key Ergonomic Issues
Control Reachability	30%	Excessive reach, poor control grouping
Visual Clarity	20%	Low contrast, glare, small fonts
Instrument Cluster	25%	Poor alignment with line of sight
Feedback Mechanisms	40%	Lack of tactile/auditory feedback
Labeling/Icons	15%	Inconsistent, unclear

Table 4
Summary of Major Cabin Control Device Component Dissatisfaction among Respondents

Control Device	% Difficult to Reach	% Difficult to See	Notes
Air Conditioning	30%	25%	Poor button placement
Entertainment System	25%	20%	Switches hard to locate
Lighting Controls	20%	15%	Unintuitive layout
Glove Box	15%	10%	Limited access space

Drivers reported that certain critical controls—such as lighting switches, HVAC controls, and instrumentation toggles—were either positioned too low or too far laterally, impairing quick and precise actuation. The absence of standardized ergonomic zones (primary, secondary, tertiary) for control placement further exacerbated operational inefficiencies. Approximately 25% of respondents noted that frequent dashboard interaction required significant postural adjustments, potentially increasing musculoskeletal strain over extended driving periods.

Visual Display and Instrumentation:

Visual ergonomics concerns included inadequate contrast between display elements and background, suboptimal font sizes, and reflections/glare under varied lighting conditions. Nearly 20% of drivers expressed difficulty in maintaining continuous visual focus on the road while simultaneously monitoring dashboard instruments, highlighting a cognitive-visual trade-off. The placement of essential indicators (speedometer, tachometer, fuel gauge) did not consistently align with the driver's natural line of sight, suggesting a misalignment with Indian driver eye height averages (~ 120–130 cm from seat base) and preferred gaze zones.

Interface Intuitiveness and Feedback:

The absence of haptic or auditory feedback on control inputs was noted, diminishing confirmation of successful operations and potentially increasing cognitive load. Additionally, inconsistent iconography

and labelling reduced intuitive understanding, especially for drivers with limited formal training or literacy challenges.

Anthropometric and Biomechanical Considerations:

Given the demographic profile of Indian truck drivers—primarily young adult males with average stature (height ~ 167.8 cm at P50) and variable upper limb reach—dashboard designs must integrate adjustable features to accommodate the lower and upper extremes of body dimensions. This encompasses the integration of adjustable steering columns and dashboard tilt mechanisms designed to align visual and manual control interfaces within anthropometrically optimized ergonomic zones, thereby reducing the need for excessive trunk rotation and anterior flexion.

Design Recommendations as shown in Table 5:

Zonal Control Placement

Implement tiered ergonomic zones with primary controls located within 20–30 cm of the steering wheel center to reduce reach distances and posture shifts.

Visual Optimization

Implement high-contrast display technologies with anti-reflective surface treatments and adaptive luminance control systems calibrated for varied ambient lighting and high-glare conditions prevalent in Indian climates.

Adjustability Features

Integrate modular dashboard architecture and dynamically adjustable instrument clusters to accommodate a broad range of driver anthropometric profiles, enhancing reachability and visual accessibility.

Feedback Mechanisms

Employ multimodal feedback systems—including haptic actuation, tactile detents, and auditory cues—to facilitate control validation, minimize cognitive load, and support intuitive interaction under dynamic driving conditions.

Standardized Iconography

Utilize universally recognizable symbols and multilingual labels to improve interface intuitiveness across diverse literacy levels.

Table 5
Recommended Dashboard Control Placement Ranges

Control Type	Optimal Horizontal Distance (cm)	Optimal Vertical Distance (cm)	Comments
Primary Controls	20–30	10–25	Within easy reach without trunk movement
Secondary Controls	30–45	25–40	Reachable with slight lean
Instrument Cluster	0–10	10–20	Aligned with natural sight line

The schematic Fig. 3 illustrates the layout of a heavy truck dashboard, segmented into primary, secondary, and tertiary control zones based on the driver's seated position. The zones reflect ergonomic reach and priority—with primary controls (e.g., steering, brakes, indicators) placed within the easiest reach to minimize posture strain and reaction time, secondary controls (e.g., HVAC, infotainment) slightly farther, and tertiary zones reserved for infrequently used features.

3. Gear Shift Lever Ergonomic Assessment

The ergonomic evaluation of the gear shift lever encompassed parameters including required actuation force, handle dimensions, positional comfort, and adjustment range. These factors are critical in mitigating upper limb fatigue and enhancing operational precision during prolonged driving tasks common among Indian long-haul truck operators. Respondent Feedback and Statistical Findings: Approximately 65% of respondents indicated satisfaction with the overall gear shift lever ergonomics, while 35% reported various discomforts related primarily to excessive actuation force and suboptimal handle dimensions. A detailed breakdown is as follows:

1. Actuation Force:

Over 30% of respondents perceived the force required to engage gears as excessive, contributing to hand and forearm fatigue during extended driving shifts. This is consistent with previous findings indicating that elevated gear shift forces are positively correlated with increased musculoskeletal loading and strain, as outlined in ISO 15079-2 (2019).

2. Handle Dimensions and Grip Comfort:

About 25% of respondents identified the shift lever handle as inadequately sized—either too large or too small—resulting in compromised grip stability and reduced control precision. Handle shape and surface texture were also noted as factors influencing comfort and ease of manipulation.

3. Lever Position and Adjustment:

A subset of respondents (~ 20%) reported difficulty in accessing the gear lever comfortably due to fixed mounting positions that do not accommodate the anthropometric variability prevalent among Indian truck drivers. Limited or non-existent adjustment mechanisms for lever position exacerbate this issue, potentially forcing drivers into awkward postures that increase risk of repetitive strain injuries.

4. Anthropometric Considerations:

Given the documented anthropometric characteristics of the Indian male truck-driving population—mean stature approximately 167 cm with relevant upper limb reach and strength constraints— It is essential that gear shift lever designs integrate adjustable mechanisms and dimensionally optimized geometries calibrated to the anthropometric characteristics of the target driver population. Ergonomic designs adhering to anthropometric percentiles (P5-P95) can ensure accommodation of a majority of drivers.

Recommendations:

Reduction of actuation force through improved mechanical advantage or assisted shifting mechanisms (e.g., synchronized or automated gearboxes). Design of handles with ergonomically optimized shape, diameter (~ 30–40 mm), and surface texture to improve grip comfort and reduce slip risk. Incorporation of adjustable mounting systems allowing drivers to customize lever position to their reach envelope.Periodic ergonomic evaluation and incorporation of driver feedback in design iterations to address dynamic operational demands.

4. Steering Wheel Ergonomics Assessment

Approximately 70–80% of respondents rated these parameters as “appropriate,” as shown in Table 6, reflecting moderate acceptance of the current steering wheel design among Indian long-haul truck drivers.

Table 6
Steering Wheel Evaluation

Steering Parameter	% Appropriate	Main Complaints
Outer Diameter	70–80%	Oversized
Grip Diameter	70–80%	Too small
Manipulation Force	70–80%	Too heavy
Height Adjustment	70–80%	Range insufficient

However, a significant subset of respondents reported ergonomic dissatisfaction. Key concerns included an oversized outer diameter, which may hinder precise steering control; a grip diameter perceived as

insufficiently large, compromising hand comfort and secure handling; excessive steering resistance, increasing physical exertion during prolonged operation; and limited height adjustment range, restricting the ability to maintain neutral wrist and arm postures. These ergonomic issues may be contextualized by Indian driver anthropometry. According to recent anthropometric surveys of Indian adult males aged 18–60, the mean stature (P50) is approximately 167 cm, with the 90th percentile (P90) at 176 cm, and mean hand dimensions—such as hand breadth and length—averaging 8.0 cm and 18.0 cm respectively (Indian Anthropometry Database, 2020). Given this variability, steering wheel dimensions designed for larger or non-representative populations may not optimally accommodate the Indian driver cohort. Independent samples t-tests assessed the relationship between driver height and perceptions of steering wheel parameters. No statistically significant correlations were observed between respondent height and ratings of outer diameter ($p = 0.34$), grip diameter ($p = 0.48$), manipulation resistance ($p = 0.41$), height adjustment range ($p = 0.52$), or fore-aft adjustment range ($p = 0.39$). This indicates that dissatisfaction with steering wheel ergonomics is broadly distributed across the height spectrum, suggesting that factors beyond stature—such as hand anthropometry, grip strength, and habitual driving postures—may be influential. Collectively, these findings underscore the critical need for steering wheel design optimization based on comprehensive Indian anthropometric datasets—encompassing stature, upper limb reach, hand dimensions, and grip strength—to ensure enhanced ergonomic compatibility and driver comfort, reduce musculoskeletal strain, and improve vehicle control in long-haul operations. Adaptive features such as variable grip diameters, adjustable resistance mechanisms, and expanded adjustment ranges should be prioritized in future cab design iterations to address these ergonomic challenges effectively.

5. Pedal Ergonomics Assessment

The ergonomic evaluation of pedal systems focused on four critical parameters: pedal tilt angle, step-on depth, actuation force, and inter-pedal spacing shown in Table 7. These parameters directly influence lower limb biomechanics, muscle activation patterns, and neuromuscular fatigue during prolonged driving operations.

1. Pedal Tilt Angle and Step-on Depth:

Approximately 70–80% of respondents indicated satisfaction with the tilt angles of the accelerator, brake, and clutch pedals, which are designed to optimize foot positioning and minimize ankle joint strain. Statistical analysis confirmed no significant correlation between driver stature and pedal tilt angle assessments ($p > 0.05$), suggesting that the current tilt configurations provide an acceptable biomechanical posture across a range of Indian drivers population.

Similarly, 70–80% of drivers found the pedal step-on depths—defined as the vertical displacement of the pedal surface upon actuation—to be ergonomically suitable. Step-on depth is crucial for ensuring effective force transmission and preventing hyperextension or excessive dorsiflexion of the ankle joint,

which can contribute to musculoskeletal discomfort or injury. No statistically significant differences in height were observed between respondents satisfied and dissatisfied with pedal step-on depth ($p > 0.05$), indicating that this parameter may be generally well-calibrated relative to driver anthropometrics.

2. Inter-Pedal Spacing:

Inter-pedal spacing is fundamental for minimizing lower limb joint stress and enabling rapid, accurate pedal transitions. Approximately 15% of respondents reported that the horizontal gap between the accelerator and brake pedals was insufficient, which can impede timely braking responses and increase risk during emergency maneuvers. An equivalent proportion perceived the vertical displacement between pedals as excessive, potentially leading to increased ankle dorsiflexion and resultant fatigue. The majority (70%) rated pedal spacing as ergonomically appropriate, consistent with anthropometric data on lower limb reach and foot clearance within the sampled demographic.

3. Pedal Actuation Force:

Actuation force directly impacts muscle fatigue and operational comfort. A notable 34% of respondents perceived the accelerator pedal force as heavier than optimal, which aligns with biomechanical models indicating that excessive resistance can elevate tibialis anterior and gastrocnemius muscle activation, accelerating fatigue onset during sustained use. For brake and clutch pedals, approximately 45% of drivers rated the required force as heavy or moderately heavy, with 15% specifically identifying it as excessively heavy, suggesting potential overexertion of the lower limb muscles.

Table 7
Truck Cabin Pedal parameter

Pedal Parameter	% Satisfied	% Too Heavy/Unsuitable
Tilt Angle	70–80%	Minor dissatisfaction
Step-on Depth	70–80%	Minor dissatisfaction
Actuation Force	66% approx.	34% (accel), 45% (brake/clutch)
Pedal Spacing	70%	30% (15% too small, 15% too large)

Using “suitable” pedal force evaluations as a baseline, independent t-tests demonstrated no significant differences in driver age across force perception categories for accelerator and clutch pedals ($p > 0.05$). However, brake pedal force evaluation showed a statistically significant age effect ($p < 0.05$); younger drivers (mean age 28 ± 4 years) were more sensitive to higher actuation forces compared to older counterparts (mean age 32 ± 8 years). This may reflect differences in muscle strength, endurance, or driving style preferences correlated with age demographics. No significant associations were observed between pedal force perception and other physical variables such as driver height, body mass index (BMI), or vehicle gross weight ($p > 0.05$), indicating that perceived pedal resistance is predominantly

influenced by subjective comfort thresholds rather than absolute anthropometric or operational parameters.

Design Implications:

These findings underscore the critical need for pedal system designs to incorporate adjustable actuation force mechanisms and optimized geometric configurations tailored to the anthropometric variability of Indian heavy truck drivers. Specifically, pedals should facilitate: Adjustable tilt angles and step-on depths to accommodate foot size and ankle range of motion, reducing musculoskeletal strain. Sufficient horizontal and vertical spacing based on lower limb reach envelope data to enable safe, rapid pedal transitions.

Variable actuation forces, possibly through power-assisted or electronically controlled pedal systems, to minimize muscle fatigue, particularly for younger drivers who demonstrate greater sensitivity to resistance. Integrating these ergonomic refinements with comprehensive anthropometric databases and biomechanical modelling will significantly enhance driver comfort, reduce fatigue-related safety risks, and promote long-term musculoskeletal health in the Indian long-haul trucking sector.

4 Conclusions and Recommendations

The results of this investigation, derived from comprehensive ergonomic surveys of Indian long-haul truck drivers, reveal pervasive deficiencies across multiple cab subsystems and human-machine interfaces. Critical components—including seating and restraint systems, steering assemblies, pedal configurations, gear shift mechanisms, dashboard ergonomics, ingress/egress design, and external visibility aids—exhibit variable but significant ergonomic inadequacies that adversely affect driver comfort, operational performance, and occupational health outcomes.

1. **Seating and Restraint Systems:**

Respondents reported substantial discomfort linked to insufficient lumbar support, excessive seat cushion firmness, suboptimal headrest and backrest design, restricted seat depth and width, and seat belts characterized by excessive tension and poorly positioned near the cervical region. These factors collectively contribute to musculoskeletal strain and early onset of fatigue during extended driving periods.

2. **Steering Interface:**

The steering wheel configuration was frequently cited for its disproportionately large outer diameter, limited grip circumference, elevated steering resistance, and inadequate vertical adjustment range. Such design shortcomings elevate upper extremity exertion, potentially diminishing driver control accuracy and increasing fatigue.

3. **Pedal Ergonomics:**

The study identified non-ideal pedal tilt angles for both accelerator and brake pedals, excessive depression depths especially for brake and clutch pedals, and insufficient inter-pedal spacing. These issues may impair lower limb biomechanics, slow response times, and exacerbate fatigue-related performance decrements.

4. **Shift Mechanism:**

Excessive actuation force requirements and ergonomically suboptimal shift lever handle dimensions were reported, hindering grip stability and operational efficiency. Such deficiencies increase the likelihood of manual transmission errors during prolonged driving sessions.

5. **Dashboard and Controls:**

Cabin dashboard layouts often lack ergonomic coherence, with critical controls and indicators placed beyond optimal reach or sight lines, thereby increasing cognitive load and elevating driver distraction risk.

6. **Ingress/Egress Design:**

Drivers commonly reported challenges with vehicle entry and exit, citing inconsistencies in step height, poor step placement, and inadequate handhold supports. These factors compromise safety, particularly under adverse environmental or lighting conditions.

7. **Driving Visibility:**

Mirror positioning and blind spot mitigation measures were deemed insufficient, reducing rearward and lateral fields of vision and raising collision risks in dense or complex traffic environments.

Collectively, these findings highlight an urgent imperative to adopt a user-cantered ergonomic framework tailored to the anthropometric and operational characteristics of Indian long-haul truck drivers. Integrating biomechanical principles and driver behavioural insights into heavy truck cabin design will be essential for enhancing operational safety, comfort, and the long-term health and performance of professional drivers. The empirical data derived from driver feedback underscore critical ergonomic deficiencies within current heavy truck cabin designs, necessitating targeted optimization aligned with anthropometric and biomechanical principles specific to the Indian driver population. The following technical recommendations are proposed:

1. **Anthropometric Integration and Design Customization:**

Long Haul truck cabin architecture must be fundamentally informed by the anthropometric profiles characteristic of Indian long-haul drivers, predominantly young adult males with defined stature and body mass distributions. Leveraging population-specific anthropometric databases (e.g., percentile-based stature, limb length, and body mass indices) will facilitate the development of adaptive design

parameters that ensure biomechanical compatibility, reduce postural strain, and enhance operator comfort and safety.

2. **Advanced Seating System Ergonomics:**

1. **Lumbar Support:** Incorporate contoured, adjustable lumbar supports engineered to conform dynamically to the sagittal spinal curvature of diverse driver statures, mitigating lower back strain and reducing the incidence of musculoskeletal disorders (MSDs).

2. **Headrest and Backrest:** Design modular, detachable headrests and backrests with variable stiffness zones and ergonomic curvature to optimize cervical and thoracic spine support during both static and dynamic postures.

3. **Seat Dimensions and Padding:** Increase seat width and depth dimensions based on 5th to 95th percentile anthropometric data, coupled with multi-density cushioning employing viscoelastic foams or gel inserts to improve pressure distribution and reduce ischemic risk points.

4. **Seatbelt Tensioning:** Develop adaptive seatbelt tensioning mechanisms that maintain secure restraint without exerting excessive compressive forces on the thoracic and cervical regions, thus enhancing both comfort and occupant safety.

3. **Steering Wheel Interface Refinement:**

1. **Dimensional Optimization:** Reduce the external diameter of the steering wheel to decrease reach and upper limb exertion while increasing grip diameter to improve hand posture and reduce grip fatigue.

2. **Force Reduction:** Employ power-assisted or electronically variable steering systems to minimize steering torque requirements, thereby reducing muscular load and enhancing precision control during extended operations.

3. **Adjustability Enhancement:** Expand vertical and angular adjustment ranges to accommodate drivers of varying anthropometrics, facilitating optimal ergonomic alignment and visibility.

4. **Pedal Ergonomics and Actuation Forces:**

1. **Tilt and Depth Calibration:** Redesign accelerator, brake, and clutch pedals with optimized tilt angles and depression depths aligned with lower limb kinematics to facilitate natural ankle dorsiflexion/plantarflexion movements and reduce fatigue.

2. **Force Minimization:** Integrate low-resistance actuation mechanisms—potentially through hydraulic or electronic assistance—to significantly lower pedal operating forces, thereby mitigating repetitive strain injuries and improving response efficacy.

5. **Gear Shift Mechanism Optimization:** Engineer gear shift levers with reduced actuation force thresholds, incorporating ergonomically contoured handles that conform to hand anthropometry, improving grip security and minimizing operational fatigue during prolonged use.

6. **Cabin Spatial Architecture and Sleeping Quarters:**

1. **Space Utilization:** Reconfigure cab interior layouts to maximize usable volume, incorporating foldable and modular sleeping platforms, particularly enhancing upper bunk clearance, to optimize rest quality and space efficiency for long-haul drivers.

2. **Ergonomic Accessibility:** Ensure ingress and egress points are designed with consistent step heights, anti-slip surfaces, and supportive handholds, improving safety during cabin entry/exit under various environmental conditions.

7. **Automation and Driver Assistance Systems:** Implement advanced driver assistance systems (ADAS) and automated control features (e.g., adaptive cruise control, automated gear shifting) aimed at reducing physical exertion and cognitive workload, thereby enhancing overall driving safety and operator endurance.

8. **Environmental Control and Vibration Mitigation:**

1. **Thermal and Acoustic Insulation:** Employ multi-layer insulation materials and noise damping technologies to stabilize cab temperature and attenuate ambient noise, enhancing operator comfort and reducing fatigue.

2. **Vibration Damping:** Integrate advanced suspension components and seat vibration isolation systems (such as active suspension or air-ride seats) to minimize whole-body vibration exposure, known contributors to chronic musculoskeletal disorders.

9. **Auxiliary Systems and Technological Enhancements:**

1. **Storage and Convenience:** Increase provision of ergonomically designed storage compartments (e.g., glove boxes with easy reach and adequate volume) to reduce clutter and improve driver organization.

2. **Connectivity and Infotainment:** Incorporate integrated communication and entertainment modules, including Bluetooth connectivity, telematics, digital driving recorders, and wireless charging stations, to support driver engagement and operational efficiency.

This comprehensive approach ensures that heavy truck cab designs are systematically aligned with the biomechanical and operational demands of Indian long-haul truck drivers, promoting improved health outcomes, enhanced safety, and superior driver experience.

Declarations

1. CONSENT TO PUBLISH

“Not applicable”.

2. Ethics statement

The SKN Sinhgad College of Engineering Ethics Committee waived the need for ethics approval for this study as it involved minimal risk and did not include any invasive procedures. Informed consent was obtained from all participants. Participants were provided with a clear explanation of the study's purpose, procedures, potential risks and benefits, and their right to withdraw at any time. Participants were also informed that their participation was voluntary and that their responses would be kept confidential.

3. Data Availability:-

All data generated or analysed during this study are included in this published article

List of Abbreviations: Not applicable

Declarations:

--Consent for publication – Not Applicable

-Availability of data and materials : No/Not applicable (this manuscript does not report data generation or analysis)

-Competing Interest – Not Applicable

-Authors Contributions – A B Rathod – Main Author and Corresponding Author ; Dr R T Vyavhare – Co Author

Corresponding Author - A B Rathod

-Acknowledgment – Not Applicable

-Funding Declaration - No Funding

-If your study is a clinical trial – No

- Consent to participate - Not Applicable

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Figures

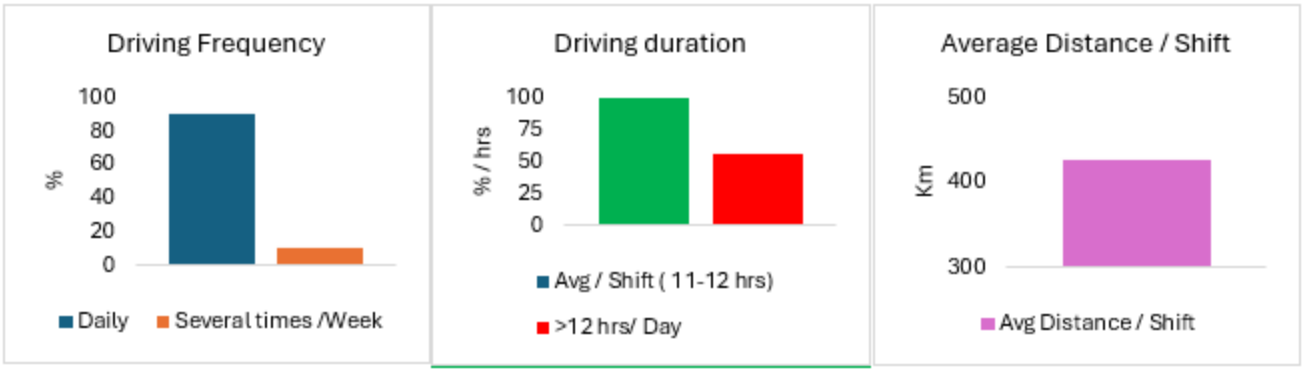


Figure 1

Distribution of Daily Driving Duration and Distance

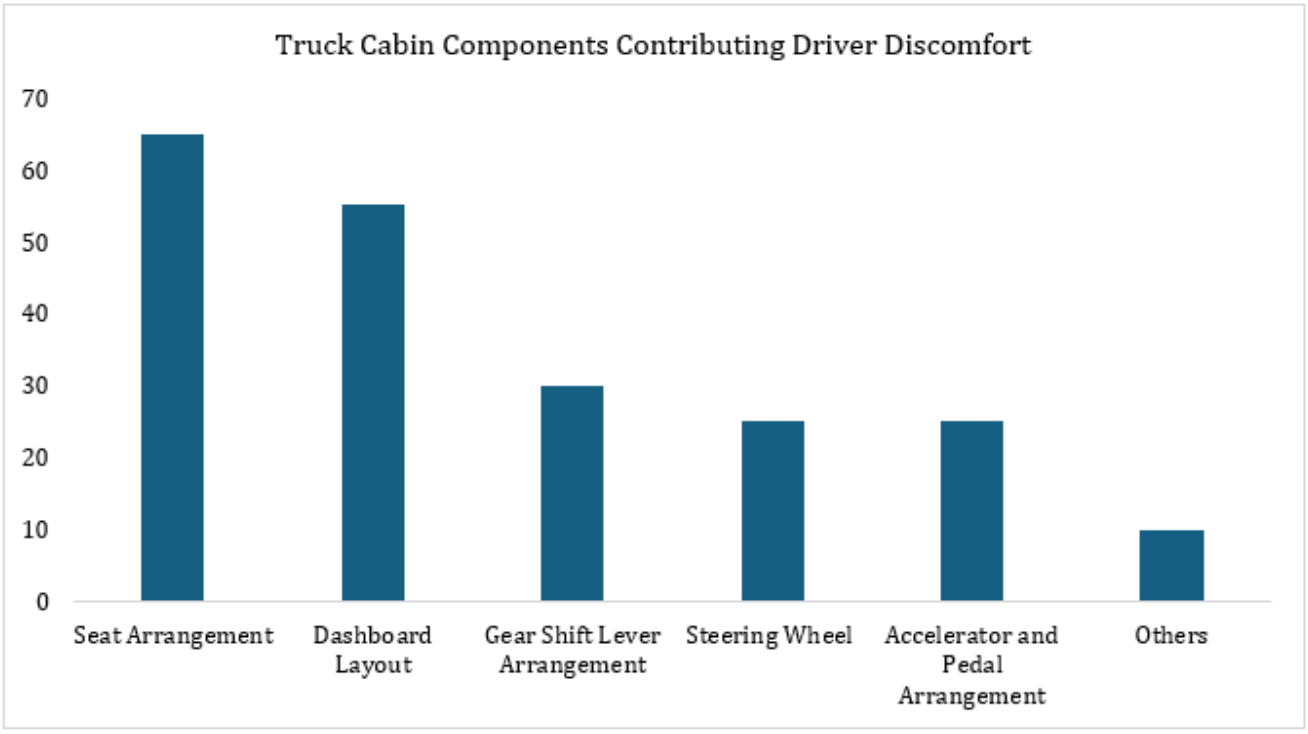


Figure 2

Truck Cabin Components Contributing Driver Discomfort

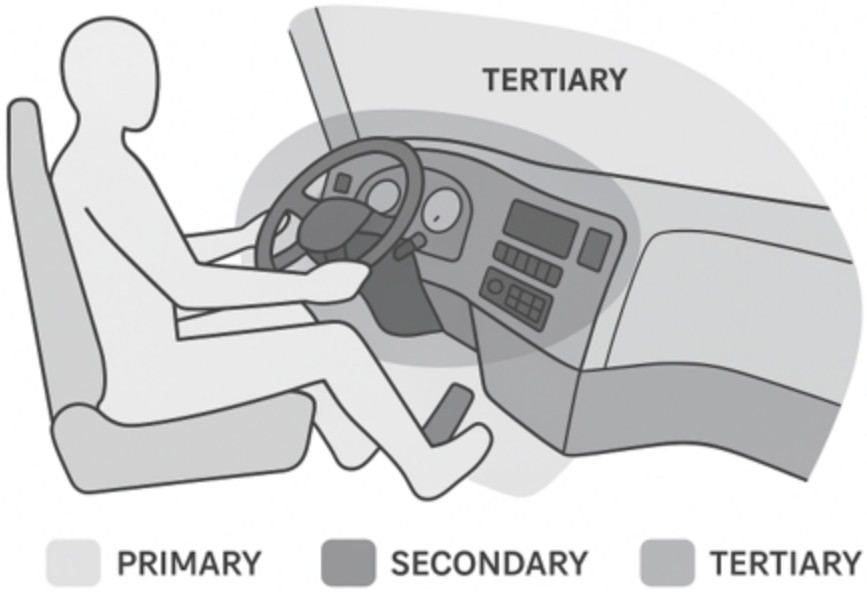


Figure 3

Dashboard Control Layout Zones