

# Bridging Passenger Clustering and User Experience Personalization in Long-Distance Railway Systems: A Rapid Literature Review

*Laila Ma'rifatul Azizah*<sup>1</sup>, *Agus Setiawan*<sup>2\*</sup>, and *Reza Giga Isnanda*<sup>1</sup>

<sup>1</sup>Department of Information Technology, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia

<sup>2</sup>Department of Informatics Engineering, Universitas Muhammadiyah Magelang, Magelang, Indonesia

**Abstract.** The rapid advancement of data-driven technologies in transportation presents new opportunities to enhance long-distance railway services. However, despite the widespread use of clustering techniques for passenger segmentation and the growing importance of user experience (UX) design, these domains remain largely disconnected in current research and practice. This study addresses this gap through a Rapid Literature Review (RLR) of 341 peer-reviewed articles published between 2019 and 2024 in the Scopus database. The selected studies were analyzed using keyword co-occurrence and thematic mapping and further classified into four passenger-type clusters: routine commuters, family travelers, budget-oriented passengers, and elderly or special-needs users. Thematic analysis identified four major research areas: UX and digital interaction, deep learning and smart mobility, intelligent public transport systems, and autonomous transport. The findings reveal a significant methodological divide: clustering is primarily applied for system optimization, while UX research focuses on interaction design, with limited integration between the two. To address this, the study proposes a conceptual framework that links clustering outputs to UX adaptation strategies for personalized railway services. This work contributes to the field of smart mobility by integrating behavioral analytics with human-centered design, offering a foundation for more adaptive, inclusive, and user-responsive railway systems. Future research is encouraged to validate the proposed framework through empirical studies and prototype development.

## 1 Introduction

Digitalization and data-driven methods are increasingly reshaping railway transport through applications in operations, predictive maintenance, and service management [1]. With the growing availability of passenger data from ticketing systems, mobile applications, and sensor-based monitoring, transport operators can now analyze

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\* Corresponding author: [setiawan@unimma.ac.id](mailto:setiawan@unimma.ac.id)

passenger behavior and preferences in unprecedented depth. These insights enable improvements in service delivery, enhance passenger satisfaction, and support evidence-based infrastructure planning.

Indonesia's railway system, established in 1867 under Dutch colonial rule and fully nationalized in 1971, is operated by the state-owned company Kereta Api Indonesia. It remains geographically concentrated in Java and Sumatra, with an operational network of approximately 6,640 km serving 277 million passengers annually as of 2022. Ongoing expansion aims to reach 10,524 km by 2030, signaling a significant transformation in the national transport sector [2]. This figure underscores the public's heavy reliance on rail services and highlights the urgent need for adaptive, personalized service strategies. However, traditional approaches to railway service design often fail to accommodate passengers' heterogeneous preferences and needs, including comfort levels, accessibility requirements, digital engagement, and in-transit service expectations.

To address these challenges, machine learning, particularly clustering techniques, offers a promising alternative. Clustering, an unsupervised learning method, enables the segmentation of passengers into meaningful subgroups based on shared behavioral or demographic traits. These segments can inform the design of targeted services and user interfaces aligned with specific passenger profiles [3,4].

Although clustering is widely used in urban mobility and multimodal transport planning [5], its integration with User Experience (UX) design principles, such as usability, accessibility, personalization, and digital interaction, in the context of long-distance railway services remains underexplored [6]. This gap represents a missed opportunity to enhance UX through intelligent, data-driven service customization.

This study aims to bridge this knowledge gap by conducting a Rapid Literature Review (RLR) that synthesizes recent advances in clustering techniques and their implications for enhancing UX in long-distance rail travel. Specifically, this research identifies clustering methodologies used for passenger classification and examines relevant UX factors in railway contexts. The overarching goal is to support the development of human-centered transportation systems that are both operationally efficient and experientially rich for diverse user groups.

## **2 Methods and materials**

### **2.1 Clustering Applications in Transportation Systems**

Clustering techniques are widely used in transport studies to understand passenger behavior, optimize route planning, and enhance service customization. K-means, hierarchical clustering, and density-based spatial clustering (DBSCAN) remain the most used algorithms for passenger segmentation and travel pattern identification.

For example, Liu et al. (2021) applied the Kernel K-means algorithm to analyze metro passenger flows in Shenzhen, revealing meaningful user clusters that could inform transit capacity planning and dedicated service strategies [5]. Similarly, Zhang and Xu (2024) combined K-means clustering with flow experience data to optimize wayfinding systems in subway environments, demonstrating how clustering outputs can be operationalized in UI/UX design for digital navigation systems [4].

In multimodal contexts, He (2021) proposed a multi-criteria journey planning approach that integrates passenger segmentation to support real-time travel recommendations and service differentiation in long-distance bus and rail systems [3]. These studies underscore clustering's utility in translating passenger heterogeneity into operational insights.

## **2.2 UX and Human-Centered Design in Railway Services**

User experience (UX) research in transport focuses on the quality of interactions between passengers and service systems. This includes interface usability, emotional satisfaction, physical comfort, and digital touchpoints throughout the travel process. However, despite growing digital integration in transport systems, UX design in railway contexts often lacks personalization grounded in behavioral data.

Journey mapping and service design methods have emerged as prominent approaches for capturing the experiential dimension of rail travel. Oliveira et al. (2020) employed journey mapping from the perspective of railway crew members to identify friction points and user needs in service delivery [7]. Similarly, Sun et al. (2020) used Quality Function Deployment (QFD) and service design techniques to assess UX in airport rail services, emphasizing the role of early-stage segmentation in service innovation [8].

Moreover, recent studies on intermodal travel behavior suggest that clustering users by psychological and attitudinal factors, such as comfort expectations or service reliability, can enhance UX and system adoption [9].

## **2.3 Gap in the Literature**

Despite the proven benefits of clustering and UX design individually, their combined application in long-distance railway contexts remains limited. While some works demonstrate the potential of user segmentation in short-distance metro systems or multimodal platforms, few studies explicitly link clustering results to UX personalization strategies in intercity train services. Furthermore, the methodological integration of unsupervised learning with human-centered design remains underdeveloped in current transportation literature.

Therefore, there is a critical need to synthesize these domains and develop frameworks that leverage clustering not only for planning but also for dynamically tailoring UX across passenger segments, an area this study seeks to advance.

## **3 Methods**

This study adopted a Rapid Literature Review (RLR) to identify and synthesize peer-reviewed academic contributions at the intersection of clustering techniques, user experience (UX), and railway transport systems. The RLR was chosen for its ability to generate timely yet methodologically rigorous insights by streamlining traditional systematic review procedures [10,11].

### 3.1 Research Scope and Objectives

This review sought to answer the following research questions:

- a. Which clustering techniques have been applied to passenger classification in transport contexts?
- b. Which UX factors are relevant in the context of long-distance railway services?
- c. How have clustering methods been integrated (or proposed for integration) with UX in rail-based service design?

### 3.2 Search Strategy

The literature search was conducted using the Scopus database, which is recognized for its comprehensive coverage of peer-reviewed journals in computer science, engineering, and human-centered design. Scopus has also been shown to be effective for rapid evidence synthesis in software and information systems research contexts.

The search was conducted using the following Boolean query syntax:

```
TITLE-ABS-KEY (clustering AND "user experience" AND (transportation OR train
OR railway OR "rail transport" OR UX))
AND PUBYEAR > 2018 AND PUBYEAR < 2025
AND DOCTYPE (ar)
AND SRCTYPE (j)
AND LANGUAGE(English)
```

Keywords included: *clustering, user experience, UX, transportation, and train.*

### 3.3 Inclusion and Exclusion Criteria

This review followed structured selection criteria (**Table 1**), guided by recent RLR methodologies in computer science [12,13]:

**Table 1.** Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles (2019–2024)	Non-peer-reviewed works, technical reports, or grey literature
Studies involving clustering in transportation	Works unrelated to transportation or UX
Studies discussing UX in railway or public mobility	Articles using clustering solely for hardware/network optimization

### 3.4 Screening and Selection Process

Screening occurred in two phases:

- a. Title and abstract screening to remove irrelevant or duplicate entries.
- b. Full-text review to assess methodological rigor and thematic alignment.

A total of 28 peer-reviewed journal articles were selected for synthesis after applying the inclusion and exclusion criteria.

### 3.5 Data Extraction and Analysis

From each study, the following elements were extracted:

- a. Publication metadata (authors, year)
- b. Research domain and objectives
- c. Type of clustering algorithm used
- d. UX dimensions discussed (e.g., comfort, accessibility, digital interaction)
- e. Integration potential between clustering and UX

The data were then analyzed using thematic coding and grouped into conceptual clusters related to:

- a. Clustering methodologies
- b. UX design factors in railway systems
- c. Integration pathways between clustering outcomes and personalized UX design

The review adhered to RLR principles that prioritize clarity, replicability, and pragmatism in evidence synthesis, particularly in applied computer science and digital service design [12].

## 4 Results

### 4.1 Overview of Article Classification

From a total of 341 peer-reviewed articles analyzed using Rapid Literature Review (RLR), the studies were mapped into two classification schemes:

- a. Passenger, Type Clusters, Based on inferred user needs and travel behavior.
- b. Thematic Clusters, Derived from keyword co-occurrence and topical focus within abstracts.

### 4.2 Passenger-Type Clusters

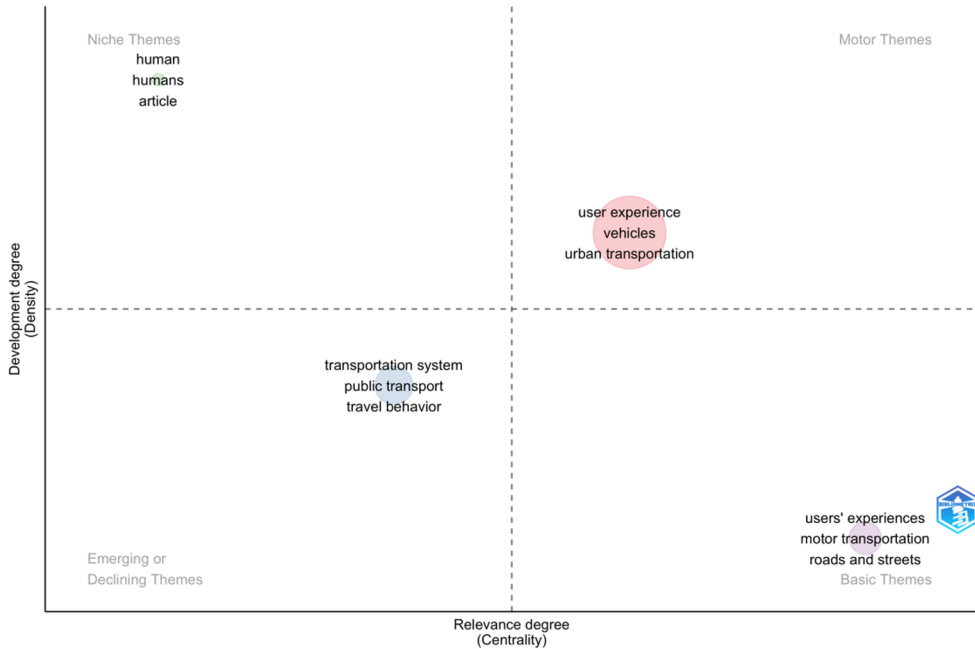
Articles were grouped into four major passenger behavior clusters based on user characteristics, service preferences, and indicators drawn from their travel patterns. A total of 218 articles (out of 341) were successfully mapped to these **Table 2**:

**Table 2.** Four Major Passenger Behavior Clusters

Cluster	Number of Articles	Key Characteristics
Routine Commuters	51	Frequent travelers with consistent weekday patterns and executive class preference.
Family Travelers	50	Group travelers, especially during weekends, often booking in family packages.
Budget Travelers	48	Price-sensitive travelers, typically selecting night departures and early promos.
Elderly and Special Needs Passenger	68	Elderly and passengers with accessibility or additional service requirements.
Unclassified	123	Articles without clear segmentation indicators for passenger grouping.

These clusters align with prior classification frameworks in mobility studies and provide a conceptual basis for personalizing UX in long-distance railway services.

### 4.3 Thematic Clustering Based on Keyword Mapping



**Fig. 1.** Thematic Map

A separate thematic mapping analysis of article keywords revealed four high-level research clusters within the corpus (**Fig. 1**):

1. Cluster 1 - Motor Themes (Core and Well-Developed)  
Human-Centered UX & Urban Mobility Systems
  - Keywords: *user experience*, *vehicles*, *urban transportation*.
  - Focus: Integration of user-centered design within intelligent mobility systems.
2. Cluster 2 - Basic Themes (Important but Underdeveloped)  
Transport Infrastructure & Mobility Context
  - Keywords: users' experiences, roads and streets, motor transportation.
  - Focus: Fundamental concepts of mobility and infrastructure.
3. Cluster 3 - Niche Themes (Specialized but Isolated)  
Human Factors and General Context
  - Keywords: human, humans.
  - Focus: General human-related descriptors.
4. Cluster 4 - Emerging or Declining Themes (Weak and Peripheral)  
Autonomous Transport & V2V Decision Systems
  - Keywords: transportation system, public transport, travel behavior.
  - Focus: Traditional transport system analysis.

A thematic mapping analysis of article keywords revealed four major research clusters. Unlike traditional clustering approaches, the thematic map positions these clusters based on their centrality (relevance) and density (development), providing deeper insight into their role within the research field.

#### **4.4 Integration Insight**

While thematic mapping shows that user experience is a core theme, indicating high relevance and strong development, and public transport-related topics fall within the emerging or declining quadrant, integration between these domains remains limited. Although several studies address user experience in intelligent transportation systems, and others focus on public transport operations and travel behaviour, only a relatively small subset explicitly applies clustering or segmentation techniques to link behavioural patterns to UX optimisation, particularly in railway contexts.

This highlights a methodological gap, as user-centred insights are not yet systematically integrated with data-driven passenger segmentation approaches. Consequently, despite the maturity of UX-related research and the continued relevance of transport system studies, their intersection, particularly through clustering-based analysis, remains underexplored. Therefore, these findings reinforce the need for a conceptual framework that integrates clustering techniques with user experience analysis, enabling more personalised, adaptive, and data-driven service design in long-distance railway systems.

### **5 Discussion**

#### **5.1 Fragmentation Between Clustering and UX in Railway Systems**

The findings from this study reveal a persistent gap between the technological sophistication of clustering-based segmentation and its application to user experience (UX) design in long-distance railway contexts. Although 218 of the 341 reviewed articles were successfully categorized into passenger-type clusters, very few explicitly linked these classifications to experiential personalization strategies. This disconnect suggests that although clustering is widely adopted in transport informatics (e.g., for travel time prediction or occupancy management), its outputs are rarely translated into actionable design principles for differentiated user engagement.

This aligns with critiques in human-centered mobility design, which note that data-driven models often remain system-centric rather than user-centric [11]. Current approaches to clustering in transport tend to emphasize optimization of routes, flows, or costs, rather than nuanced customization of service features aligned with specific passenger profiles.

#### **5.2 Thematic Silos in Literature**

The thematic analysis, based on co-word mapping, reveals four major thematic areas spanning different levels of development and relevance. The motor theme, characterised

by keywords such as user experience, vehicles, and urban transportation, indicates a well-developed and highly central research focus on integrating user-centred design within modern mobility systems.

In contrast, themes related to motor transport, roads and streets, and users' experiences are classified as basic themes, suggesting that although they are widely used and foundational to the field, they remain less conceptually developed. Meanwhile, transportation system, public transport, and travel behaviour appear in the emerging or declining quadrant, reflecting a transitional state in which traditional transport system research is either evolving towards more technology-driven approaches or losing prominence.

Despite the prominence of user experience as a central research theme, the integration of user-centred design with system-level transport optimisation remains limited. Studies focusing on UX tend to emphasise digital interaction and interface design, whereas research on public transport and travel behaviour often concentrates on operational efficiency and system performance. This indicates a form of theoretical and methodological fragmentation, in which connections between behavioural segmentation, system efficiency, and experiential design are not yet fully established.

Furthermore, although emerging research directions point towards increasingly intelligent and automated mobility systems, there remains limited discussion of how these developments will address diverse passenger needs, including accessibility, ageing populations, and digital inclusion. This gap highlights the need for integrative approaches that combine clustering-based behavioural analysis with user experience optimisation, particularly in railway contexts.

### **5.3 Implications for Theories of Future Transportation**

The findings can be situated within emerging frameworks of Mobility-as-a-Service (MaaS) and Post-Automation Public Transport, which advocate for modular, data-informed, and user-personalized systems. As MaaS evolves, long-distance railway systems will need to move beyond static service models and adopt adaptive infrastructures that reflect the diversity of passenger intentions, constraints, and values.

Passenger clustering can be instrumental in this shift. For instance:

- a. Routine Travelers profiles could inform scheduling algorithms tied to workforce flows.
- b. Family Travelers clusters may guide bundled service packages with gamified UX.
- c. Elderly and Special segments could drive innovation in inclusive design, aligning with universal access mandates.

To realize this potential, however, UX must be repositioned not as an interface layer but as an embedded logic of transport design, responsive to the psychological and behavioral diversity captured through clustering.

## **6 Conclusion**

This study examines the intersection of clustering techniques and user experience (UX) design in long-distance railway transport through a Rapid Literature Review (RLR) of

341 peer-reviewed articles published between 2019 and 2024. The findings reveal that although clustering methods are widely used for system optimization, their integration into UX-driven service design remains limited, highlighting a clear divide between technical and human-centered research. To address this gap, the study proposes a conceptual framework that links passenger clusters to key UX dimensions, such as comfort, accessibility, and digital interaction, to support personalized service strategies. This work contributes to the advancement of Mobility-as-a-Service (MaaS) and human-centered smart mobility by highlighting the role of behavioral analytics in enabling more adaptive, inclusive, and user-responsive railway systems.

This study is limited to a secondary analysis based on a literature review and does not include empirical validation using real passenger data or prototype testing. Future research should extend the proposed framework through empirical clustering using real-world passenger behavior datasets from railway operators, as well as through UX co-design workshops with distinct passenger groups. In addition, simulation or agent-based modelling can be employed to evaluate adaptive service configurations in real-time scenarios. Further studies are also needed to examine how UX personalization intersects with ethical considerations, including algorithmic fairness, accessibility equity, and data privacy in the context of public transportation.

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