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Assessing Performance at A Multimodal Interchange: A Case Study of New Delhi Railway Stations

May 2024

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A Case Study of New Delhi Railway Station

Master of Planning
(Transport Planning and Logistics Management)

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2022MPTPLM002

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Thesis Report

In the Partial fulfillment of the requirement for the Award of degree of

Master of Planning

(Transport Planning and Logistics Management)

By

Uzma Mekrani

2022MPTPLM002

Under the guidance of

Dr. Nikhil Ranjan Mandal

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May 2024

Declaration

I **Uzma Mekrani**, Scholar No. **2022MPTPLM002** hereby declare that the thesis titled **"Assessing Performance at Multimodal Interchange: A Case Study of New Delhi Railway Station"** submitted by me in partial fulfillment for the award of **Master of Planning**, at School of Planning and Architecture, Bhopal, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

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Signature of the Student

Date:

Certificate

This is to certify that the declaration of **Uzma Mekrani** is true to the best of my knowledge and that the student has worked under my guidance in preparing this thesis.

RECOMMENDED

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Signature of the Guide
Dr. Prof. Nikhil Ranjan Mandal

ACCEPTED

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Prof. Saurabh Popli
Head of Department of Transport Planning, Bhopal

May 2024

Acknowledgement

الحمد لله (Alhamdulillah), all praise and thanks are due to Allah (SWT), the Most Gracious, the Most Merciful, for His blessings, guidance, and strength throughout my Master's thesis journey.

The journey I have spent in Masters in Planning (transport Planning and Logistic Management), SPA, Bhopal. from August 2022 to May 2024 as a post graduate is a memorable one for me as it is rich in attaining knowledge and helped me discover my potential. I am indebted to all those who have contributed and made it possible for me.

I would like to express my sincere gratitude to my thesis Guide, Dr. Nikhil R. Mandal for their invaluable guidance, support, and encouragement throughout this research journey. Dr. Nikhil R. Mandal 's insightful feedback proved to be instrumental in shaping this research and keeping me motivated.

In addition, I would like to thank the following faculty members for their willingness to share their expertise and provide valuable insights during my research: Dr. Mayank Dubey, Dr. Mohit Dev and Adil Ata Azmi. Their guidance and comments were particularly helpful in refining my work.

I want to express my deepest appreciation to my friends and family, especially Suhail Masood, Shubhi Agarwal, Hiya Singh, and Elisha. Their unwavering support and encouragement throughout this challenging but rewarding experience were invaluable. I am particularly grateful to my parents Nadira Barmiki and Danish Mekrani and my sister Alfia for their constant belief in me. A special thanks to my aunt and uncle who helped me during my survey.

I would also like to acknowledge the support of my junior colleagues, Muskan Singh, Devanshi and Siddharth who provided valuable assistance Finally, I extend my heartfelt thanks to anyone who may have offered support or guidance during this journey, even if their names remain unmentioned. Your contributions, big or small, are deeply appreciated This thesis would not have been possible without the contributions of all these individuals. Thank you.

Uzma Mekrani

2022MPTPLM002

Abstract

Multimodal interchanges, where users seamlessly transition between different transportation modes, are fundamental to the efficiency of urban transportation systems. Optimizing the performance of these interchanges is crucial for enhancing the overall user experience and promoting a shift towards public transport, thus fostering more sustainable mobility patterns. New Delhi Railway Station (NDLS), a major multimodal interchange within Delhi's transport network, exhibits a concerning pattern: lower public transport ridership compared to other key interchanges in the city. This discrepancy indicates potential performance shortcomings that may stem from inadequate integration between regional and urban transport modes, accessibility issues within the interchange, or other operational inefficiencies.

This research delves into the factors influencing performance at NDLS, offering insights into how the interchange can be improved to increase user satisfaction, convenience, and public transport usage. Employing a mixed-methods approach, the study combines quantitative and qualitative data analysis for a comprehensive understanding. User surveys are designed to capture detailed insights into travel patterns, perceptions of the interchange's performance, and user priorities for improvement. Additionally, secondary data, including public transport schedules, demographic information, and existing ridership statistics provides a broader context for understanding operational patterns and potential bottlenecks.

A thorough literature review frames the study within current academic and practical knowledge on multimodal interchange performance evaluation. This was complemented by extensive site visits to NDLS, offering firsthand observations of operational challenges, wayfinding difficulties, and user interactions within the interchange environment. Statistical analysis, such as Kruskal-Walli’s test, is applied to assess potential differences in how various user groups perceive performance, helping to pinpoint specific needs and expectations based on demographics and travel characteristics. The Analytic Hierarchy Process (AHP) is employed to develop a robust performance index, systematically assigning weights to the identified factors. This index will enable performance quantification, aiding in

systematic evaluation and benchmarking of multimodal interchanges over time and across locations.

The study's findings pinpoint specific areas where NDLS falls short in terms of performance, offering evidence-based recommendations for improvement. By highlighting how perceptions of performance may vary based on demographics and travel behaviour, the research illuminates' opportunities for targeted enhancements that address diverse user needs. Furthermore, the developed performance index will provide transport planners, architects, designers, and stakeholders with a valuable tool for informed decision-making about resource allocation and strategic investments designed to enhance the interchange.

Keywords: Multimodal Transit Hubs (MMTHs), User Experience Optimization, Service Quality, Pedestrian Level of Service (PLOS), Walkability, Connectivity, Public Transport, Urban public transport, Regional public transport

सारांश

मल्टीमॉडल इंटरचेंज, जहां उपयोगकर्ता विभिन्न परिवहन साधनों के बीच निर्बाध रूप से संक्रमण करते हैं, शहरी परिवहन प्रणालियों की दक्षता के लिए मौलिक हैं। समग्र उपयोगकर्ता अनुभव को बढ़ाने और सार्वजनिक परिवहन की ओर बदलाव को बढ़ावा देने के लिए इन इंटरचेंजों के प्रदर्शन को अनुकूलित करना महत्वपूर्ण है, इस प्रकार अधिक टिकाऊ गतिशीलता पैटर्न को बढ़ावा मिलता है। नई दिल्ली रेलवे स्टेशन (एनडीएलएस), दिल्ली के परिवहन नेटवर्क के भीतर एक प्रमुख मल्टीमॉडल इंटरचेंज, एक चिंताजनक पैटर्न प्रदर्शित करता है: शहर में अन्य प्रमुख इंटरचेंजों की तुलना में कम सार्वजनिक परिवहन सवारियां। यह विसंगति संभावित प्रदर्शन कमियों को इंगित करती है जो क्षेत्रीय और शहरी परिवहन साधनों के बीच अपर्याप्त एकीकरण, इंटरचेंज के भीतर पहुंच संबंधी मुद्दों या अन्य परिचालन अक्षमताओं से उत्पन्न हो सकती है।

यह शोध एनडीएलएस में प्रदर्शन को प्रभावित करने वाले कारकों पर प्रकाश डालता है, यह अंतर्दृष्टि प्रदान करता है कि उपयोगकर्ता की संतुष्टि, सुविधा और सार्वजनिक परिवहन उपयोग को बढ़ाने के लिए इंटरचेंज को कैसे बेहतर बनाया जा सकता है। मिश्रित-तरीकों के दृष्टिकोण को नियोजित करते हुए, अध्ययन व्यापक समझ के लिए मात्रात्मक और गुणात्मक डेटा विश्लेषण को जोड़ता है। उपयोगकर्ता सर्वेक्षणों को यात्रा पैटर्न, इंटरचेंज के प्रदर्शन की धारणाओं और सुधार के लिए उपयोगकर्ता प्राथमिकताओं में विस्तृत अंतर्दृष्टि प्राप्त करने के लिए डिज़ाइन किया गया है। इसके अतिरिक्त, सार्वजनिक परिवहन कार्यक्रम, जनसांख्यिकीय जानकारी और मौजूदा सवारियों के आंकड़ों सहित द्वितीयक डेटा परिचालन पैटर्न और संभावित बाधाओं को समझने के लिए एक व्यापक संदर्भ प्रदान करता है।

एक संपूर्ण साहित्य समीक्षा मल्टीमॉडल इंटरचेंज प्रदर्शन मूल्यांकन पर वर्तमान शैक्षणिक और व्यावहारिक ज्ञान के भीतर अध्ययन को तैयार करती है। इसे एनडीएलएस की व्यापक साइट यात्राओं द्वारा पूरक किया गया था, जो परिचालन चुनौतियों, रास्ते खोजने की कठिनाइयों और इंटरचेंज वातावरण के भीतर उपयोगकर्ता इंटरैक्शन की प्रत्यक्ष टिप्पणियों की पेशकश करता था। सांख्यिकीय विश्लेषण, जैसे क्रुस्कल-वाल्ली का परीक्षण, विभिन्न उपयोगकर्ता समूहों के प्रदर्शन को समझने के तरीके में संभावित अंतर का आकलन करने के लिए लागू किया जाता है, जिससे जनसांख्यिकी और यात्रा विशेषताओं के आधार पर विशिष्ट आवश्यकताओं और अपेक्षाओं को इंगित करने में मदद मिलती है। विश्लेषणात्मक पदानुक्रम प्रक्रिया (एएचपी) को एक मजबूत प्रदर्शन सूचकांक विकसित करने के लिए नियोजित किया जाता है, जो पहचाने गए कारकों को व्यवस्थित रूप से महत्व देता है। यह सूचकांक समय के साथ और स्थानों पर मल्टीमॉडल इंटरचेंजों के व्यवस्थित मूल्यांकन और बेंचमार्किंग में सहायता, प्रदर्शन परिमाणीकरण को सक्षम करेगा।

अध्ययन के निष्कर्ष उन विशिष्ट क्षेत्रों को इंगित करते हैं जहां एनडीएलएस प्रदर्शन के मामले में कम पड़ता है, सुधार के लिए साक्ष्य-आधारित सिफारिशें पेश करता है। जनसांख्यिकी और यात्रा व्यवहार के आधार पर प्रदर्शन की धारणाएं कैसे भिन्न हो सकती हैं, इस पर प्रकाश डालते हुए, अनुसंधान लक्षित संवर्द्धन के अवसरों पर प्रकाश डालता है जो विविध उपयोगकर्ता आवश्यकताओं को संबोधित करते हैं। इसके अलावा, विकसित प्रदर्शन सूचकांक परिवहन योजनाकारों, वास्तुकारों, डिजाइनरों और हितधारकों को संसाधन आवंटन और इंटरचेंज को बढ़ाने के लिए डिज़ाइन किए गए रणनीतिक निवेश के बारे में सूचित निर्णय लेने के लिए एक मूल्यवान उपकरण प्रदान करेगा।

मुख्य शब्द: मल्टीमॉडल ट्रांजिट हब (एमएमटीएच), उपयोगकर्ता अनुभव अनुकूलन, सेवा गुणवत्ता, पैदल यात्री सेवा स्तर (पीएलओएस), चलने योग्यता, कनेक्टिविटी, सार्वजनिक परिवहन, शहरी सार्वजनिक परिवहन, क्षेत्रीय सार्वजनिक परिवहन

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Abbreviations

A&C - Accessibility & Connectivity

AS - Staff Assistance

CA - Comfort Areas

CT - Coordination

EOD - Ease of Direction/Wayfinding

ER - Efficiency & Reliability

FS - Frequency

IIC - Inclusive Info Communication

LOS - Level of Service

MMI - Multimodal Interchange

MMTH - Multimodal Transit Hub

PA - Passenger Amenities

PLOS - Pedestrian Level of Service

PT - Public Transport

QS - Quality of Walkway

RO - Retail Outlets

RTI - Real-time information

SS - Security

TB - Ticketing Booth

TD - Transfer Distance

UA - Accessibility

UE - User Experience (already defined)

UX - User Experience

WA - Waiting Areas

CHAPTER 1: INTRODUCTION

1 Background

1.1 The Challenges of Urbanization and the Need for Sustainable Mobility

The rapid pace of urbanization poses a significant challenge to transportation systems on a global scale. Uncontrolled urban growth and the phenomenon of urban sprawl have created a severe imbalance between transportation demand and supply, particularly in rapidly developing nations (Banister, 2005). This imbalance manifests in numerous problems that directly impact urban residents' lives, including worsening traffic congestion, environmental degradation in the form of air and noise pollution, and a decline in overall quality of life.

The ease of access to private vehicles has fueled a greater reliance on personal automobiles in many cities. While private vehicles offer convenience, their widespread use directly contributes to congestion issues and exacerbates environmental pollution (Rodrigue et al., 2013). To transition towards sustainable urban development, creating a shift away from personal vehicle reliance is critical.

1.2 Public Transport and Multimodal Interchanges: A Key Solution

Developing efficient and seamless public transportation systems is fundamental to addressing the challenges posed by rapid urbanization. Public transport, including diverse modes such as buses, trains, metros, and ferries, offers a viable alternative to private vehicles, with the potential to alleviate traffic congestion, improve air quality, and provide more equitable access to opportunities across urban areas (Litman, 2021). For public transport to become a truly attractive option, a focus on integration and ease of use is vital.

Multimodal interchanges (MMIs) are the backbone of integrated public transport networks. These strategically located hubs enable convenient transfers between different transport modes (Chowdhury & Ceder, 2016). A well-designed MMI significantly boosts the efficiency and attractiveness of the overall public transport system. By allowing passengers to seamlessly switch between regional rail networks, local bus services, metro lines, taxis, ride-hailing options, and even cycling and pedestrian infrastructure, MMIs encourage people to choose public transport over-relying on private vehicles.

1.3 The Importance of User Perceptions in Optimizing MMI Performance

Understanding how users experience and perceive MMIs is crucial for evaluating their performance and pinpointing areas for improvement. User perceptions directly shape decisions related to travel mode choice and play a significant role in determining the overall success of an interchange in promoting public transport use. It is important to acknowledge that user perceptions are multifaceted and influenced by an array of factors (de Oña et al., 2013).

Socio-demographic characteristics such as a person's age, gender, income level, physical abilities, and social background can affect how they perceive and experience an MMI. Similarly, travel habits, including trip purpose, the frequency of public transport use, and familiarity with the interchange, also influence an individual's expectations and priorities (Jain & Lyons, 2008). Recognizing the diverse needs and perspectives of different user groups is essential for designing inclusive and equitable transportation systems.

1.4 Introduction: The Case of New Delhi Railway Station (NDLS)

New Delhi Railway Station (NDLS) occupies a critical node within the transportation network of India's bustling capital city. As one of the country's busiest railway stations, NDLS functions as a major multimodal interchange, playing a vital role in both regional and urban mobility (Indian Railways, 2022). Its connections to the extensive Delhi Metro system, numerous local bus routes, taxis, and auto-rickshaws provide passengers with multiple options for continuing their journeys within and beyond the city limits. NDLS's strategic location and its role in connecting different modes of transport make it a central hub for millions of passengers every year.

1.5 Performance Challenges and the Need for Improvement

While NDLS serves a vital purpose, it faces several performance challenges that hinder its ability to serve as an effective multimodal interchange. A key issue lies in the relatively low public transport ridership at NDLS compared to other major interchanges in Delhi. This suggests potential shortcomings in the interchange's design, connectivity, or the overall experience it offers, which may discourage passengers from opting for public transport modes (Delhi Development Authority, 2021). Investigating the underlying reasons for this discrepancy is crucial for making NDLS a more user-friendly and efficient transportation hub.

1.6 Need of the study:

Addressing the performance challenges at NDLS is crucial for several reasons.

Optimizing Interchange Efficiency: Improving NDLS's performance will optimize the flow of passengers within the station and between various modes. This has the potential to reduce congestion, improve travel times, and enhance the overall efficiency of Delhi's transportation network.

Promoting Public Transport Use: Making NDLS a more user-friendly interchange will encourage and support public transport use. Seamless transfers, intuitive wayfinding, and a pleasant user experience all contribute to making public transport a more attractive choice for both residents and visitors to Delhi, contributing to a modal shift away from private vehicles.

Fostering Sustainable Urban Development: Increasing public transport ridership directly benefits the city's efforts towards sustainable urban development. Reducing reliance on private vehicles has the potential to alleviate traffic congestion and improve air quality, positively impacting the environment.

Creating a More Inclusive Transportation Hub: Addressing issues related to accessibility and safety at NDLS will create a more equitable and inclusive transportation hub, empowering individuals of all abilities and socioeconomic backgrounds to fully utilize the urban transport system.

1.7 Research Aim

Aim: To improve user experience at multimodal transit Interchange.

This thesis aims to investigate the factors influencing the performance of New Delhi Railway Station (NDLS) as a multimodal interchange, with a focus on the passenger experience and the interplay between regional and urban transport modes. The overarching goal is to provide insights that help improve the interchange's functionality, accessibility, and overall appeal, leading to increased public transport ridership and a more sustainable mobility pattern.

1.8 Objectives

- To:Identify various factors influencing user experience at multimodal interchange
- To: Assess Current Performance at Multimodal Interchange
- To: Create a comprehensive service quality index

- To: Develop recommendations for enhancing service quality at multimodal interchanges

1.9 Methodology

This study investigated the factors influencing user experience at multimodal transportation interchanges, with a specific focus on New Delhi Railway Station (NDLS). The methodology adopted a sequential, mixed-method approach, incorporating both quantitative and qualitative data collection and analysis techniques (ref Fig.2).

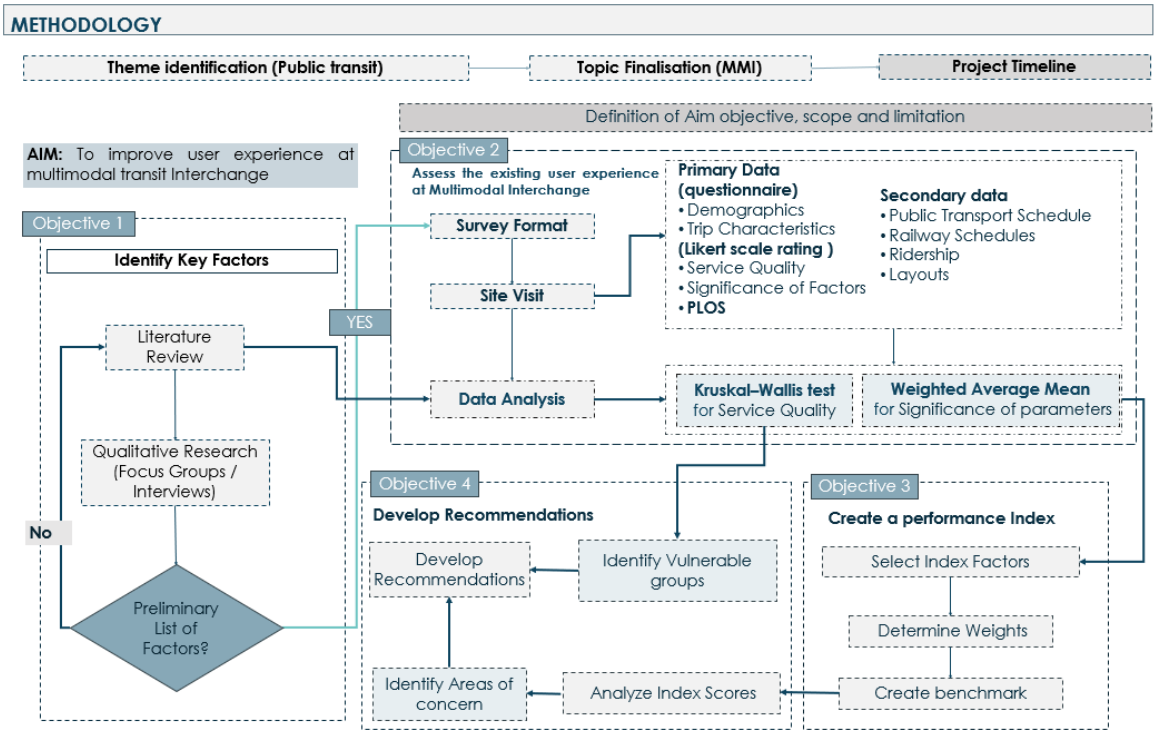


Figure 1-1 Detailed Methodology of the study

The primary aim of this study was to improve user experience at NDLS by determining the impact of multimodal interactions on passenger experience. To achieve this aim, the following research objectives were established:

Objective 1: Assess the Existing User Experience - This objective involved comprehensively evaluating how passengers perceived the current user experience at NDLS across various dimensions. Data collection methods targeted a representative sample of passengers with diverse travel characteristics and demographics.

Objective 2: Identify Key Factors - This objective aimed to pinpoint the critical factors shaping user experience at NDLS. A combination of literature review and data analysis was employed to identify these factors.

Objective 3: Develop a Performance Index - This objective focused on establishing a robust performance index to quantitatively assess user experience at NDLS. The index incorporated key factors identified in Objective 2 and enabled ongoing performance evaluation and comparisons.

Objective 4: Develop Recommendations - Based on the findings from the preceding objectives, this objective entailed formulating targeted recommendations for enhancing user experience at NDLS. These recommendations addressed critical areas for improvement across various aspects of the interchange's operations.

1.9.1 Data Collection

The data collection process for this study utilized a multi-pronged approach, leveraging both quantitative and qualitative methods to gain comprehensive insights into user experience at NDLS.

Literature Review - A thorough review of relevant academic literature and professional publications was conducted to explore existing knowledge on user experience in multimodal transportation interchanges. This review focused on factors influencing user experience, performance evaluation frameworks, and best practices in interchange design and operation.

Secondary Data Analysis - Existing data sources maintained by NDLS authorities and relevant government agencies were explored to gather secondary data on passenger ridership, demographics, travel patterns, and interchange layout.

Questionnaires - A structured questionnaire was developed to collect quantitative data on passenger perceptions of user experience at NDLS. The questionnaire targeted a representative sample of passengers encompassing a range of demographics and travel characteristics. The survey instrument incorporated Likert scale questions to gauge passenger satisfaction levels on various aspects of the interchange's operation. Additionally, the questionnaire included a section where passengers were asked to rank the relative importance of each parameter. This

ranking exercise aimed to capture how passengers prioritize various aspects of their experience at NDLS. The parameters included:

- Ease of Direction/ Wayfinding
- Availability of Signage
- Information Systems
- Universal Accessibility
- Restrooms
- F&B Options
- Retail Outlets & Luggage Storage Options
- Waiting Areas
- Schedule & Frequency Integration
- Transfer Efficiency
- Efficiency Ticketing
- Real-time information
- Security
- Staff Assistance
- Feedback Mechanism
- Inclusive Maps/layouts Availability

Videography for Pedestrian Counts - To assess pedestrian flow and identify potential bottlenecks within the interchange, video recordings were made at various locations within NDLS. Pedestrian volume counts were derived from these videos to determine the Pedestrian Level of Service (PLOS) across different interchange zones.

Data collection efforts adhered to ethical research protocols, ensuring informed consent from participants and maintaining the confidentiality of all collected data.

1.9.2 **Data Analysis**

Data collected through the aforementioned methods were subjected to rigorous analysis using appropriate quantitative and qualitative techniques.

Quantitative Data Analysis - Data collected through the questionnaire survey were analysed using statistical methods. Descriptive statistics were employed to summarize passenger demographics and travel characteristics. Likert scale

responses were analysed to determine central tendencies, dispersion, and potential correlations between user experience and various influencing factors.

Qualitative Data Analysis - Data obtained from focus groups and interviews were analysed thematically. A thematic analysis approach involved identifying, coding, and categorizing recurring themes within the collected qualitative data. This allowed for the development of a rich understanding of user experiences, challenges, and suggestions for improvement.

1.9.3 Development of Performance Index

Building upon the findings from the literature review, data analysis, and an understanding of best practices, a multimodal transport interchange performance index was developed for NDLS. This index served as a robust framework for comprehensively assessing user experience at the interchange. The performance index encompassed a balanced set of key factors derived from the literature review, secondary data analysis, and findings from the quantitative and qualitative data collection phases. These factors included elements such as:

- Accessibility & Connectivity
- Passenger Amenities
- Efficiency & Reliability
- User Experience

1.10 Significance of the Study

The findings of this study have the potential to make significant contributions to both theory and practice:

Theoretical Contribution: It expands the understanding of multimodal interchange performance evaluation and the factors influencing user experience. The development and application of a comprehensive performance evaluation framework will add to the existing body of knowledge in transportation planning and design.

Practical Implications: The findings will inform transportation planners, decision-makers, and operators, empowering them to make data-driven decisions about improvements to NDLS and potentially other multimodal interchanges within India and similar contexts. The recommendations will guide strategic interventions designed to enhance user experiences and encourage public transport use.

1.11 Scope of the study

This research primarily focuses on passenger movements and the critical interface between regional and urban transport modes at New Delhi Railway Station (NDLS). By examining factors influencing passenger experience and performance, the study aims to identify areas for improvement to enhance user satisfaction, convenience, and overall efficiency within the interchange. The specific goals of the research include:

Identifying key performance factors: Determining the primary elements that contribute to positive or negative passenger experiences within NDLS.

Assessing user perceptions: Evaluating how passengers with diverse demographics and travel patterns perceive the interchange's performance across identified factors.

Developing a performance index: Creating a robust framework to systematically quantify the performance of NDLS, enabling benchmarking and comparisons over time.

Proposing targeted recommendations: Providing evidence-based recommendations to improve physical infrastructure, operational aspects, and overall user experience at NDLS, promoting seamless passenger journeys.

1.12 Limitations

This research acknowledges the following limitations:

Freight Exclusion: While freight transport plays a vital role in multimodal transport networks, this study focuses specifically on passenger movements. The complexity of freight logistics and its unique requirements are beyond the scope of this research.

Data Constraints: The availability and quality of data on specific aspects of interchange operations may pose limitations. Data collection methods and the potential for biases will need to be carefully considered.

Generalizability: Findings derived from the specific case of NDLS may have limited generalizability to other interchanges with significantly different characteristics, scales, or operational models. It is essential to consider the unique context of NDLS when interpreting and applying the results..

CHAPTER 2 LITERATURE STUDY

2 Literature Review

The increasing complexity of urban environments and the growing demand for sustainable, efficient transportation solutions have changed the landscape of modern mobility. Multimodal transportation systems, strategically centered around multimodal interchanges (MMIs), offer a promising solution for reducing congestion, enhancing accessibility, and promoting environmentally friendly travel choices. This literature review examines the key performance indicators (KPIs) that shape the success of MMIs. It explores how elements like accessibility, user experience, operational efficiency, and the integration of pedestrian networks contribute to the overall effectiveness of these transportation hubs. Additionally, this review investigates how individual user characteristics, policy initiatives, and established standards influence the design and implementation of successful MMIs.

2.1 Transportation Systems: A Foundation for Urban Development

Efficient and well-functioning transportation systems are fundamental to the economic prosperity, social well-being, and environmental sustainability of modern cities. They play a critical role in facilitating the movement of people and goods, enabling access to jobs, education, healthcare, and other essential services (World Bank, 2020). As urban populations continue to grow globally, the demand for efficient and sustainable transportation solutions is ever-increasing.

2.2 Multimodal Transportation

In response to growing urban mobility challenges, transportation planners are increasingly turning to multimodal transportation systems. These systems integrate various transport modes, such as buses, trains, metros, cycling networks, and pedestrian pathways, to provide users with a wider range of travel options (Givoni & Chen, 2016). Multimodal transportation offers several advantages, including:

- **Reduced Traffic Congestion**: By encouraging a shift away from private vehicles, multimodal systems can help to alleviate traffic congestion and its associated negative impacts on air quality, noise pollution, and travel times (WRI, 2022).

- **Improved Accessibility:** Multimodal transportation can enhance accessibility for individuals who may not have access to a car, including those with disabilities, low-income residents, and seniors (Errampalli et al., 2018).
- **Environmental Sustainability:** By promoting the use of public transportation, cycling, and walking, multimodal systems can contribute to a reduction in greenhouse gas emissions and a more sustainable urban environment (Srivastava & Singh, 2019).

2.3 The Crucial Role of Multimodal Interchanges

A key component of effective multimodal transportation systems is multimodal interchanges (MMIs). These interchanges are designated locations where passengers can conveniently transfer between different modes of transport (Sarkar & Mallikarjun, 2018). The design, operation, and overall performance of MMIs significantly influence user experience, travel efficiency, and the overall attractiveness of multimodal travel.

2.4 Key Performance Indicators (KPI)

To optimize MMIs and maximize their benefits, it's crucial to understand and measure their performance across various dimensions. This literature review delves into the key performance indicators (KPIs) used to evaluate MMIs, examining how these indicators influence user perceptions and contribute to the

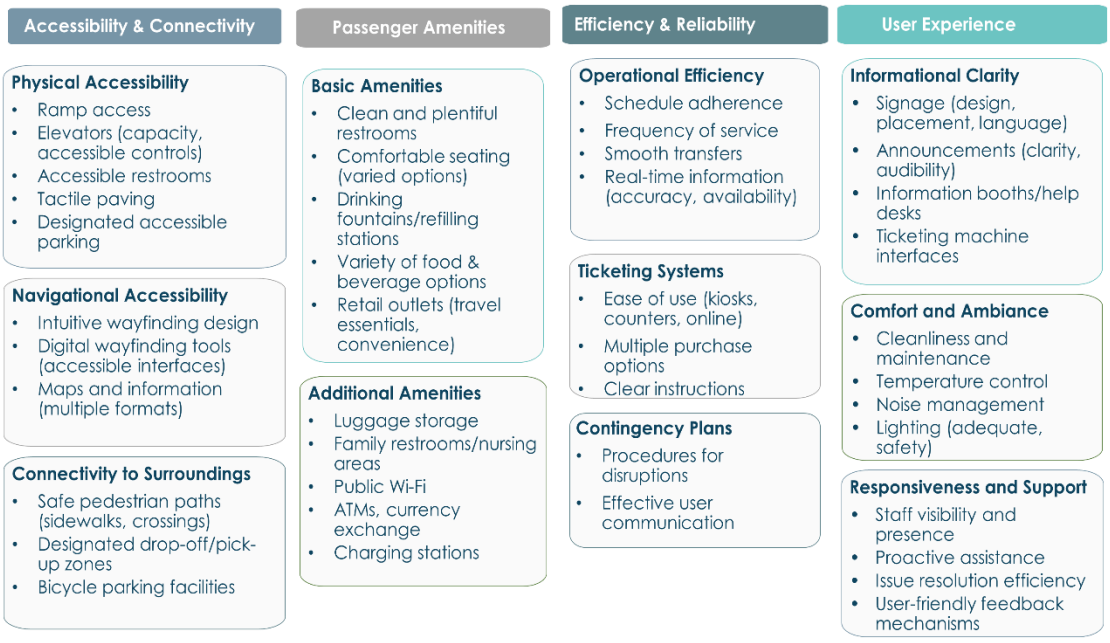


Figure 2-1 Performance Indicators

overall success of multimodal transportation systems. These KPIs can be broadly grouped into the following categories:

2.4.1 Accessibility & Connectivity:

In today's urban landscape, multimodal transit interchanges serve as vital hubs, connecting passengers seamlessly between various transportation modes. However, for these interchanges to reach their full potential and encourage ridership, accessibility and connectivity must be prioritized. This section delves into the critical parameters that contribute to an accessible and connected interchange experience, fostering a user-centric environment for all travelers.

Physical Accessibility

- Physical accessibility ensures that individuals with disabilities can navigate the interchange environment independently and with dignity. It transcends mere compliance with regulations and embodies the principle of universal design, catering to diverse mobility needs (Eboli & Mazzulla, 2007). Here's a closer look at the key elements that contribute to a physically accessible interchange:
- Ramp access: Well-maintained ramps with gentle gradients are crucial for connecting different levels within the interchange. These ramps should adhere to recommended width and handrail specifications to ensure effortless movement for wheelchairs, mobility scooters, and users with walking difficulties (American Association of State Highway and Transportation Officials [AASHTO], 2020).
- Elevators (capacity, accessible controls): Adequate numbers of elevators with sufficient capacity are essential to accommodate peak passenger flow, particularly during transfers between busy routes. Elevator doors should have extended opening times and accessible call buttons positioned at appropriate heights. Additionally, incorporating Braille or tactile signage and audible announcements for floor numbers fosters user independence for visually impaired individuals (Eboli & Mazzulla, 2007).
- Accessible restrooms: Restrooms designed with inclusivity in mind promote user comfort and dignity. Features like wider stalls with grab bars, lower sinks with knee clearance, and accessible toilet paper dispensers cater to

users with various mobility limitations. Additionally, providing adult-sized changing tables in designated family restrooms benefits travelers with young children or those requiring assistance (National Center for Universal Design in Housing [NCUDH], 2012).

- Tactile paving: Tactile paving with contrasting textures serves as a vital wayfinding tool for visually impaired users. Installed along pathways, these textured surfaces create a detectable difference underfoot, guiding users through the interchange environment (De Ona et al., 2012). International guidelines recommend specific surface textures and placement patterns to ensure optimal usability (International Organization for Standardization [ISO], 2009).
- Designated accessible parking: Close proximity parking spaces designated specifically for individuals with disabilities should be readily available throughout the interchange. These spaces should be clearly marked with the international symbol of access (ISA) and positioned within a reasonable walking distance of entrances and elevators to minimize inconvenience (Eboli & Mazzulla, 2007).
- Voice-activated information systems: These systems empower users to access real-time information on routes, gate locations, and amenities using voice commands, promoting user independence for individuals with visual impairments or limited dexterity (Allen et al., 2019).
- Real-time location tracking for wheelchairs and mobility scooters: Implementing a tracking system can provide staff with the ability to locate and assist wheelchair users or those requiring mobility assistance, particularly in case of emergencies (World Health Organization [WHO], 2005).

By incorporating these features, interchanges can become more inclusive and responsive to the diverse needs of their users.

Navigational Accessibility:

Navigational accessibility ensures that users can orient themselves and find their way around the interchange effortlessly, regardless of their familiarity with the

environment or their cognitive abilities (Hernandez & Monzon, 2016). This fosters a sense of control and reduces anxiety, particularly for first-time visitors or those with cognitive impairments. Here are key considerations for achieving navigational accessibility:

- Intuitive wayfinding design: The layout of the interchange should be clear and easy to understand, with a logical flow that minimizes backtracking and confusion. This includes strategically placed signage with clear directions, color-coding for different zones, and designated routes for specific passenger types (e.g., passengers with luggage, families with children) (Eboli & Mazzulla, 2007).
- Signage (design, placement, and language): Signage plays a critical role in user orientation. Signs should be large enough to be easily readable from a distance and positioned at appropriate eye levels to cater to users of varying heights. Using clear fonts, high-contrast colors, and pictograms alongside text can enhance comprehension for users with limited literacy or language proficiency (De Ona et al., 2012). Additionally, incorporating signage in multiple languages can cater to a diverse ridership base in globalized cities.
- Digital wayfinding tools (accessible interfaces): Interactive digital kiosks or maps with accessible interfaces empower users with real-time information on routes, gate locations, and amenities. These tools can be touch-operated or voice-activated, catering to users with varying technological literacy and physical abilities (Allen et al., 2019). For visually impaired users, integrating screen reader compatibility and audio descriptions of maps and routes ensures they can access information independently.
- Information provision: Providing information in a variety of formats fosters inclusivity and caters to users with diverse needs and preferences. This includes:
- Clear and concise signage: As discussed earlier, well-designed signage remains crucial.
- Digital maps with accessibility features: Interactive digital maps with features like zoom capabilities, text-to-speech functionality, and compatibility with screen readers empower users with visual impairments to navigate the interchange (Allen et al., 2019).
- Audio announcements: Clear and audible announcements in multiple languages provide real-time updates on gate changes, delays, and other important information. These announcements should be strategically placed throughout the

interchange and delivered at a moderate pace to allow for comprehension (De Ona et al., 2012).

- Staff training and assistance: A well-trained and approachable staff presence can significantly enhance navigational accessibility. Staff should be familiar with the layout of the interchange and able to provide clear directions and assistance to users who require it. Additionally, training staff in basic sign language skills can further improve communication with users who are deaf or hard of hearing (AASHTO, 2020).

Connectivity to Surroundings

Seamless connectivity between the interchange and surrounding areas plays a significant role in promoting multi-modal travel journeys and encouraging ridership. It creates a smooth transition between different modes of transportation, enhancing the overall travel experience (Eboli & Mazzulla, 2007). Key factors to consider for optimal connectivity include:

- Safe pedestrian paths (sidewalks, crossings): Well-maintained sidewalks with clear markings and accessible pedestrian crossings are crucial. These elements ensure safe and convenient movement for users entering or exiting the interchange on foot, promoting walking and active travel (De Ona et al., 2012). Additionally, incorporating features like lowered curbs and tactile warnings at pedestrian crossings further enhances accessibility for users with visual impairments.
- Designated drop-off/pick-up zones: Designated zones for dropping off or picking up passengers by car or ridesharing services help to reduce congestion and improve traffic flow around the interchange, creating a more organized and efficient environment (Eboli & Mazzulla, 2007). Signage and clear markings should readily identify these zones to avoid confusion and ensure smooth passenger pick-up and drop-off.
- Bicycle parking facilities: Secure and convenient bicycle parking facilities encourage cycling as a feeder mode to access the interchange. These facilities should be well-lit, monitored, and offer a variety of parking options, including racks for standard bicycles and secure lockers for e-bikes (Institute for Transportation & Development Policy [ITDP], 2020). Additionally, providing bicycle repair stations with basic tools empowers cyclists to address minor mechanical issues on the go.

- Public transport connections: Efficient and reliable connections to other public transportation modes, such as buses, trams, and metro lines, are crucial for seamless multi-modal travel. This can be achieved through:
- Integrated ticketing systems: A single ticketing system that allows users to pay for travel on various modes of transportation with one ticket reduces waiting times and simplifies transfers (Yen et al., 2018).
- Coordinated schedules: Timetables for different public transport modes should be synchronized to minimize waiting times at interchanges and ensure smooth connections between services.
- Mixed-use development: Developing mixed-use areas around interchanges creates vibrant communities and encourages walking and cycling. This can involve incorporating residential spaces, commercial establishments, and recreational areas within walking distance of the interchange (ITDP, 2020).
- Pedestrian-friendly infrastructure: Prioritizing pedestrian-friendly infrastructure in the surrounding areas, such as wide sidewalks, street trees, and public plazas, encourages walking and creates a more pleasant environment for users (ITDP, 2020).

2.4.2 **Passenger Amenities:**

Passenger amenities play a crucial role in shaping the user experience at multimodal transit interchanges. While the primary function of an interchange is to facilitate transfers between different modes of transportation, well-designed amenities can transform the waiting period into a more pleasant and productive experience. This section explores the various categories of passenger amenities and their significance in creating user-centric interchanges.

Basic amenities form the foundation of a comfortable and convenient interchange experience. These amenities ensure that passengers' fundamental needs are met, fostering a positive first impression and encouraging ridership.

- Clean and Plentiful Restrooms: Clean and well-maintained restrooms are essential for users traveling long distances or with young children. An adequate number of restrooms should be available throughout the interchange, catering to both genders and people with disabilities (Abreu e Silva & Bazrafshan, 2013). Universal design principles should be applied, incorporating features like grab bars in stalls, lower sink vanities, and

accessible signage in Braille and raised lettering. Additionally, providing family restrooms with designated diaper-changing stations and private spaces for breastfeeding demonstrates user consideration, particularly for families traveling with young children (Allen et al., 2020).

- Comfortable Seating (Varied Options): A variety of seating options caters to different user preferences and needs. This may include individual chairs with armrests for added comfort, benches with backrests for relaxation, and high-top seating for those who prefer to stand and work while waiting. Providing designated seating areas for families with children or elderly passengers demonstrates user consideration (Allen et al., 2020). Incorporating elements like built-in power outlets for laptops and mobile devices further enhances usability for passengers on the go.
- Drinking Fountains/Refilling Stations: Access to clean drinking water is essential, especially for travelers on long journeys. Incorporating readily accessible drinking fountains throughout the interchange allows users to stay hydrated conveniently. Additionally, installing water refilling stations encourages the use of reusable water bottles, promoting sustainability and reducing reliance on single-use plastics (Li et al., 2020).
- Variety of Food & Beverage Options: A variety of food and beverage options caters to diverse traveler preferences and dietary needs. This may include restaurants offering sit-down meals, cafes with grab-and-go options, convenience stores for quick purchases, and vending machines for snacks and drinks (Allen et al., 2019). The selection of food vendors should ideally reflect the local culture and offer healthy choices alongside indulgent options. For passengers with dietary restrictions, ensuring clear labeling and allergen information is crucial.

Additional amenities can elevate the user experience at interchanges and cater to a wider range of passenger needs. These amenities demonstrate a commitment to passenger comfort and convenience, fostering a more positive perception of the interchange as a destination in itself.

- Luggage Storage: Secure luggage storage facilities allow passengers to explore the surrounding area or run errands without having to worry about

their belongings (Li et al., 2020). This is particularly beneficial for travelers with long layovers or those who wish to explore the city before catching their connecting transport. Luggage storage options can range from coin-operated lockers to staffed cloakrooms, catering to different needs and budgets.

- Public Wi-Fi: Free and reliable public Wi-Fi access allows passengers to stay connected, work online, or access entertainment during their wait times (Lois et al., 2018). This is crucial in today's digital world, where staying connected is essential for many travelers. Offering high-speed Wi-Fi ensures a seamless online experience for passengers catching up on work emails, browsing the internet, or streaming media.
- ATMs, Currency Exchange: ATMs and currency exchange services provide users with convenient access to cash, particularly for international travelers (Lois et al., 2018). Strategically placed ATMs within the interchange ensure passengers can withdraw cash readily. Currency exchange services can be particularly helpful for travelers arriving from abroad, allowing them to convert their currency for local use.
- Charging Stations: Charging stations for mobile devices and laptops ensure passengers can stay connected and productive throughout their journey (Lee et al., 2013). These stations should be conveniently located throughout the interchange and offer compatibility with various device types. The integration of wireless charging pads can further enhance user convenience.
- Retail Outlets and Services: A curated selection of retail outlets and services can transform the interchange into a one-stop shop for travelers. This may include convenience stores for travel essentials, bookstores or newsstands for reading materials, and phone repair shops for unexpected technical difficulties (Li et al., 2020). Additionally, incorporating services like dry cleaners or shoe repair shops can cater to last-minute needs and enhance the overall user experience.
- Lost and Found Services: A dedicated lost and found service provides a central location for passengers to report lost items and potentially recover

them (Li et al., 2020). This fosters a sense of security and demonstrates a commitment to passenger well-being.

- Information Desk/Kiosks: A well-staffed information desk staffed with multilingual personnel can assist passengers with navigating the interchange, finding their connections, and obtaining information on local attractions or services (Allen et al., 2019). Interactive information kiosks with touchscreens or voice-activated interfaces offer a self-service option for passengers to access real-time information on schedules, gate locations, and amenities (Li et al., 2020). These kiosks should be accessible for users with disabilities, incorporating features like screen readers and audio descriptions.
- Passenger Assistance Services: For passengers with disabilities or those requiring additional assistance, dedicated services can ensure a smooth and stress-free travel experience. This may include:
- Mobility assistance: Staff trained to provide assistance to passengers with wheelchairs, mobility scooters, or other mobility needs (AASHTO, 2020).
- Visual and auditory assistance: Staff equipped to assist visually impaired or hearing-impaired passengers with navigation, information retrieval, and communication (AASHTO, 2020).
- Escort services: Escort services for unaccompanied minors or elderly passengers can provide peace of mind and ensure their safety while navigating the interchange (Li et al., 2020).

Creating a Welcoming and Engaging Environment

Beyond providing functional amenities, interchanges can further elevate the user experience by fostering a welcoming and engaging environment. This can be achieved through:

- Art and Architecture: Integrating art installations, sculptures, or architectural features can create a stimulating and visually appealing environment. Public art programs can showcase local talent and contribute to the cultural identity of the interchange (Li et al., 2020).

- Natural Elements: Incorporating natural elements like indoor plants, water features, or skylights can create a more calming and biophilic atmosphere. This can help reduce stress levels and enhance passenger well-being during their wait times (Li et al., 2020).
- Entertainment Options: A curated selection of entertainment options can help passengers pass the time during their wait. This may include:
- Play areas for children: Designated play areas with age-appropriate equipment can keep children occupied and entertained (Allen et al., 2020).
- Vending machines with games or interactive displays: Interactive vending machines or digital displays can offer passengers a fun and engaging way to pass the time (Li et al., 2020).
- Live music or performances: Scheduling occasional live music performances or artistic displays can create a more vibrant and engaging atmosphere within the interchange (Li et al., 2020).
- Cleanliness and Maintenance: A clean and well-maintained environment is essential for creating a positive user experience. Regular cleaning and maintenance ensure a hygienic and aesthetically pleasing space for passengers (Li et al., 2020).

Considering Sustainability

In today's environmentally conscious world, incorporating sustainable practices into passenger amenities demonstrates a commitment to environmental responsibility. This can be achieved through:

- Energy-efficient lighting and HVAC systems: Implementing energy-efficient lighting and heating, ventilation, and air conditioning (HVAC) systems reduces energy consumption and minimizes the environmental footprint of the interchange (Li et al., 2020).
- Recycling and waste reduction programs: Encouraging recycling through strategically placed bins and promoting waste reduction initiatives demonstrate environmental awareness and responsible resource management (Li et al., 2020).

- Sustainable building materials: Utilizing sustainable building materials during construction, such as recycled content or locally sourced materials, contributes to a more environmentally friendly infrastructure (Li et al., 2020).

2.4.3 **Efficiency and Reliability:**

Efficiency and reliability are fundamental aspects of successful multimodal transit interchanges. They directly influence user experience and ridership by ensuring timely transfers and minimizing disruptions. This section explores key operational factors that contribute to an efficient and reliable interchange environment, fostering a seamless travel experience for all users.

Schedule Adherence

Schedule adherence refers to the consistency of public transportation modes in maintaining their published timetables. It is a critical factor influencing overall trip predictability and reliability for interchange users (Transportation Research Board, 2018). Here's a breakdown of the elements that contribute to schedule adherence:

- Real-time information systems: Real-time information systems provide passengers with up-to-date arrival and departure times for connecting services. This empowers users to make informed decisions about their transfers and minimizes waiting times at the interchange (Gerrard & Turner, 2002).
- Infrastructure maintenance: Regular and proactive maintenance of infrastructure, including tracks, signals, and vehicles, helps to minimize delays caused by mechanical failures or unexpected disruptions (Transportation Research Board, 2018).
- Traffic management strategies: Implementing effective traffic management strategies in the vicinity of the interchange can help to reduce congestion and ensure smooth flow of incoming and outgoing traffic (Gerrard & Turner, 2002).
- Crew scheduling and training: Well-trained and adequately scheduled staff play a vital role in maintaining on-time performance. This includes dispatchers, drivers, and other personnel responsible for the operation of

various transportation modes serving the interchange (Transportation Research Board, 2018).

Frequency of Service

Frequency of service refers to the headway, or time interval, between consecutive departures of a particular public transport mode. A higher frequency translates to shorter waiting times for users and increased schedule flexibility (Gerrard & Turner, 2002). Here are some factors to consider:

- Demand-responsive scheduling: Incorporating demand-responsive scheduling strategies, particularly for less frequently used routes, can optimize resource allocation and reduce passenger wait times (Transportation Research Board, 2018).
- Network planning and coordination: Effective network planning and coordination between different transportation modes ensures timetables are synchronized, minimizing the need for long layovers at interchanges (Gerrard & Turner, 2002).
- Peak hour considerations: Increasing service frequency during peak hours can cater to higher passenger volumes and minimize overcrowding on platforms and waiting areas (Transportation Research Board, 2018).

Smooth Transfers

Smooth transfers minimize the time and hassle involved in changing between different public transportation modes at the interchange. This is crucial for maintaining passenger satisfaction and encouraging ridership (Gerrard & Turner, 2002). Here are some key aspects to consider:

- Clear signage and wayfinding: Clear and concise signage, coupled with digital information displays, should effectively guide users towards their connecting services (Gerrard & Turner, 2002). Information should be multilingual to cater to diverse ridership needs.
- Physical proximity of platforms: Designing the interchange layout with platforms for connecting services in close proximity minimizes walking distances and reduces transfer times for passengers (Transportation Research Board, 2018).

- Integration of ticketing systems: A unified ticketing system that allows users to pay for travel on various modes of transportation with a single ticket eliminates the need for separate purchases and reduces transfer wait times (Yen et al., 2018).

Contingency Plans

Even with robust planning and infrastructure, unforeseen disruptions can occur. Having well-defined contingency plans helps to minimize the impact of these disruptions on passenger journeys and ensures a swift return to normal operations (Gerrard & Turner, 2002). Here are factors to consider when creating contingency plans:

- Communication protocols: A clear communication strategy ensures timely and accurate information is disseminated to passengers regarding any disruptions or delays (Transportation Research Board, 2018). This can be achieved through public announcements, digital signage updates, and social media alerts.
- Alternative travel options: Providing alternative travel options, such as shuttle services or rerouting information, can help passengers reach their destinations in case of service disruptions on specific routes (Gerrard & Turner, 2002).
- Staff training for emergencies: Staff should be adequately trained to handle emergency situations and provide assistance to passengers during disruptions (Transportation Research Board, 2018).

Performance Measurement

Continuously monitoring and measuring performance metrics is crucial for identifying areas for improvement and ensuring the long-term efficiency and reliability of the interchange. Here are some key performance indicators (KPIs) to track:

- On-time performance: Tracking the percentage of public transportation services arriving and departing according to schedule provides valuable insights into system reliability (Transportation Research Board, 2018).

- Passenger wait times: Monitoring average passenger wait times at platforms and for connecting services helps to identify bottlenecks and areas for improvement (Gerrard & Turner, 2002).
- Customer satisfaction surveys: Regularly conducting customer satisfaction surveys allows passengers to voice their feedback on the efficiency and reliability of the interchange (Transportation Research Board, 2018).
- Number of complaints: Tracking the number of complaints received regarding delays, missed connections, or other service disruptions helps to identify recurring issues (Transportation Research Board, 2018).

By analyzing these KPIs, interchange authorities can make data-driven decisions to optimize operations, improve schedule adherence, and minimize wait times. This continuous improvement process fosters a more efficient and reliable interchange environment, ultimately enhancing the user experience for all passengers.

Technological Advancements

Technological advancements offer exciting opportunities to further enhance efficiency and reliability at multimodal transit interchanges. Here are some promising applications:

- Real-time arrival and departure information: Leveraging real-time data and machine learning algorithms can provide passengers with highly accurate arrival and departure predictions, minimizing wait times and anxiety (Transportation Research Board, 2018).
- Automated ticketing systems: Implementing automated ticketing systems with contactless payment options can significantly reduce wait times at ticket booths and streamline the boarding process (Transportation Research Board, 2018).
- Dynamic route planning: Integrating real-time traffic and service information into mobile apps can empower users to plan their journeys dynamically, considering potential delays and suggesting alternative routes or modes of transportation (Gerrard & Turner, 2002).

2.4.4 User Experience

User experience (UX) sits at the heart of successful multimodal transit interchanges. By prioritizing the needs and expectations of passengers throughout their journey, interchanges can transform into user-centric spaces that foster ridership, promote sustainable travel choices, and contribute to the vibrancy of urban environments. This section delves into the various elements that contribute to a positive UX at multimodal transit interchanges.

Informational Clarity

- Signage (design, placement, language): Clear and concise signage is the foundation of a user-friendly interchange. Signage should be designed with the following principles in mind:
- Clarity: Simple, easy-to-understand language and universally recognizable symbols are essential (International Organization for Standardization [ISO], 2009). Avoid jargon and technical terms that may confuse passengers unfamiliar with the interchange.
- High contrast and legibility: Signage should have a high contrast ratio between text and background for optimal readability, even in low-light conditions. Utilize large fonts and clear lettering to ensure legibility from a distance (National Center for Universal Design in Housing [NCUDH], 2012).
- Logical placement: Strategically placed signage throughout the interchange ensures passengers can easily find their way to platforms, exits, amenities, and information booths. A hierarchical approach, with main directional signs followed by more specific ones, can guide users progressively (De Ona et al., 2012).
- Multilingual options: Catering to diverse ridership needs, particularly in areas with high tourist volumes, necessitates multilingual signage. A combination of pictograms and translated text can ensure clear communication across languages (De Ona et al., 2012).
- Announcements (clarity, audibility): Clear and audible announcements regarding arrivals, departures, gate changes, and other important

information are crucial for keeping passengers informed (De Ona et al., 2012). Announcements should be:

- Concise and well-articulated: Avoid overly long or complex announcements. Deliver information in a clear and concise manner, ensuring easy comprehension.
- Regularly scheduled: Provide frequent updates, particularly during peak hours or when there are schedule changes or disruptions.
- Multilingual: Consider pre-recorded announcements in multiple languages or a system with real-time translation options to cater to diverse passenger needs (De Ona et al., 2012).
- Audible in ambient noise: Adjust announcement volume to ensure they are audible over background noise levels within the interchange (World Health Organization [WHO], 2005).
- Information booths/help desks: Staffed information booths or readily available help desks with multilingual personnel provide a human touch and personalized assistance to passengers (Allen et al., 2019). These resources can be particularly helpful for those unfamiliar with the interchange layout, ticketing systems, or surrounding area.
- Digital information displays: Interactive digital information displays with touchscreens or voice-activated interfaces offer a self-service option for passengers to access real-time information on schedules, gate locations, amenities, and nearby points of interest (Li et al., 2020). These displays should be:
- User-friendly interface: An intuitive and user-friendly interface with clear menus and navigation options is essential for users with varying technological literacy (Allen et al., 2020).
- Accessibility features: Incorporate accessibility features such as screen reader compatibility and audio descriptions for visually impaired users (Allen et al., 2020).

Comfort and Ambiance

- Cleanliness and maintenance: A clean and well-maintained environment is essential for creating a positive user experience (Li et al., 2020). Regular cleaning and maintenance ensure a hygienic and aesthetically pleasing space for passengers. This includes restrooms, waiting areas, platforms, and all common areas within the interchange.
- Temperature control: Maintaining a comfortable temperature throughout the interchange is crucial for passenger comfort (Li et al., 2020). This can be achieved through a combination of heating, ventilation, and air conditioning (HVAC) systems that are energy-efficient and environmentally conscious. Consider incorporating natural ventilation strategies where possible to supplement climate control systems.
- Seating options: A variety of seating options caters to different user preferences and needs. This may include individual chairs with armrests for added comfort, benches with backrests for relaxation, and high-top seating for those who prefer to stand and work while waiting (Allen et al., 2020). Providing designated seating areas for families with children or elderly passengers demonstrates user consideration. Incorporating elements like built-in power outlets for laptops and mobile devices further enhances usability for passengers on the go.
- Lighting design: Well-designed lighting plays a significant role in creating a welcoming and comfortable ambiance (Li et al., 2020). A balance between natural and artificial light is ideal, with adjustable lighting controls allowing passengers to personalize their environment. Avoid harsh glare and ensure adequate lighting levels for reading, using mobile devices, or navigating the interchange safely.
- Noise control: Managing noise levels within the interchange contributes to a more relaxing and enjoyable user experience (Eboli & Mazzulla, 2007). This can be achieved through sound-absorbing materials like acoustic panels on ceilings and walls. Strategic placement of plants and greenery can also help to reduce noise pollution.
- Aesthetics and wayfinding: The overall aesthetics of the interchange, including architecture, artwork, and public art installations, can contribute to

a visually appealing and stimulating environment (Li et al., 2020). Incorporating elements that reflect the local culture or history can create a sense of place and identity for the interchange. Furthermore, ensure that the aesthetic design principles complement the wayfinding system, ensuring a visually cohesive and user-friendly experience.

Responsiveness and Support

- Staff training: Staff at the interchange, including customer service representatives, security personnel, and maintenance crew, should be well-trained and equipped to address passenger needs effectively (Allen et al., 2019). Training should cover areas such as:
- Customer service: Delivering exceptional customer service involves clear communication, courtesy, and a willingness to assist passengers with inquiries and concerns.
- Accessibility awareness: Staff should be trained to understand and address the needs of passengers with disabilities, ensuring a seamless and inclusive travel experience (AASHTO, 2020).
- Emergency response procedures: Staff should be prepared to handle emergencies efficiently, prioritizing passenger safety and providing clear instructions in case of unforeseen disruptions.
- Lost and found services: A dedicated lost and found service provides a central location for passengers to report lost items and potentially recover them (Li et al., 2020). This fosters a sense of security and demonstrates a commitment to passenger well-being.
- Feedback mechanisms: Providing accessible and user-friendly feedback mechanisms, such as comment boxes, online surveys, or mobile app integration, allows passengers to voice their opinions and suggestions regarding the interchange (Allen et al., 2019). Encouraging feedback demonstrates a commitment to continuous improvement and allows interchange authorities to identify areas for enhancement in terms of user experience.

A Holistic Approach to User Experience

A successful user experience at a multimodal transit interchange requires a holistic approach that considers all the elements discussed above. Here are some key takeaways:

- User-centered design: Throughout the planning, design, and operational phases, prioritize the needs and expectations of passengers. Conduct user research, gather feedback, and involve stakeholders to ensure the interchange caters to diverse user groups.
- Integration and cohesion: Ensure all elements of the interchange, from signage and information systems to amenities and staff interaction, function seamlessly together to create a cohesive user experience.
- Continuous improvement: Regularly assess user experience through surveys, feedback mechanisms, and observation. Utilize data and feedback to identify areas for improvement and implement changes that enhance user satisfaction.
- By adopting a user-centric approach and fostering a culture of continuous improvement, interchanges can create a positive and memorable experience for all passengers. This, in turn, can lead to increased ridership, reduced reliance on private vehicles, and a more sustainable and efficient urban transport network.

2.4.5 **Demographics**

Age, gender, income, education level, and disability status can influence travel needs, priorities, and expectations for MMIs (Chauhan et al., 2023; Errampalli et al., 2018).

- **Age:** Older adults often place a higher value on accessibility features such as ramps, elevators, ample seating, clear signage, and well-lit spaces, as these factors directly impact ease of navigation and physical comfort (Chauhan et al., 2023; Errampalli et al., 2018). Younger users may focus on amenities that support their technology-integrated lifestyles, such as Wi-Fi availability, charging stations, or F&B options (Chauhan et al., 2023).
- **Gender:** Women tend to prioritize safety and security within MMIs. Incorporating design elements like visible security personnel, emergency call

boxes, well-maintained facilities, and ample lighting throughout the interchange can significantly enhance the overall user experience for women (Kim et al., 2018). Additionally, the MMI's design can adopt gender-inclusive principles to make the space welcoming and safe for all users.

- **Income and Education Level**: Socioeconomic status can influence expectations about MMIs. Users with lower incomes may place greater importance on affordable transportation options and integrated ticketing systems for accessibility (Errampalli et. al, 2018). Clear, multilingual signage and the availability of staff to aid are especially important for users with various education levels, ensuring that everyone can navigate the interchange with confidence (Li & Loo, 2016).
- **Disability Status:** Accessibility is of utmost importance for users with disabilities. Features such as accessible restrooms, ramps, elevators, tactile paving, priority seating, and adherence to universal design principles are crucial for creating inclusive MMIs that accommodate individuals with a wide range of mobility needs (Errampalli et al., 2018; Li & Loo 2016).

2.4.6 Travel Characteristics**:**

Trip purpose, travel frequency, familiarity with the interchange, and luggage can impact how users navigate and utilize the facilities within the MMI (Chauhan et al., 2023).

- **Trip Purpose:** The purpose of a user's journey through an MMI influences their priorities. Commuters often place a high value on reliable service, real-time information, and efficient transfers to ensure timely arrivals and minimize disruptions to their schedules (Zuniga-Garcia et al., 2018). Leisure travelers, on the other hand, may prioritize comfort-focused amenities like ample seating, varied F&B options, or retail outlets to pass time during longer waits or unexpected connections (Chauhan et al., 2023).
- **Travel Frequency and Familiarity**: Frequent users of an MMI become familiar with its layout and tend to place greater emphasis on operational efficiency and real-time information, particularly during unexpected service disruptions. First-time users often benefit significantly from intuitive wayfinding systems, clear

and multilingual signage, and helpful staff who can provide guidance (Li & Loo, 2016; Chauhan et al. 2023).

- **Luggage:** Travelers with bulky luggage or multiple bags place a premium on ample space to maneuver, elevators or escalators as alternatives to stairs, and secure luggage storage facilities for the freedom to explore hands-free (Li & Loo, 2016).

2.4.7 Walking Accessibility for Multimodal Interchanges

To promote sustainable transportation practices and seamless connectivity within multimodal interchanges (MMIs), a strong emphasis on walkability is crucial. Bivina et al. (2019), in their study on Delhi's metro stations, highlight the intricate relationship between the built environment, individual socioeconomic characteristics, perceptions of safety, and the likelihood of accessing the MMI on foot. Key takeaways from their research include:

- **Safety and Security:** Well-lit walkways, safe crossings, traffic calming measures, and a visible security presence significantly enhance perceived safety and motivate people to walk to and from the MMI. These elements are particularly important for encouraging women, children, and seniors to utilize pedestrian routes confidently.
- **Built Environment: Micro and Meso Scales**: Both the immediate surroundings of the MMI (micro-scale) and the broader neighborhood context (meso-scale) play crucial roles. Sidewalk quality, street lighting, clear signage, shading, and the presence of street vendors or other activities all influence walkability. Urban planners must consider these aspects holistically for seamless pedestrian access.
- **Individual Perceptions**: While infrastructure is essential, so too is addressing individual perceptions of safety and comfort. Socioeconomic characteristics and prior experiences within urban environments may influence how likely an individual is to consider walking as a viable mode for accessing the MMI.
- Quantifying Pedestrian Experience: To design MMIs that prioritize pedestrians, it's vital to utilize standards and conduct assessments that

measure the Pedestrian Level of Service (PLOS). Here's how these tools empower evidence-based decisions:

- **Guidelines & Manuals**: Documents like the Highway Capacity Manual (HCM), the Indian Roads Congress (IRC) Guidelines for Pedestrian Facilities, and international best practices offer a blueprint for designing safe, accessible, and comfortable pedestrian infrastructure. These standards specify elements like sidewalk widths, crossing design, lighting requirements, and traffic signal timing to optimize pedestrian flow and prioritize safety.
- **PLOS Assessment:** PLOS utilizes a standardized scale (typically A thr ough F) to quantify the quality of pedestrian experience. It considers factors such as pedestrian density, conflicts with vehicles, walkway obstructions, perceived comfort, and safety. By conducting PLOS assessments before and after changes to an MMI and its surrounding infrastructure, planners can identify potential barriers and measure the success of their interventions.
- **Addressing Gaps & Prioritizing Improvements:** Standards and PLOS assessments help illuminate areas where MMIs might fall short in accommodating pedestrians. This data-driven approach allows for targeted interventions to prioritize accessibility upgrades, enhance connectivity with surrounding residential or commercial hubs, and create an environment that encourages more people to choose walking as their preferred mode to access the MMI.
- By emphasizing walkability, integrating standards, and utilizing PLOS as a performance metric, MMIs can become true catalysts for sustainable transportation, fostering healthy, inclusive, and resilient multimodal networks.

2.5 Defining Pedestrian Level of Service

PLOS is a standardized measure of how pedestrians perceive the quality of infrastructure and their overall walking environment. It typically uses a letter-based scale (A to F, with A representing optimal conditions) to quantify factors such as

pedestrian comfort, safety, delays, and freedom of movement (Transportation Research Board, 2016).

2.5.1 Key resources for PLOS methodologies include:

Highway Capacity Manual (HCM): Provides widely recognized LOS criteria for pedestrian facilities, incorporating space, speed, and flow rates (Transportation Research Board, 2016).

Indo-HCM: Offers India-specific adaptations of HCM methods, accounting for mixed traffic conditions and pedestrian behavior in Indian cities (CSIR-Central Road Research Institute, 2017).

2.5.2 Factors Affecting PLOS

PLOS is influenced by a complex interplay of physical, operational, and perceptual characteristics of the built environment:

Physical Infrastructure:

Sidewalks: Width, surface quality, continuity, buffers from traffic, presence of obstructions (Kim et al., 2018).

Crossings: Type (signalized, mid-block), visibility, markings, safety features (medians, raised crosswalks) (Bivina et al., 2020)

Lighting: Adequate illumination for safety and visibility at night.

Amenities: Seating, shade trees, public restrooms.

2.5.3 Operational Characteristics:

Pedestrian Volumes: Density, flow rates, potential for crowding, particularly during peak MMI usage hours.

Traffic Characteristics: Speed limits, traffic volumes, conflicts with vehicles and cyclists (Kim et al., 2018).

Transit Interface: Efficient layout of bus stops, ride-share zones, integration with pedestrian pathways.

2.5.4 Perceived Qualities:

Safety and Security: Presence of security personnel, well-lit areas, crime statistics (particularly impactful for women, the elderly, and solo travelers) (Kim et al., 2018).

Aesthetics: Attractive landscaping, architectural design, cleanliness and maintenance (Li & Loo, 2016).

Wayfinding: Clear signage, visual cues, ease of navigation, especially within complex MMIs.

2.5.5 . PLOS Assessment Methodologies

A mixture of quantitative and qualitative methods provides the most comprehensive picture of the pedestrian experience:

Quantitative Approaches:

HCM & Indo-HCM: Utilize formulas factoring in pedestrian space, walking speeds, flow rates, and delays to calculate a PLOS score (A-F) (Transportation Research Board, 2016; CSIR-Central Road Research Institute, 2017).

Pedestrian Volume Counts: Data collection using video analysis, manual counts, or sensors provides essential input for calculating PLOS and identifying high-traffic areas.

Qualitative Approaches:

User Surveys and Interviews: Capture subjective perceptions of safety, comfort, convenience, and overall satisfaction with pedestrian facilities around MMIs (Bivina et al., 2020; Li & Loo, 2016).

Observations: Systematic observations of pedestrian behavior, conflicts, and bottlenecks helps identify specific pain points and areas for improvement.

2.5.6 The Unique Challenges of PLOS within MMIs

MMIs must address particular complexities to maintain high PLOS standards:

Managing Peak Flows: MMIs experience surges in pedestrian traffic during commute hours. Infrastructure must accommodate large volumes without compromising comfort or safety (Kim et al., 2018).

Internal Navigation: Multi-level layouts, escalators, ramps, and transfer points require careful design and signage to ensure accessibility for all and minimize crowding (Li & Loo, 2016).

Integration with Surrounding Networks: PLOS depends on connectivity with feeder routes. Abrupt transitions between MMI facilities and poorly maintained external sidewalks discourage walking access.

Diverse User Needs: MMIs serve a wide range of demographics, and PLOS assessments must address the needs of the elderly, visually impaired individuals, persons with physical disabilities, and those with luggage or strollers (Li and Loo, 2016).

2.5.7 Capacity Analysis for Optimized Pedestrian Experiences

Highway Capacity Manuals (both the international HCM and the India-specific Indo-HCM) provide vital tools for capacity assessment and pedestrian-centric traffic flow modelling:

Understanding Pedestrian Behaviour: Metrics like critical gaps and waiting times guide the design of safe intersections and crosswalks, minimizing pedestrian delay and enhancing overall experience.

Pedestrian Flow Modelling: Analysis tools aid planners in identifying potential bottlenecks and designing facilities that can seamlessly accommodate peak pedestrian traffic volumes.

2.6 Standards And Codes

Multimodal transportation hubs (MMTHs) are essential for integrated transportation systems, promoting seamless transitions between diverse modes. To maximize their efficiency, safety, and user-friendliness, it's crucial to adhere to a robust framework of standards, codes, and guidelines. This literature review explores several key documents influencing multimodal hub development:

Highway Capacity Manuals (HCM, Indo-HCM): Tools for capacity analysis and traffic flow modelling.

- Indian Road Congress (IRC) Guidelines: Emphasis on pedestrian facilities and traffic management.
- National Urban Transport Policy (NUTP) 2014: A holistic approach to sustainable urban mobility.
- Multimodal Transport Hubs: Good Practice Guidelines: International best practices and insights.

Well-defined standards and guidelines establish a common foundation for planning, design, and management of multimodal hubs. They offer a range of benefits, including:

Enhanced Safety: Prioritizing safety features for pedestrians, cyclists, and passengers through design specifications for crosswalks, signage, lighting, and waiting areas.

Improved Efficiency: Optimizing traffic flow, transport integration, and hub operations using evidence-based capacity analysis methodologies.

Universal Accessibility: Designing for inclusion, adhering to accessibility norms, and ensuring facilities are user-friendly for individuals with disabilities, seniors, and families.

Environmental Sustainability: Integrating sustainable design principles to promote greener transport modes and reduce carbon footprints.

Aesthetics and Urban Integration: Creating aesthetically pleasing hubs that harmonize with the surrounding urban fabric and contribute positively to the city's image. Sustainable urban mobility depends on designing environments that prioritize safe, accessible, and comfortable pedestrian movement. Pedestrian Level of Service (PLOS) is a performance metric that encapsulates the quality of the walking experience. MMIs must prioritize PLOS, aiming to create seamless connections between pedestrian networks and various transportation modes. This review explores PLOS definitions, assessment methods, influencing factors, and strategies for optimizing PLOS within the MMI context.

2.6.1 **IRC 103-2012 (Pedestrian Facilities)**

Comprehensive guidance on the design of sidewalks, crosswalks, overbridges, underpasses, and other vital pedestrian infrastructure elements, promoting safety, accessibility, and inclusivity.

2.6.2 **Indo-HCM 2017: Pedestrian Volumes and Multimodal Concerns**

- The Indo-HCM provides valuable insights for addressing pedestrian volumes and multimodal transit hubs in the Indian context. It stresses the importance of:
- Pedestrian Critical Gap & Waiting Time: Understanding these factors are crucial for designing safe and efficient crosswalks.

- **Pedestrian Flow Modelling**: Analysing pedestrian movements and patterns to optimize infrastructure and accommodate varying volumes.
- PLOS for Multimodal Hubs: Using standardized metrics to assess the quality of service for pedestrians, ensuring facilities are designed with their needs at the forefront.

2.7 Policy and Scheme

- **National Urban Transport Policy (NUTP) 2006:** While not explicitly focused on MMIs, the NUTP 2006 underpins modern urban mobility in India. Its emphasis on prioritizing pedestrians, cyclists, and integrated public transport systems lays the groundwork for people-centric MMIs (Ministry of Urban Development, 2006).
- **Guidelines for Multimodal Integration:** Issued by the Ministry of Housing and Urban Affairs, these guidelines offer a detailed framework for planning, design, and management of MMIs. They address pedestrian connectivity, accessible infrastructure, multimodal transport integration, and operational aspects of interchanges (Ministry of Housing and Urban Affairs, 2023).
- **Transit-Oriented Development (TOD) Policy:** TOD plays a synergistic role for MMI success. Policies promoting mixed-use, high-density development around transit hubs support walking, cycling, and the use of public transport to access MMIs (Ahluwalia et al., 2021; National Institute of Urban Affairs, 2014)
- **Jawaharlal Nehru National Urban Renewal Mission (JNNURM):** This mission provided financing for numerous MMI projects and infrastructure improvements emphasizing multimodal connectivity (Government of India, n.d.).
- **Ministry of Railways Station Redevelopment:** This ongoing program aims to modernize major Indian railway stations into multimodal hubs, incorporating improved access, public transport integration, and commercial zones (Press Information Bureau, 2022).
- **Smart Cities Mission:** Sustainable mobility is a key goal of this mission. Many Smart Cities projects involve upgrading MMIs to include pedestrian-focused

improvements, technological enhancements, and better connectivity with various transport modes (Ministry of Housing and Urban Affairs, n.d.).

2.8 Seamless Integration of Transport Modes

To achieve truly sustainable and efficient mobility, various modes of transport must work harmoniously. Givoni and Chen (2016) examine the concept of air-rail integration, using the Shanghai Hongqiao Integrated Transport Hub in China as a case study. Despite the potential advantages, widespread implementation of such integrated hubs remains a challenge. China, facing a surge in demand for transportation services, serves as a prime example of a nation actively pursuing air-rail integration models to enhance connectivity. By analyzing the supply and demand dynamics of the Shanghai Hongqiao Hub, valuable insights emerge on policy recommendations to optimize this integration and promote sustainable multi-modal travel options.

Srivastava & Singh (2019) focus on the intersection of public transportation modes within urban environments. They stress the need to design intermodal and multimodal transportation networks, incorporating metro rails, bus rapid transit systems, monorails, and other modes, to tackle traffic congestion and improve overall efficiency. Their research underlines the importance of understanding traffic patterns, particularly at intersections, to ensure seamless traffic flow and address bottlenecks. Traffic homogeneity analysis emerges as a promising tool to assess the resilience of road segments within the network and guide interventions for greater flexibility and robustness.

2.9 Scenario of Multimodal Transit Hubs in India

The Indian government is investing heavily in multimodal transit hubs (MTHs), with plans to construct 500 new MTHs in addition to the 100 that already exist (Ministry of Housing and Urban Affairs, 2023). This significant investment is expected to have a major impact on transportation in India.

MTHs are transportation centers that connect multiple modes of transportation, such as buses, trains, and metros (National Institute of Urban Affairs, 2019). They can also include other amenities, such as shopping malls, restaurants, and hotels. MTHs are designed to make it easier and more convenient for people to travel, and they can also help to reduce congestion and pollution.

A study by the World Resources Institute (WRI, 2022) found that MTHs have the potential to reduce travel time by up to 30% and greenhouse gas emissions by up to 20%. Some of the benefits of MTHs include:

Reduced travel time: MTHs can save people time by providing a single location where they can transfer between different modes of transportation. This can eliminate the need to make multiple transfers or travel long distances between different transportation hubs.

Reduced congestion: MTHs can help to reduce congestion by providing a centralized location where people can travel to and from. This can help to reduce traffic on roads and highways, making it easier and faster for people to get around.

Reduced pollution: MTHs can help to reduce pollution by encouraging people to use public transportation and other sustainable modes of transportation. This can improve air quality and reduce greenhouse gas emissions.

Improved accessibility: MTHs can make transportation more accessible for people with disabilities and other groups with mobility challenges. By providing a single location where people can access different modes of transportation, MTHs can make it easier for everyone to get around.

The largest MTH in India is the Anand Vihar Transit Hub in Delhi. Other notable MTHs in India include the Sarai Kale Khan Area MTH in Delhi, the Kempegowda International Airport MTH in Bengaluru, the Lokmanya Tilak Terminus MTH in Mumbai, and the Chennai Egmore MTH (Ministry of Housing and Urban Affairs, 2023).

The construction of new MTHs throughout India is a positive development that is expected to have a number of benefits for the country. MTHs can help to improve transportation efficiency, reduce congestion and pollution, and make transportation more accessible for everyone.

2.10 The Indian Context: Challenges and Potential

India's rapidly growing urban population and increasing demand for transportation pose unique challenges and opportunities for multimodal interchanges. Some notable factors affecting MMI development in India include:

High Population Densities: Designing interchanges to handle very large passenger volumes while maintaining efficiency and safety is vital (Ministry of Housing and Urban Affairs, 2023).

Diverse Socio-Economic Landscape: Accommodating the needs of a wide range of users across different income groups, educational backgrounds, and abilities is essential for inclusive and equitable MMIs (Chauhan et al., 2023).

Rapid Urbanization and Infrastructure Needs: The fast pace of urbanization necessitates integrated planning for interchanges within broader transportation networks and urban development strategies (WRI, 2022).

2.11 Prioritizing User-Cantered Design

To ensure optimal user experiences within MMIs, prioritizing user-centered design is essential. This approach encompasses the following principles:

Understanding Diverse Needs: Employing various research methods like surveys, focus groups, observations, and community collaborations can yield valuable insights into the specific requirements and priorities of the local user base (Sadhukhan et al., 2015).

Tailored Experiences: Where feasible, MMIs should strive to incorporate features and services that cater to distinct demographics and travel needs. This might include quiet areas for focused work or relaxation, designated family-friendly zones for comfort and convenience, enhanced safety measures in spaces frequented by women, and ticketing assistance counters with human interaction for individuals with limited technology access.

Adaptability and Continuous Improvement: MMIs should establish a robust system for collecting ongoing user feedback through surveys, comment boxes, or digital platforms. This data allows interchange management to pinpoint areas for improvement, modify services as needed, and adapt to evolving demographics, travel patterns, and technological advancements for continuous optimization (Zuniga-Garcia et al., 2018).

2.12 Challenges and Opportunities for Multimodal Interchanges

While multimodal interchanges offer numerous benefits, their development and management also present challenges that need to be addressed:

- **Complexity of Coordination:** Integrating multiple transport modes often involves coordination among various stakeholders, including government agencies, transport operators, and private companies. Effective governance models are needed to streamline decision-making and ensure seamless operations (Goel et al., 2016)
- **Financing and Cost Considerations**: Developing and maintaining high-quality interchanges can require significant financial investments. It's essential to explore sustainable funding mechanisms and innovative partnerships to ensure long-term viability (WRI, 2022).
- **Land Availability and Constraints**: In dense urban areas, acquiring adequate land for large-scale interchanges can be difficult and costly (Ministry of Housing and Urban Affairs, 2023).
- **Adapting to Changing Demands**: Interchanges need to be flexible and adaptable to accommodate evolving travel patterns and future transportation technologies, such as autonomous vehicles or on-demand mobility services (Aparicio et al., 2020).

2.13 Best Practices for Multimodal Interchange Design and Management

This international resource draws upon global experience to offer valuable recommendations for multimodal hub design and operation:

Effective Governance: Stresses the importance of sound governance models, sustainable financing strategies, and architectural design guidelines to ensure long-term hub success and aesthetic appeal.

Harnessing Technology: Embracing the potential of digital technologies for passenger information systems, hub operations, and data-driven efficiency improvements.

Promoting Inclusion: Emphasizing universal accessibility, addressing gender-specific needs in hub design to create safe and welcoming spaces for all users, and empowering women in the transportation sector.

- Global experience provides valuable lessons and best practices for the design and management of effective multimodal interchanges. Key considerations include:

- Universal Design Principles: Prioritizing accessibility for people with disabilities through features such as ramps, elevators, tactile paving, and clear signage is essential for creating inclusive and equitable transportation hubs (Li & Loo, 2016).
- Human-Centered Design: Understanding user needs, behaviors, and preferences through surveys, focus groups, and observational studies should inform the design process (Bivina et al., 2020).
- Intuitive Wayfinding: Clear signage, visual cues, and digital information displays are essential for aiding navigation and reducing confusion, especially within complex interchanges (Li & Loo, 2016).
- Integration with Land Use: Interchanges should be seamlessly integrated with surrounding land uses, promoting walkability, bikeability, and convenient access via public transportation (Zuniga-Garcia et al., 2018; WRI 2022).
- Technological Innovations: Smart technologies, such as real-time information systems, integrated ticketing applications, and passenger flow monitoring can significantly enhance the user experience and operational efficiency of interchanges (WRI, 2022).
- Aesthetics and Ambiance: Well-designed interchanges with attention to lighting, landscaping, and cleanliness can contribute to a positive user experience and a sense of place (Li & Loo, 2016).

2.14 Tools and Techniques for Analysis:

This study employs a sequential, multi-method approach to gain nuanced insights into how user experiences at the New Delhi Railway Station (NDLS) are influenced by demographic factors, travel characteristics, and their preferences for various interchange features.

2.14.1 The Kruskal-Wallis Test

The Kruskal-Wallis test, a non-parametric counterpart of the one-way ANOVA, was used to investigate whether significant differences exist in user experience perceptions across various demographic groups (e.g., age, gender, travel purpose) and travel characteristics (e.g., frequency of use, luggage). This analysis is crucial

for identifying potential disparities in service quality and ensuring that improvement strategies address the needs of all NDLS users equitably. (Siegel & Castellan, 1988)

2.14.2 Weighted Average Mean

To determine the relative importance users place on different features and functionalities within the interchange, a weighted average mean was calculated. Survey respondents ranked various 'Feature Preference Indicators' (FPIs) such as 'Ease of Wayfinding,' 'Availability of Signage,' 'Restroom Facilities,' and 'Security.' By assigning weights to these rankings, we can establish a hierarchy of user preferences, revealing the aspects of NDLS that have the most significant impact on user experience.

2.14.3 K-means Clustering

K-means clustering, an unsupervised machine learning algorithm, was applied to segment users based on their satisfaction levels with FPIs and their demographic and travel characteristics. This clustering allows for the identification of distinct user groups with shared experiences and needs. Recommendations can then be tailored to address the specific challenges and priorities of each cluster, ensuring improvement strategies are effectively targeted. [Jain, 2010]

2.14.4 Analytic Hierarchy Process (AHP)

To create a comprehensive and user-centric performance index for NDLS, the Analytic Hierarchy Process (AHP) was employed. AHP breaks down complex decisions into hierarchical structures, enabling pairwise comparisons to determine the relative importance of factors [Citation: Saaty, 1980]. FPIs were systematically grouped into broader categories, such as 'Accessibility,' 'Efficiency,' and 'Amenities,' based on the literature review and user feedback. Users then compared these categories and individual FPIs within them, providing the weights to structure a multi-dimensional index that accurately reflects their priorities

2.14.5 Integrating Insights for Action

The findings from these analyses will be integrated to provide a holistic understanding of user experience at NDLS. The Kruskal-Wallis test results will inform efforts to address any identified disparities. The weighted average mean will guide resource allocation towards the most highly valued FPIs. K-means clustering

will enable the development of tailored recommendations for user segments identified.

By combining these techniques, the performance index encapsulates the features most important to users while facilitating targeted interventions to improve the experience for diverse groups. This integrated analysis paves the way for evidence-based recommendations and continuous monitoring of NDLS's performance in meeting the evolving needs of its users.

CHAPTER 3: Data Collection

3 Data collection

This chapter details the comprehensive data collection process employed in this thesis, the goal of which is to improve the user experience in multimodal hubs within the context of connecting urban and regional transport. The study focuses specifically on the megacity of Delhi, India, offering a rich environment where diverse transit modes intersect and a massive population of commuters with varying needs converge.

3.1 Site Selection: Delhi as a Strategic Study Location

The vibrant megacity of Delhi, the capital of India, was selected as the focus of this thesis due to its complex multimodal transport network and teeming population of over 20 million (2 crore) residents. As a major economic and cultural hub, Delhi boasts the nation's busiest airport, the Indira Gandhi International Airport, along with several crucial railway stations. The New Delhi Railway Station, along with Old Delhi, Nizamuddin, and smaller stations like Ghaziabad, Tilak Bridge, and Okhla Mandi, form a dense rail network serving the wider region.

3.1.1 Multimodal Transit Hubs in Focus

Seven key transit hubs have been strategically selected for this study: IGIT3, IGIT1, Sarai Kale Khan, Chandni Chowk, Kashmere Gate, Anand Vihar, and New Delhi Railway Station. These hubs showcase a diversity of transport modes and varying levels of passenger activity. The New Delhi Railway Station stands out as the busiest hub, with an overwhelming average of 5,00,000 (5 lakh) passengers daily. Further analysis of metro ridership reveals the scale of activity within these hubs:

- New Delhi: 133,648
- NDLS AEL: 33,114
- Sarai Kale Khan-Nizamuddin: 33,218
- Chandni Chowk: 136,697
- Terminal-1 IGI Airport: 9,942
- Anand Vihar ISBT: 73,315
- IGI Airport: 27,688

Modal Diversity and Interconnectivity

The table below highlights the intricate web of transport options available at each selected transit hub:

Table 3.1 Parameter for Site selection

Name	Kashmere Gate	New Delhi Railway Station	Chandni Chowk	Anand Vihar Terminal	Sarai Kale Khan	IGI T3	IGI T1
Daily Footfall	2,40,000	5,00,000	2,50,000	80,000	65,000-97,000	5,95,000	
Metro Ridership	2,40,480	166762	136696	73,315	33218	33114	27688
Bus	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Railway	No	Yes	Yes	Yes	Yes	No	No
Airway	No	No	No	No	No	Yes	Yes
Metro	3	Yes	Yes	Yes	Yes	Yes	Yes
Local Tr	No	Yes	Yes	Yes	Yes	No	No
IPT	Yes	Yes	Yes	Yes	Yes	No	No
Taxi	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Exp Metro	No	Yes	No	No	No	No	No
ISBT	Yes	No	No	Yes	Yes	No	No

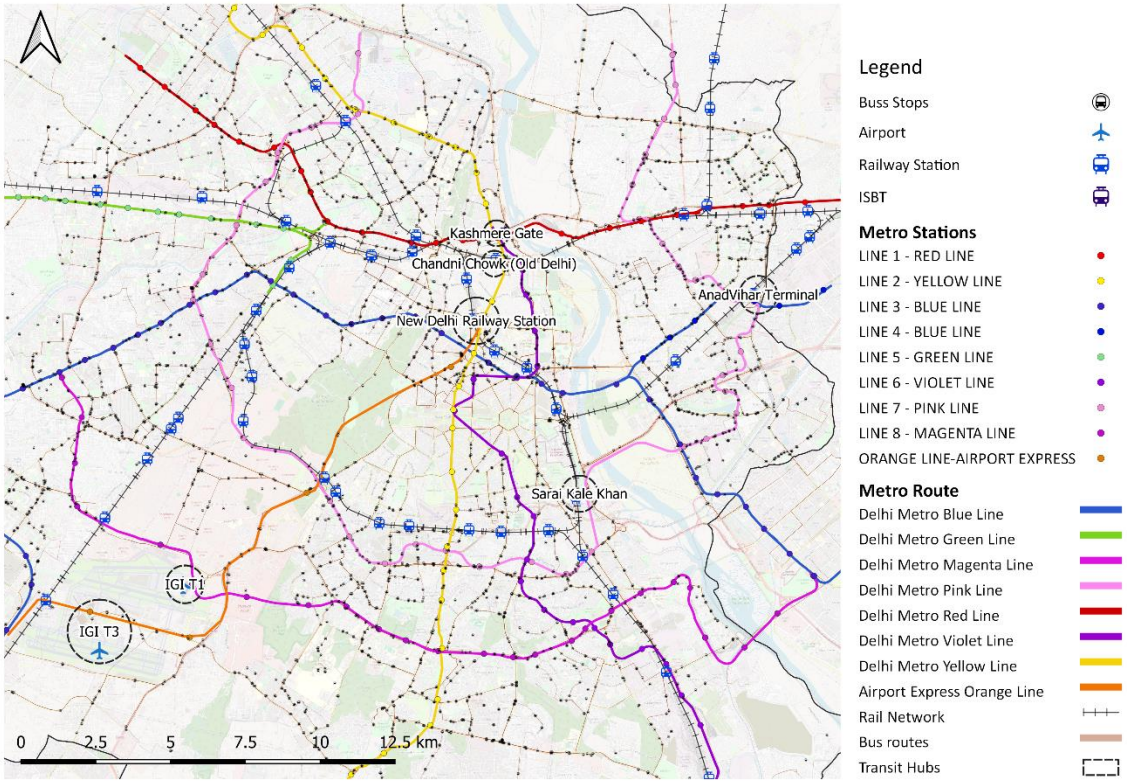


Figure 3-1 Transit Hubs in New Delhi

3.2 **Data Sources and Rationale**

Data for this research was obtained through a multifaceted strategy combining primary and secondary sources. The primary focus fell on the following three prominent transportation agencies in Delhi:

Delhi Metro Rail Corporation (DMRC): DMRC's extensive metro network plays a critical role in Delhi's urban mobility. Data garnered focused on ridership trends, station layouts for understanding passenger flow, and network characteristics.

Delhi Transport Corporation (DTC): DTC operates the largest bus network in Delhi, providing essential transport across the city and surrounding regions. Data collected included bus routes, schedules, depot locations, bus counts, and depot-wise ridership counts.

Delhi Integrated Multi-Modal Transit System (DIMTS): DIMTS plays a crucial role in integrating different transport modes in Delhi. Data from DIMTS focused on bus routes, schedules, and origin-destination ticketing information.

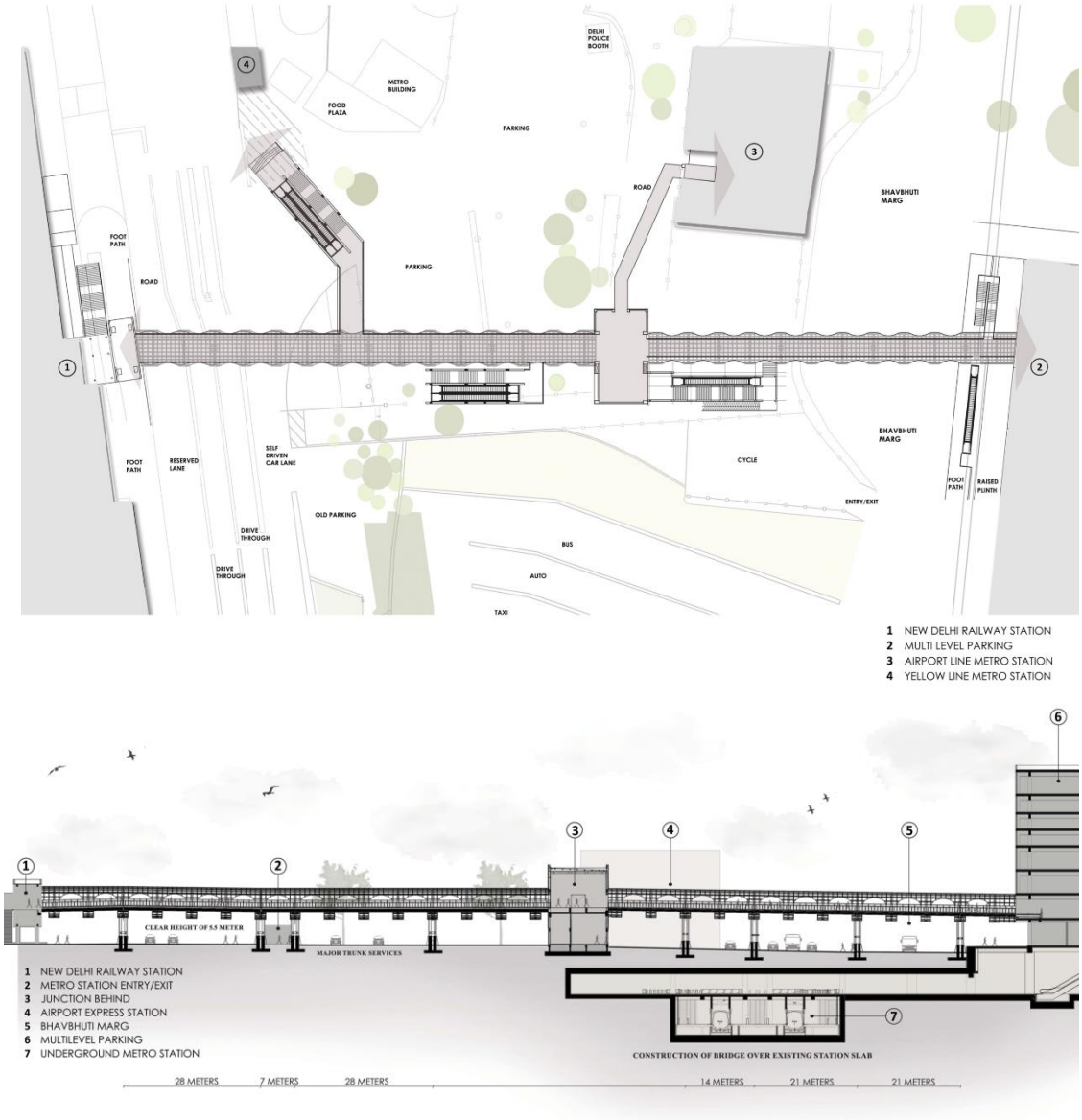


Figure 3-2 Layout of Foot Over Bridge at NDLS

The inclusion of these agencies provided a holistic perspective on the major modes of public transportation in Delhi. Data from these sources enabled a thorough analysis of network infrastructure, service patterns, and passenger volumes, laying a strong foundation for further study of user behavior and preferences.

3.3 **Data Types and Collection Methodology**

The data collected is by secondary sources as well as primary surveys were conducted.

3.3.1 **Secondary Data**

The first phase involved acquiring existing data from relevant agencies:

Delhi Metro Rail Corporation (DMRC): Specific data requests were submitted for ridership statistics, network information, and station layouts to understand passenger movement patterns, transport service connectivity, and the physical design elements of the interchange.

Delhi Transport Corporation (DTC): Requests focused on bus network details, including routes, schedules, depot locations, and the overall scale of bus services to analyze the integration of bus transport with the NDLS interchange.

Delhi Integrated Multi-Modal Transit System (DIMTS): Data acquisition centered on broader network information, potentially including ridership patterns and connectivity metrics, to supplement the DMRC and DTC data and provide a holistic view of the Delhi transport system.

Types of Secondary Data

Ridership Data: Annual, daily, monthly, and weekly counts to analyze usage volumes and variations across timescales (e.g., peak vs. off-peak hours). Depot-level breakdowns and origin-destination data to map passenger movement patterns within the NDLS interchange and its connections to the surrounding transport network.

Network Information: Detailed bus and metro routes, schedules, frequencies, and depot locations to visualize the physical transport network in Delhi and how it connects to NDLS.

Station Design: Comprehensive layouts of NDLS, including platform locations, entry/exit points, internal walkways, ticket counters, information kiosks, and interchange zones to analyze the layout's impact on passenger flow, potential bottlenecks, and overall functionality.

3.3.2 Primary Data

Primary data collection aimed to capture firsthand insights into user experiences, preferences, and the factors influencing the efficiency with which they navigate NDLS. It employed a blend of qualitative and quantitative methods:

Qualitative Assessment

Inventory & Documentation:

- **Photographs and Videos**: Systematic photographic and video documentation to record the physical attributes, conditions, and usage patterns within NDLS and its surrounding multimodal hubs. These visuals provide a detailed snapshot of the existing infrastructure, serving as a reference for analyzing layout, signage, accessibility elements, crowd flow, and other aspects that impact user efficiency and experience.
- **Measurements:** Physical distances between key points within the interchange (e.g., metro station entry to bus stop, ticket counter to platform) to quantify transfer distances and assess the ease and efficiency of intermodal connections.
- **Accessibility Assessment**: Detailed documentation of accessibility-focused infrastructure, including ramps, lifts, escalators, tactile paving, and signage. Availability, functionality, and condition of these elements are crucial for understanding inclusivity and ease of navigation, especially for users with disabilities or mobility restrictions.
- **Connectivity Assessment:** Evaluation of how seamlessly different transport modes connect within the NDLS interchange. Focus placed on transfer points, signage, ease of transitions, and the overall design of spaces facilitating intermodal movement.
- **Amenity Assessment**: Documentation of essential amenities such as:
- **Waiting Areas**: Availability, condition, capacity, and design features affecting user wait time experiences.
- **Restrooms:** Availability, accessibility, cleanliness, and condition.
- **Ticketing Facilities**: Number of counters, signage, ease of use, and queue management. Assessment of both physical counters and digital ticketing options is important in a modern context.
- **Signage and Information Kiosks:** Availability, visibility, clarity, language inclusivity, and comprehensiveness of the information provided.
- **Food Options**, Luggage Storage, Retail Outlets: Availability, variety, and accessibility.

- **Walkability Assessment**: Thorough examination of the pedestrian environment surrounding NDLS, including:
- **Sidewalks and Pathways**: Presence, continuity, width, surface condition, obstacles, and separation from traffic.
- **Street Furniture:** Seating, shade structures, lighting, and trash receptacles.
- **Surveillance:** Presence of security cameras, security personnel, well-lit areas, and emergency call boxes. Assessing the actual and perceived sense of safety created for different users is vital for understanding barriers to pedestrian access.
- **Additional Pedestrian-Focused Features**: Curb cuts, tactile paving for the visually impaired, pedestrian crossings, traffic calming measures, landscaping, and dedicated cycling infrastructure.

3.3.3 Questionnaire Survey

A well-structured questionnaire survey was developed with a sample size of 383 to ensure statistical validity. The questionnaire delved into:

Socio-demographics:

Age, gender, income, profession, qualification, and disability status to build a comprehensive user profile base.

Travel Characteristics:

Trip purpose (e.g., work, leisure, social), frequency of travel, typical journey length, travel direction, luggage situation, and the mode(s) used in conjunction with rail travel. This data helps understand the decision-making processes and motivations influencing travel patterns, informing how to best integrate NDLS into multi-modal journeys.

Efficiency Factors:

- Ease of reaching NDLS using their preferred mode(s)
- Clarity of information on schedules, routes, and transfers
- Time spent waiting at different stages of the journey (e.g., time waiting for the train, time spent in a transfer queue)

- User perception of how delays or disruptions are communicated
- Ease of finding their way within NDLS (clear signage, logical layout) * Challenges or delays caused by confusing signage or poor wayfinding * Level of crowding at various points and its impact on navigation * Adequacy of information for planning the route through the station
- **Accessibility Considerations:** Specific barriers faced by users with disabilities, the elderly, those with heavy luggage, or families with strollers * Availability and functionality of accessibility infrastructure (ramps, elevators, etc.) * Perceptions of safety, especially for vulnerable groups at different times of the day

Observational Videos for Passenger Flow Analysis

Video recordings were strategically captured to analyze real-world passenger movement within NDLS. Key locations and at least two distinct times of day were selected to capture variations in crowd density.

Focus of Recordings:

- Crowd flow and dynamics during peak and off-peak hours to identify bottlenecks and potential friction points.
- Wayfinding behavior, highlighting areas where signage might be inadequate or where users visibly hesitate, slowing their progress.
- Dynamics of intermodal transfers, observing delays, ease of movement between different modes, and how passengers navigate ticket barriers or cross-platform transfers.
- **Video Analysis:** * Quantitative analysis: Using video analysis tools to count pedestrians for objective calculations of passenger flow at various points within NDLS. This can be used to pinpoint areas where crowding creates significant delays in journey times. * Qualitative analysis: Identifying patterns of behavior such as queue lengths, wait times, areas of congestion, detours users take when intended pathways are blocked, and how users use or bypass infrastructure.

Walkability: Sidewalks, pathways, street furniture, shade, illumination, and surveillance were crucial factors considered. Additionally, other pedestrian-

focused features were evaluated to assess the overall quality of walking experience around the multimodal hubs.

Observational Videos to Assess PLOS: Video recordings were made at 7 key locations across 2 days, gathering a total of 20 observation points. This focused on capturing real-time user behavior like crowd flow, waiting patterns, queue length, wayfinding struggles, and the dynamics of inter-modal transfers. Analysis of these videos provides valuable insights into user pain points and potential areas of optimization.

CHAPTER 4: Data Analysis:

4 Data Analysis

4.1 Sample Size and Overview

In this comprehensive analysis, we delve into the multifaceted dimensions of user profiles, experiences, and service quality assessments at a multimodal transit hub, based on a dataset comprising 383 respondents. This research is pivotal in shaping the future of transit hubs by providing actionable insights into user preferences and areas needing improvement. Each segment of data collected not only enriches our understanding of commuter behavior and preferences but also guides strategic enhancements to make transit hubs more efficient, user-friendly, and inclusive.

4.2 Demographics and User Profile

4.2.1 Gender Distribution

With 270 male respondents (approximately 70%) and 113 female respondents (approximately 30%), our sample presents a gender imbalance, suggesting a revisitation of sampling strategies in future studies to ensure a more equitable gender representation. This gender skew may influence the perceived importance of various hub services and amenities, highlighting the necessity for gender-inclusive planning and design strategies.

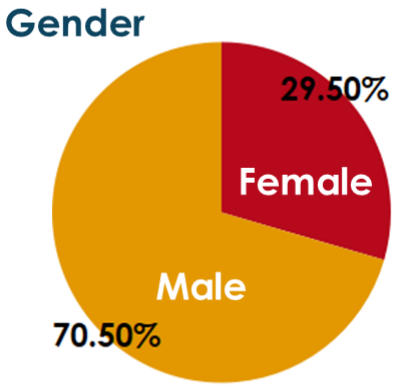


Figure 4-1 Gender Distribution

4.2.2 Age Distribution

The age distribution skews towards younger demographics, with a significant concentration in the 25–30-year age group (131 individuals), followed by the 18-25 age group (102 individuals). Older age groups are underrepresented, particularly those aged 60 and above, with only 18 respondents. This demographic distribution underscores the need for amenities and services that cater to the needs and preferences of a primarily young commuter base while not neglecting the older demographic's specific requirements.

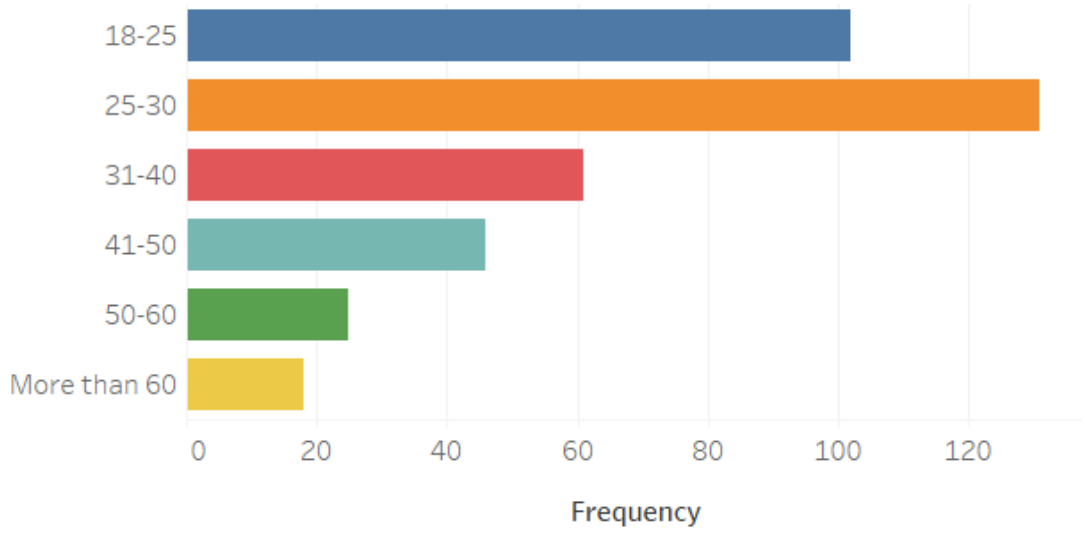


Figure 4-2 Age Distribution

4.2.3 Qualification Attainment

A notable level of educational attainment among respondents, with significant numbers holding Bachelor's (162 individuals) and Master's degrees (122 individuals), suggests that the transit hub serves a highly educated user base.

4.2.4 Income Distribution

Table 4.1

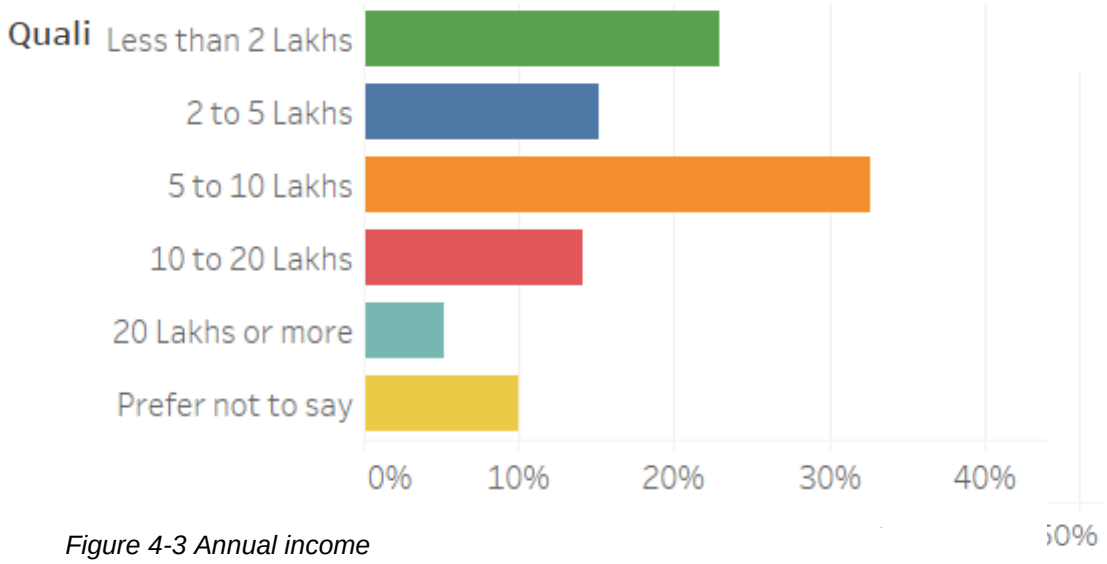


Figure 4-3 Annual income

Income levels predominantly ranged from 5 to 10 lakhs per annum among 125 respondents, though 38 respondents opted not to disclose their income. This variability in income distribution, coupled with the non-disclosure preferences, indicates the need for a broad spectrum of services and amenities that cater to diverse economic backgrounds.

4.3 Trip Characteristics and Preferences

4.3.1 Mode Choice and Trip Characteristics

The preference for the metro (202 respondents) as the primary mode of transport underscores the importance of seamless integration between the metro service and other modalities. The cab/taxi services, represented by 94 respondents, further highlight the need for efficient coordination between ride-sharing platforms and public transit services to enhance door-to-door travel experiences.

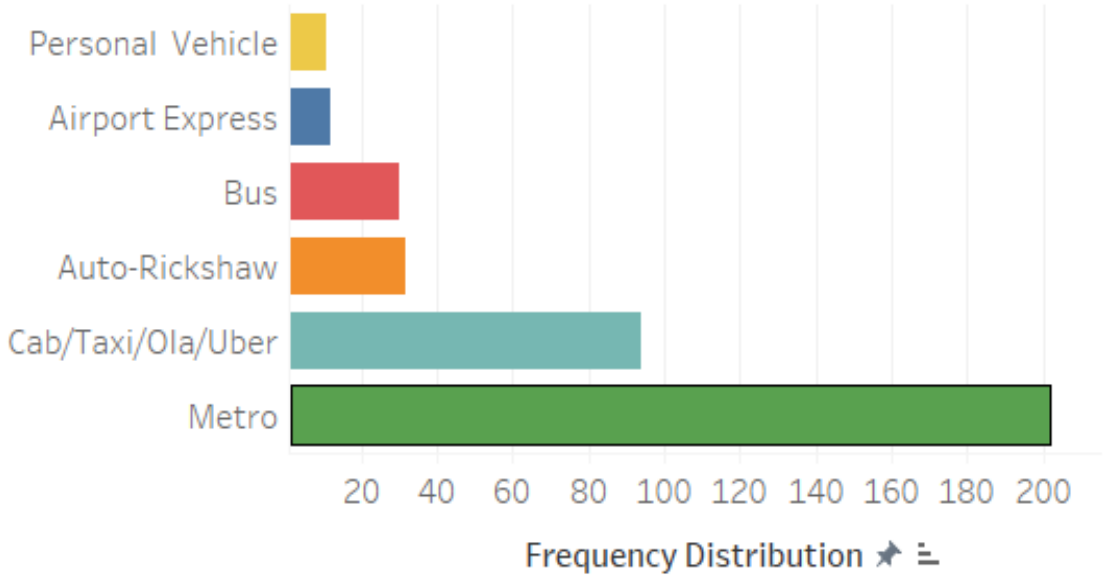
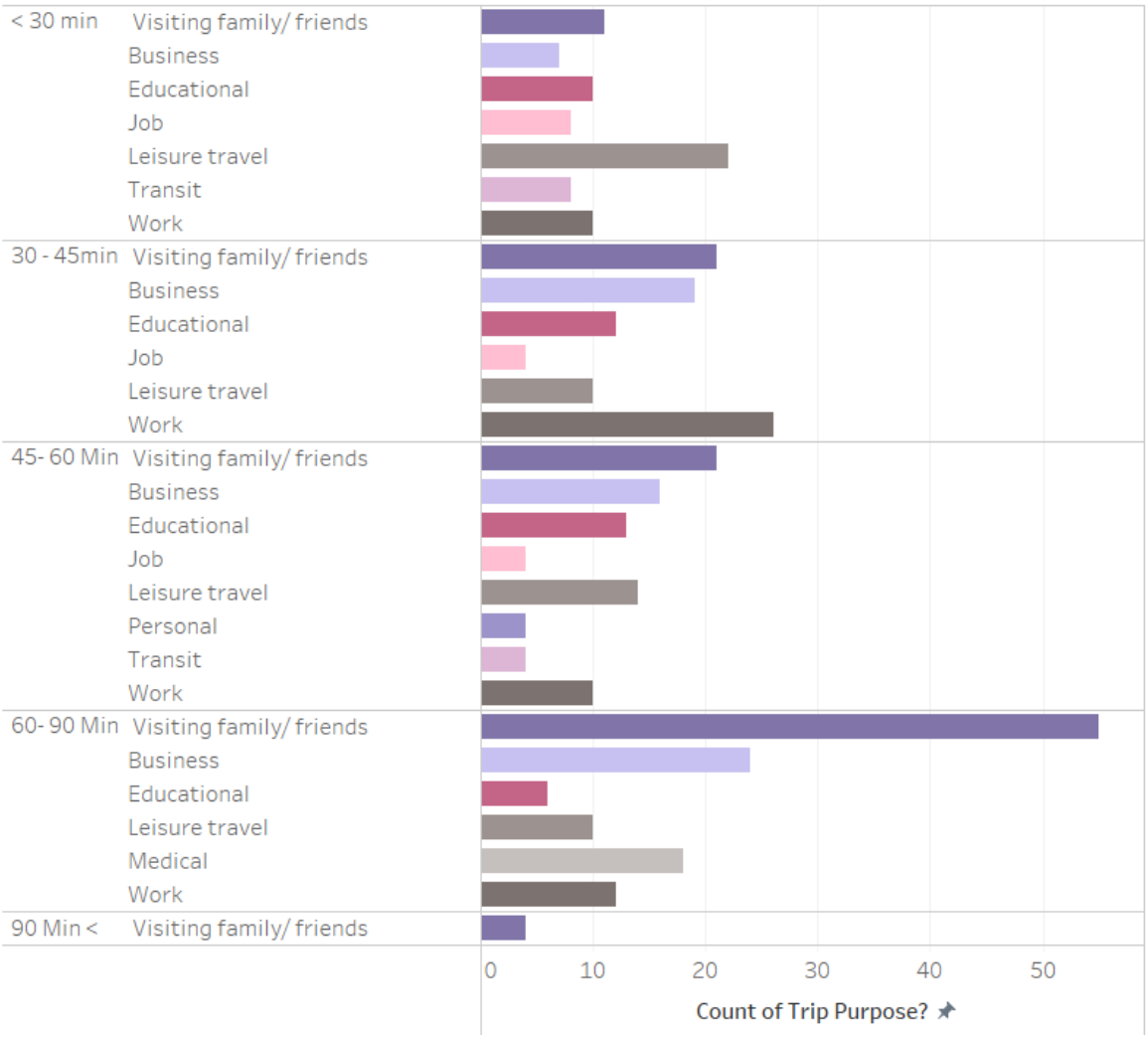


Figure 4-4 Mode Choice

4.3.2 Time of Travel and Trip Purpose

The data points to significant usage during the peak periods of 2 pm – 5:59 pm and 10 am - 1:59 pm, emphasizing the need for strategic operational planning to manage passenger flow and service demand effectively. The dominance of business travel (140 respondents) as a trip purpose, followed by visits to family (112 respondents), signals the importance of aligning hub services with the nuanced needs of these user groups.



4.3.3 Annual Frequency and Travel Companions

The mix of regular and occasional users, with a noteworthy number traveling three times a year (78 individuals) or ten times a year (48 respondents), highlights the necessity for a user-centric approach that caters to both frequent and first-time visitors. The predominance of solo travelers (220 individuals) and those traveling with one companion (96 individuals) informs the design and planning of communal spaces, seating arrangements, and wayfinding systems.

4.3.4 Luggage Quantity

The luggage profile, with most respondents carrying one (139 individuals) or two bags (155 individuals), accentuates the need for efficient luggage management solutions to facilitate a smooth and hassle-free transit experience.

4.4 Performance Indicator rating

This analysis delves into the performance indicators across various aspects of a Multimodal Interchange (MMI), as captured in a 384-respondent survey using a 5-

point Likert scale. It identifies critical service areas, uncovers trends within the railway station and public transport sections of the MMI, and offers recommendations for targeted improvement to enhance overall user experience.

4.4.1 Data Overview

The frequency distribution reveals that respondents evaluated multiple services on a scale ranging from "Excellent" to "Very Poor." These performance indicators include:

- Food & Beverage Options
- Retail Outlets
- Signage
- Schedule Integration
- Ease of Direction/Wayfinding
- Ticketing Efficiency
- Maps/Layout Availability
- Waiting Areas
- Information Booths
- Universal Accessibility
- Luggage Storage
- Staff Assistance
- Restrooms
- Time Coordination Between Modes

4.5 Accessibility and Connectivity

The research analyzed the aspects in 4 categories as suggested above, starting with the user perceptions of accessibility and connectivity (A&C) at a Multimodal Transit Interchange (MMTI) by analyzing user rating data. This data offers a window into the user journey, revealing valuable insights into user experiences and pinpointing areas for improvement. Ultimately, the goal is to optimize the functionality and user-friendliness of the MMTI, ensuring a smooth and inclusive experience for all passengers.

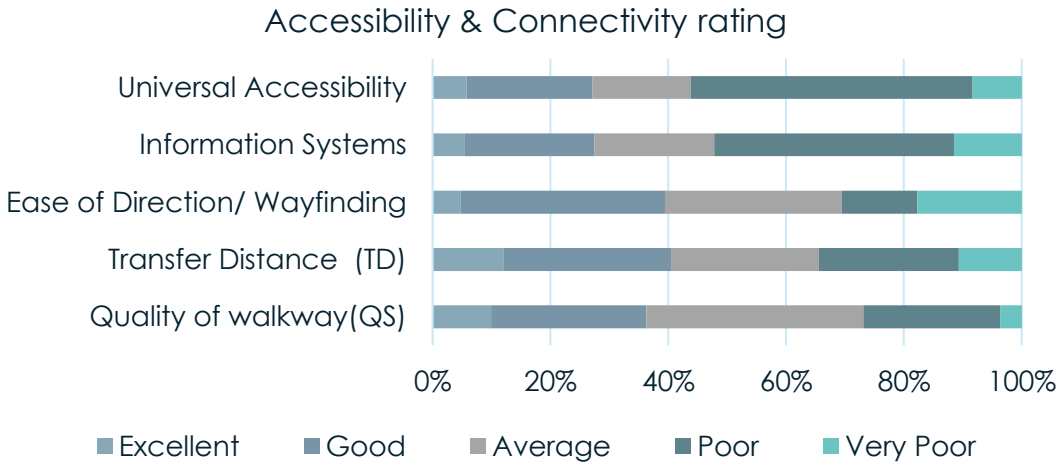


Figure 4-5 Accessibility and Connectivity Rating of NDLS

The research identified a spectrum of user experiences with A&C at the MMTI. While some parameters received a significant portion of positive ratings, indicating user satisfaction, others highlighted areas requiring significant improvement. For instance, users generally found navigating the MMTI layout straightforward. This is evidenced by the high frequency of "Good" ratings and a median of 3.00 for Ease of Direction/Wayfinding. This is further supported by "Good" being the most frequent rating (mode) for this parameter. Here, clear signage and a well-organized layout appear to be facilitating a positive user experience.

Figure 4-8 Universal accessibility issues

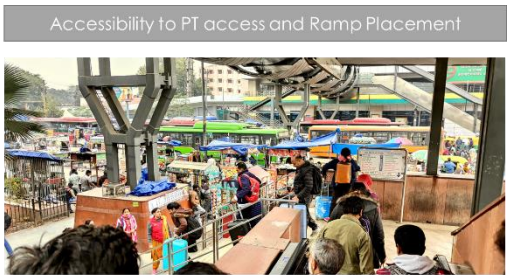


Figure 4-8 Universal Accessibility issues

In stark contrast, Universal Accessibility emerged as a critical concern. The prevalence of "Poor" ratings and a low mean (average) of 2.68 suggest the MMTI might not be adequately equipped to cater to users with disabilities. This highlights a crucial area demanding immediate attention. The research suggests a significant gap exists between the current design and the needs of users with diverse abilities.

Figure 4-8 Hinderance in Signages

While the Quality of Walkway received a higher mean (3.10) compared to other parameters, a closer look revealed room for improvement. The presence of "Poor" and "Very Poor" ratings suggests that not all walkways might be in optimal condition or meet user expectations. Regular maintenance and potential upgrades based on user feedback can significantly enhance the walking experience within the MMTI. Here, the research indicates a need to ensure consistent quality across

all walkways, addressing issues like uneven surfaces, inadequate lighting, or a lack of handrails.

Universal Design Gaps: The current layout has not been designed with universal accessibility principles in mind, leading to barriers and inconveniences for various users. As well as the wayfinding aids fail to offer clear and intuitive guidance for passengers.

The research proposes several recommendations to address the identified concerns and create a more inclusive environment. Conducting a comprehensive Universal Accessibility Audit is essential. This audit should focus on identifying and eliminating existing barriers that hinder accessibility for users with disabilities. Implementing ramps, elevators, and accessible restrooms are crucial steps. Additionally, ensuring clear signage with Braille, tactile lettering, and potentially multilingual options would significantly promote inclusivity. By incorporating these recommendations, the MMTI can bridge the gap between its current design and the needs of a diverse user base.

While Ease of Direction/Wayfinding seems to be functioning well, there's always space for optimization. Implementing color-coding for different areas or installing interactive digital maps for complex layouts can further enhance user experience, especially for first-time visitors. Upgrading or expanding informational displays, announcements, and maps can significantly improve the effectiveness of Information Systems. Ensuring clarity, ease of access, and real-time information dissemination is vital for a seamless user experience. Here, the research suggests building upon the existing strengths in wayfinding by incorporating additional user-friendly elements.

By analyzing user A&C ratings and implementing targeted improvements, the MMTI can transform from a functional space to a user-friendly environment that caters to the diverse needs of all passengers. This not only enhances the overall user experience but also promotes equitable access to public transportation for everyone. Ultimately, by prioritizing accessibility and connectivity, the MMTI can become a truly inclusive transportation hub that fosters a positive experience for all users.

Table 4.2 Kruskal Wallis Test for Accessibility and Connectivity Rating with respect to Demographics and travel characteristics

Null hypothesis	Test	Sig.	Remarks
The distribution of AC is the same across categories of Annual Frequency.	Independent-Samples Kruskal-Wallis Test	0.002	Reject the null hypothesis.
The distribution of AC is the same across categories of Mode choice.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
The distribution of AC is the same across categories of Trip Purpose.	Independent-Samples Kruskal-Wallis Test	0.036	Reject the null hypothesis.
The distribution of AC is the same across categories of Time spent on railway station.	Independent-Samples Kruskal-Wallis Test	0.015	Reject the null hypothesis.
The distribution of AC is the same across categories of age	Independent-Samples Kruskal-Wallis Test	0.040	Reject the null hypothesis.
The distribution of AC is the same across categories of Gender.	Independent-Samples Mann-Whitney U Test	0.654	Retain the null hypothesis.
The distribution of AC is the same across categories of qualifitcation.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.
The distribution of AC is the same across categories of Annual_Income.	Independent-Samples Kruskal-Wallis Test	0.459	Retain the null hypothesis.

Kruskal-Wallis Test Analysis for Accessibility & Connectivity (A&C) Ratings

The research employed the Kruskal-Walli's test, a non-parametric statistical test, to analyze user A&C ratings across various user categories. This test helps determine if there's a statistically significant difference in the distribution of A&C ratings between these categories.

The results indicate that we should reject the null hypothesis for most categories, implying that the distribution of A&C ratings is statistically different across those groups. Here's a breakdown of the relevant findings:

Significant Differences:

- Annual Frequency: Users who frequent the MMTI more often might have a different experience with A&C compared to infrequent users.
- Mode Choice: Passengers arriving by car, bus, train, or other modes might have varying experiences due to factors like dedicated pathways or ease of transferring between modes.
- Trip Purpose: Commuter needs may differ from leisure travelers, impacting their perception of A&C.
- Time Spent at Station: Passengers with longer layovers might be more critical of amenities or signage compared to those passing through quickly.

- Qualification: Users with different qualification levels (education or professional background) might have varying expectations or needs regarding accessibility features.

Whereas there is no Significant Difference in the responses of the Gender: The test suggests A&C ratings are not statistically different based on gender.

Improvement

By understanding these variations, the MMTI can tailor its improvement efforts for more targeted impact:

- Develop user-friendly signage and maps specifically for first-time visitors.
- Provide additional amenities and services for passengers with longer layovers, catering to potential needs like comfortable seating, charging stations, or clear information displays.
- Conduct further research to understand the specific needs of users with different qualification levels to ensure the MMTI caters to a diverse range of abilities and backgrounds.
- Evaluate accessibility features for different travel modes (e.g., buses, trains) and consider improvements for smoother transfers or enhanced accessibility for specific modes.
- By addressing these aspects and considering user categories, the MMTI can create a more inclusive and user-friendly experience for all passengers regardless of their background or travel purpose.

4.6 Pedestrian Level of Service

4.6.1 Passenger Equivalent Factor (PEF) Profile

This study employs Passenger Equivalent Factors (PEFs) to quantify and compare the impact of different passenger types on interchange efficiency. Chandra's formula, **{(An/Ap)*(Vp/Vn)},** defines PEFs, where:

An: Area of passenger with no luggage

Ap: Area of passenger with attributed luggage

Vp: Speed of passenger with attributed luggage

Vn: Speed of passenger with no luggage

For this analysis, PEFs were derived mainly based on speed variations associated with passenger attributes. A thorough passenger categorization strategy was developed, combined with anthropometric measurements for area calculations, resulting in 12 categories:

1) Passenger without luggage
2) Passenger with polybag/lunch bag
3) Passenger with backpack
4) Passenger with duffle bag
5) Passenger with 2 duffle bags
6) Passenger with duffle bag & backpack
7) Passenger with trolley bag
8) Passenger with trolley bag & backpack
9) Passenger with trolley bag & duffle bag
10) Passenger with trolley bag, duffle bag, & backpack
11) Passenger with infant
12) Passenger with a person requiring disability assistance

Each category is further subdivided by gender (male, female).

4.6.2 **Base Case: Passenger Without Luggage**

This category serves as the baseline for the study. Adult males without luggage are used to define the standard passenger equivalent factor (PEF).

Without luggage	
(x (m) y (m)	0.63 X 0.75
Area (sqm)	0.47
Speed (m/min)	52

Extensive sampling was done at various locations to determine typical free-flow walking speeds. Anthropometric measurements were taken to calculate the average area of influence (the space occupied by the passenger's body during movement). Specific findings include:

- **Adult Male:** Area of influence = 0.47 sqm, Average Speed = 52 m/min
- **Adult Female:** Area of influence = 0.38 sqm, Average Speed = 49 m/min
- **Child:** Area of influence = 0.22 sqm, Average Speed = 40 m/min

4.6.3 Passenger with Polybag/ Lunch Bag

With Polybags/ HandBags	
(x (m) y (m)	0.75 X 0.75
Area (sqm)	0.56
Speed (m/min)	41.6

Passengers in this category carry small bags or lunch bags. Area of influence and speed vary with gender, age, and the exact item carried. Example findings include:

- **Adult Male:** Area of influence = 0.56 sqm, Average Speed = 41.6 m/min
- **Adult Female:** Area of influence = 0.47 sqm, Average Speed = 39.2 m/min

4.6.4 Passenger with Duffle Bag

With Duffle Bag	
(x (m) y (m)	0.87 X 0.75
Area (sqm)	0.65
Speed (m/min)	34.36

These passengers carry a single duffle bag and are further classified by gender and age:

- **Adult Male:** Area of influence = 0.65 sqm, Average Speed = 34.36 m/min
- **Adult Female:** Area of influence = 0.55 sqm, Average Speed = 32.28 m/min
- **Older Adult:** Area of influence = 0.65 sqm, Average Speed = 28.7 m/min

4.6.5 Passenger with Backpack

With Backpack	
(x (m) y (m)	0.63 X 1.03
Area (sqm)	0.64
Speed (m/min)	38.1

Backpacks primarily impact the Y-axis dimension of a passenger's area of influence. Area and speed within this category depend on the backpack's size and weight. Passengers with backpacks are subcategorized by age and gender:

- **Child:** Area of influence = 0.24 sqm, Average Speed = 32.47 m/min
- **Adult Male:** Area of influence = 0.64 sqm, Average Speed = 38.1 m/min
- **Adult Female:** Are a of influence = 0.52 sqm, Average Speed = 37.64 m/min

4.6.6 Passenger with 2 Duffle Bags

With 2 duffle bag	
(x (m) y (m)	1 x 0.75
Area (sqm)	0.75
Speed (m/min)	26.6

Carrying two duffle bags significantly impacts both area of influence and speed,

primarily observed in adult male and female passengers.

- **Adult Male:** Area of influence = 0.75 sqm, Average Speed = 26.6 m/min
- **Adult Female:** Area of influence = 0.70 sqm, Average Speed = 24.47 m/min

4.6.7 Passenger with Duffle Bag & Backpack

This combination further increases the passenger's area of influence in both X and Y dimensions.

- **Adult Male:** Area of influence = 0.89 sqm, Average Speed = 29.6 m/min
- **Adult Female:** Area of influence = 0.77 sqm, Average Speed = 26.32 m/min

4.6.8 Passenger with Trolley Bag

Trolley bags lead to a significant increase in area of influence and a noticeable decrease in speed.

With trolley bag	
(x (m) y (m)	1.11 X 1.77
Area (sqm)	1.96
Speed (m/min)	28.56

- **Adult Male:** Area of influence = 1.96 sqm, Average Speed = 28.56 m/min
- **Adult Female:** Area of influence = 1.52 sqm, Average Speed = 26.30 m/min

4.6.9 Passenger with Trolley Bag & Backpack

This combination further expands the area of influence and decreases speed due to the weight and maneuverability challenges

With trolley and duffle bag	
(x (m) y (m)	1.36 X 1.77
Area (sqm)	2.4
Speed (m/min)	26.6

- **Adult Male:** Area of influence = 2.14 sqm, Average Speed = 27.46 m/min
- **Adult Female:** Area of influence = 1.61 sqm, Average Speed = 25.12 m/min

The development of PLOS involves a six-step process to assess how well an interchange caters to pedestrians. Here's a breakdown of each step:

4.7 Assessment of Pedestrian Level of Service

To assess the effectiveness and connectivity of public transportation options, data for a PLOS (Pedestrian Level of Service) assessment was collected at three key locations:

- **Footover Bridge**: This crucial hub connects various public transport modes and plays a significant role in how people navigate the transportation

network. The assessment likely focused on pedestrian flow, ease of transfer between modes, and any potential bottlenecks or congestion points.

- **Railway Station Entry Point:** Data gathered here helps understand passenger volume entering the railway system. This may help assess connection timing between trains and other modes of transport.
- **Metro Exit Point:** This location provides insights into how passengers disperse upon leaving the metro system. It can reveal popular onward destinations and the connectivity with other transportation options.

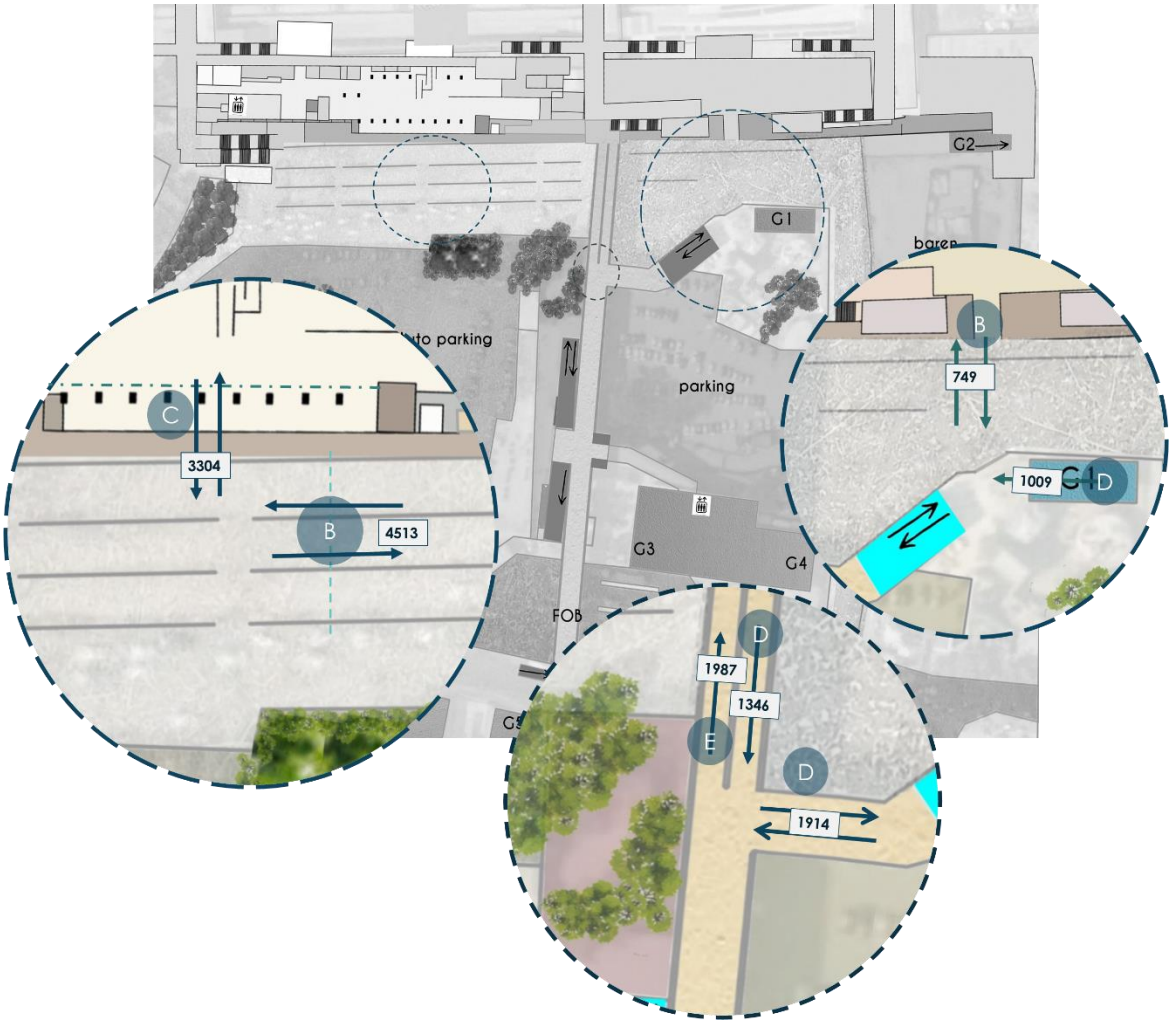


Figure 4-9 PLOS assessment Locations

PLOS Assessment Data Points

The PLOS assessment likely collected a range of data, including:

- **Passenger volume**: How many people use each location at different times of day.

- **Transfer times**: How long does it take to transfer between transport modes.
- **Accessibility**: Observing ease of navigation, particularly for individuals with disabilities.
- **Signage**: Assessing the clarity and usefulness of signs and directions.
- **Pedestrian behaviors:** How people walk, interact, and navigate within these locations.
- **Safety considerations**: Any potential hazards or areas where people feel unsafe

Step 1: Define and Collect Data

Define Level of Service (LOS): Establish the benchmark categories that will be used to evaluate pedestrian experience

Data Collection: Gather primary data during peak hours using Google API and manual pedestrian volume counts at various locations within the interchange. This data will be used to formulate the Passenger Equivalent Factor (PEF).

Passenger Attributes: Consider various passenger attributes that may influence their movement, such as speed and area occupied (square meters).

Effective Width: Conduct a reconnaissance survey to measure the usable walking area (effective width) for pedestrians in different parts of the interchange.

Chandra's Formula: Apply Chandra's formula to calculate the PEF, which considers a passenger's speed and area with different luggage configurations.

Table 4.3 LOS Assessment for Location 1(Railway station to airport Express at FOB)

Time	PEF	Density	Space	Flow Rate	Avg. Speed	Capacity V/C Ration
		(ped/ m^2	(m^2/Ped)	(Ped/m)	(m/s)	(V/C)
1 min	112	0.86	1.16	48.74	0.51	0.58
2 min	51	0.39	2.56	22.09	0.52	0.26
3 min	89	0.69	1.46	38.74	0.54	0.46
4 min	34	0.26	3.78	14.96	0.67	0.18
5 min	50	0.39	2.59	21.78	0.61	0.26
6 min	38	0.29	3.39	16.65	0.60	0.20
7 min	69	0.53	1.88	30.13	0.49	0.36
8 min	133	1.02	0.98	57.91	0.50	0.69
9 min	81	0.62	1.61	35.04	0.50	0.42
10 min	75	0.57	1.74	32.48	0.52	0.39
11 min	**156**	**1.20**	**0.83**	**67.83**	**s0.50**	**0.81**

12 min	107	0.82	1.21	46.57	0.50	0.55
13 min	135	1.04	0.96	58.61	0.48	0.70
14 min	109	0.83	1.20	47.17	0.52	0.56
15 min	107	0.82	1.21	46.52	0.50	0.55

Calculate Additional Metrics

- **Average Speed:** The typical speed at which pedestrians are moving within a specific area.
- **Density:** The number of pedestrians per square meter of space.
- **Space:** The average area available per pedestrian (calculated by dividing total available space by pedestrian count).
- **V/C Ratio:** This refers to the volume-to-capacity ratio, which indicates how close pedestrian flow is to exceeding the capacity of a particular area. A ratio above 1 suggests overcrowding.

For the above stretch the LOS is been assessed as LOS E.

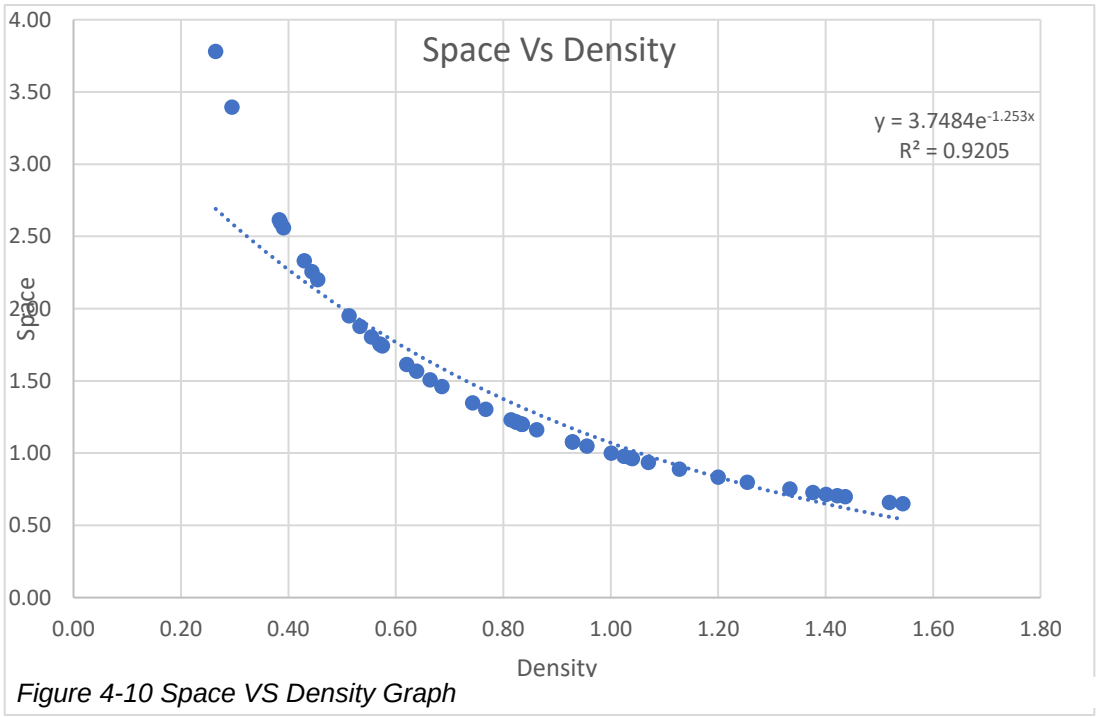


Figure 4-10 Space VS Density Graph

4.8 Passenger Amenities: Unveiling Passenger Needs at the Railway Station

This analysis sheds light on passenger experiences with various amenities offered at a railway station. By examining user ratings for restrooms, luggage storage,

waiting areas, retail outlets & services, and food & beverage (F&B) options, the research unveils valuable insights for improving passenger satisfaction.

The analysis reveals a pressing need to address restroom facilities. An overwhelming majority of users rated restrooms as "Poor" or "Very Poor," resulting in the lowest overall satisfaction score. This necessitates immediate action to enhance hygiene, functionality, and cleanliness within restrooms. Upgrading fixtures, ensuring adequate supplies, and implementing thorough cleaning procedures are crucial steps towards achieving this goal.

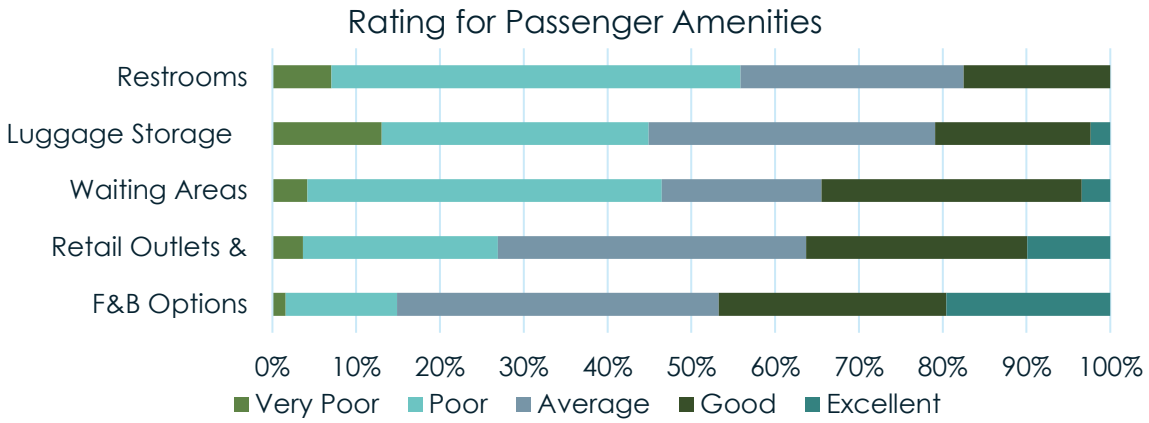


Figure 4-11 Rating for Passenger Amenities

Luggage storage, while faring better than restrooms, still presents some room for improvement. While the most frequent rating category is "Good," the presence of negative ratings suggests potential shortcomings. Further investigation into these negative responses could reveal user concerns regarding storage capacity, security measures, or the overall convenience of luggage storage facilities. Analyzing user feedback can guide targeted improvements, such as expanding storage capacity, implementing more robust security measures, or streamlining the luggage drop-off and retrieval process.

Passenger experiences with waiting areas paint a mixed picture. The high prevalence of "Average" ratings indicates a neutral perception, but a significant number of negative ratings suggests areas for improvement. User feedback

regarding waiting areas should be analyzed to identify specific concerns. This might involve a lack of comfortable seating, inadequate ventilation or lighting, or the absence of amenities like charging stations. Addressing these issues can significantly enhance passenger comfort and satisfaction while waiting for their trains.

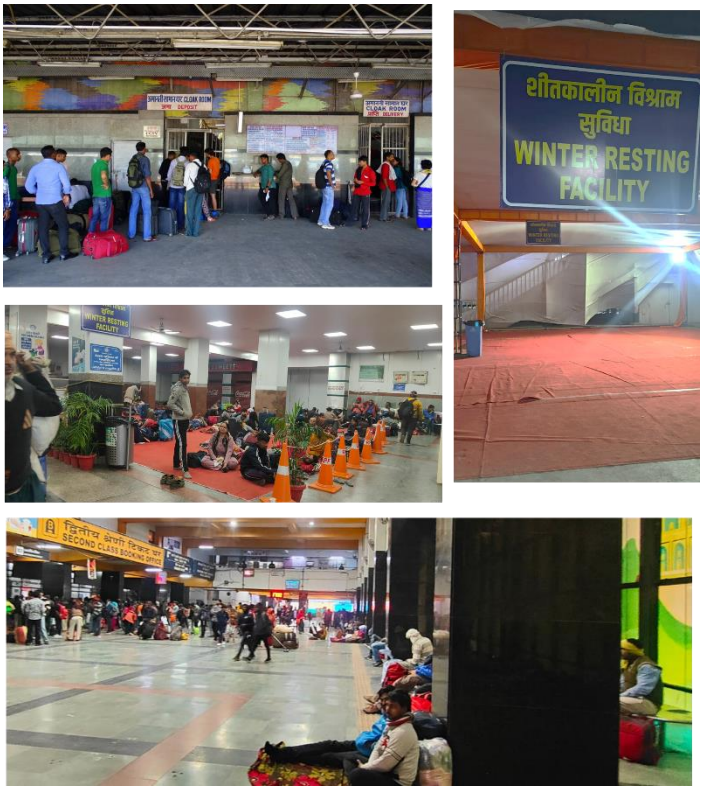


Figure 4-12 Issues in Passenger amenities at NDLS

Retail outlets & services and F&B options emerge as the most successful amenities based on user ratings. The high proportion of "Good" or "Excellent" ratings, combined with a mean score exceeding 3.00 for both categories, suggests that these offerings are generally meeting passenger expectations. However, maintaining this positive perception is crucial. Regularly soliciting user feedback can ensure that these amenities continue to evolve and adapt to passenger needs.

By prioritizing user feedback and implementing targeted improvements across all amenities, the railway station can transform into a more passenger-centric environment. Addressing critical areas like restrooms and strategically enhancing other amenities will contribute to a more comfortable, convenient, and positive overall experience for all passengers this analysis delves into user ratings for key aspects like signage, transfers, ticketing, and schedule integration.

Table 4.4 Kruskal Wallis Test for Passenger Amenities Rating with respect to Demographics and travel characteristics

Null hypothesis	Test	Sig.	Remarks
The distribution of PA is the same across categories of Annual Frequency.	Independent-Samples Kruskal-Wallis Test	0.003	Reject the null hypothesis.
The distribution of PA is the same across categories of Mode choice.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.
The distribution of PA is the same across categories of Trip Purpose.	Independent-Samples Kruskal-Wallis Test	0.432	Retain the null hypothesis.

The distribution of PA is the same across categories of Time spent on railway station.	Independent-Samples Kruskal-Wallis Test	0.076	Retain the null hypothesis.
The distribution of PA is the same across categories of age	Independent-Samples Kruskal-Wallis Test	0.613	Retain the null hypothesis.
The distribution of PA is the same across categories of Gender.	Independent-Samples Mann-Whitney U Test	0.539	Retain the null hypothesis.
The distribution of PA is the same across categories of qualifitcation.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.
The distribution of PA is the same across categories of Annual Income.	Independent-Samples Kruskal-Wallis Test	0.418	Retain the null hypothesis.

4.8.1 Analysis of Kruskal-Wallis Test Results for Passenger Amenities (PA)

The Kruskal-Wallis test results shed light on how user ratings for passenger amenities (PA) vary across different passenger categories. Here's a breakdown of the findings:

- **Significant Differences:**
    - **Annual Frequency:** User ratings of PA are statistically different for passengers with varying frequencies of travel (e.g., frequent vs. infrequent travelers). This suggests that how often someone uses the station might influence their perception of the amenities offered.
    - **Mode of Choice:** The way passengers arrive at the station (train, bus, car, etc.) appears to influence their experience with amenities. This could be due to factors like specific needs of travelers arriving by different modes (e.g., secure storage for bicycles).
    - **Qualification:** Passengers with different qualification levels (education or professional background) might have varying expectations or needs regarding amenities, leading to statistically different ratings.
- **No Significant Differences:**
    - **Trip Purpose:** The purpose of a trip (commute, leisure, etc.) doesn't seem to significantly impact the overall perception of amenities.
    - **Time Spent at Station:** The amount of time spent at the station doesn't statistically influence user ratings of amenities.

- **Age:** Age doesn't appear to be a major factor in how passengers perceive the amenities offered.
- **Gender:** The test suggests no significant difference in amenity ratings based on gender.
- **Annual Income:** Passenger income doesn't statistically influence their perception of amenities.

These findings offer valuable insights for improving passenger amenities:

- **Tailoring Amenities to User Frequency:** Consider the needs of frequent travelers who may rely more heavily on certain amenities like luggage storage or charging stations.
- **Catering to Different Modes of Arrival:** Evaluate if specific amenities cater to the needs of passengers arriving by various modes of transportation. For example, secure bicycle parking for cyclists or lockers for large luggage.
- **Understanding Qualification-Based Needs:** Further research might be needed to understand how qualification level influences amenity needs. This could help tailor offerings or provide targeted information (e.g., signage in multiple languages).

While factors like trip purpose, time spent at the station, age, and income don't show significant statistical influence overall, it's still important to consider them in conjunction with user feedback. Passengers might have specific needs within these categories that could be addressed.

By understanding how user experiences with amenities can vary depending on their background and travel characteristics, the railway station can prioritize improvement efforts for a more targeted impact. This will lead to a more user-centric environment that caters to the diverse needs of all passengers

This analysis delves into passenger experiences with various aspects that contribute to their overall journey at the railway station. By examining user ratings for Signage Availability, Transfer Efficiency, Ticketing Efficiency, and Schedule & Frequency Integration, the research unveils valuable insights for improvement.

Signage Availability: A Guiding Light

The analysis shines a light on Signage Availability as a strong point. The high frequency of "Good" ratings indicates that passengers generally find station signage clear, informative, and strategically placed. This highlights the importance of maintaining well-designed signage that effectively guides passengers throughout the station, fostering a smooth and stress-free travel experience.

4.9 Transfer Efficiency & Reliability (ER)

However, Transfer Efficiency paints a contrasting picture. The prevalence of "Poor" ratings suggests that many passengers find transferring between different modes of transportation within the station difficult or inefficient. To address this, consider conducting an audit to identify bottlenecks that contribute to a poor transfer experience. Here are some potential areas for improvement:

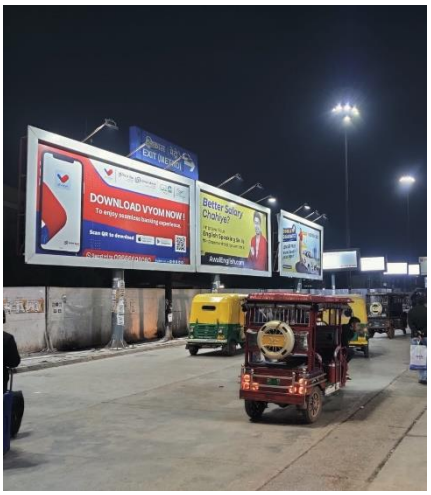


Figure 4-13 Footpath utilised by Advertisements

- **Signage:** Are there clear and strategically placed signs specifically for transfers, guiding passengers to their connecting stations or platforms?
- **Walking distances:** Can designated walking routes be optimized to minimize the distance between connecting stations?
- **Accessibility:** Are there accessible pathways for passengers with disabilities or those carrying heavy luggage?

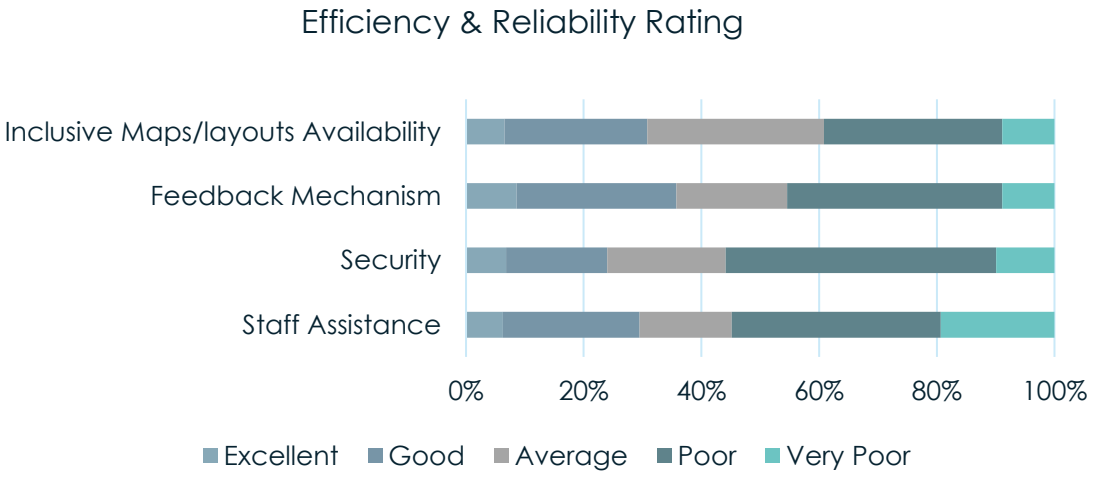


Figure 4-14 Rating For Efficiency and Reliability

By addressing these issues and implementing targeted solutions like clearer transfer signage, designated walking routes, or even exploring options to reduce walking distances, the station can significantly enhance the transfer experience for all passengers.

Figure 4-15 Lack of Staff assistance

Ticketing Efficiency and Schedule & Frequency Integration: A Balancing Act

Ticketing Efficiency and Schedule & Frequency Integration receive a mixed bag of reviews. While the average scores suggest a neutral overall perception, the presence of both positive and negative ratings indicates room for improvement. Here's how to delve deeper:

- **Ticketing Efficiency:** Analyze ticketing processes to identify delays or inefficiencies. Explore options like:
    - Increasing the number of ticketing machines.
    - Streamlining online ticketing platforms.
    - Enhancing staff training for faster and more efficient service.
- **Schedule & Frequency Integration:** Analyze user feedback regarding schedules and frequency to identify areas for improvement:
    - On-time performance can be a major concern. Investigate factors contributing to delays and implement solutions to ensure trains run closer to schedule.
    - Train schedules can be optimized to minimize waiting times for passengers, especially during peak hours.
    - An increase in train frequency during peak hours can help meet passenger demand and reduce crowding on platforms.

By implementing these improvements, the station can contribute to a smoother ticketing experience and a more reliable and predictable travel experience overall.

Table 4.5 Kruskal Wallis Test for ER with respect to Demographics and travel characteristics

Null hypothesis	Test	Sig.	Remarks
The distribution of ER is the same across categories of Annual Frequency.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
The distribution of ER is the same across categories of Mode choice.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
The distribution of ER is the same across categories of Trip Purpose.	Independent-Samples Kruskal-Wallis Test	0.012	Reject the null hypothesis.
The distribution of ER is the same across categories of Time spent on railway station.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
The distribution of ER is the same across categories of age	Independent-Samples Kruskal-Wallis Test	0.021	Reject the null hypothesis.
The distribution of ER is the same across categories of Gender.	Independent-Samples Mann-Whitney U Test	0.271	Retain the null hypothesis.
The distribution of ER is the same across categories of qualifitcation.	Independent-Samples Kruskal-Wallis Test	0.033	Reject the null hypothesis.
The distribution of ER is the same across categories of Annual Income.	Independent-Samples Kruskal-Wallis Test	0.457	Retain the null hypothesis.

4.9.1 Kruskal-Wallis Test Analysis for Efficiency & Routing (ER)

The Kruskal-Wallis test results shed light on how user ratings for Efficiency & Routing (ER) vary across different passenger categories. Here's a breakdown of the key findings:

- **Significant Differences:**
    - **Annual Frequency, Mode Choice, Trip Purpose, Time Spent, Age, and Qualification:** User experience with ER aspects (signage, transfers, ticketing, scheduling) can vary depending on how often someone travels (annual frequency), how they arrive (mode choice), their trip purpose (commute vs. leisure), the amount of time spent at the station, age, and qualification level.
    - For example, frequent travelers might be more familiar with signage and ticketing procedures compared to infrequent travelers. Passengers with luggage might find transfers more challenging compared to those traveling light. Similarly, passengers with different qualification levels might have varying expectations or needs regarding efficiency aspects.
- **No Significant Difference:**
    - **Gender:** The test suggests no significant difference in ER ratings based on gender.

Understanding the Implications

These findings highlight the importance of considering a passenger's background and travel characteristics when planning improvements. Here's how:

- **Frequent travelers:** Provide easily accessible information on any changes to signage, ticketing procedures, or schedules.
- **Mode of choice:** Develop targeted signage or information displays catering to the specific needs of passengers arriving by different modes of transportation (e.g., cyclists needing bicycle parking information).
- **Trip purpose:** Tailor passenger information based on trip purpose. Commuters might prioritize on-time performance, while leisure travelers might be more interested in amenities.

By prioritizing user feedback and implementing targeted improvements across all ER aspects, the railway station can transform into a more efficient and user-friendly environment for all passengers, regardless of their background or travel needs. This will contribute to a more positive and seamless travel experience overall.

4.10 User Experience

This analysis sheds light on passenger perceptions of various aspects that contribute to the overall User Experience (UX) at the railway station. By examining

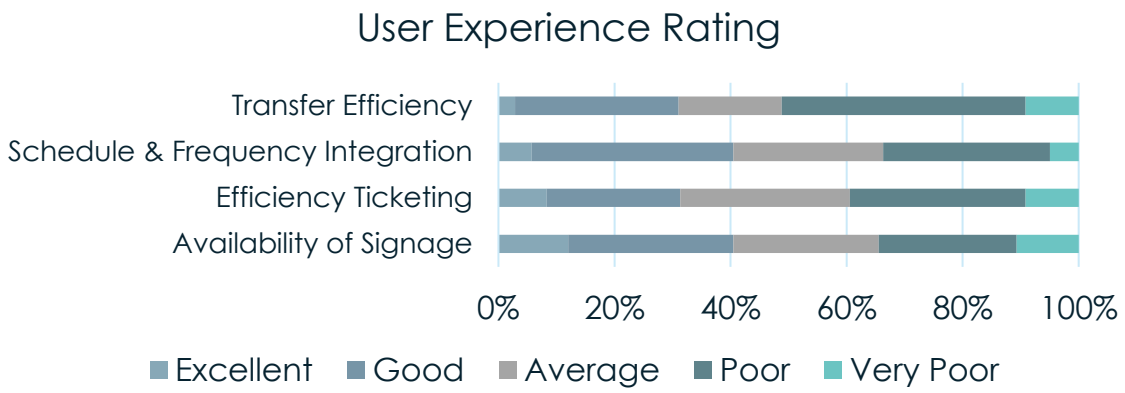


Figure 4-16 User Experience rating

user ratings for Staff Assistance, Security, Inclusive Maps/Layouts Availability, and Feedback Mechanism, the research offers valuable insights for creating a more positive and efficient environment for all.

Empowering Staff

Staff Assistance and Security, while receiving some positive feedback, also show a concerning number of negative ratings. To bridge this gap, consider:

- **Targeted Staff Training:** Implement programs focused on:
    - **Communication Skills:** Train staff to communicate effectively with passengers from diverse backgrounds.
    - **Station Knowledge:** Equip staff with in-depth knowledge about the station layout, services, and real-time information.
    - **Customer Service Excellence:** Foster a service-oriented mindset that prioritizes passenger needs and provides exceptional assistance.

Enhancing Security and Peace of Mind

- **Increased Security Presence:** Boost the visibility of security personnel through more frequent patrols, especially in vulnerable areas.

Figure 4-17 Long ques at Entry point and ticket kiosk

- **Collaboration with Local Law Enforcement:** Develop strong partnerships with local law enforcement to deter criminal activity and ensure a safe environment.
- **Promoting Inclusivity and Accessibility**

Inclusive Maps/Layouts Availability emerges as a relative strength. However, maintaining and improving accessibility is crucial:

- **Regular Reviews and Updates:** Continually review and update station maps and layout information to adhere to inclusive design principles.
- **Multi-Sensory Design:** Incorporate clear visual elements, Braille, tactile wayfinding systems, and multi-lingual options.

Building a Feedback Loop: Listening and Responding to Passengers

The Feedback Mechanism offers an opportunity to gather valuable user insights. Here's how to improve it:

- **Promote Awareness:** Increase passenger awareness of the feedback system through clear signage, announcements, and staff recommendations.
- **Multiple Channels:** Provide diverse channels for feedback, such as online surveys, suggestion boxes, or mobile applications.
- **Active Analysis and Response:** Develop a system to analyze feedback effectively and implement targeted improvements based on passenger concerns.

4.10.1 Kruskal-Wallis Test Analysis for User Experience (UE)

The Kruskal-Wallis test results highlight how user experience with various aspects (staff assistance, security, etc.) can vary depending on passenger characteristics:

- **Significant Differences:**
    - **Annual Frequency, Mode Choice, Trip Purpose, Time Spent, and Qualification:** Passengers with varying travel habits (frequent vs. infrequent), modes of arrival (train, bus, car), trip purposes (commute, leisure), time spent at the station, and qualification levels might have different experiences with UX aspects.
    - For instance, infrequent travelers require more assistance navigating the station layout compared to frequent travelers. Similarly, passengers with disabilities or those with limited mobility might find navigating the station more challenging and require additional support from staff or clearer signage.
- **No Significant Difference:**
    - **Age & Gender:** The test suggests that age and gender might not be significant factors influencing overall UX perception.

By prioritizing user feedback and implementing these improvements, the railway station can transform into a more user-friendly environment. This includes fostering a well-trained and helpful staff, prioritizing security measures, maintaining inclusive design standards, and actively incorporating passenger feedback. This user-

centric approach will not only reduce passenger stress but also cultivate a more positive perception of the railway service as a whole. Ultimately, these efforts will lead to a more efficient, secure, and enjoyable travel experience for everyone

Null hypothesis	Test	Sig.	Remarks
The distribution of UE is the same across categories of Annual Frequency.	Independent-Samples Kruskal-Wallis Test	0.009	Reject the null hypothesis.
The distribution of UE is the same across categories of Mode choice.	Independent-Samples Kruskal-Wallis Test	0.001	Reject the null hypothesis.
The distribution of UE is the same across categories of Trip Purpose.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
The distribution of UE is the same across categories of Time spent on railway station.	Independent-Samples Kruskal-Wallis Test	0.025	Reject the null hypothesis.
The distribution of UE is the same across categories of age	Independent-Samples Kruskal-Wallis Test	0.765	Retain the null hypothesis.
The distribution of UE is the same across categories of Gender.	Independent-Samples Mann-Whitney U Test	0.443	Retain the null hypothesis.
The distribution of UE is the same across categories of qualifitcation.	Independent-Samples Kruskal-Wallis Test	0.011	Reject the null hypothesis.
The distribution of UE is the same across categories of Annual Income.	Independent-Samples Kruskal-Wallis Test	0.013	Reject the null hypothesis.

4.11 Level of Importance Rating for the parameters:

- **Most Important:** Signage (S) and Accessibility (UA) are rated as the most important amenities with the highest mean scores (4.98 and 4.9 respectively) and a very high number of ratings in the "Very Important" category (84 and 85 respectively). This indicates that passengers consider clear and accessible signage, along with features that cater to diverse abilities, to be essential for a smooth travel experience.
- **Very Important:** Several other amenities are also rated as very important, including Real-time information (RT), Inclusive Info communication (IB), Ease of Access (EA), Transfer Distance (TD), Coordination (CT), Restrooms (R), Frequency (FS), Ease of Direction/Wayfinding, and Information Booths. These amenities received a high number of ratings in the "Very Important" category.
- **Less Important:** Amenities like Retail Outlets, Comfort Areas (CA), Waiting Areas (WA), Staff Assistance (SA), Ticketing (TB), Space for

Luggage (SL), and Security (SS) have a lower concentration of ratings in the "Very Important" category and a more spread-out distribution across other importance levels. This suggests that while these amenities are still considered important, they might not be as critical for passengers as those ranked higher.

Overall, the table reveals that passengers prioritize clear signage, accessibility features, real-time information, and ease of navigating the station. While other amenities are also considered important, they might not be as critical for overall satisfaction.

The table (Table 4.6 Average Weightage for Rating of Preferences) with parameter and sub-parameter weightages offers valuable insights into passenger preferences for a positive railway station experience. Here's a breakdown of the analysis supporting each category and its sub-parameters:

Table 4.6 Average Weightage for Rating of Preferences

Parameter	Weightage	Sub parameter	Weightage
Accessibility & Connectivity	**0.33**	Ease of Direction/ Wayfinding (EOD)	**0.18**
		Information booths	**0.17**
		Accessibility (UA)	**0.23**
		Quality of walkway (QS)	**0.19**
		Transfer time (TT) & TD	**0.23**
Passenger Amenities	**0.22**	Restrooms (R)	**0.24**
		Retail (RO)	**0.17**
		Waiting (WA)	**0.18**
		Space for Luggage	**0.20**
		Comfort areas	**0.22**
Efficiency & Reliability	**0.25**	Coordination (CT)	**0.22**
		Ease of Access (EA)	**0.20**
		Signage (S)	**0.20**
		Ticketing Booth (TB)	**0.17**
		Real time information (RTI)	**0.21**
User Experience	**0.23**	Security (SS)	**0.23**
		Staff (AS)	**0.21**
		Frequency (FS)	**0.29**
		Inclusive Info Communication (IIC)	**0.27**

1. Accessibility & Connectivity (A&C) (Weightage: 0.33):

This category receives the highest weightage (0.33), highlighting its critical role in passenger experience. Passengers prioritize aspects that enable them to navigate the station seamlessly, regardless of ability.

- **Sub-parameter weightages reflect this priority:**
    - **Accessibility (UA) (0.23):** This sub-parameter receives the highest weightage within A&C, emphasizing the importance of features like ramps, elevators, and accessible restrooms catering to passengers with disabilities.
    - **Ease of Direction/Wayfinding (EOD) (0.18):** Clear signage and intuitive navigation systems are crucial for passengers to find platforms, exits, and amenities efficiently.
    - **Information Booths (0.17):** While helpful, information booths play a secondary role compared to EOD signage for wayfinding.
    - **Transfer Time (TT) & Transfer Distance (TD) (0.23):** Passengers value minimizing the time and distance needed to transfer between platforms or exits. This contributes to a smoother and less stressful travel experience.

2. Passenger Amenities (PA) (Weightage: 0.22):

This category receives a significant weightage (0.22), indicating that amenities contribute to passenger comfort while waiting at the station. However, its weightage is lower than A&C, suggesting amenities are not as critical for the core travel experience.

- **Sub-parameter weightages prioritize essential amenities:**
    - **Restrooms (R) (0.24):** Clean and well-maintained restrooms are considered the most important amenity within PA, reflecting their necessity for basic comfort.
    - **Space for Luggage (0.20), Waiting Areas (WA) (0.18), and Comfort Areas (CA) (0.22):** These amenities contribute to passenger comfort during waiting times. Space for luggage receives a slightly higher weightage compared to waiting areas, potentially indicating a higher perceived need for secure luggage storage.

- **Retail Outlets & F&B Options (RO) (0.17):** While convenient, retail options receive the lowest weightage within PA, suggesting they are not essential for the core travel experience but can enhance it for some passengers.

3. Efficiency & Reliability (ER) (Weightage: 0.25):

This category receives a moderate weightage (0.25), highlighting the importance of a smooth and predictable travel experience.

- **Sub-parameter weightages focus on streamlining processes:**
  - **Coordination (CT) (0.22):** Well-coordinated services (e.g., with local transportation) contribute to a seamless arrival and departure experience.
  - **Ease of Access (EA) (0.20):** User-friendly station entry and exit points are crucial for efficient passenger flow.
  - **Signage (S) (0.20):** Clear and informative signage is essential not just for wayfinding but also for navigating ticketing procedures, platforms, and other amenities.
  - **Ticketing Booth (TB) (0.17) & Real-time Information (RTI) (0.21):** Efficient ticketing procedures are important (though slightly less than signage), while real-time information is valued but not the most critical factor for efficiency. Passengers might prioritize efficiency in procedures over having the most up-to-date information at all times.

4. User Experience (UX) (Weightage: 0.23):

This category receives a moderate weightage (0.23), indicating that factors beyond core functionality contribute to a positive overall experience.

- **Sub-parameter weightages prioritize safety and convenience:**
  - **Security (SS) (0.23):** Passengers prioritize a safe and secure environment within the station.
  - **Staff (AS) (0.21):** Helpful and service-oriented staff contribute to a positive experience.

- **Frequency (FS) (0.29):** Frequent train services are the most important factor within UX, minimizing waiting times and ensuring passengers can reach their destinations efficiently.
- **Inclusive Info Communication (IIC) (0.20):** Providing information in multiple formats caters to diverse needs and enhances the passenger experience for a wider range of passengers.

Overall Analysis:

The weightages highlight that passengers prioritize accessibility, clear navigation, efficient travel processes, a secure environment, and frequent train services. While amenities contribute to comfort, they are considered less critical for the core travel experience.

Recommendations:

Based on the analysis of weightages, here are some recommendations for improving the railway station experience:

- **Focus on Accessibility & Connectivity (A&C):** Invest in features that enhance accessibility for passengers with disabilities, improve signage and wayfinding systems, and minimize transfer times and distances.
- **Prioritize Efficiency & Reliability (ER):** Ensure efficient ticketing procedures, clear and informative signage, and well-coordinated services for a smooth travel experience.
- **Maintain a Secure User Experience (UX):** Prioritize passenger safety by implementing effective security measures and provide helpful and service-oriented staff.
- **Optimize Passenger Amenities (PA):** Maintain clean and well-maintained restrooms, offer comfortable waiting areas with luggage storage facilities, and consider the value of retail options based on passenger demographics and ridership patterns.
- **Conduct periodic surveys or collect passenger feedback** to validate these priorities and identify any emerging needs.

By focusing on these recommendations, railway station authorities can create a more user-centric environment that caters to the diverse needs of passengers and enhances their overall travel experience.

4.12 Prioritizing Passenger Experience in Multimodal Interchanges: A Combined Approach with AHP and Benchmarking

Creating Multimodal Interchanges (MMIs) that prioritize passenger experience is no longer a luxury, but a necessity. These transit hubs play a vital role in connecting passengers across different modes of transportation, and a positive experience can significantly impact their overall journey satisfaction. This analysis explores how the Analytic Hierarchy Process (AHP) and benchmarking techniques can be leveraged to achieve this goal.

Understanding Passenger Needs: The Core of User-Centric MMIs

The foundation for any successful MMI development or improvement strategy lies in understanding passenger needs. Passengers prioritize factors that contribute to a smooth, efficient, and comfortable travel experience. Through surveys, workshops, or focus groups, we can gather valuable insights into these priorities. Common themes often include:

- **Accessibility & Connectivity (A&C):** This encompasses aspects like ease of access for passengers with diverse abilities, clear wayfinding signage, and minimized transfer times between platforms or exits. Seamless navigation within the MMI reduces stress and ensures passengers reach their destinations efficiently.
- **Efficiency & Reliability (ER):** Streamlined travel processes contribute significantly to a positive experience. Passengers value user-friendly ticketing procedures, clear and informative signage for navigating the MMI, and well-coordinated services (e.g., with local transportation) for a smooth arrival and departure experience.
- **User Experience (UX):** Security, staff assistance, and amenities all contribute to a positive user experience. Passengers feel more secure in an environment with effective security measures. Additionally, helpful and service-oriented staff can address concerns and provide guidance. Amenities like clean restrooms, comfortable waiting areas with luggage

storage facilities, and potentially retail options depending on passenger demographics and ridership patterns, further enhance the overall experience.

The Analytic Hierarchy Process (AHP): Structuring Passenger Preferences

The Analytic Hierarchy Process (AHP) is a powerful tool for making complex decisions by structuring pairwise comparisons of different factors based on their relative importance to a specific objective. In the context of MMIs, AHP helps us prioritize the various passenger experience criteria we identified earlier.

Here's a breakdown of the AHP process for MMI development:

1. **Identifying Key Criteria:** As mentioned previously, the first step involves defining the key criteria influencing passenger experience at MMIs. These typically include Accessibility & Connectivity (A&C), Efficiency & Reliability (ER), User Experience (UX), and Passenger Amenities (PA).
2. **Constructing the AHP Matrix:** A core step in AHP involves creating a comparison matrix. This matrix compares each criterion with every other criterion to determine which one is more important for passenger experience. Scores are assigned based on a scale (e.g., 1 for equal importance, 3 for moderate importance, 5 for strong importance, and 7 for extreme importance).

Matrix				
Parameters	Accessibility & Connectivity	Passenger Amenities	Efficiency & Reliability	User Experience
Accessibility & Connectivity	1	5	3	4
Passenger Amenities	0.2	1	0.33	0.5
Efficiency & Reliability	0.33	3	1	2
User Experience	0.25	2	0.5	1
Sum	1.78	11	4.83	7.5

Figure 4-18 AHP matrix for KPI's

3. **Weighting Criteria:** Based on the pairwise comparisons in the matrix, AHP calculates weights for each criterion. These weights reflect the relative importance of each factor in influencing passenger experience. For

instance, if A&C receives a consistently higher score in the comparisons with other criteria, it will have a higher weight, indicating its greater significance for passengers.

Parameters	Accessibility & Connectivity	Passenger Amenities	Efficiency & Reliability	User Experience	Criteria Weight
Accessibility & Connectivity	0.56	0.45	0.62	0.53	0.54
Passenger Amenities	0.11	0.09	0.07	0.07	0.08
Efficiency & Reliability	0.19	0.27	0.21	0.27	0.23
User Experience	0.14	0.18	0.10	0.13	0.14

Figure 4-19 Criteria Weight calculation

4. **Consistency Check:** To ensure consistency in the pairwise comparisons, AHP calculates a Consistency Ratio (CR). A CR less than 0.1 indicates acceptable consistency. If the CR is greater than 0.1, the pairwise comparisons might need to be revised to improve consistency.

Lamda max.	4.047
Consistency Index	0.0157
Consistency Ratio	C.I / R.I
	0.0174
C.I	0.0174<<0.1

Figure 4-20 Consistency Check

5. **AHP Index and MMI Assessment:** Once consistency is established, the AHP Index is calculated for different MMI design proposals or improvement options. This index considers both the weights assigned to each criterion (derived from the pairwise comparisons) and the ratings of sub-criteria within each criterion. The MMI option with the highest AHP Index is likely to provide the most positive passenger experience.

Benchmarking for Enhanced Insights: Learning from Existing MMIs

While AHP provides a valuable framework for prioritizing passenger preferences, it can be further enhanced by incorporating benchmarking techniques. Benchmarking involves comparing the performance of an MMI against a set of pre-defined metrics with similar MMIs. This allows us to identify best practices and areas for improvement.

K-means clustering, a data mining technique, can be used to group MMIs with similar characteristics based on passenger survey data. This enables us to

compare an MMI, like New Delhi Railway Station (NDLS), with its most relevant peers within the same K-means cluster.

Here's how benchmarking can be integrated with AHP:

- **Performance Equation:** The final equation derived from the AHP process (MMII = 0.54 AC + 0.08 PA + 0.23 ER + 0.14 UE) represents the weighted average of the criteria based on their relative importance. This formula can be used to assess the performance of an MMI based on how well it addresses each criterion as weighted by passenger preferences.

MMII = 0.54 AC + 0.08 PA + 0.23 ER + 0.14 UE

Figure 4-21 Performance Equation of NDLS MMI

• **Benchmarking for MMII**	
• A	• 0-1.35
• B	• 1.36-1.98
• C	• 1.99-2.4
• D	• 2.41-3.03
• E	• 3.04-5

- **Benchmarking Analysis:** By using K mean clustering the benchmark criteria are set. The benchmark is made using 50 samples. And rest 250 sample survey rating for NDLS is assessed to give a overall rating of 2.80, with a corresponding Level of Service (LOS) of D. This indicates room for improvement. By comparing NDLS's score with other MMIs authorities can pinpoint specific areas where NDLS falls short. For instance, if other MMIs in the cluster consistently score higher in Accessibility & Connectivity (A&C) due to their well-designed wayfinding systems, NDLS can prioritize improvements in this area.

Benefits of a Combined Approach: Data-Driven Decisions for Improved MMIs

Leveraging AHP and passenger preferences, along with benchmarking data, empowers railway station authorities to make data-driven decisions regarding MMI development and improvement. This combined approach offers several significant benefits:

- **Structured Approach:** AHP provides a systematic framework for prioritizing passenger needs during MMI development or improvement. It facilitates a clear understanding of which factors matter most to passengers, ensuring resources are allocated effectively to address these priorities.
- **Data-Driven Decisions:** Both AHP and benchmarking rely on passenger data. AHP uses pairwise comparisons and potentially survey data to understand relative importance, while benchmarking utilizes survey data and LOS ratings from existing MMIs to identify best practices and target improvement areas. This ensures that decisions are not based on subjective assumptions but on concrete data reflecting passenger preferences and industry standards.
- **Continuous Improvement:** Benchmarking allows for ongoing performance evaluation. By periodically comparing the MMI's performance with relevant peers, authorities can identify areas where they are falling behind and implement targeted improvements to maintain a competitive edge and a positive passenger experience.

Conclusion: MMIs Designed for People

By prioritizing passenger experience through a combined approach of AHP and benchmarking, railway station authorities can create MMIs that cater to diverse passenger needs. This not only enhances passenger satisfaction but also contributes to a more efficient and reliable overall transportation network. Ultimately, MMIs designed with user experience at the forefront will lead to a more positive and seamless travel experience for everyone.

Additional Considerations:

- While this analysis focuses on AHP and K-means clustering, other decision-making tools and data mining techniques can be explored for further insights.

- Sub-criteria can be incorporated within each main AHP criterion for a more granular analysis. For instance, A&C could include sub-criteria like elevator availability, signage clarity, and pedestrian crossing efficiency.
- Continuously gathering passenger feedback through surveys or suggestion boxes allows for evolving MMI designs that adapt to changing passenger needs and preferences.

By embracing a data-driven approach that prioritizes passenger experience, railway station authorities can transform MMIs from mere transit hubs into user-friendly spaces that facilitate a smooth and enjoyable travel experience.

4.13 **Issues Identified**

Ticketing Strain: Long queues and out-of-order kiosks indicate ticketing system bottlenecks.

Poor Coordination: Misaligned schedules between rail and other transport modes cause long waits, especially outside of peak hours.

Inefficient Transfers: Long distances or confusing layouts lead to longer transit times and missed connections.

Staffing Shortages: Lack of staff support highlights a need for better staffing levels and training for assisting diverse users.

Limited Feedback: Insufficient feedback mechanisms create a disconnect between users and management.

Accessibility Barriers: Lack of inclusive maps and accessible resources hinders users with disabilities.

5 Way forward and Recommendations.

5.1 Recommendations

The recommendations are Clustered into 3 depending on the urgency and importance of the Factors, 1 high priority, medium and last lower priority. Followed by these is the Innovative Innovations, which may be help in addressing certain challenge by utilizing technological advancement

5.1.1 High Priority

- Accessibility & Connectivity: Address age-related disparities and physical barriers. This is foundational to an inclusive interchange.
- Security: Prioritize any urgent security concerns, as safety is paramount.
- Restroom and Cloakroom: Hygiene and basic facilities are essential for a positive experience.

5.1.2 Medium Priority

Staffing: While not as urgent as fundamental accessibility or safety, inadequate staffing detracts from the overall experience.

Ticketing Bottlenecks: Long delays and frustration can significantly impact user satisfaction.

Coordination & Connectivity: Improving mismatched schedules, especially for off-peak hours, significantly widens the interchange's usability.

5.1.3 Lower Priority

Wayfinding & Signage: Important, but less critical if users can generally get around, even if inefficiently.

Waiting Areas: Focus on this after addressing core needs.

Feedback Mechanisms: While valuable, having a system in place is less urgent than addressing immediate pain points.

5.2 Innovative Interventions

5.2.1 Smart Interchanges: Optimizing the Passenger Experience

Multimodal interchanges face the challenge of balancing efficiency, safety, and user-friendliness for a diverse range of passengers. This report outlines key recommendations for implementing smart technologies and innovative design

approaches to create interchanges that prioritize user needs, optimize facility operations, and foster accessibility.

5.2.2 Enhancing Passenger Comfort and Convenience

Smart Restroom Solutions: Integrating real-time occupancy sensors with a central display or app can significantly improve restroom availability and reduce wait times. Data-driven cleaning schedules based on usage patterns further optimize the passenger experience and facility hygiene.

5.2.3 Advanced Wayfinding:

Accessibility-focused Apps: Mobile applications designed specifically for users with mobility impairments or visual disabilities are crucial, providing routes tailored to accessibility infrastructure (ramps, elevators, etc.).

Wearable Integration: Haptic feedback devices (smartwatches, discreet wearables) offer an alternative guidance method for those who prefer hands-free directions, especially when visually impaired or when managing luggage.

5.2.4 Gamification and Interactive Waiting Zones

Incentivized Feedback: A points-based system within interchange apps can encourage users to provide feedback on facility conditions and service quality. Rewards promote participation and valuable insights for improvements.

Interactive Waiting Areas: Integrating games or engaging displays in areas prone to delays can reduce perceived wait times, particularly for families traveling with children.

Temporary Amenities: During renovations or peak demand periods, pop-up solutions like restrooms, seating, or mobile charging stations significantly improve user experiences.

5.2.5 Prioritizing Seamless Transfers and Security

Late-Night Connectivity: Strategic partnerships with ride-sharing providers or dedicated interchange shuttles ensure reliable transportation options outside of regular public transportation hours. Integrating booking options within a central interchange app boosts user convenience.

Smart Journey Planning: An intelligent app factoring in user preferences (speed vs. accessibility), real-time delays, and interchange-specific information empowers users to make informed travel decisions, minimizing delays and stress.

Augmented Reality (AR) Wayfinding: Live AR overlays, accessible via smartphones or smart glasses, provide real-time directions within the physical interchange. This is vital for smooth transfers, especially in complex interchanges.

Interactive Information Kiosks: Provide visual maps and estimated walking times between transfer points for those who prefer static information.

5.2.6 Proactive Security Measures:

Wearable SOS Devices: Discreet panic buttons with GPS tracking linked to emergency services offer rapid response and peace of mind for vulnerable users.

Crowdsourced Safety Mapping: Within interchange apps, a designated system for users to anonymously flag well-lit/safe zones and potentially unsafe zones creates a dynamic safety map to inform route choices and targeted security patrols.

5.2.7 Maximizing Operational Efficiency and User-Centricity

Virtual Help Desks: QR codes or interactive signage connect users to remote help personnel for assistance, allowing for flexible staff deployment.

Staff Adaptability: Cross-training staff in ticketing, first aid, and assisting those with disabilities fosters a dynamic workforce and facilitates timely responses during surges in demand or unexpected situations.

5.2.8 Data-Driven Feedback Mechanisms:

Social Media Analysis: Geotagging allows analysis of social media posts within interchange locations to identify sentiment trends and address potential issues proactively.

5.2.9 Accessibility as a Core Principle

Beacon-Based Navigation: Beacons within interchanges transmit spoken directions to compatible apps or devices, assisting visually impaired users with seamless navigation.

VR Empathy Training: Simulations for staff provide a deeper understanding of challenges faced by those with disabilities, leading to more informed and empathetic assistance.

5.2.10 Implementation and Evaluation

Prioritizing these recommendations requires a phased approach. Key considerations include:

Pilot Programs: Test specific technologies in a controlled area before full implementation.

Data Collection: Use sensors and feedback systems to evaluate the effectiveness of solutions.

Cost-Benefit Analysis: Weigh the costs of smart technologies against operational savings and improved user satisfaction.

Public-Private Collaboration: Partnerships with technology providers enable access to cutting-edge solutions.

By strategically integrating these recommendations, multimodal interchanges can transform into welcoming, efficient, and inclusive transportation hubs, enhancing the overall passenger experience.

Annexure

PLOS Assessment of Other stretches

Towrd Railway Station (FOB)					
	Density	Space	Flow Rate	Avg. Spee	Capacity V/C Ration
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
55.80	0.43	2.33	24.26	0.57	0.29
120.70	0.93	1.08	52.48	0.52	0.63
108.40	0.83	1.20	47.13	0.54	0.56
200.70	1.54	0.65	87.26	0.52	1.04
108.60	0.84	1.20	47.22	0.54	0.56
96.60	0.74	1.35	42.00	0.57	0.50
124.20	0.96	1.05	54.00	0.54	0.64
72.10	0.55	1.80	31.35	0.53	0.37
86.30	0.66	1.51	37.52	0.52	0.45
130.10	1.00	1.00	56.57	0.51	0.67
178.90	1.38	0.73	77.78	0.52	0.93
184.80	1.42	0.70	80.35	0.55	0.96
186.70	1.44	0.70	81.17	0.52	0.97
197.40	1.52	0.66	85.83	0.51	1.02
135.20	1.04	0.96	58.78	0.55	0.70
Toward Metro (FOB)					
	Density	Space	Flow Rate	Avg. Spee	Capacity V/C Ration
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
70.90	0.45	2.20	30.83	0.50	0.31
89.10	0.57	1.75	38.74	0.50	0.39
69.20	0.44	2.25	30.09	0.49	0.30
208.00	1.33	0.75	90.43	0.53	0.90
119.70	0.77	1.30	52.04	0.54	0.52
59.70	0.38	2.61	25.96	0.58	0.26
99.60	0.64	1.57	43.30	0.51	0.43
88.90	0.57	1.75	38.65	0.52	0.38
80.00	0.51	1.95	34.78	0.51	0.35
127.00	0.81	1.23	55.22	0.49	0.55
195.60	1.25	0.80	85.04	0.50	0.85
218.50	1.40	0.71	95.00	0.52	0.95
166.90	1.07	0.93	72.57	0.52	0.72
175.90	1.13	0.89	76.48	0.51	0.76
144.90	0.93	1.08	63.00	0.51	0.63

PL 16 Entry/Exit					
	Density	Space	Flow Rate	Avg. Spee	Capacity V/C Ration
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
273.20	0.42	2.37	18.97	0.56	0.36
199.62	0.31	3.25	13.86	0.51	0.26
234.16	0.36	2.77	16.26	0.54	0.31
188.94	0.29	3.43	13.12	0.57	0.25
117.56	0.18	5.51	8.16	0.51	0.16
208.74	0.32	3.10	14.50	0.57	0.28
216.16	0.33	3.00	15.01	0.56	0.29
229.70	0.35	2.82	15.95	0.59	0.30
162.52	0.25	3.99	11.29	0.59	0.21
233.92	0.36	2.77	16.24	0.53	0.31
266.46	0.41	2.43	18.50	0.53	0.35
166.38	0.26	3.89	11.55	0.50	0.22
259.36	0.40	2.50	18.01	0.53	0.34
324.88	0.50	1.99	22.56	0.50	0.43
222.44	0.34	2.91	15.45	0.48	0.29
Towards Entry					
	Density	Space	Flow Rate	Avg. Spee	Capacity V/C Ration
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
78.50	0.50	1.99	34.13	0.57	0.34
48.40	0.31	3.22	21.04	0.52	0.21
46.20	0.30	3.38	20.09	0.62	0.20
42.80	0.27	3.64	18.61	0.62	0.19
10.70	0.07	14.58	4.65	0.64	0.05
42.30	0.27	3.69	18.39	0.58	0.18
67.70	0.43	2.30	29.43	0.58	0.29
56.00	0.36	2.79	24.35	0.61	0.24
27.40	0.18	5.69	11.91	0.69	0.12
62.90	0.40	2.48	27.35	0.53	0.27
55.70	0.36	2.80	24.22	0.55	0.24
31.60	0.20	4.94	13.74	0.52	0.14
69.20	0.44	2.25	30.09	0.53	0.30
67.60	0.43	2.31	29.39	0.55	0.29
35.80	0.23	4.36	15.57	0.53	0.15

Metro to Ground level					
	Density	**Space**	**Flow Rate**	**Avg. Spee**	**Capacity V/C Ration**
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
76.60	0.57	1.76	33.30	0.55	0.43
50.90	0.38	2.65	22.13	0.56	0.28
54.20	0.40	2.49	23.57	0.52	0.30
58.60	0.43	2.30	25.48	0.58	0.33
81.50	0.60	1.66	35.43	0.57	0.45
83.90	0.62	1.61	36.48	0.52	0.47
46.60	0.35	2.90	20.26	0.62	0.26
83.80	0.62	1.61	36.43	0.54	0.47
40.10	0.30	3.37	17.43	0.65	0.22
50.20	0.37	2.69	21.83	0.61	0.28
74.10	0.55	1.82	32.22	0.55	0.41
107.10	0.79	1.26	46.57	0.55	0.60
105.60	0.78	1.28	45.91	0.51	0.59
61.40	0.45	2.20	26.70	0.61	0.34
111.10	0.82	1.22	48.30	0.50	0.62
Under FOB					
	Density	**Space**	**Flow Rate**	**Avg. Spee**	**Capacity V/C Ration**
PEF	(ped/ m2	(m2/Ped)	(Ped/m)	(m/s)	(V/C)
241.74	0.29	3.44	105.10	0.57	0.19
304.38	0.37	2.73	132.34	0.52	0.25
278.28	0.33	2.99	120.99	0.57	0.22
438.30	0.53	1.90	190.57	0.54	0.35
214.74	0.26	3.87	93.37	0.55	0.17
250.02	0.30	3.33	108.70	0.57	0.20
345.42	0.42	2.41	150.18	0.56	0.28
230.58	0.28	3.61	100.25	0.56	0.19
204.66	0.25	4.07	88.98	0.56	0.17
347.40	0.42	2.39	151.04	0.51	0.28
422.28	0.51	1.97	183.60	0.53	0.34
389.52	0.47	2.14	169.36	0.54	0.31
460.62	0.55	1.81	200.27	0.52	0.37
477.00	0.57	1.74	207.39	0.52	0.38
307.80	0.37	2.70	133.83	0.54	0.25

		Area (sqm)	PEF	Average Speed (m/min)
Without Luggage	Male (15-59yr)	0.47	1	52
	Female (15-59yr)	0.39	0.9	49
With polybag/lunch bag	Male (15-59yr)	0.56	1.5	41.6
	Female (15-59yr)	0.47	1.3	39.2
With bag pack	Male (15-59yr)	0.65	1.9	38.1
	Female (15-59yr)	0.52	1.5	37.64
With Duffle Bag	Male (15-59yr)	0.65	2.1	34.36
	Female (15-59yr)	0.55	1.9	32.28
With Duffle &Bag pack	Male (15-59yr)	0.9	3.3	29.6
	Female (15-59yr)	0.77	3.2	26.32
With Trolley Bag	Male (15-59yr)	1.96	7.6	28.56
	Female (15-59yr)	1.52	6.4	26.3
With Trolley & Bag pack& Duffle Bag	Male (15-59yr)	2.41	11.8	22.4
With Trolley &Duffle Bag	Male (15-59yr)	2.41	10	26.6
	Female (15-59yr)	1.83	8.6	23.31
kids	5-14 YRS	0.22	0.6	40
	5-14 YRS	0.22	0.6	40
With Infant (0-4 Yr)		0.51	1.6	34.36
With Infant (0-4 Yr)		0.51	1.6	34.36

Questionnaire and formats

Survey by School of Planning and Architecture (Transport Department)

PEDESTRIAN PATH NETWORK INVENTORY SURVEY

Enumerator(s) Name :

From	To	Length	Surface		Footpath		Street Light (yes/no)			Benches			Trash Can			Bike Stand			Footpath Encroachment		Availibity of signage	no. of siganges directing towward PT	Existing Pedestrian Safety Measures	Universal Accessibility	Remarks
			Type	Quality	Width (m)	Curb Height	Type	Count	Dist. between 2	Type	Count	Dist. between 2	Type	Count	Dist. between 2	Type	Count	Dist. between 2	Type	Heavy/ Moderate/ Low)					

	No Luggage		Only Hand Bag		Only BAGPACK		1 DUFFLE BAG		g (Duffle+Bagp		1 TROLLEY		2 Trolley bags		and duffel / Ba		kids		with infant	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	
1 min																						
2 min																						
3 min																						
4 min																						
5 min																						
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15 min																						

योजना एवं वास्तुकला विद्यालय, भोपाल
School of Planning and Architecture, Bhopal
An Institute of National Importance, Ministry of Education, Government of India

Gender_____ Age_____ Family size____ Luggage_____ Time____

Q1. Which mode did you choose to arrive/ Depart from NDLS?

a. Bus
b. Metro
c. Airport Express
d. Cab/Taxi/Ola/Uber
e. Auto
f. E-rikshaw
g. Ring rail
h. Private vehicle

Others _____

Q2. Trip Purpose?

a. Educational
b. Leisure travel
c. Business
d. Work
e. Visiting family/ Relatives
f. Transit

Others _____

Q3. Origin _____ **Destination** _____

Q4. How early do you prefer to reach the railway station? _____

Q5 Time taken to reach railway station from the Origin/ Destination (in Delhi) _____

Q4. **Annual Frequency?**

a. 1 time
b. 2-5 times
c. 5- 10 times
d. More than 10

Q5. **How often do you use Bus?**

a. Every time
b. Occasional
c. Rare
d. Never

Q6. How often do you use Metro?

a. Every time
b. Occasional
c. Rare
d. Never

Q9. Time taken to reach platform/ waiting area from the transit hub/ Platform?

a. Less than 5 mins
b. 5-10 mins
c. 10 – 15 mins
d. More than 15 mins

Q10. What is your Qualification?

a. Highschool
b. Intermediate
c. Bachelors
d. Masters
e. Doctorate
f. Others

Q11. What is your annual Income?

a. Less than 2 lakhs
b. 2 – 5 Lakhs
c. 5 – 10 lakhs
d. More than 10 lakhs

Q12 Which factors affects your mode choice while traveling to/from NDLS? _____

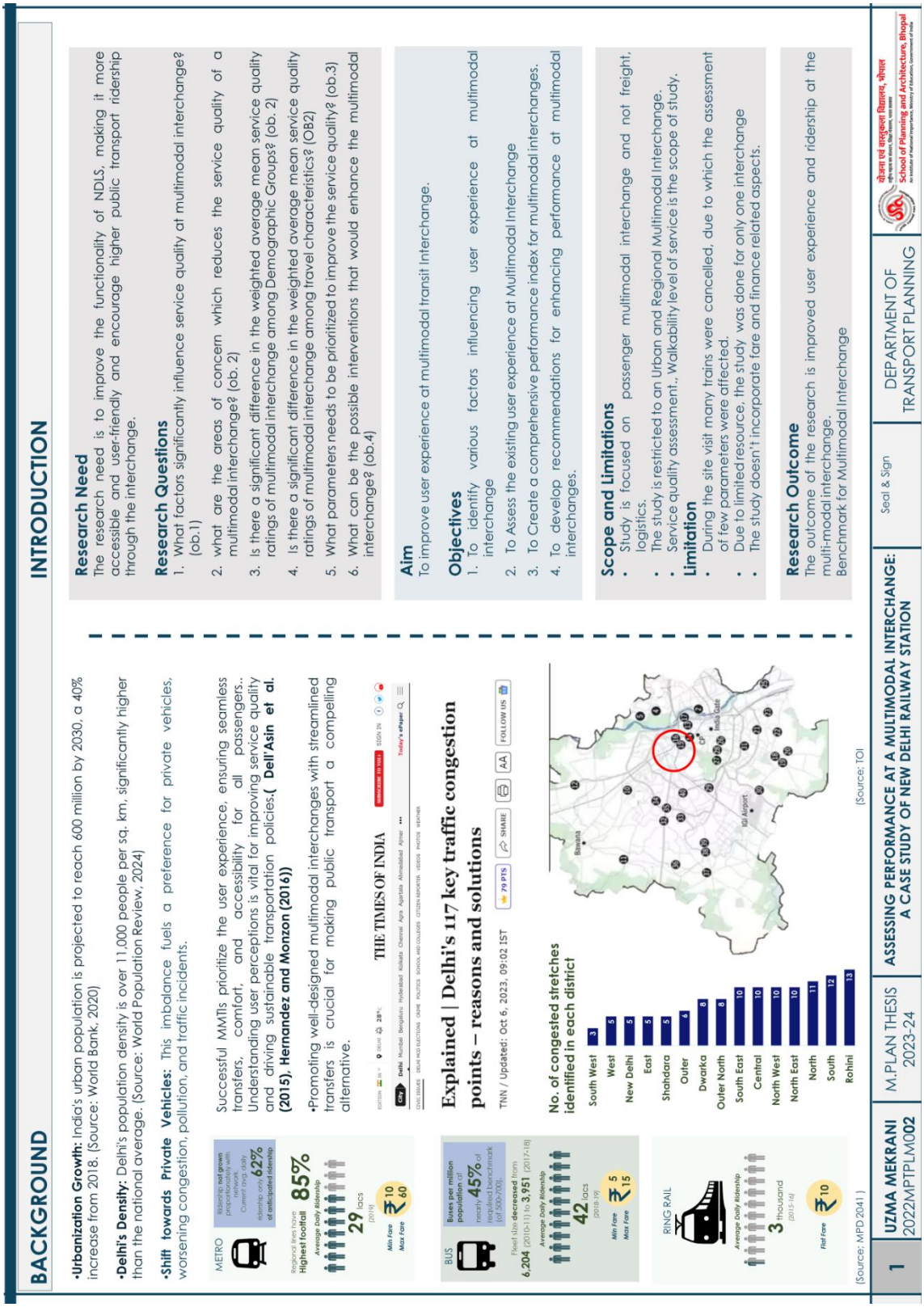
Note* This confidential survey supports academic research only; your responses will not be shared or used for any other purpose.

योजना एवं वास्तुकला विद्यालय, भोपाल
School of Planning and Architecture, Bhopal
An Institute of National Importance, Ministry of Education, Government of India

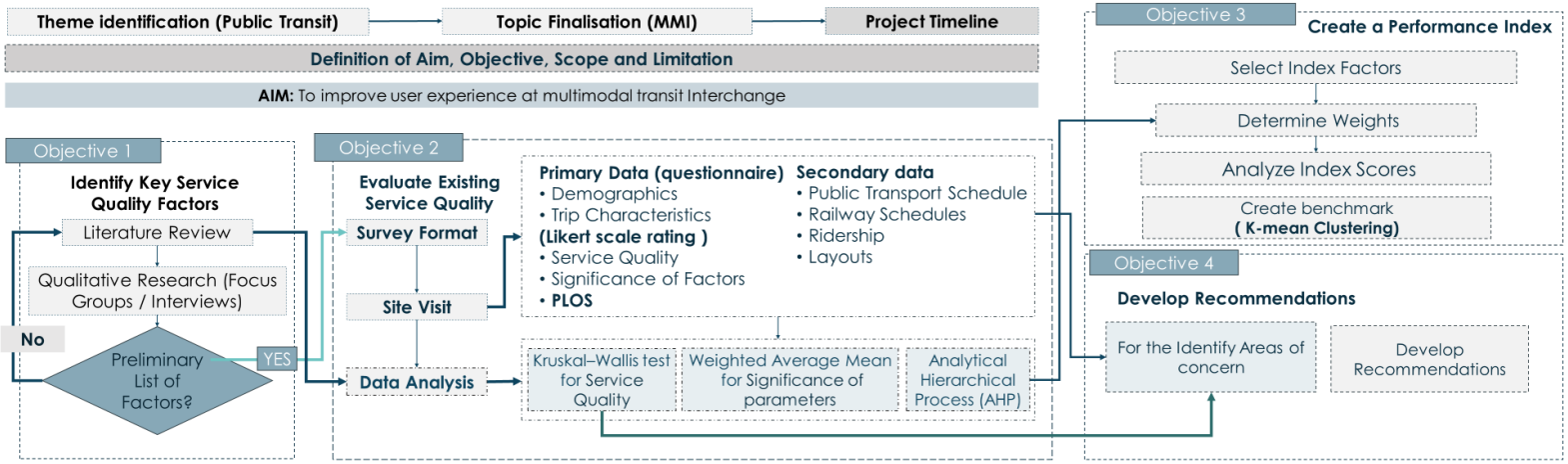
Rate the following for MMII (1means unsatisfactory, 10 means satisfactory)	1	2	3	4	5
Ease of Direction/ Wayfinding (EOD)					
Information booths					
Accessibility (UA)					
Quality of walkway (QS)					
Transfer time (TT) & TD					
Restrooms (R)					
Retail (RO)					
Waiting (WA)					
Space for Luggage					
Comfort areas					
Coordination (CT)					
Ease of Access (EA)					
Signage (S)					
Ticketing Booth (TB)					
Real time information (RTI)					
Security (SS)					
Staff (AS)					
Frequency (FS)					
Inclusive Info Communication (IIC)					
Rate the following preferences for MMII (1means unsatisfactory, 10 means satisfactory)	1	2	3	4	5
Ease of Direction/ Wayfinding (EOD)					
Information booths					
Accessibility (UA)					
Quality of walkway (QS)					
Transfer time (TT) & TD					
Restrooms (R)					
Retail (RO)					
Waiting (WA)					
Space for Luggage					
Comfort areas					
Coordination (CT)					
Ease of Access (EA)					
Signage (S)					
Ticketing Booth (TB)					
Real time information (RTI)					
Security (SS)					
Staff (AS)					
Frequency (FS)					
Inclusive Info Communication (IIC)					

Note* This confidential survey supports academic research only; your responses will not be shared or used for any other purpose.

Sheets


BACKGROUND
•Urbanization Growth: India's urban population is projected to reach 600 million by 2030, a 40% increase from 2018. (Source: World Bank, 2020)
•Delhi's Density: Delhi's population density is over 11,000 people per sq. km, significantly higher than the national average. (Source: World Population Review, 2024)
•Shift towards Private Vehicles: This imbalance fuels a preference for private vehicles, worsening congestion, pollution, and traffic incidents.
METRO
Ridership not grown proportionately with network. Current ridership only 62% of anticipated ridership
Regional lines have Highest footfall
Average Daily Ridership
29 lacs (2019)
Min Fare ₹ 10
Max Fare ₹ 60
Successful MMTs prioritize the user experience, ensuring seamless transfers, comfort, and accessibility for all passengers.. Understanding user perceptions is vital for improving service quality and driving sustainable transportation policies.(Dell'Asin et al. (2015), Hernandez and Monzon (2016))
•Promoting well-designed multimodal interchanges with streamlined transfers is crucial for making public transport a compelling alternative.
THE TIMES OF INDIA
Explained | Delhi's 117 key traffic congestion points – reasons and solutions
TNN / Updated: Oct 6, 2023, 09:02 IST
70 PTS SHARE FOLLOW US
BUS
Buses per million population at nearly 45% of required benchmark (of 500-700).
Fleet size decreased from 6,204 (2010-11) to 3,951 (2017-18)
Average Daily Ridership
42 lacs (2018-19)
Min Fare ₹ 5
Max Fare ₹ 15
No. of congested stretches identified in each district
South West 3
West 5
New Delhi 5
East 5
Shahdara 5
Outer 6
Dwarka 8
Outer North 8
South East 10
Central 10
North West 10
North East 10
North 11
South 12
Rohini 13
Bawana
IGI Airport
India Gate
(Source: TOI)
RING RAIL
Average Daily Ridership
3 thousand (2015-16)
Flat Fare ₹ 10
(Source: MPD 2041)
INTRODUCTION
Research Need
The research need is to improve the functionality of NDLS, making it more accessible and user-friendly and encourage higher public transport ridership through the interchange.
Research Questions
1. What factors significantly influence service quality at multimodal interchange? (ob.1)
2. what are the areas of concern which reduces the service quality of a multimodal interchange? (ob. 2)
3. Is there a significant difference in the weighted average mean service quality ratings of multimodal interchange among Demographic Groups? (ob. 2)
4. Is there a significant difference in the weighted average mean service quality ratings of multimodal interchange among travel characteristics? (OB2)
5. What parameters needs to be prioritized to improve the service quality? (ob.3)
6. What can be the possible interventions that would enhance the multimodal interchange? (ob.4)
Aim
To improve user experience at multimodal transit Interchange.
Objectives
1. To identify various factors influencing user experience at multimodal interchange
2. To Assess the existing user experience at Multimodal Interchange
3. To Create a comprehensive performance index for multimodal interchanges.
4. To develop recommendations for enhancing performance at multimodal interchanges.
Scope and Limitations
• Study is focused on passenger multimodal interchange and not freight, logistics.
• The study is restricted to an Urban and Regional Multimodal Interchange.
• Service quality assessment., Walkability level of service is the scope of study.
Limitation
• During the site visit many trains were cancelled, due to which the assessment of few parameters were affected.
• Due to limited resource, the study was done for only one interchange
• The study doesn't incorporate fare and finance related aspects.
Research Outcome
The outcome of the research is improved user experience and ridership at the multi-modal interchange.
Benchmark for Multimodal Interchange
1
UZMA MEKRANI
2022MPTPLM002
M.PLAN THESIS
2023-24
ASSESSING PERFORMANCE AT A MULTIMODAL INTERCHANGE: A CASE STUDY OF NEW DELHI RAILWAY STATION
Seal & Sign
DEPARTMENT OF TRANSPORT PLANNING
School of Planning and Architecture, Bhopal

METHODOLOGY



Literature Review

Authors	Study Area	Socio-demographics (SD)	Travel characteristics (TC) analyzed	Statistical analysis technique	Factors Analyzed	Critical Factors/Results
Abreu e Silva and Bazrafshan (2013)	Lisbon, Portugal, metropolitan area (LMA)	No SD factors directly examined	Not explicitly stated	Structural Equation Modelling (SEM)	Access, Connection & Reliability, Information, Amenities, & Safety & Security	Guidance signs positively affected user perception, while graffiti and litter negatively affected perception
Allen et al. (2019)	Madrid Metro	Age, Gender, Nationality	Travel Day of the Week, Travel Purpose, Travel Frequency, Ticket Type, Time of Day	Structural Equation System (SEM-MGA)	Service quality attributes, Customer satisfaction, Critical Incidents	All satisfaction constructs significantly predicted loyalty and overall satisfaction
Allen et al. (2020)	Milan, Italy	Age, Gender, Education Level, Income	Ticket Type, Access Mode, Time of Day, Travel Frequency	Structural Equation Multiple Indicator Multiple Cause (SEM-MIMIC)	Reliability, Safety, Comfort, Customer's intent to recommend the service	Overall Satisfaction was the key outcome variable
Chia et al. (2016)	Brisbane, Australia	Age, gender, income, education level, occupation, driving license, vehicle ownership	Travel purpose, travel mode	ANOVA Testing and Cluster Analysis	Socio-economic characteristics AND their relationship to interchange usage	Walking time to bus stop was a significant factor
De Ona et al. (2012)	Granada metropolitan bus	No SD factors directly examined	Frequency, Proximity, Speed, Safety	CART (classification and regression tree) model	Information, Punctuality, Safety, Courtesy, Cleanliness, Space, Temperature, Accessibility, Fare, Speed, Frequency, Proximity	Frequency (Pre-evaluation) & Speed, Proximity, Safety (Post-evaluation) were most important
Dell'Asin et al. (2015)	Gothenburg Transport Hub	No SD factors directly examined	Not explicitly stated	Multiple Correspondence Analysis (MCA)	Supply, Time, Space, Information, Services	Services & Interconnectivity were key to positive perception

Authors	Study Area	Socio-demographics (SD)	Travel characteristics (TC) analyzed	Statistical analysis technique	Factors Analyzed	Critical Factors/Results
Eboli and Mazzulla (2007)	University of Calabria	Age, Gender, Driver's License, Car Ownership, Socio-Economic class, Residing Inside/Outside Urban Area	Travel Mode, Trip purpose, Bus Service Frequency, Route, Duration	Structural Equation Modelling (SEM)	Service planning & reliability, Comfort & other factors, Network design	Service planning & reliability had the most significant impact
Hernandez and Monzon (2016)	Ilford (London, UK)	No SD factors directly examined	Not explicitly stated	Principal Component Analysis (PCA)	Safety & Security, Information, Transfer conditions	Identified key groupings of service attributes
Ho et al. (2020)	Tyneside, UK	Age, Car ownership, Occupation	Travel Frequency, Travel Mode, Day of Travel	Multinomial Logit Model (MNL)	Factors influencing mode choice for accessing interchanges	Study focused on mode choice, not interchange experience
Iseki and Taylor Jinliao et al. (2018)	12 stations around the US Nanjing Metro, China	Age, gender, income	Travel time	Connection & Reliability, Safety Importance-Satisfaction (I-S) ANOVA Testing and Cluster Analysis	Connection & Reliability, Safety Factors related to transfer time within stations	Safety was rated most important and most satisfactory Study focused on walk time, not overall satisfaction
Kim et al. (2018)	Seoul metropolitan area, South Korea	Age, gender	Travel purpose, transfer time	Rasch Analysis	Information, Mobility, Comfort, Convenience, Safety & Security	Information & Convenience were deemed most important
Li and Loo (2016)	Shanghai, China	Age	Travel purpose, travel frequency, interchange mode, luggage, persons accompanying, ticket purchase, transfer	Analysis of Variance (ANOVA) Testing	Signage, Information provision, Time coordination between modes, Luggage delivery facilities, Through ticketing, Interchange discount	These factors were shown to significantly affect satisfaction
Li et al. (2020)	Xi'an, China	Age, Gender, Occupation, Income, Car Ownership	Travel Purpose, Ticketing Method, Access Mode, Departure Mode, Access Time, Departure Time	Bayesian Binomial Logit (BBL) Model	Factors related to passengers' choice of interchange access/egress modes	Study focused on mode choice, not interchange experience
Lois et al. (2018)	Moncloa interchange, Spain	Age, gender, income, driving license	Travel purpose, queuing	Regression Analysis and Path Analysis	Information, Safety & Security	Information and Safety & Security significantly predicted satisfaction
Meena et al. (2019)	Mumbai, India	Age, Gender, Occupation, Income	Travel Purpose, Travel Mode, Travel Cost, Travel Distance, Waiting Time, Walking Time, Driving License	Multinomial Logit (MNL), Nested Logit (NL) models	Factors influencing the choice of interchange mode	Study focused on mode choice, not interchange experience
Meng et al. (2018)	Singapore	Age, gender, occupation	Transfer walking time, travel distance, travel purpose	Linear Regression	Factors associated with passengers' tolerance levels of transfer walking time	Study focused on walk time, not overall satisfaction
Nathanail (2008)	Hellenic railways, Greece	No SD factors directly examined	Not explicitly stated Improved Transfer Facilities, Pedestrian Safety, Visual Communication, Prioritize fare, Commuters' preferences	Multicriteria Evaluation (Grading & Weightage)	Itinerary Accuracy, System Safety, Cleanliness, Passenger Comfort, Servicing, Passenger Information	System Safety, Accuracy, Servicing were ranked most important
Sadhukhan et al. (2015)	Kolkata, India	Age, Gender, Income		Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Access Time, Pedestrian pathway, Fare, Pedestrian environment, Pedestrian Crossing, Level Change, Visual Communication	Pedestrian environment and Pedestrian pathway were most crucial
Sadhukhan et al. (2016)	Kolkata, India	Income	Travel time	Random Parameter Logit (RPL) Model	Willingness-to-pay (WTP) for specific interchange improvements	Study focused on WTP, not satisfaction levels
Sadhukhan et al. (2018)	Kolkata, India	Gender, Car ownership	Travel frequency	Relative to an Identified Distribution Integral Transformation (RIDIT) analysis	Factors related to satisfaction with transfer facilities	No direct link to specific service attributes
Sarkar and Mallikarjun (2018)	Agartala, India	Age, gender, education, income, driving license, vehicle ownership, family size	Travel mode, travel purpose, travel frequency, travel time, travel cost	Structural Equation Modelling (SEM)	Comfort, Flexibility, Travel time, Travel Cost, Vehicle Ownership	Attitude and perception (comfort, flexibility) significantly predicted mode choice
Yen et al. (2018)	Southeast Queensland (SEQ), Australia	Age, income, education level, employment status	Travel time, travel cost, travel purpose	Multinomial Logit Modelling	Factors influencing passenger preferences, including attitudes toward transfers	Travel Time, Travel Cost, Vehicle Ownership, Comfort, Flexibility were significant. Proposed zone-based fares without inter-zone transfer penalties
Zhao and Li (2017)	Beijing, China	Age, gender, income, car ownership	Travel distance, travel time, travel mode	Multilevel Logistic Regression	Factors influencing cycling to access metro stations	Green spaces, mixed land use, cycling infrastructure, and public bike-sharing encouraged cycling access
Zhao et al. (2018)	Beijing High-Speed Train Station, China	Age, gender, income, education level	Travel purpose, travel distance, travel range, persons accompanying, long-distance travel frequency	Decision Tree and Binary Logistic Regression	Factors influencing passengers' egress mode choices for the interchange	Study focused on mode choice, not interchange experience

LITERATURE REVIEW

Objective 1

Socio-Demographics

- Age
- Gender
- Occupation
- Income
- Vehicle Ownership
- Education Levels
- Driving License
- Family Size
- Nationality
- Marital Status

Travel Characteristics

- Purpose
- Frequency
- Time
- Cost
- Mode
- Distance
- Transfer Time
- Time of the Day
- Vehicle Ownership
- Ticket Taking time
- Luggage

Accessibility & Connectivity

Physical Accessibility
- Ramp access
- Elevators (capacity, accessible controls)
- Accessible restrooms
- Tactile paving
- Designated accessible parking

Navigational Accessibility
- Intuitive wayfinding design
- Digital wayfinding tools (accessible interfaces)
- Maps and information (multiple formats)

Connectivity to Surroundings
- Safe pedestrian paths (sidewalks, crossings)
- Designated drop-off/pick-up zones
- Bicycle parking facilities

Passenger Amenities

Basic Amenities
- Clean and plentiful restrooms
- Comfortable seating (varied options)
- Drinking fountains/refilling stations
- Variety of food & beverage options
- Retail outlets (travel essentials, convenience)

Additional Amenities
- Luggage storage
- Family restrooms/nursing areas
- Public Wi-Fi
- ATMs, currency exchange
- Charging stations

Efficiency & Reliability

Operational Efficiency
- Schedule adherence
- Frequency of service
- Smooth transfers
- Real-time information (accuracy, availability)

Ticketing Systems
- Ease of use (kiosks, counters, online)
- Multiple purchase options
- Clear instructions

Contingency Plans
- Procedures for disruptions
- Effective user communication

User Experience

Informational Clarity
- Signage (design, placement, language)
- Announcements (clarity, audibility)
- Information booths/help desks
- Ticketing machine interfaces

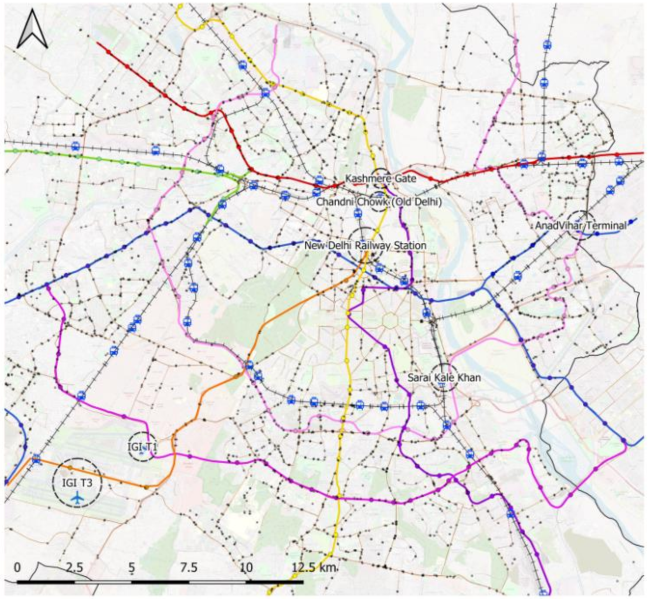
Comfort and Ambiance
- Cleanliness and maintenance
- Temperature control
- Noise management
- Lighting (adequate, safety)

Responsiveness and Support
- Staff visibility and presence
- Proactive assistance
- Issue resolution efficiency
- User-friendly feedback mechanisms

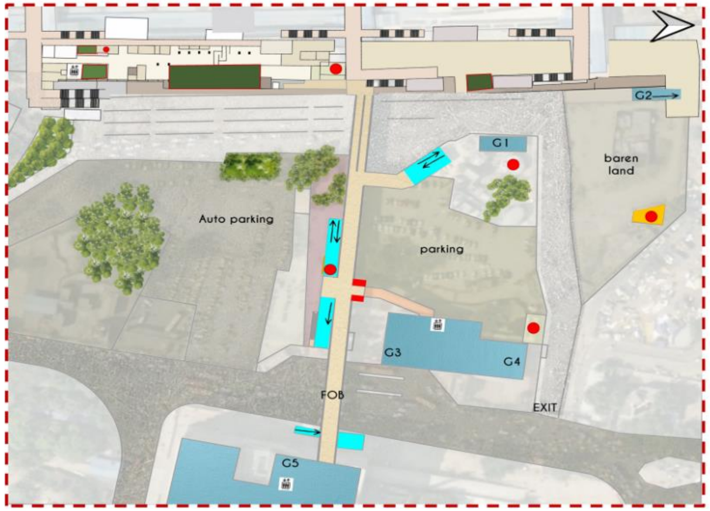
SITE SELECTION

Objective 1

Name		New Delhi Railway Station	Kashmere Gate	Chandni Chowk (Old Delhi)	Anand Vihar Terminal	Sarai Kale Khan	IGI T3	IGI T1
Daily Footfall		5,00,000	2,40,000	2,50,000	80,000	65,000-97,000	5,95,000	
Metro Ridership		166762	2,40,480	136696	73,315	33218	33114	27688
Mode availability	Bus	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Railway	Yes	No	Yes	Yes	Yes	No	No
	Airway	No	No	No	No	No	Yes	Yes
	Metro	Yes	3	Yes	Yes	Yes	Yes	Yes
	Local Train	Yes	No	Yes	Yes	Yes	No	No
	IPT	Yes	Yes	Yes	Yes	Yes	No	No
	Taxi	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Express Metro	Yes	No	No	No	No	No	No
	ISBT	No	Yes	No	Yes	Yes	No	No



Average Daily Ridership at NDLS (Dec 2023)
1. Railway – 5.6 Lakhs
2. Metro – 1,33,648
3. Express Metro – 33,114
4. Avg. Bus Ridership – 25,000



5	UZMA MEKRANI 2022MPTPLM002	M.PLAN THESIS 2023-24	ASSESSING PERFORMANCE AT A MULTIMODAL INTERCHANGE: A CASE STUDY OF NEW DELHI RAILWAY STATION	Seal & Sign	DEPARTMENT OF TRANSPORT PLANNING	योजना एवं वास्तुकला विद्यालय, भोपाल School of Planning and Architecture, Bhopal

DATA COLLECTION

Objective 2

Category	Literature	Quality Rating Parameter
Accessibility & Connectivity	**Physical Accessibility:** Ease of navigation for those with disabilities (ramps, elevators, tactile paving, clear signage, etc.) & **Wayfinding:** Ease of finding platforms, connecting transport, key destinations (physical & digital tools)	Ease of Direction/ Wayfinding
	Transfer time & Distance: The physical distance & time users must walk when switching between modes.	Transfer time (TT) & TD
	Quality of Walkway: smooth, wide, free of cracks or obstructions, shade structures to protect pedestrian	Quality of walkway(QS)
	Information: Comprehensive info boards, help desks, announcements on platforms, connections, etc.	Information Systems
	Connectivity to Surroundings: Safe, accessible sidewalks, clear routes to destinations, bike parking, drop-off zones	Universal Accessibility
Passenger Amenities	**Basic Amenities:** Clean restrooms, , drinking fountains/refill stations	Restrooms
	Food & Beverage: Variety of options (healthy, affordable), catering to different dietary needs	F&B Options
	Retail: Essentials, travel items, newsstands	Retail Outlets &
	Luggage Storage: Lockers or staffed services	Luggage Storage Options
	Family-Friendly: ample seating (varied options), Dedicated restrooms, nursing areas, child-friendly zones	Waiting Areas
Efficiency & Reliability	**Schedule Adherence:** On-time performance of different modes, minimizing delays	Schedule & Frequency Integration
	Frequency: Sufficient frequency, especially during peak hours, minimizing long waits	
	Signage: Clear, well-placed, easy-to-understand, available in multiple languages as needed	Availability of Signage
	Transfer Efficiency: Smooth transfers, clear signage, minimized walking distances	Transfer Efficiency
	Ticketing: Ease of use, multiple options (kiosks, online, counters), efficient handling of queues	Efficiency Ticketing
	Real-time Information: Accurate, up-to-date displays and announcements on delays, platform changes, etc.	Real time information
User Experience	**Security:** Visible security, cameras, well-lit areas, emergency call points	Security
	Staff Assistance: Visible, approachable staff, proactive assistance, knowledgeable about the interchange	Staff Assistance
	Issue Resolution: Quick response to problems, clear escalation paths, keeping users informed	Feedback Mechanism
	Inclusivity: Signage, announcements in multiple languages, staff sensitivity training	Inclusive Maps/layouts Availability

Travel characteristics
- Luggage's
- No. of Person Accompanying
- Transfer Time
- Travel Frequency & Purpose
- Travel distance & Direction

Socio Demographic
- Age
- Gender
- Annual Income
- Qualification

Qualitative Assessment (Inventory & Photographs, Videos)
- Safety (Illumination & surveillance)
- Availability of Street furniture
- Distance & connectivity
- Waiting area or Seating
- Shaded Pathways
- Que length
- Availability of Signages
- Information regarding ticketing
- Maintenance and cleanliness
- Pedestrian count

Accessibility & Connectivity

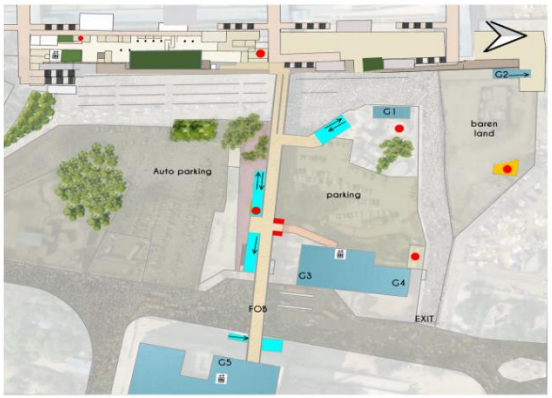
Objective 2

Hinderance in signage

Staircase & Escalator Utilization

Footpath & Road utilization

Accessibility to PT access and Ramp Placement



Accessibility & Connectivity rating

Null Hypothesis	Test	Sig.[a,b]	Decision
The distribution of AC is the same across categories of age	**Independent-Samples Kruskal-Wallis Test**	**0.040**	**Reject the null hypothesis.**
The distribution of AC is the same across categories of Gender.	Independent-Samples Mann-Whitney U Test	0.654	Retain the null hypothesis.
The distribution of AC is the same across categories of qualifitcation.	Independent-Samples Kruskal-Wallis Test	0.601	Retain the null hypothesis.
The distribution of AC is the same across categories of Annual_Income.	Independent-Samples Kruskal-Wallis Test	0.459	Retain the null hypothesis.
The distribution of AC is the same across categories of Mode_choice.	Independent-Samples Kruskal-Wallis Test	0.544	Retain the null hypothesis.
The distribution of AC is the same across categories of Time_spent_on_railway_station.	Independent-Samples Kruskal-Wallis Test	0.504	Retain the null hypothesis.
The distribution of AC is the same across categories of Trip_Purpose.	Independent-Samples Kruskal-Wallis Test	0.633	Retain the null hypothesis.
The distribution of AC is the same across categories of Annual_Frequency.	Independent-Samples Kruskal-Wallis Test	0.591	Retain the null hypothesis.

Inferences:

Age

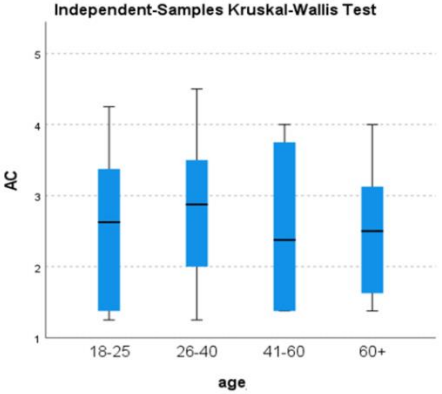
The p-value (0.040) suggests a statistically significant difference in Accessibility & Connectivity ratings across age groups. This implies that **age might be a factor influencing how passengers perceive accessibility and connectivity at the station**. Older adults might face more challenges navigating the station compared to younger passengers.

Gender, Qualification, Annual Income, Mode Choice, Time Spent at Station, Trip Purpose, and Annual Frequency

The p-values for these categories are all above 0.05, indicating that there's no statistically significant evidence to suggest a difference in Accessibility & Connectivity ratings based on these factors. However, it's important to note that with a larger sample size, even small variations might become statistically significant.

- **Universal Design Gaps:** The current layout has not been designed with universal accessibility principles in mind, leading to barriers and inconveniences for various users.
- **Signage Inefficiencies:** Wayfinding aids fail to offer clear and intuitive guidance for passengers.

Independent-Samples Kruskal-Wallis Test



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Accessibility & Connectivity - PLOS

Step 1: Determine Pedestrian Space

Step 2: Determine Pedestrian Travel Speed

Step 3: Determine Pedestrian LOS Score

Step 4: Determine Pedestrian LOS

Without luggage	
(x (m) y (m)	0.63 X 0.75
Area (sqm)	0.47
Speed (m/min)	52

With Polybags/ HandBags	
(x (m) y (m)	0.75 X 0.75
Area (sqm)	0.56
Speed (m/min)	41.6

With Backpack	
(x (m) y (m)	0.63 X 1.03
Area (sqm)	0.64
Speed (m/min)	38.1

With trolley and duffle bag	
(x (m) y (m)	1.36 X 1.77
Area (sqm)	2.4
Speed (m/min)	26.6

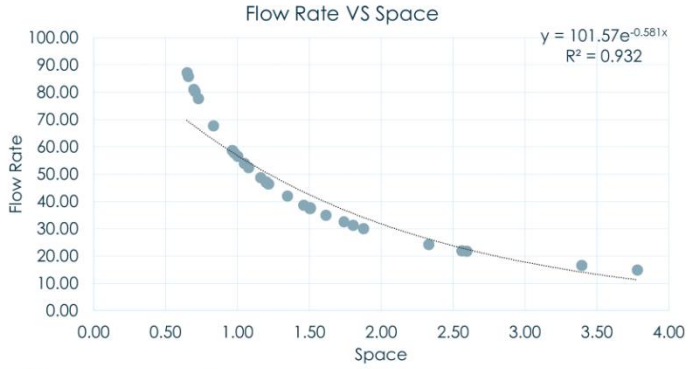
With Duffle Bag	
(x (m) y (m)	0.87 X 0.75
Area (sqm)	0.65
Speed (m/min)	34.36

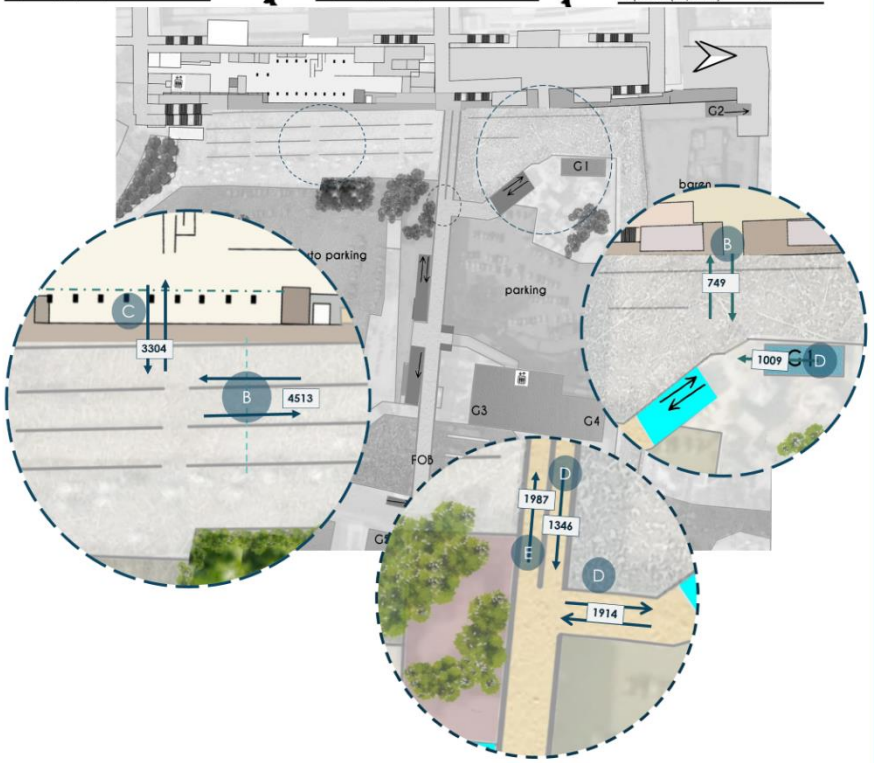
With trolley bag	
(x (m) y (m)	1.11 X 1.77
Area (sqm)	1.96
Speed (m/min)	28.56

With 2 duffle bag	
(x (m) y (m)	1 x 0.75
Area (sqm)	0.75
Speed (m/min)	26.6

With Infants, Toddlers	
(x (m) y (m)	0.55 X 0.92
Area (sqm)	0.51
Speed (m/min)	34.36

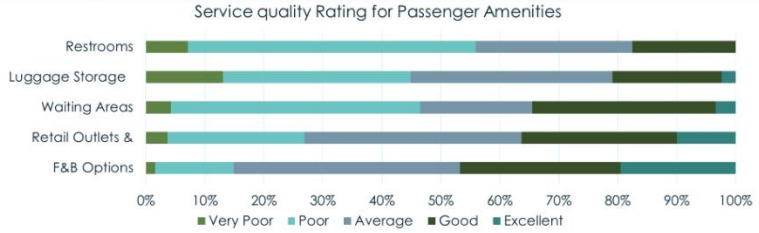
Time	PEF	Density (ped/ m²)	Space (m²/Ped)	Flow Rate (Ped/m)	Avg. Speed (m/s)	Capacity V/C Ration (V/C)
1 min	112	0.86	1.16	48.74	0.51	0.58
2 min	51	0.39	2.56	22.09	0.52	0.26
3 min	89	0.69	1.46	38.74	0.54	0.46
4 min	34	0.26	3.78	14.96	0.67	0.18
5 min	50	0.39	2.59	21.78	0.61	0.26
6 min	38	0.29	3.39	16.65	0.60	0.20
7 min	69	0.53	1.88	30.13	0.49	0.36
8 min	133	1.02	0.98	57.91	0.50	0.69
9 min	81	0.62	1.61	35.04	0.50	0.42
10 min	75	0.57	1.74	32.48	0.52	0.39
11 min	**156**	**1.20**	**0.83**	**67.83**	**s0.50**	**0.81**
12 min	107	0.82	1.21	46.57	0.50	0.55
13 min	135	1.04	0.96	58.61	0.48	0.70
14 min	109	0.83	1.20	47.17	0.52	0.56
15 min	107	0.82	1.21	46.52	0.50	0.55



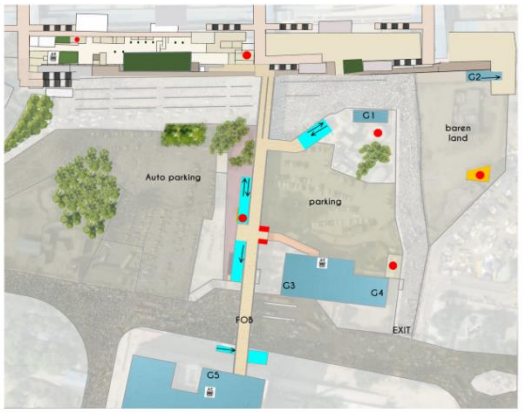


Passenger Amenities

Objective 2



Null Hypothesis	Sig.[a,b]	Decision
The distribution of PA is the same across categories of age	0.613	Retain the null hypothesis.
The distribution of PA is the same across categories of Gender.	0.539	Retain the null hypothesis.
The distribution of PA is the same across categories of qualifications.	0.501	Retain the null hypothesis.
The distribution of PA is the same across categories of Mode choice.	0.701	Retain the null hypothesis.
The distribution of PA is the same across categories of Time spent on railway station.	0.076	Retain the null hypothesis.
The distribution of PA is the same across categories of Annual Frequency.	0.063	Retain the null hypothesis.
The distribution of PA is the same across categories of Trip Purpose.	0.432	Retain the null hypothesis.



Inferences

- **Demographics and Travel Patterns:** There appears to be no strong relationship between overall interchange ratings for passenger amenities and user demographics (e.g., age, gender) or travel characteristics (e.g., trip purpose, frequency). This suggests dissatisfaction might be widespread across different user groups.
- **Restroom and Cloakroom Concern**: These facilities consistently receive low overall ratings, indicating a critical area for improvement across the interchange.
- **Waiting Areas:** insufficient waiting areas cause overcrowding and negatively impact passenger experience, leading to people seeking refuge elsewhere and requiring temporary arrangements.

Cloakroom Limitations:

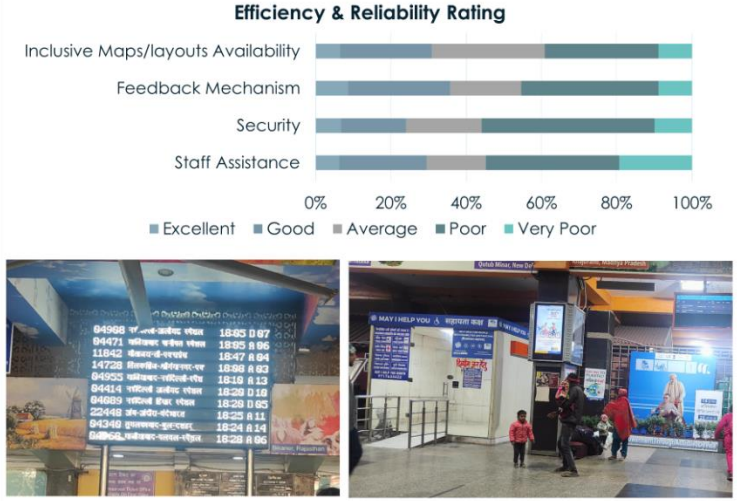
- The primary issue with cloakrooms is their limited spatial presence (only at platforms 1 and 16) and inadequate space within those facilities. This significantly restricts their utility for many passengers.

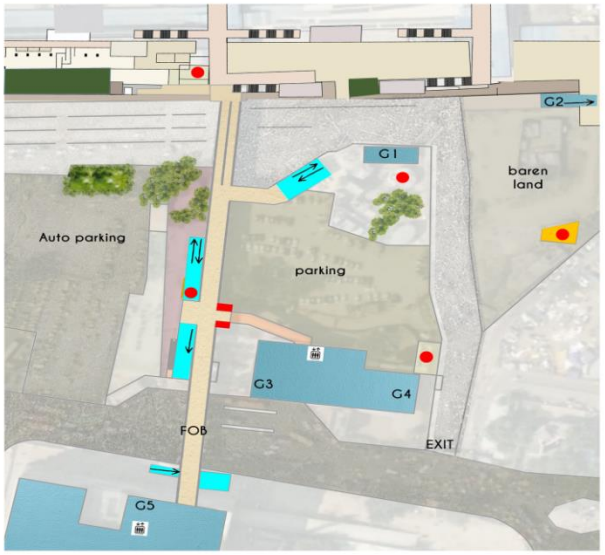
Washroom Concerns:

- While the number of washroom stalls seems sufficient, maintenance is severely lacking, resulting in poor conditions. Additionally, a lack of feedback mechanisms prevents users from easily reporting issues for timely resolution.

Efficiency & Reliability

Objective 2





User Experience

Inferences:

- **Ticketing Strain:** Long queues and out-of-order kiosks indicate ticketing system bottlenecks.
- **Poor Coordination:** lack of Public transport availability after 11pm.
- **Inefficient Transfers**: Long distances or confusing layouts lead to longer transit times
- **Staffing Shortages**: Lack of staff support highlights a need for better staffing levels and training for assisting diverse users.
- **Limited Feedback:** Insufficient feedback mechanisms create a disconnect between users and management.
- **Accessibility Barriers**: Lack of inclusive maps and accessible resources hinders users with disabilities.

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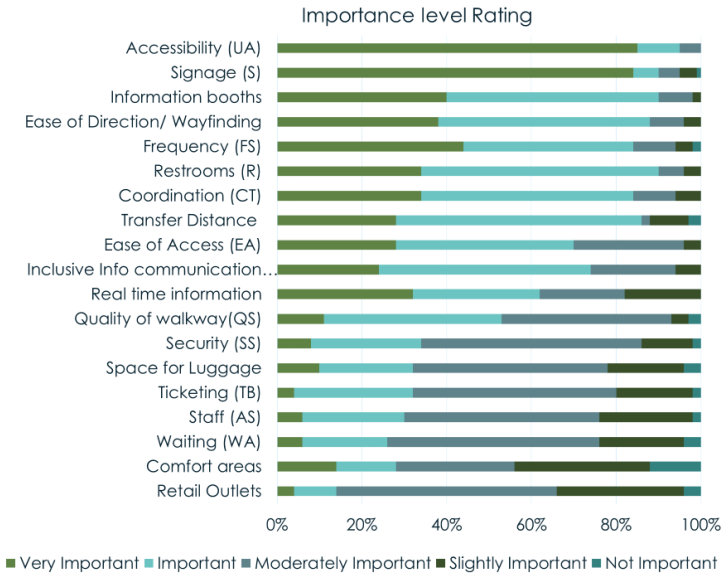
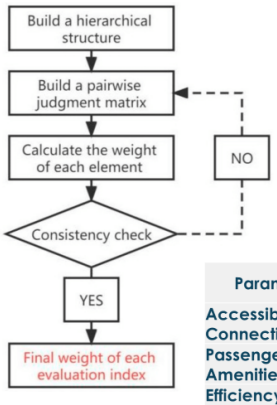
Parameters Weightage assessment



Parameter	Weightage	Sub parameter	Weightage
Accessibility & Connectivity	0.33	Ease of Direction/ Wayfinding (EOD)	0.18
		Information booths	0.17
		Accessibility (UA)	0.23
		Quality of walkway(QS)	0.19
		Transfer time (TT) & TD	0.23
Passenger Amenities	0.22	Restrooms (R)	0.24
		Retail (RO)	0.17
		Waiting (WA)	0.18
		Space for Luggage	0.20
		Comfort areas	0.22
Efficiency & Reliability	0.25	Coordination (CT)	0.22
		Ease of Access (EA)	0.20
		Signage (S)	0.20
		Ticketing Booth (TB)	0.17
		Real time information (RTI)	0.21
User Experience	0.23	Security (SS)	0.23
		Staff (AS)	0.21
		Frequency (FS)	0.29
		Inclusive Info Communication (IIC)	0.27

Analytical Hierarchical Process

Objective 3



Matrix				
Parameters	Accessibility & Connectivity	Passenger Amenities	Efficiency & Reliability	User Experience
Accessibility & Connectivity	1	5	3	4
Passenger Amenities	0.2	1	0.33	0.5
Efficiency & Reliability	0.33	3	1	2
User Experience	0.25	2	0.5	1
Sum	1.78	11	4.83	7.5

Parameters	Accessibility & Connectivity	Passenger Amenities	Efficiency & Reliability	User Experience	Criteria Weight
Accessibility & Connectivity	0.56	0.45	0.62	0.53	0.54
Passenger Amenities	0.11	0.09	0.07	0.07	0.08
Efficiency & Reliability	0.19	0.27	0.21	0.27	0.23
User Experience	0.14	0.18	0.10	0.13	0.14

Weighted Sum value matrix							
Parameters	Accessibility & Connectivity	Passenger Amenities	Efficiency & Reliability	User Experience	Weighted Sum	Criteria Weight	w/c
Accessibility & Connectivity	0.54	0.42	0.70	0.56	2.22	0.54	4.10
Passenger Amenities	0.11	0.08	0.08	0.07	0.34	0.08	4.02
Efficiency & Reliability	0.18	0.25	0.23	0.28	0.95	0.23	4.06
User Experience	0.14	0.17	0.12	0.14	0.56	0.14	4.01
							4.05

MMII = 0.54 AC + 0.08 PA + 0.23 ER + 0.14 UE

Lamda max.	4.047
Consistency Index	0.0157
Consistency Ratio	C.I / R.I
	0.0174
C.I	0.0174<<0.1

By using Kmean Clustering Benchmarking is done from 50 samples of the survey data
2.38 is the Rating for NDLS as per the remaining survey data – **LOS C**

Benchmarking for MMII	
A	3.04-5
B	2.41-3.03
C	1.99-2.4
D	1.36-1.98
E	0-1.35

Issues & Recommendation

Innovative Interventions

Objective 4

Priority	Issue Category	Specific Issues	Recommendations
High	Accessibility & Connectivity	Age-related disparities in A&C perception Escalators ending in stairs, obstructed ramps, limited elevators	• Conduct a thorough accessibility audit with experts and users with disabilities. • Modify staircases, ensure unobstructed ramps, optimize elevator placement. • Incorporate universal design in renovations • "Try It Out" sensory tours for staff empathy building
	Restroom & Cloakroom	Restroom maintenance issues, lack of feedback mechanisms. Cloakroom space limitations and insufficient availability.	• Prioritize restroom cleanliness, rigorous maintenance. • Implement easy-to-use feedback mechanisms. • Increase cloakroom availability on more platforms. • Assess feasibility of expanding existing cloakroom space.
	Coordination & Connectivity	Mismatched schedules and infrequent service between rail and other modes.	• Coordinate schedules with bus/metro. • Explore on-demand or flexible transit for off-peak hours. • Provide clear, up-to-date multimodal schedule information. • Develop a real-time journey planning app
Medium	Staffing	Limited staff presence & support, insufficient diversity training.	• Strategically deploy staff based on needs. • Provide training in accessibility, problem-solving, customer service (explore VR for empathy).
	Ticketing Bottlenecks	Out-of-order kiosks, long queues, inadequate staff support	• Increase operational kiosks, explore temporary fixes. • Ensure staff availability during peak times. • Cross-train staff for kiosk support. • Offer multiple ticketing options (online, kiosks, counters). • Consider contactless payment integration
	Security	Potential actual or perceived safety risks	• Assess security based on crime stats, surveys, observation. • Enhance measures (personnel, cameras, lighting, emergency call points, consider innovative approaches like wearable SOS devices).
Lower	Wayfinding & Signage	Confusing, overlapping, poorly visible signage	• Engage a wayfinding consultant for assessment. • Redesign signage with clarity, hierarchy, uncluttered design. • Strategically position signage for visibility.
	Waiting Areas	Overcrowding, insufficient space, need for temporary solutions	• Expand permanent waiting areas based on demand. • Partner with nearby businesses for temporary overflow space.
	Feedback Mechanisms	Insufficient channels for user input	• Implement diverse feedback methods (surveys, comment boxes, accessible online forms, help desks, consider gamification). • Create a visible process for addressing feedback.

Smart Restrooms

- **Real-time Occupancy Sensors:** Improve cleaning efficiency and user awareness of availability.

Personalized Wayfinding

- **Accessibility-focused Apps:** Customized routes for those with mobility needs.
- **Wearable Integration:** Haptic feedback (vibrations) for navigation assistance.

Gamification

- **Rewards for Feedback:** Motivate participation with badges or points.
- **Interactive Waiting Areas:** Reduce perceived wait times, especially for children.

Temporary Amenities

- **Pop-up Solutions:** Mobile restrooms, seating, etc., during peak times or renovations.

Coordination & Connectivity

- **Late-Night Partnerships:** Ride-hailing or shuttles to fill public transport gaps.
- **Smart Journey Planning:** App factoring in preferences, real-time data, and accessibility.

Transfer Design

- **AR Wayfinding:** Live camera view with overlaid directions for seamless guidance.
- **Interactive Kiosks:** Visuals and walking times to help plan transfers efficiently.

Security

- **Wearable SOS Devices:** Discreet panic alerts with location tracking.
- **Crowdsourced Safety Mapping:** App for users to report safe/unsafe zones.

Staffing

- **Virtual Help Desks:** Remote assistance via QR codes or signage.
- **Skill Exchange:** Cross-training for flexible deployment in busy areas.

Feedback Mechanisms

- **Social Media Analysis:** Mine geotagged posts for sentiment trends.

Accessibility

- **Beacon-Based Navigation:** Spoken directions, aiding visually impaired users.
- **VR Empathy Training:** Simulations for staff to understand diverse needs.

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