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Strategies and technologies for mitigating airborne transmission risks in public transportation

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1 Introduction

Airborne infections present significant challenges to the public transportation sector, threatening both public health and financial viability. The rapid spread of COVID-19 underscored the role of public transportation in propagating respiratory diseases, necessitating effective mitigation strategies (Cucinotta & Vanelli, 2020; Lan et al., 2020). The rapid spread of COVID-19 underscored the role of public transportation in propagating respiratory diseases, necessitating effective mitigation strategies. This paper presents a systematic review of measures employed by public transportation agencies to protect passengers and staff while ensuring uninterrupted service. The primary aim is to summarize available countermeasures to control airborne transmission risks and provide practical recommendations to prepare transportation systems for future epidemics.

2 Methodology

A systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Studies were retrieved from Web of Science and PubMed using keywords such as "public transportation," "COVID," "airborne infection," and "transmission." Eligible studies, published between 2013 and 2023, had to report countermeasures employed by public transportation to minimize viral spread. The final selection included 49 studies involving quantitative, qualitative, and mixed-method research. Data were extracted independently by two reviewers and summarized based on countermeasures categorized into air quality improvement, cleaning, mask-wearing, and social distancing.

3 Main findings

The review identified four primary countermeasures for mitigating airborne transmission in public transportation: air quality improvement, sanitization, face mask usage, and social distancing.

- **Air Quality Improvement**: Enhanced ventilation, including the use of mechanical filtration systems like High Efficiency Particulate Air (HEPA) filters, and increased use of natural ventilation by opening windows, were widely adopted. These measures were effective in reducing viral load in enclosed environments like buses and trains. For instance, studies by Bertone et al. (2022) demonstrated that enhanced ventilation significantly reduced transmission risk. Studies showed that ventilation with overhead

gaspers and open windows significantly reduced infection risk by up to 92% compared to closed environments.

- **Sanitization**: Regular cleaning of high-contact surfaces, such as handrails and seats, emerged as a critical countermeasure. Studies indicated that contamination levels were higher on frequently touched surfaces than in ambient air. Moreno et al. (2021) found that contamination was primarily on surfaces like handrails, emphasizing the need for rigorous sanitization. Contactless payment systems and sanitizer dispensers were introduced to reduce the need for physical interaction with contaminated surfaces.
- **Face Mask Usage**: Mandatory mask-wearing was consistently reported as an effective, low-cost measure to reduce infection rates. Simulation models demonstrated that mask usage reduced transmission risk by over 90%, particularly when combined with other countermeasures like improved ventilation. Gkiotsalitis and Cats (2021) supported these findings, highlighting mask-wearing as a key intervention.
- **Social Distancing**: Social distancing presented challenges due to the inherently crowded nature of public transportation. However, crowd management techniques, such as limiting the number of passengers per vehicle and using reservation systems for seating, helped minimize transmission risks. Bertone et al. (2022) also suggested reservation systems as a practical approach for managing passenger density. Off-peak travel incentives were also introduced to manage passenger density during peak hours.

4 Discussion

The findings emphasize the importance of integrating multiple countermeasures to ensure a safer environment for passengers and staff. Effective air quality management and sanitization protocols help minimize viral spread, while mandatory mask usage and crowd management support safer interaction within enclosed spaces. The adoption of technology-driven solutions, such as automated mask detection and real-time passenger information systems, could further enhance the safety and efficiency of public transportation during epidemics.

The study highlights critical gaps in preparedness, such as the lack of pre-established contingency plans for airborne infection management. According to Zhang et al. (2021), only a minority of cities had effective contingency plans for public transit. Most public transportation systems lacked contingency protocols, leaving them vulnerable during the initial phases of the COVID-19 pandemic. Moving forward, transportation agencies must invest in developing and implementing comprehensive plans to manage future outbreaks effectively. These plans should include lessons learned from previous pandemics (Abduljabbar et al., 2022). This involves creating infrastructure that supports advanced air filtration, enhancing real-time information dissemination, and integrating automated safety protocols.

Despite challenges like peak-hour congestion and limited resources for continuous sanitization, the experience of the COVID-19 pandemic provided valuable lessons in proactive risk management. Developing comprehensive preparedness strategies, emphasizing alternatives to service closures, and employing technology-driven interventions are key recommendations to maintain operational resilience and ensure passenger safety.

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