Library Progress International
Vol.43 No.2, Jul-Dec 2023: P. 456-460

Print version ISSN 0970 1052
Online version ISSN 2320 317X

Original Article *Available online at www.bpasjournals.com*

Improving Cattle Transport Systems: A Comprehensive Review of Design, Welfare, and Technology

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How to cite this article: Sandip S. Patil, Jayant H. Bhangale (2023) Improving Cattle Transport Systems: A Comprehensive Review of Design, Welfare, and Technology. *Library Progress International,* 43(2) 456-460

ABSTRACT
This paper reviews data from governmental reports, research studies, and practical observations, particularly focusing on stressors that cattle experience during transport. By analyzing designs from developed countries and comparing them to Indian practices, this study emphasizes the importance of localized solutions. The goal is to bridge the gap between international standards and Indian requirements, ensuring both productivity and welfare improvements in cattle transportation.
This paper reviews the challenges, gaps, and existing practices in cattle transportation with a focus on Indian scenarios. Despite significant contributions to the global cattle population, India faces severe welfare and logistical issues due to outdated and unsafe transportation facilities. By analyzing current technologies, practices, and governmental guidelines, this study identifies key stressors such as overcrowding, insufficient ventilation, and lack of proper handling facilities. The paper also reviews international practices, available technologies, and design guidelines to propose actionable insights and highlight gaps in implementing safe and humane cattle transport systems.

KEYWORDS
Cattle transportation, Transport facility design, Indian livestock sector

Introduction

Farm animals undergo transportation at least once in their lives, primarily due to reasons such as ownership transfer and Rostagno (2009) highlighted the improvement in environmental or feeding conditions, or transportation to the abattoir. However, these processes can significantly impact their well-being, as they are subjected to various stressors during handling, loading, transportation, and unloading.
In 2023, India boasted the world's largest cattle inventory, with 305.5 million head, surpassing Brazil and China, Genaro (2019) this accounted for approximately 30% of the global inventory. (Figure 1). However, despite this significant cattle population, the transportation of these animals poses grave concerns. Foreign Agricultural Service (2024) shows that trucks often carry cattle in such densely packed conditions that their movement becomes severely restricted. The Animal Welfare Board of India, along with numerous other animal welfare organizations, has collected evidence highlighting widespread abuse of cattle during transportation across the country.
Cattle transportation remains a significant concern in rural areas of India, primarily due to the lack of safe transport facilities and prevailing attitudes toward animal safety. The transport of animals in India is associated with high rates of injuries, disease transmission, accidents, and fatalities. Governmental accident reports and investigations highlight the prominent issue of safety during cattle transportation in the Indian context. Approximately 6% of cattle deaths occur during transportation, as reported in the Road Accident Report for India in 2021. The primary

contributing factor to these accidents is the absence of dedicated facilities for cattle transportation.

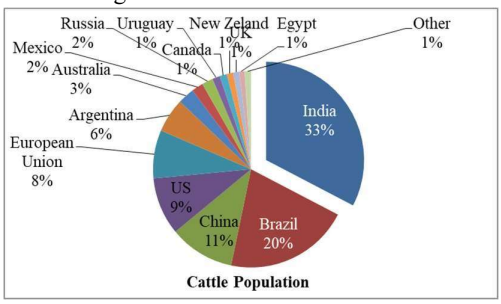

Figure 1 : World Cattle population

However, the lack of safe and humane transport facilities contributes to high mortality and injury rates during transit. Overcrowding, poor ventilation, and inadequate vehicle design exacerbate these issues, affecting animal welfare and productivity. This paper aims to study existing transportation systems, review related research, and propose design improvements tailored to Indian conditions.

1. Objectives

The objective of this study is to address the critical challenges in cattle transportation systems, with a focus on Indian conditions, by identifying gaps and proposing practical, humane solutions. This aligns with the need highlighted in the abstract to reduce stress, injuries, and mortality during transit through innovative designs and compliance with welfare standards. Specifically, the study evaluates modular transport designs and explores the application of Computational Fluid Dynamics (CFD) to optimize ventilation and airflow within vehicles, aiming to minimize thermal and physical stress. By integrating advanced technologies like IoT-based monitoring and ergonomic vehicle designs, the research seeks to propose cost-effective, scalable solutions tailored to India's unique socio-economic and rural contexts. The conclusion reinforces this objective by emphasizing the importance of adapting global best practices to local conditions and prioritizing the enforcement of welfare guidelines to ensure sustainable and humane cattle transportation.

2. Literature Review

Research on cattle transportation highlights critical welfare concerns and operational inefficiencies. Overcrowding, poor ventilation, and insufficient handling facilities are frequently cited as key stressors during transit (Broom,2003) (Bhatt,2021). Studies emphasize the importance of adequate space, ventilation systems, and stress mitigation strategies to reduce transportation-induced injuries and mortality (Gilkeson,2016) (Padalino,2018). For example, Broom (2003) identified transport stressors such as overcrowding and handling procedures as significant contributors to animal distress. Additionally, improper loading and unloading practices further exacerbate injuries and increase stress among cattle (Earley,2013).

International studies provide valuable insights into mitigating transport challenges. In the European Union, strict regulations on space allowances and ventilation have demonstrated significant improvements in animal welfare (Padalino,2018). Similarly, CFD has been used to optimize airflow and heat dissipation in transport vehicles, providing a model for enhancing cattle comfort during transit (Gilkeson,2016). However, these solutions are not directly translatable to Indian conditions, as they fail to consider factors such as tropical climates, poor infrastructure, and the socio-economic status of transporters (Purnima,2018). Table 1 shows the stressors in cattle transportation and with effect on cattle.

Table 1. Stressors in cattle transportation

S. N.	Stress	Stressor	Effect
1	Behavioral	Overcrowding	Fear
			Aggressive interaction
2	Nutritional	Fasting	Dehydration & hunger
3	Physical	Overloading	Bruising & injuries
		Improper Facilities	

4	Infectious	Dust, Exposure	Diseases

Indian research on cattle transportation remains limited. Most studies focus on breed improvement, disease control, and productivity enhancement rather than on technical transport solutions (Minka,2017), (Van Engen,2018). Practical surveys reveal that short-distance and small-scale transport needs, which dominate in rural India, are rarely addressed (Hakan,2021) (Burdick,2011). This review underscores the urgent need for research tailored to India's specific requirements.

3. Different Available Technologies

Globally, technological advancements have significantly improved livestock transportation systems. Computational Fluid Dynamics (CFD) is widely used to simulate and analyze airflow, ventilation patterns, and temperature regulation in livestock vehicles. Studies by Gilkesona et al. (2017) highlight the effectiveness of CFD in identifying airflow inefficiencies and optimizing vent placement to ensure uniform cooling and reduce thermal stress (Gilkeson,2016). However, its application in India remains minimal due to limited awareness and cost constraints.

Innovations such as IoT-based monitoring systems, adjustable partitions, and shock-absorbent flooring are standard in developed countries (Mitchell,2008). IoT sensors track environmental parameters like temperature and humidity, allowing real-time adjustments to ensure animal comfort. Vehicles equipped with non-slip flooring and smooth partitions minimize injuries during transit (Burdick,2011). Additionally, advanced suspension systems reduce vibrations, providing a smoother ride for cattle (Van Engen,2018).

In India, most transport vehicles lack even basic facilities like adequate ventilation or proper loading mechanisms (Purnima,2018) (Minka,2017). Open-air trucks with wooden slats are commonly used, often resulting in overcrowding and heat stress during transport (Hakan,2021). International best practices, such as those in the United States and Europe, offer valuable design parameters, including defined air inlets and outlets, modular compartments, and climate control systems (Padalino,2018).

While these technologies provide a roadmap, adapting them to India requires cost-effective and scalable solutions. For instance, modular cage designs tailored to Indian vehicle dimensions and road conditions can significantly enhance safety and efficiency. Integrating CFD-based analysis with low-cost ventilation systems can further improve animal welfare during transit.

4. Findings

1. Indian cattle transportation systems lack adequate facilities, leading to high stress and injury rates.
2. Research on transport-specific design solutions in India is limited, with most studies focusing on breed improvement and disease control.
3. International practices provide valuable insights but require adaptation to Indian contexts.
4. Key challenges include a lack of enforcement of animal welfare laws, poor infrastructure, and limited awareness among stakeholders.

In context with the Indian scenario, some highlighted findings from the research are,

a) Critical Welfare Challenges:

Indian cattle transportation systems are plagued by issues such as overcrowding, insufficient ventilation, and improper handling, leading to high stress, injuries, and mortality rates (Broom,2003) (Minka,2017).

b) Research Gaps in Ventilation Optimization:

Limited use of advanced tools like Computational Fluid Dynamics (CFD) to analyze airflow and heat stress in transport vehicles in India has left ventilation systems largely unoptimized (Gilkeson,2016).

c) Neglect of Modular Transport Designs:

While modular transport systems with adjustable compartments are widely adopted in developed nations, Indian practices still rely on rudimentary and overcrowded vehicles, compromising animal welfare (Padalino,2018).

d) Non-compliance with Welfare Standards:

Although guidelines such as IS 14904:2007 exist, enforcement is weak, and awareness among stakeholders remains low, leading to poor adherence to these standards as per the Central Zoo Authority Report 2011 (Purnima,2018).

e) **Inadequate Adaptation of Advanced Technologies**:

Technologies such as IoT-based monitoring, shock-absorbent flooring, and adjustable ventilation systems are scarcely used in India due to economic and infrastructural constraints (Burdick,2011).

f) Small-Scale Needs Overlooked:

Short-distance and small-scale transport, which are predominant in rural India, are not adequately addressed by existing research and policy frameworks (Hakan,2021), (Van Engen,2018).

5. Limitations and Research Gaps

Despite the significant role of India in global cattle production, existing studies focus predominantly on large-scale transportation systems designed for developed countries, which do not align with India's rural and tropical conditions (Bhatt,2021) (Van Engen,2018). There is a notable neglect in research on safe cattle transport facilities and modular compartment designs that address India's unique needs, particularly for small-scale farmers (Broom,2003) (Minka,2017). Moreover, while ventilation and heat stress in livestock transportation have been extensively studied using tools like Computational Fluid Dynamics (CFD) in other countries, minimal work has been done to apply these insights to Indian transport vehicles (Gilkeson,2016). The enforcement of animal welfare standards, such as IS 14904:2007, remains inadequate, with limited studies exploring strategies for improving adherence in practice (Purnima,2018). Additionally, advanced technologies, including IoT-based monitoring systems and adjustable partitions, are rarely adopted in Indian contexts due to economic and infrastructural constraints (Burdick,2011), (Mitchell,2008). Lastly, most existing research focuses on long-distance, large-scale cattle transportation, leaving a critical gap in addressing the short-distance and small-scale transportation needs relevant to the majority of Indian farmers (Hakan,2021), (Earley,2013).

6. Conclusion

This review highlights significant gaps and challenges in cattle transportation systems in India. The findings emphasize the urgent need for innovative, cost-effective solutions tailored to the country's rural and tropical contexts. Modular cage designs, coupled with CFD-based ventilation optimization, can greatly enhance animal welfare by mitigating stress and injury during transit.

Furthermore, the adoption of technologies like IoT monitoring and adjustable partitions, adapted to Indian socio-economic realities, offers a pathway to improving transportation safety and efficiency. Addressing these gaps requires not only technological innovation but also stronger enforcement of existing welfare guidelines and increased awareness among transporters and stakeholders. By prioritizing humane and efficient cattle transportation, India can reduce mortality rates, enhance productivity, and set a benchmark for sustainable livestock management. Future research should focus on developing scalable solutions that align with local needs while incorporating international best practices for animal welfare.

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