FACTORS AFFECTING WILLINGNESS TO USE TRANSFER BASED PUBLIC TRANSPORT NETWORK

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Degree of Master of Science

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DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The above candidate has carried out research for the PhD/MPhil/Masters thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Prof. J.M.S.J. Bandara

Signature of the Supervisor: Date: 25.08.2025

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Pakkiyarajah Saranjan

ABSTRACT

This study examines the primary factors influencing passengers' willingness to use transfer-based urban public transport systems, emphasizing the interplay between service attributes and user demographics. In contrast to direct bus routes, transfer-based networks offer improved coverage and operational efficiency but face barriers such as increased waiting times, inconvenience, and perceived complexity. A multi-stage methodology was employed, combining Multi-Criteria Decision Analysis (MCDA) and a Stated Preference (SP) survey to evaluate passenger priorities and simulate decision-making behavior. The MCDA identified critical service factors as key drivers of user satisfaction. The SP survey further quantified passenger preferences under varying travel characteristics. By utilizing the Mixed Logit Model, the study revealed that reduced waiting times, fewer transfers, accessible information, and competitive fares significantly increase the likelihood of choosing transfer-based options. These preferences were found to be moderated by sociodemographic parameters like age, gender, and frequency of travel, underscoring the necessity for inclusive and user-specific planning techniques. The results underscore how crucial it is to take passenger behavior and preferences into account when designing sustainable and effective transportation systems. The study offers practical insights for policymakers and transit agencies to enhance the attractiveness and functionality of transfer-based networks in rapidly urbanizing environments.

Keywords: Transfers, Human Factors Public Transport, MCDA, Machine Learning, and Numerical Modelling

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LIST OF ABBREVIATIONS

Abbreviation	Description
AHP	Analytic Hierarchy Process
CBA	Cost-Benefit Analysis
CL	Conditional Logit
LL	Log-Likelihood
MCA	Multi-Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MLM	Mixed Logit Model
MNL	Multinomial Logit
NL	Nested Logit
PT	Public Transport
SMLE	Simulated Maximum Likelihood Estimation
SP	Stated Preference

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CHAPTER 1

1. INTRODUCTION

Urban transport systems generally comprise two main components: public and private transportation. While private transport offers flexibility and personal convenience, it has a major impact on disparate access, environmental deterioration, and traffic congestion. On the other hand, public transit is essential for encouraging environmentally friendly movement, cutting emissions, and guaranteeing accessible for people from all socioeconomic backgrounds.

Despite its importance, public transportation systems, especially in developing urban settings, face numerous challenges. One key issue is the prevalence of overlapping and inefficient direct bus networks, which often lead to resource wastage, long idle times, poor frequency, and unreliable services. These inefficiencies reduce passenger satisfaction and discourage public transport usage, prompting many to shift toward private modes.

To address these issues, integrated transfer-based public transport systems have emerged as a potential solution. These systems optimize routes by reducing redundancy and improving coverage through planned transfers. Transfer-based networks allow for better connectivity, operational efficiency, and system scalability. However, while technically sound, the concept of transfers introduces new challenges, such as increased waiting time, inconvenience during interchanges, lack of coordination between services, and perceived complexity in journey planning.

A major gap in current transport planning is the lack of thorough understanding of user behavior and preferences related to transfers. Many transport policies and network designs overlook how passengers perceive transfers, what discourages them from using such systems, and which factors influence their willingness to accept multi-leg journeys. Without addressing these behavioral aspects, the successful implementation of transfer-based systems remains difficult.

Since users are the key stakeholders of transfer-based public transport, it is crucial to understand their inclination towards transfer-based systems. If they are unwilling to accept and make use of transfer-based networks, public transportation systems will be very difficult to implement and run successfully. The acceptance and adoption of public transport related initiatives such as route restructuring to reduce redundancies, integrated ticketing systems, schedule coordination for smooth transfers, and infrastructure improvements at transfer points by users are crucial for ensuring the sustainability and effectiveness of the public transportation. Understanding user references, concerns, and motivations with relation to the transfer-based bus transport system is therefore essential.

This study's primary goal is to determine and measure the major determinants of passengers' propensity to use transfer-based urban transport networks and to comprehend the ways in which these determinants interact with various user attributes in the framework of sustainable urban mobility.

These three objectives serve as a guide for the study:

- To identify and quantify the relative importance of service-related factors such as number of transfers, walking time, and information availability on user willingness to use transfer-based urban transport systems.
- To examine how user charact eristics such as effect of age, gender, and travel moderate the willingness to adopt transfer-based networks
- To develop a predictive transport choice model that captures the relationship between user preferences, socio-demographic characteristics, and service attributes using suitable discrete choice modeling techniques.

In addressing the first objective, the study will analyze how specific service features such as the walking time, number of transfers required and the availability of travel information impact passengers' willingness to use transfer-based networks. Quantifying these factors will help prioritize which aspects are most critical for improving user acceptance and satisfaction.

For the second objective, the research will investigate how willingness to use transfer-based systems varies among different demographic groups, such as age and gender, travel frequency etc. This will reveal whether certain groups are more sensitive to specific barriers or facilitators within transfer-based networks, enabling planners to design targeted and inclusive strategies.

The third objective focuses on developing a model of willingness to choose transfer-based networks. This involves applying transport choice modeling methods, such as discrete choice models or network-based approaches, to capture the complex interplay between service attributes and user characteristics. Such models can simulate and predict passenger choices under various scenarios, providing valuable insights for optimizing network design and policy interventions to enhance the attractiveness and sustainability of urban transport systems

This study plans to conduct a thorough investigation of the numerous variables that influence passengers' perceptions of and actions in relation to transfer-based public transport systems. By carefully breaking down each of these elements, hope to add value to the conversation around urban transport systems by emphasizing the requirements and preferences of passengers which is not fully investigated by the previous studies.

Policymakers and transport operators can effectively support the adoption of transfer-based systems by customizing initiatives based on their understanding of passengers' preferences and attitudes towards them. For instance, prior studies have shown how crucial it is to address elements like simplicity, safety, and dependability to increase the allure of transfer-based systems (Guo & Wilson, 2004). Policymakers and transportation authorities can design more sustainable and user-centered urban transportation systems by integrating these results into their planning and decision-making processes.

Additionally, the knowledge gathered from this study can be applied by transportation providers to enhance the planning and functioning of transfer-based bus transportation networks. Transport agencies can improve the user experience and encourage the usage of public transport by adapting their service offerings to the requirements and preferences of their passengers.

Lastly, this study provides commuters with crucial details regarding the advantages and possible disadvantages of employing transfer-based systems. Commuters might choose their travel habits more wisely if they are aware of the elements impacting their propensity to transfer. By using this information, commuters will be better equipped to select the modes of transportation that most closely match their requirements and tastes, making their commutes more effective and pleasurable overall.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Background

The drawbacks and inefficiency in public transport systems often drive users to opt for private vehicle transport. Deciding between private transport and public transportation (PT) is a complex process that is impacted by a number of variables. According to Kingham S., et al. (2001), important factors include service quality, lack of connectivity, personal travel costs, access distance to and from stations, and the distance between home and work. Furthermore, Tertoolen G., et al. (1998) highlight that traveler often demonstrate behavioral resistance all through transitions to PT. Users prefer private transportation for emotive (enjoyment of driving) and symbolic (status in society) reasons in addition to pragmatic ones like comfort, convenience, and freedom (Hiscock et al., 2002).

However, the increase in private vehicle usage has led to a surge in total motor vehicle numbers, resulting in serious transportation challenges for urban commuters, especially in rapidly growing metropolitan areas. The difference between the availability and demand for resources in the transportation network, due to the rise in vehicle ownership outpacing infrastructure development, has been well documented (Yang, Y., Chen, J., & Du, Z., 2020). As urban populations expand and economic activity intensifies, the need for effective transit alternatives becomes more urgent, placing immense pressure on existing infrastructure and services.

Within this literature review, particular attention will also be given to the issues associated with direct bus transport, the significance and the purpose of transfers in networks of public transportation, and the different factors influencing passengers' willingness to choose transfer-based public transport systems. In addition, the review will cover analytical methods and numerical modeling approaches used to study these phenomena, providing a comprehensive foundation for understanding and improving urban transit networks.

2.2 Challenges in Direct bus network

The existing literature highlights the hesitancy of passengers to adopt transfer-based transport systems, mainly because of the disadvantages they experience (Chowdhury, S., 2014). These systems often raise concerns about increased travel time, complexity, and uncertainty, as passengers are required to transition between different modes of transportation during their journeys.

Moreover, the literature also points to issues within direct bus networks, such as overlapping routes that can lead to inefficiencies and reliability problems. These overlapping routes often result in redundant services, increased operational costs, and inconsistent service frequencies, which in turn can undermine the overall reliability and efficiency of the network. Such inefficiencies may further discourage passengers from using public transport, whether direct or transfer-based, highlighting the need for a more nuanced understanding and optimization of urban transit systems.

While this reluctance is well recognized, there remains a significant gap in understanding the specific causes behind passengers' aversion to transfer-based systems. Additionally, although some researchers emphasize the potential benefits of integrated multimodal transportation networks, such as improved connectivity and reduced environmental impact (Redman et al., 2013), a comprehensive assessment of passengers' preferences, expectations, and concerns is still lacking.

2.3 Significance of transfer-based networks

Transfer-based bus transport systems are fundamental to improving the efficiency and integration of public transportation networks. By allowing passengers a wide variety of travel routes compared to direct-service transport networks, these systems can significantly enhance network coverage and flexibility (Vuchic, 2015). When transfers are well-planned and synchronized, disruptions are minimized and the overall attractiveness of the system increases. One of the major operational advantages of transfer-based networks is their ability to reduce overlapping routes, which are common in direct-service networks and often lead to inefficiencies, increased operational costs, and reliability issues. Through careful planning and route optimization, transfer-based systems streamline operations, making public transport more cost-effective and comprehensive (Ceder et al., 2013).

A critical aspect in the success of transfer-based networks is the management of transfer penalties such as the perceived inconvenience, time loss, or uncertainty associated with making a transfer. These penalties are central to plan for public transportation, impacting ridership projections, designing networks and stations, and developing marketing plans (Knowles et al., 2019). By analyzing passengers' revealed route choices when alternatives are available, planners can estimate these penalties and better understand transfer preferences, which helps in optimizing transfer station locations and improving user experience (Guo & Wilson, 2011).

Moreover, the use of advanced data analytics, such as origin-destination matrices derived from smart card data, enables transit agencies to reorganize and refine intracity bus lines for more efficient transfer-based operations (Kim et al., 2014). Synchronizing transfers across the network further boosts efficiency and service reliability, ensuring that passengers experience seamless connections and reduced waiting times (Ceder et al., 2013). The importanc of transfer-based networks dwells in their potential to create a more integrated, reliable, and user-friendly public transport system, provided that transfer penalties are minimized and network inefficiencies are systematically addressed.

2.4 Factors affecting willingness to Choose Transfer based Public Transport Network

Transfer-based public transport networks are influenced by several factors that affect user satisfaction and overall efficiency. One such factor is the frequency of the fleet in every route, which impacts capacity and reliability. Transfer synchronization can minimize missed connections and delays, improving the overall efficiency of the network. A lower number of transfers and lesser walking distance can enhance user satisfaction, as safety and comfort, capacity, responsiveness, safety and reliability are significant factors influencing user satisfaction.

For transfer-based networks, having access to sufficient information is essential since understanding transfer penalties has significant consequences for public transport planning. Seating availability in the transfer routes, age or elder-friendly (age factors/elders' resistance), and well-connected transfer points can enhance user satisfaction and accessibility. The introduction of new alternative routes can optimize the passenger-route assignment, providing more efficient and convenient travel options.

Increased safety and security, routes involving lesser traffic congestion, and discounted prepaid bus tickets for transfers can improve user satisfaction and reduce operational costs. Availability of seating at terminal/station, protection from adverse weather, adequate lighting, and environmentally friendly travel options (Ex: Electric vehicles) can enhance user comfort and safety. Restroom facilities at terminal/station are also essential for user satisfaction and convenience.

These factors are critical in designing and implementing efficient and user-friendly transfer-based public transport networks. By addressing these factors, public transport agencies can create a more integrated, efficient, and user-friendly system that better serves the diverse needs of their communities.

2.5 Multi-Criteria Analysis

While alternative methods like Cost-Benefit Analysis (CBA), Conjoint Analysis, and Regression-Based Approaches could be employed, MCDA was selected for this study due to its capacity to address decision-making problems involving multiple and conflicting criteria. CBA, while valuable for assessing economic efficiency, tends to focus on monetary valuation and can overlook important qualitative or user-preference factors (Bhagtani, N. E. H. A., 2008). Conjoint Analysis is useful in understanding stakeholder preferences but often involves complex designs and renders the weighting of criteria less transparent (Louviere, J. J., et. Al., 2015). Regression models are effective for probing causal relationships but are less equipped to rank and compare diverse decision criteria explicitly (Beaubien, J. M., 2005). By contrast, MCDA is recognized in the literature for its structured, transparent approach, allowing comprehensive prioritization and weighting of diverse criteria in complicated situations involving decision-making (Marsh et al., 2014).

MCDA allows decision-makers to systematically evaluate and compare different alternatives based on various criteria, providing a structured framework for decision-making. This method is particularly valuable when dealing with diverse and conflicting objectives, as it enables a comprehensive assessment of the trade-offs between different criteria. Research by Aldian and Taylor (2005) and Dragan et al. (2018) highlights the significance of MCDA techniques in addressing the challenges of determining criteria weights in decision-making processes.

Within the realm of MCDA, the Weighted Mean Method stands out as a preferred normalization technique due to its simplicity and practicality (Triantaphyllou, E., 2000). Relative importance between the identified factors were needed to identify in this study. A simplified method needed to employed in the analysis to get the better understanding. Among various techniques, the Weighted Mean Method was used for normalization, offering a simple yet effective way to assign and aggregate criteria weights (Zavadskas, E. K., et. Al., 2014). While alternative options like the Analytic Hierarchy Process (AHP), TOPSIS, and entropy weighting exist, the Weighted Mean Method was preferred for its ease of use, transparency, and suitability for survey-based data.

By giving each criterion a weight according to its relative value, this approach enables decision-makers to measure each criterion's importance in the process of making decisions. The Weighted Mean Method is advantageous as it provides a straightforward approach to aggregating criteria, ensuring that each criterion's contribution is appropriately considered in the decision-making process. Studies by Ginevicius and Podvezko (2005) and Jahanshahloo et al. (2006) emphasize the utility of the Weighted Mean Method in determining criteria weights objectively and efficiently.

2.6 Adoption on Machine Learning for Numerical Modelling

The role of modeling in understanding and predicting travel preferences is paramount, particularly when employing techniques like the Mixed Logit Model (MLM) and Logistic Regression. In travel behavior studies, individual variability and the association between alternative choices are critical attributes that the Mixed Logit Model excels at capturing. This model allows for variations in preferences among individuals and considers the influence of random parameters, thereby accommodating the complexities inherent in travel decision-making (Seghieri et al., 2018). In the context of transportation, MLM has demonstrated versatility, accommodating choices ranging from binary (yes/no) to more nuanced quantitative preferences, making it adaptable to a variety of transport scenarios (Ye et al., 2020).

Logistic Regression, on the other hand, is a widely used statistical method that estimates the likelihood of an outcome based on one or more predictor variables. It is particularly suited for binary and categorical outcomes, such as whether a traveler prefers one transport option over another. This model is valuable in transport preference analysis as it permits the integration of multiple explanatory variables such as cost, convenience, and demographic factors into a single framework, thus enhancing the robustness of predictions (Li et al., 2018). Although machine learning methods are increasingly utilized in travel behavior analysis, researchers point out that logistic regression retains its advantages due to its simplicity and interpretability (Christodoulou et al., 2019). Furthermore, logistic regression has been shown to produce probability estimates that are essential for understanding decision-making dynamics, and its performance aligns well with established statistical metrics for model calibration (Tan et al., 2020).

Although a number of elements are acknowledged in the literature as influencing the decision to use transfer-based public transportation, less is known about how important these aspects are in the perspective of users. Without clear prioritization, designing targeted interventions or policies becomes challenging. To address this, the study will employ the Weighted Mean Method within a Multi-Criteria Decision Analysis (MCDA) method to assign explicit weights to each factor based on user input. This approach allows for a transparent and straightforward estimation of the relative significance of each criterion, thereby enhancing understanding of user preferences.

Another notable gap is the lack of specific models capturing user perceptions and the psychological reluctance associated with transfer-based public transport systems. Although transfer penalties and travel complexity are recognized, these perceptions have not been systematically modeled to explain their impact on passengers' willingness to use transfer-based networks. This study will address this gap by applying regression models and leveraging machine learning algorithms to model these perceptions and evaluate how transfer-related factors influence user acceptance of transfer-based public transport networks.

Overall, this research advances beyond simply identifying influencing factors by integrating them within a unified framework that prioritizes their importance and explicitly models user perceptions, particularly in the context of transfer-based public transport systems, thereby filling critical gaps in the existing literature.

CHAPTER 3

3 METHODOLOGY

3.1 Introduction

There are two primary components to the structured methodological approach used in this study:

1. Identification of qualitative and quantitative factor prioritization using Multi-Criteria Analysis (MCA)
2. Quantitative factor selection for SP survey Numerical modeling based on stated preference (SP) survey data.

These two stages ensure a systematic evaluation of the factors influencing transfer-based public transport systems and facilitate the development of predictive models to analyze passenger preferences.

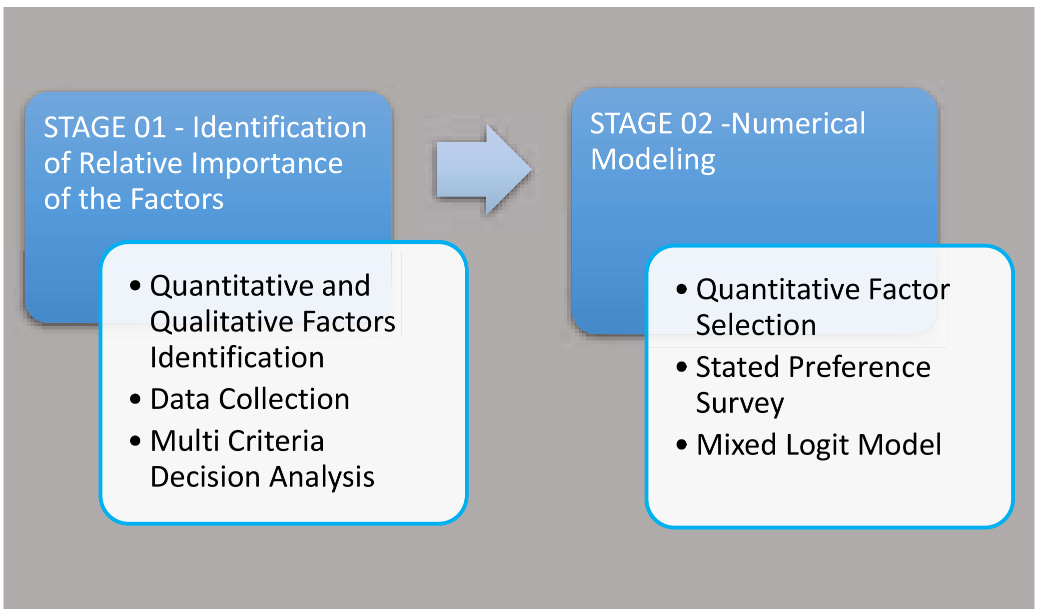


Figure 3.1: Main stages of the methodology

The first phase involves identifying and prioritizing the (qualitative and quantitative) factors affecting both direct and transfer-based public transport systems. A Multi-Criteria Analysis (MCA) framework was employed for prioritizing the identified factors. This process considered a range of criteria, including safety, affordability, waiting times, transfer convenience, and real-time information availability. Factors were weighted based on opinions and survey responses, ensuring that the most influential elements were selected for further analysis.

The identified factors were categorized into two groups to identify what are the factors are influencing the public bus transport in the general perspective (Including both direct and transfers) and the perspective of only transfer based element factors. This categorization helps to identify the impact of the factors in both two scenarios.

Both categorizations are:

- Common factors influencing both direct and transfer-based networks, such as safety, environmental sustainability, and affordability.
- Transfer-specific factors, including transfers count in the travel, walking distances, and transfer synchronization.

The first phase of the analysis aimed to identify user preferences toward both qualitative and quantitative factors by examining behavioral responses. Based on the outcomes of this stage, only the qualitative components were retained, resulting in a refined set of factors for the second phase of the study. This refinement was essential, as the next phase involved numerical modeling, which required a quantitative scale to derive preference values for the selected factors.

Building on the factors selected in the first phase, the second part of the methodology focuses on numerical modeling to quantify the impact of these factors on passenger decision-making. To find out how passengers perceive about different aspects of transfer-based public transportation systems, a Stated Preference (SP) survey was created and carried out. The survey was structured to capture user preferences under hypothetical scenarios with varying travel attributes, allowing for a detailed assessment of trade-offs passengers make when choosing public transport options.

The collected SP data was then used to develop a numerical model, employing econometric and machine learning techniques to analyze passenger choices. This modeling approach helps quantify the effects of key factors such as transfer penalties, waiting times, and fare structures, providing insights into the behavioral responses of public transport users. The model outputs offer valuable guidance for optimizing transfer-based networks and improving passenger satisfaction.

A thorough explanation of the factor selection procedure, data gathering strategies, and numerical modeling approaches employed in this investigation can be found in the topics that follow.

3.2 Identified Factors for the Multi Criteria Analysis

Transfer-based public transport networks are influenced by a variety of factors which are related for the user behavior that impact the transport efficiency, accessibility, and user satisfaction. The selection of factors in this study is firmly based on insights drawn from past literature, empirical studies, and established practices in public transport planning, as listed in Table 3.1 These factors can be categorized into those affecting both direct and transfer-based networks and those specific to transfer-based systems. To align with one of the main objectives of the study (identifying user preferences among the factors influencing the choice of transfer-based transport). While some factors are common to all public transport modes, this categorization helps to isolate the unique aspects of transfer-based travel, enabling a clearer and more focused analysis of user preferences.

Table 3.1: Identified Factors and Relevant Studies

Factor	Discussion	Reference
Frequency of the fleet in every route	Capacity and reliability are key factors affecting user satisfaction in public transport.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Less missed connections and delay	Transfer synchronization enhances public transport system efficiency by reducing missed connections and delays.	Taylor, B. D., & Fink, C. N. (2003).
Lesser number of transfers	A customized modular bus system design optimizes passenger-route assignments, decreasing the need for transfers.	Ceder, A., et. Al, 2013
Lesser walking distance	User satisfaction is influenced by factors like safety, comfort, responsiveness, and tangible elements, including shorter walking distances.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Availability of adequate information	Planning for public transportation, including network forecasting, station and network design, and marketing, requires an understanding of transfer penalties.	Grisé, E., & El-Geneidy, A. (2019).
Seating availability in transfer routes	Capacity directly affects user satisfaction, making seat availability an important factor.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Age or elder-friendly considerations	Safety and comfort significantly influence satisfaction, particularly for elder passengers.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Well-connected transfer points	Transfer synchronization ensures better-connected transfer points, improving overall system efficiency.	Taylor, B. D., & Fink, C. N. (2003).
Introduction of new alternative routes	Modular bus system designs provide alternative route options, optimizing passenger experiences.	Ceder, A., et. Al, 2013
Increased safety and security	Safety is a critical factor influencing passenger satisfaction in public transport.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Routes with less traffic congestion	Reliability is a significant satisfaction factor, and routes avoiding congestion improve overall reliability.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Discounted prepaid bus tickets	Affordable fares, such as discounted transfer tickets, play a key role in improving user satisfaction.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Seating availability at terminal/station	Availability of seating facilities at stations and terminals contributes significantly to user satisfaction.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Protection from adverse weather	Safety and comfort, including protection from adverse weather, are significant factors affecting satisfaction.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Adequate lighting	Safety and comfort are enhanced by adequate lighting at transfer points and terminals.	Susilawati, M., & Nilakusmawati, D. P. E. 2017

Environmentally friendly travel options	Sustainable options like electric vehicles promote safety, comfort, and environmental responsibility, enhancing user satisfaction.	Susilawati, M., & Nilakusmawati, D. P. E. 2017
Restroom facilities at terminal/station	Safety and comfort, including access to clean and adequate restroom facilities, are critical to user satisfaction.	Susilawati, M., & Nilakusmawati, D. P. E. 2017

3.2.1 Factors Influencing user willingness to use Both Direct and Transfer-Based Networks

Several factors impact the efficiency of both direct and transfer-based public transport systems as identified and tabulated in Table 3.1 These include fleet frequency, which determines service reliability and passenger convenience, and safety measures, which contribute to a secure travel experience. Environmental sustainability and passenger comfort also play significant roles, as eco-friendly transport options and well-maintained vehicles improve the overall commuting experience. Additionally, fare policies and affordability influence public transport adoption, making pricing strategies a key consideration for transport planners.

Table 3.2: Factors Affecting Both Direct and Transfer-Based Networks

Factors Affecting Both Direct and Transfer-Based Networks
Increased Safety and Security
Routes involving Lesser Traffic congestion
Discounted prepaid bus ticket for the transfers
Availability of the seating at terminal/station
Protection from adverse weather
Adequate Lighting
Environmentally friendly travel options (Ex: Electric vehicles)
Restroom facilities at the terminal/station

3.2.2 Factors Influencing user willingness to use (Only) Transfer-Based Networks

In transfer-based networks, additional factors come into play that specifically affect the transfer experience. Transfer convenience, including the number of required transfers and walking distances, directly impacts passenger satisfaction. ourney efficiency is further impacted by the impact of transfer penalties and the availability of real-time transfer information. Seating availability at transfer points is crucial for passenger comfort, particularly for those with mobility challenges. Furthermore, the introduction of alternative routes and well-planned terminal infrastructure, including amenities like restrooms and weather-protected waiting areas, enhances the accessibility and usability of transfer hubs.

Table 3.3: Factors Affecting only Transfer related Factors

Factors Affecting only Transfer related Factors
Higher Frequency of public transport in routes (Less Waiting times)
Lesser missed connections and delays
Lesser Number of transfers
Lesser Walking distance
Availability of adequate information
Seating availability in the transfer routes
Age or Elder friendly (Age factors/ Elders' resistance)
Well-connected Transfer points
Introduction of new alternative routes

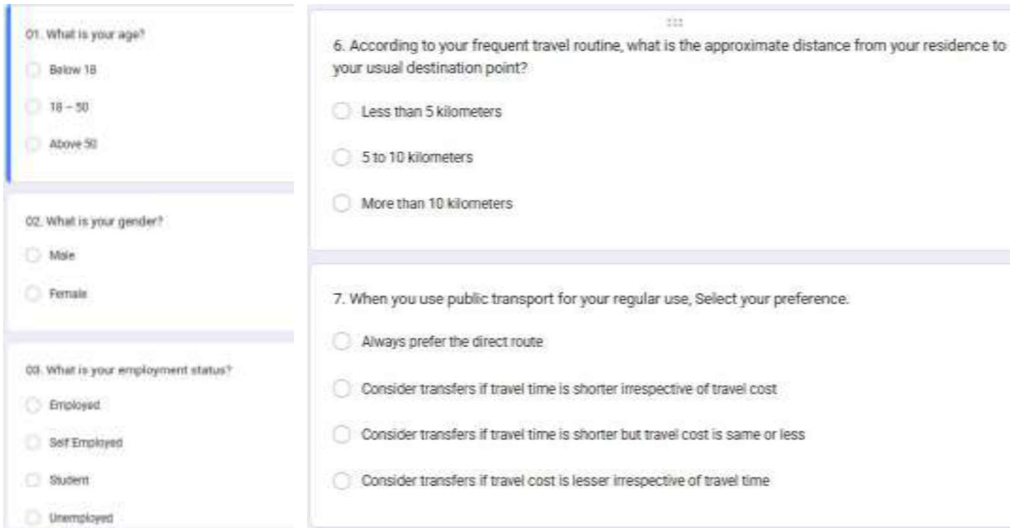
3.3 Data Collection

Preliminary data collection and analysis was conducted to identify the factors which are having the higher impact on the passengers' perceptions. To analyze passenger perceptions of the identified factors, an online questionnaire was designed and distributed. To capture the large amount of passenger sample size, the survey received over 390 sample responses, ensuring statistically reliable results with a 5% margin of tolerance and a 95% confidence level in the conclusions and the results (Singh, A. S., & Masuku, M. B., 2014). The questionnaire aimed to gather insights into passenger travel behavior, factor preferences, and the relative importance of various aspects influencing public transport choices.

3.3.1 Questionnaire Data Collection

The survey collected demographic data, including age and gender, to analyze how different passenger groups interact with public transport systems. Understanding demographic variations is crucial in identifying differences in travel behavior, preferences, and constraints across diverse user groups.

In addition to demographic details, participants provided insights into their travel habits, specifying the frequency of using only direct public transport versus both direct and transfer-based systems. This distinction helped in categorizing users into different segments, such as those who frequently rely on transfer-based networks versus those who prefer direct routes.


01. What is your age?
Below 18
18 – 50
Above 50

02. What is your gender?
Male
Female

03. What is your employment status?
Employed
Self Employed
Student
Unemployed

6. According to your frequent travel routine, what is the approximate distance from your residence to your usual destination point?
Less than 5 kilometers
5 to 10 kilometers
More than 10 kilometers

7. When you use public transport for your regular use, Select your preference.
Always prefer the direct route
Consider transfers if travel time is shorter irrespective of travel cost
Consider transfers if travel time is shorter but travel cost is same or less
Consider transfers if travel cost is lesser irrespective of travel time

Figure 3.2: Screenshots of Online Questionnaire Form

3.3.2 Factor Importance and Weighting

To evaluate the significance of various factors influencing public transport user preferences, a Likert scale-based survey was conducted. On a rating system, participants were tasked to rate each factor (e.g., 1 to 5), where 1 indicated minimal importance and 5 represented a highly influential factor in their decision-making. This approach allowed the study to systematically quantify passenger perceptions and identify which aspects of transfer-based systems had the most substantial impact on user satisfaction and convenience.

Based on how much consider passengers placed on each factor, a weight was assigned to it. Higher weights indicated a greater influence on travel behavior, while lower weights suggested a relatively minor effect. This weighting process helped in prioritizing key elements that require improvement in transfer-based public transport systems.

Figure 3.3: Likert Scale used for getting the preferences of the Users for Each Factors Under Two Categorization

3.4 Multi Criteria analysis

To analyze and objectively evaluate the relative relevance of the several elements impacting public transportation decisions, a Multi-Criteria Decision Analysis (MCA) approach was used. MCDA enables the incorporation of passenger perceptions, captured through a Likert-scale survey, into a structured framework where individual preferences are aggregated, normalized, and ranked by using the Weighted Mean Method of MCDA. This method ensures that each factor's impact is evaluated based on both the frequency and intensity of user responses, allowing for a more comprehensive and transparent prioritization process (Triantaphyllou, E., 2000). The analysis was divided into two main parts as discussed above:

- Factors common to both direct and transfer-based networks, and
- Factors specific to transfer-based networks

providing a clearer understanding of passenger needs across different public transport contexts.

Since the Weighted Mean approach was utilized to determine the relative significance of the factors in this investigation, Wi denotes the weightage value based on the Likert scale, and mi denotes the frequency or number of the weightage. Therefore, the following equation provides the Cumulative Weightage of importance for factors.

$$\text{Cumulative Weightage} = \sum_i^n mi \times Wi$$

The following formula was used to determine the final weightage, where Wi stands for the weightage value on the Likert scale and mi for the weightage frequency (where I is from 1 to 5).

$$\text{Final Weightage} = \sum_i^n \frac{mi \times Wi}{mi}$$

For Example:

$$\text{Final Normalized Weightage}_{(\text{Increased Safety and Security})} = \frac{180\times5+156\times4+44\times3+8\times2+4\times1}{180+56+44+8+4}$$

3.5 Stated Preference Survey

In this study, a stated preference (SP) survey was employed to understand and quantify user preferences regarding different public transport options. The SP survey allows researchers to capture how individuals would make choices between different transport scenarios, often by asking them to evaluate various hypothetical situations. To ensure the survey reflected actual preferences and provided meaningful results, the factors chosen for the survey were based on the findings from a multi-criteria analysis (MCA).

After the MCA results were obtained, factors that had the highest normalized weightage were selected for the stated preference survey. These were the aspects that had the greatest influence on the passengers' decision-making process and were deemed critical in shaping user behavior.

3.5.1 Factor Selection for SP Survey

To ensure the effectiveness and relevance of the Stated Preference (SP) survey, factors were assessed based on their normalized weightage per user. The selection criteria involved comparing each factor's weightage against the average normalized value for its respective category.

Factors exceeding the average threshold were considered for inclusion in the SP survey, while those below were excluded. The evaluation was conducted separately for factors affecting both direct and transfer-based networks and factors specific to transfer-based networks.

3.5.1.1 Factors Affecting Both Direct and Transfer-Based Networks

This category includes factors that influence public transport users regardless of whether they are using direct or transfer-based services. The calculated average normalized weightage for these factors was 3.625. Table 3.4 presents the factors that were assessed, highlighting those that met the selection criteria.

Table 3.4: Normalized Weightages of Factors Affecting Both Direct and Transfer-Based Networks

Factors Affecting Both Direct and Transfer-Based Networks	Normalized Weightage
Increased Safety and Security	**4.276**
Routes involving Lesser Traffic congestion	**3.806**
Discounted prepaid bus ticket for the transfers	**3.694**
Availability of seating at terminal/station	**3.663**
Protection from adverse weather	**3.643**
Adequate Lighting	3.398
Environmentally friendly travel options (Ex: Electric vehicles)	3.388
Restroom facilities at the terminal/station	3.133
Average of the normalized weightage	**3.625**

3.5.1.2 Factors Specific to Transfer-Based Networks

In addition to general factors, the study analyzed elements specifically related to transfer-based public transport networks. The average normalized weightage for these factors was 3.946, serving as the threshold for selection. Table 3.5 provides a summary of the findings.

Table 3.5:Normalized Weightages of Factors Affecting only Transfer-Based Networks

Transfer related Factors	Normalized Weightage
Higher Frequency of public transport in routes (Less Waiting times)	**4.347**
Lesser missed connections and delays	**4.316**
Lesser Number of transfers	**4.235**
Lesser Walking distance	**4.133**
Availability of adequate information	**3.980**
Seating availability in the transfer routes	3.796
Age or Elder friendly (Age factors/ Elders' resistance)	3.735
Well-connected Transfer points	3.663
Introduction of new alternative routes	3.306
Average of the normalized weightage	**3.946**

The most critical factors influencing public transport user preferences and transfer convenience were identified for the initial consideration. Factors for the SP survey finalized by considering the quantitative factors from the preliminary MCDA analysis. The inclusion of these factors in the SP survey ensures that the study captures user perceptions effectively, providing valuable insights for optimizing public transport systems and improving multimodal travel experiences.

Table 3.6: Initial selected factors for SP survey

Transfer related Factors	**Factors Affecting Both Direct and Transfer-Based Networks**
Higher Frequency of public transport in routes (Less Waiting times)	Increased Safety and Security
Lesser missed connections and delays	Routes involving Lesser Traffic congestion
Lesser Number of transfers	Discounted prepaid bus ticket for the transfers
Lesser Walking distance	Availability of the seating at terminal/station
Availability of adequate information	Protection from adverse weather

For the final consideration, several factors critical to user preferences and transfer convenience in public transport systems were identified. While these factors were diverse, some qualitative elements were excluded, and certain related factors were merged to form broader categories for clarity and effective data capture and numerical modeling. Identified factors were finalized according to the SP survey and numerical modeling. This approach ensures that the SP survey focuses on essential variables that capture user perceptions comprehensively.

Final Categorized Quantitative Factors gathered from:

1. Number of Transfers:
   Captures user preferences regarding the complexity of their travel due to number of transfers.
2. Total Walking Time:
   Accounts for walking distances at transfer points, which significantly impact passenger convenience.
3. Total Average Waiting Time:
   Includes waiting durations at terminals and transfer points.
4. Availability of Information:
   Encompasses the ease of access to real-time information about transfers and routes.
5. Traffic Congestion on Routes Compared to Direct Route:
   Evaluates user concerns regarding congestion levels when choosing transfer-based versus direct routes.
6. Cost of Bus Travel (Ticket Cost Comparison):
   Examines the fare differences between direct and transfer-based journeys, including discounts.

7. Seating Availability: Assesses the availability of seating at terminals and during travel, which influences comfort and satisfaction

By adopting this streamlined categorization, the survey captures user preferences while balancing practicality and the need for actionable insights to optimize public transport systems.

3.6 Stated Preference Survey Questionnaire

To develop a robust numerical model for analyzing transfer-based public transport preferences, a Stated Preference (SP) survey was carried out using the finalized set of quantitative factors. The SP method was selected because it allows for controlled experimental design, enabling the capture of hypothetical choice behavior under systematically varied service attributes. This is particularly valuable for studying preferences in contexts (such as transfer-based networks) where revealed preference (RP) data may be limited or not fully reflective of potential improvements or changes.

For the SP survey design, there are many methods exist such as Full Factorial, Fractional Factorial, Orthogonal, D-efficient, Bayesian Efficient, etc. D-Efficient Design was utilized in this study since the combinations of the full factorial is too large, using the advance model like Mixed Logit model, and can be estimated with the few choice sets. Combinations of attribute levels are selected in a D-efficient design in order to minimize the variance-covariance matrix determinant of the estimated parameters. This design method is more suitable for this occasion because it gives the most precise parameter estimates with the fewest respondents or choice sets.

The questionnaire was carefully designed to include 10 different hypothetical scenarios, each presenting variations of key factors such as transfer discounts, service frequency, walking distance between transfers, safety and security levels, and the availability of facilities at transfer stations. Each scenario posed a realistic travel choice between a transfer-based route and a direct bus network option, allowing participants to make trade-offs among different service attributes.

Response fatigue was minimized in the D-efficient design through several key strategies. Blocking was used to divide the full set of choice tasks into 10 scenarios, with each respondent required to make one selection per scenario. This helped reduce cognitive load and survey length. Realistic constraints were applied to eliminate implausible or illogical combinations, ensuring that the choice tasks remained intuitive and believable. Additionally, the order of alternatives within each choice set was randomized to prevent repetitive patterns and maintain respondent engagement throughout the survey.

The scenario selection was guided by four key principles (Relevance, Variation, Practicality and alignment with research objectives). Relevance ensured that factors were chosen based on preliminary research and stakeholder input as highly influential to passenger preferences. Variation was incorporated by systematically changing factor levels across scenarios to reflect a wide range of realistic travel conditions as denoted in Table 3.7. Practicality was considered by designing scenarios that were plausible and easy for participants to imagine. Alignment with research objectives was maintained by structuring scenarios to directly explore how service attributes influence passengers' willingness to choose transfer-based routes over direct services.

To accurately capture respondents' preferences between transfer-based and direct routes, a detailed explanation was provided at the beginning of the SP survey. A clear description of the transfer-based network, along with the relevant factors, was presented, and respondents were instructed on how to position themselves in each scenario as if they were actual travelers. Comprehensive guidelines were also given to ensure that participants carefully evaluated every scenario before indicating their choices, thereby enhancing the reliability and validity of the collected responses, as detailed in Appendix II.

By analyzing the choices made by participants across these varied scenarios, it was possible to develop a numerical model capable of quantifying the relative influence of each factor on decision-making. Machine learning algorithms were employed to build this model. By measuring each factor's impact on passengers' decision-making, this model seeks to offer insightful information for improving public transportation networks.

The analysis was carried out using a machine learning algorithm called "Logistic Regression" to estimate passenger transfer preferences and form the Mixed Logit Model. The approach included several steps to guarantee precise estimation and trustworthy results.

The dataset consisted of responses from 48 passengers, each of whom evaluated 10 different transfer preference scenarios, resulting in a total of 480 entries used for the numerical modeling. This number of observations represents sample for the large number of users for sufficient data to achieve a 95% confidence level for the model results as stated by Singh, A. S., & Masuku, M. B. (2014) for the permisible lits of the sample sizes. However, it is important to mention that, despite the relatively large number of entries, the underlying sample size of 48 individuals may limit the diversity of perspectives captured.

Consequently, the findings may not fully represent the broader passenger population. This limitation was primarily due to time constraints. Future research with a larger and more diverse sample could enhance the robustness and generalizability of the results, providing a wider understanding of varying passenger preferences.

Sociodemographic characteristics including age, gender, frequency of travel, and number of transfers were examples of independent variables along with trip-specific attributes like walk time, waiting time, cost, congestion levels, and seat availability. The dependent variable represented the passenger's transfer preference across different scenarios.

What is your age?

- Below 18
- 18 – 50
- Above 50

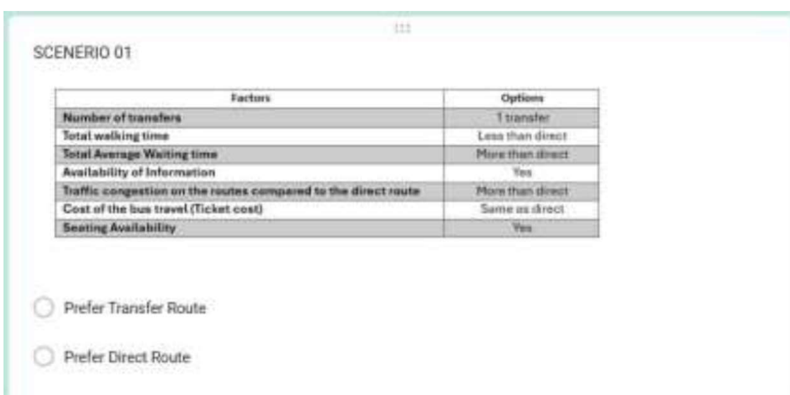
Gender: Please indicate your gender.

- Male
- Female

Figure 3.4: Questions for General Information in SP Survey Questionnaire

Table 3.7: Factors and their levels for the options

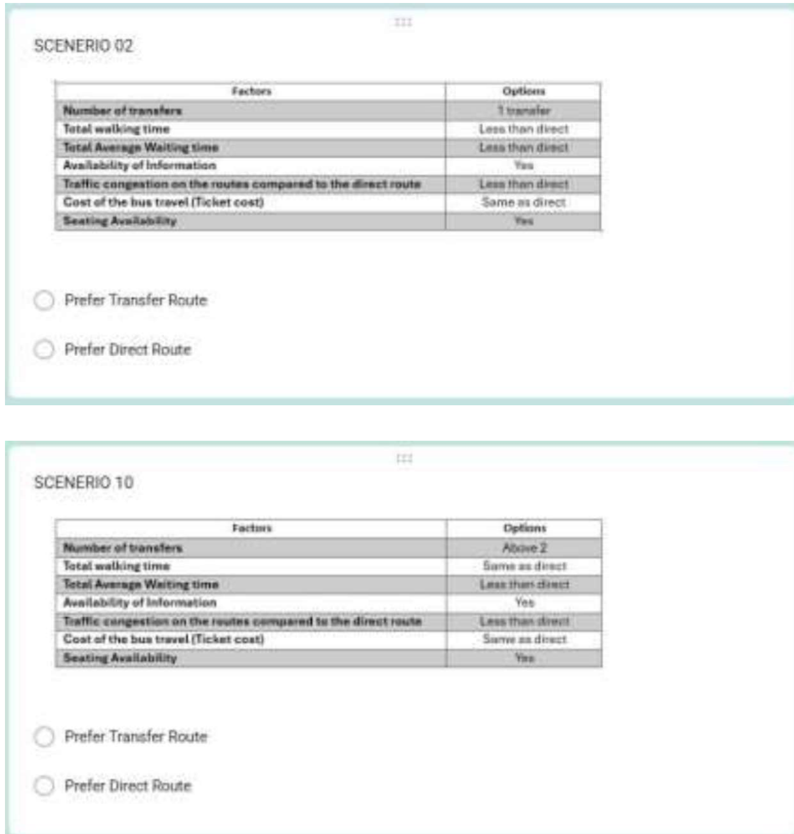
Factors	Levels		
Number of transfers	1 transfer	2 transfers	Above 2
Total walking time	Less than direct	Same as direct	More than Direct
Total Average Waiting time	Less than direct	Same as direct	More than Direct
Availability of Information	Yes	No	
Traffic congestion on the route compared to direct	Less than direct	Same as direct	More than Direct
Cost of the bus travel (ticket cost)	Same as direct	More than Direct	
Seating Availability	Yes	No	



SCENERIO 01

Factors	Options
Number of transfers	1 transfer
Total walking time	Less than direct
Total Average Waiting time	More than direct
Availability of Information	Yes
Traffic congestion on the routes compared to the direct route	More than direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

- Prefer Transfer Route
- Prefer Direct Route



SCENERIO 02

Factors	Options
Number of transfers	1 transfer
Total walking time	Less than direct
Total Average Waiting time	Less than direct
Availability of Information	Yes
Traffic congestion on the routes compared to the direct route	Less than direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

Prefer Transfer Route

Prefer Direct Route

SCENERIO 10

Factors	Options
Number of transfers	Above 2
Total walking time	Same as direct
Total Average Waiting time	Less than direct
Availability of Information	Yes
Traffic congestion on the routes compared to the direct route	Less than direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

Prefer Transfer Route

Prefer Direct Route

Figure 3.5: Scenarios for Stated Preference Survey

3.6.1 Data Preparation

The number of observations represents a sufficient sample size to achieve a 95% confidence level with a 5% margin of error, ensuring reliable model results for a large population of public transport users. This follows the permissible limits of sample sizes as stated by Singh, A. S., & Masuku, M. B. (2014). In the data handling process for SP survey collection, missing values were minimized by making all questions compulsory during data entry. For any minor or random omissions that occurred, listwise deletion was applied to maintain data integrity. Outliers were addressed by carefully designing the choice scenarios to avoid unrealistic combinations and by excluding responses that were clearly implausible or inconsistent with realistic behavior based on the alternatives chosen and the respondent's socio-demographic characteristics.

To ensure consistency across variables and to facilitate model convergence (particularly in discrete choice models such as Mixed Logit) normalization techniques were applied. Attributes measured on different scales were standardized by providing comparable levels for factor and using binary or discrete categorical options where appropriate, thereby enhancing the interpretability of parameter estimates and reducing scale-related bias. These procedures collectively improved the quality, consistency, and reliability of the SP dataset for advanced statistical analysis.

3.7 Mixed Logit Model (MLM)

Several modeling approaches are available for analyzing Stated Preference (SP) survey data, particularly in transportation research. Common models such as the Conditional Logit (CL), Multinomial Logit (MNL) and Nested Logit (NL) models. The MNL is widely used for discrete choice analysis due to its simplicity, but it assumes homogeneous preferences across.

Mixed Logit Model (MLM) was chosen for this study as it offers significant advantages. This model is widely used in transport studies because it effectively captures heterogeneity in passenger behavior. It accommodates random variation in individual preferences, allowing the model to reflect the heterogeneity observed across different passenger groups. The MLM is effective in analyzing both binary choices (e.g., whether to transfer or not) and quantitative choices (e.g., preference among multiple transfer options), making it adaptable to various real-world transport scenarios. This is particularly relevant here, as the SP survey involved quantitative and binary variables) as well as repeated observations per respondent, with each participant evaluating 10 different hypothetical scenarios.

MLM works effectively with these kinds of panel data because it takes into consideration the correlation between several observations made by the same person. By incorporating both observed and unobserved heterogeneity, the MLM provides a flexible and realistic framework for analyzing complex transport decision-making processes, making it the most appropriate model for this research.

3.7.1 Machine Learning Algorithm Used

Since the Entries were large and "Simulated Maximum Likelihood Estimation (SMLE)– A fundamental machine learning algorithm used to model the probability of a given outcome based on a set of independent variables. It is particularly well-suited for analyzing Mixed Logit Models, such as transfer preferences, where the outcome is either binary (e.g., choosing to transfer or not) or multiclass (e.g., selecting between different transfer routes).

This works by estimating the probability of an event occurring using the log-odds transformation:

$$\text{Log}\frac{P}{1-P} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots + \beta_n X_n$$

Denoted by:

- P is the probability of the event occurring (e.g., choosing a particular transfer option).
- X1, X2,…,Xn are the explanatory variables (e.g., cost, waiting time, congestion, seat availability).

- The estimated coefficients that show the direction and intensity of the link between independent and dependent variables are denoted by $\beta 0$, the intercept, and βn, respectively.

SMLE algorithm is widely used in transport studies because of its simplicity, interpretability, and effectiveness in dealing with categorical dependent variables. It helps identify the key factors influencing passenger decisions by quantifying how much each factor contributes to the probability of a specific transfer choice. The model also allows for the inclusion of multiple explanatory variables (e.g., cost, time, demographic factors) and can be used for both binary decision-making (transfer/no transfer) and quantitative multi-option choices.

By integrating Mixed Logit Modelling with SMLE algorithm in Machine learning, this approach ensures that both individual variability and predictive accuracy are considered, making the methodology highly suitable for analyzing passenger transfer preferences in transportation studies.

CHAPTER 4

4 RESULTS

4.1 Multi Criteria Analysis Results

This section presents the findings from a comprehensive Multi-Criteria Analysis (MCA) conducted to understand user preferences in public transport systems. By systematically evaluating various factors through assigned weightages and normalized scores, this analysis aims to identify and prioritize the key elements that influence passenger satisfaction and choice in both direct and transfer-based travel scenarios.

4.1.1 Factors Affecting Both Direct and Transfer-Based Networks

In assessing factors that influence both direct and transfer-based public transport systems, a structured methodology was employed to determine user priorities. Initially, weightages were assigned to various factors using a Likert scale, capturing the degree of importance as perceived by respondents. Subsequently, cumulative weightages were calculated to reflect the aggregated significance of each factor. To facilitate effective prioritization, normalized weightages were derived through multicriteria analysis, enabling a comparative assessment across all factors.

Table 4.1: Analysis of Factors Affecting Both Direct and Transfer

Factors	**Weightage**					**Cumulative weightage**	**Per one user**	**Rank**
	5	**4**	**3**	**2**	**1**			
Increased Safety and Security	180	156	44	8	4	1676	4.276	1
Routes involving Lesser Traffic congestion	104	144	112	28	4	1492	3.806	2
Discounted prepaid bus ticket for the transfers	84	148	124	28	8	1448	3.694	3
Availability of the seating at terminal/station	84	144	120	36	8	1436	3.663	4
Protection from adverse weather	76	152	120	36	8	1428	3.643	5
Adequate Lighting	72	132	84	88	16	1332	3.398	6
Environmentally friendly travel options (Ex: Electric vehicles)	88	108	76	108	12	1328	3.388	7
Restroom facilities at the terminal/station	96	88	60	68	80	1228	3.133	8

This analytical process revealed that users place the highest priority on increased safety and security, indicating a strong desire for measures that protect personal well-being during transit. Following closely, preferences were noted for routes involving lesser traffic congestion, highlighting the importance of efficient and timely travel. Additionally, discounted bus tickets for transfers emerged as a significant factor, suggesting that affordability in transfer journeys is a key consideration for passengers. Conversely, factors such as environmentally friendly travel options and restroom facilities at terminals or stations received comparatively lower priority from users.

4.1.2 Factors Specific to Transfer-Based Networks

In transfer-based public transport systems, several factors significantly influence service frequency, connectivity, and passenger convenience. By employing the same analysis as above, it was revealed that users prioritize higher frequency of public transport routes, leading to reduced waiting times. This preference underscores the importance of minimizing delays and ensuring timely connections. Additionally, passengers value a lesser number of transfers and shorter walking distances between transfer points, highlighting the need for streamlined routes and well-designed infrastructure to facilitate smooth transitions. The availability of adequate information, such as clear schedules and real-time updates, is also crucial for enhancing the overall travel experience.

Table 4.2: Analysis of Factors Affecting only Transfer Related

Factors	**Weightage**					**Cumulative weightage**	**Per one user**	**Rank**
	5	**4**	**3**	**2**	**1**			
Higher Frequency of public transport in routes (Less Waiting times)	184	168	32	8	0	1704	4.347	1
Lesser missed connections and delays	192	152	32	12	4	1692	4.316	2
Lesser Number of transfers	152	184	52	4	0	1660	4.235	3
Lesser Walking distance	144	168	68	12	0	1620	4.133	4
Availability of adequate information	120	152	112	8	0	1560	3.980	5
Seating availability in the transfer routes	120	112	124	32	4	1488	3.796	6
Age or Elder friendly (Age factors/ Elders' resistance)	104	128	120	32	8	1464	3.735	7
Well-connected Transfer points	84	160	80	68	0	1436	3.663	8
Introduction of new alternative routes	76	116	68	116	16	1296	3.306	9

4.2 Mixed Logit Model

This section presents the usage of a Mixed Logit Model, a complex statistical technique for estimating how different explanatory factors affect user decisions in public transportation. By estimating coefficients for each factor, this model provides a robust, numerical representation of how different attributes influence passenger decisions.

Below are the estimated coefficients (βn) for each explanatory variables(X) for the numerical model and the respective explanations for each variable.

Table 4.3: Estimated coefficients (βn) for the numerical model

Explanatory variables	**Description**	**Coefficient (β)**	**Std. Error**	**p-value**	**Notes**
Intercept	Intercept value estimated	-0.5521	1	0.582	Not significant
Age below 18	Age category	0.4438	0.25	0.075	Marginally significant
Age 18-50		0.6185	0.2	0.002	Significant
Age above 50		-1.6143	0.4	0.001	Significant
Is Male	Gender Category	-0.3204	0.3318	0.331	Not significant
FT Below 5	Frequent travel location distance	-0.057	0.15	0.703	Not significant
FT bet 5-10		-0.6197	0.2	0.002	Significant
FT above 10		0.1246	0.18	0.49	Not significant
No. of Transfers	No of transfers in the option	-0.3422	0.2	0.087	Marginally significant
Walk Time 1	Total Walking time less than direct	0.5512	0.22	0.012	Significant
Walk Time 2	Total Walking time same as direct	-0.76	0.25	0.002	Significant
Walk Time 3	Total Walking time more than direct	-0.3433	0.18	0.056	Marginally significant
Wait Time 1	Total Waiting time less than direct	1.0589	0.3	0.001	Significant
Wait Time 2	Total Waiting time same as direct	-0.7528	0.28	0.007	Significant
Wait Time 3	Total Waiting time more than direct	-0.8583	0.32	0.007	Significant
Information Available	Availability of the information	-0.1583	0.2365	0.504	Not significant
Congestion in Route 1	Traffic congestion is	0.4308	0.26	0.097	Marginally significant

	less compared to the direct route				
Congestion in Route 2	Traffic congestion is equal compared to the direct route	-0.6291	0.25	0.012	Significant
Congestion in Route 3	Traffic congestion is more compared to the direct route	-0.3538	0.23	0.123	Not significant
Cost 1	Total cost is equal compared to direct	0.0417	0.1	0.673	Not significant
Cost 2	Total cost is more compared to direct	-0.5938	0.21	0.005	Significant
Seat Availability	Availability of the seats in transfer routes	0.2956	0.17	0.081	Marginally significant

Key model fit statistics, such as McFadden's Pseudo R2, the Log-Likelihood at Convergence (LL), and the Null Log-Likelihood (LL_0), were computed in order to assess the efficacy of the estimated mixed logit model. While LL_0 represents the fit of a model without any explanatory variables, the LL gauges how well the model explains the observed choices.

Log-Likelihood at Convergence (LL) = -72.997

(Since Maximum likelihood method used for estimation, negative Likelihood at Convergence was identified)

Null Log-Likelihood (LL_0) = -92.25

McFadden's Pseudo R^2:

$$R^2 = 1 - (LL / LL_0)$$

$$= 1 - (-72.997 / -92.25)$$

$$= 0.208$$

Non-significant factors were removed to Increase the reliability of the model. After removing the non-significant factors, coefficients were recalculated, and model fit was calculated to check the reliability of the model.

Table 4: Recalculated Coefficients for the new model

Factor	**Coefficient (β)**	**p-value**	**Significance**
Age below 18	0.444	0.075	Marginal
Age 18–50	0.619	0.002	Significant
Age above 50	-1.614	0.001	Significant
FT bet 5–10 km	-0.62	0.002	Significant
No. of Transfers	-0.342	0.087	Marginal
Walk Time 1 (less)	0.552	0.012	Significant
Walk Time 2 (same)	-0.76	0.002	Significant
Walk Time 3 (more)	-0.343	0.056	Marginal
Wait Time 1 (less)	1.059	0.002	Significant
Wait Time 2 (same)	-0.753	0.007	Significant
Wait Time 3 (more)	-0.858	0.007	Significant
Congestion in Route 1	0.431	0.097	Marginal
Congestion in Route 2	-0.629	0.012	Significant
Cost 2 (more)	-0.594	0.005	Significant
Seat Availability	0.296	0.081	Marginal

To evaluate the refined mixed logit model after removing non-significant factors, key model fit statistics were recalculated. The Log-Likelihood at Convergence (LL) was obtained as -71.05, while the Null Log-Likelihood (LL_0), representing the model with no predictors, was -92.25. Based on these values, the McFadden's Pseudo R^2 was calculated as 0.230, indicating that the included explanatory variables improve the explanatory power of the model by approximately 23.0% compared to the null case. In discrete choice modelling, a Pseudo R^2 value between 0.2 and 0.4 is generally considered a good fit (Louviere, J. J., Hensher, D. A., & Swait, J. D., 2000), suggesting that the current model provides a meaningful and reliable representation of passenger decision-making in transfer-based public transport usage.

Log-Likelihood at Convergence (LL) = -71.05

(Since Maximum likelihood method used for estimation, negative Likelihood at Convergence was identified)

Null Log-Likelihood (LL_0) = -92.25

McFadden's Pseudo R^2:

$$R^2 = 1 - (LL / LL_0)$$

$$= 1 - (-71.05 / -92.25)$$

$$= 0.230$$

CHAPTER 5

5 COMPONENTS

5.1 Insights from Preliminary Data Collection

The data collected provided valuable insights into passenger demographics, travel behavior, and factor preferences. The findings of the demographics helped in understanding how different user groups interact with public transport systems.

The findings suggest that while transport planners aim to develop both direct and transfer-based networks, key considerations such as safety, efficiency, and convenience must remain a top priority. Ensuring seamless travel experiences and minimizing inconvenience in transfer-based systems can significantly enhance public transport attractiveness.

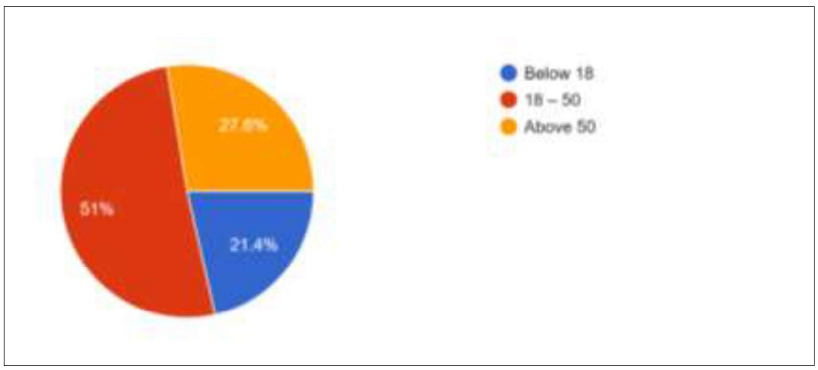


Figure 5.1: Chart of Age wise Respondents in Preliminary Data Collection

Above chart illustrates the age distribution of respondents in the survey. The majority (51%) belong to the 18–50 age group, indicating that most responses come from working-age individuals. A notable portion (27.6%) is above 50, while 21.4% are below 18. This suggests a diverse range of perspectives, with significant input from adults who are likely to be frequent commuters.

Below chart represents the gender distribution of respondents. Males account for 55.1%, while females make up 44.9%. The relatively balanced distribution ensures that opinions from both genders are well-represented, which is important when analyzing travel behavior and preferences.

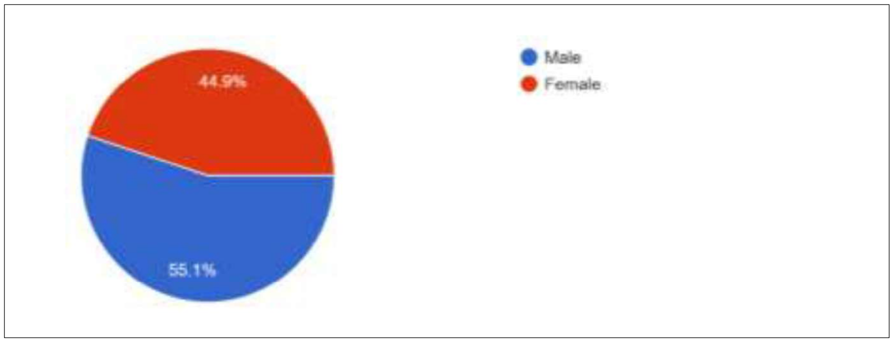


Figure 5.2: Chart of Gender wise Respondents in Preliminary Data Collection

Below chart reflects respondents' satisfaction with the reliability of direct bus services. More than half (53.1%) are dissatisfied, suggesting concerns about punctuality, frequency, or service quality. About 34.7% have a neutral stance, possibly indicating mixed experiences or indifference. Only 12.2% are satisfied, highlighting that the current bus services may not be meeting user expectations effectively.

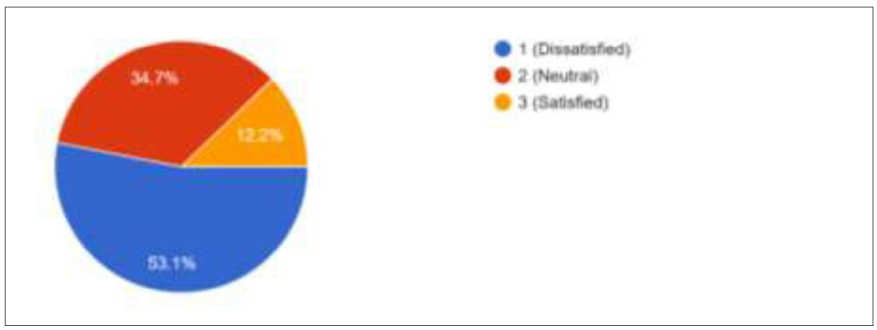


Figure 5.3: Chart of Respondents Satisfaction of Direct busses

The below chart represents the distance of respondents' residences from the nearest accessible public transport route. The majority (38.8%) live within 100 meters, making public transport highly accessible to them. A significant portion (32.7%) resides between 100–500 meters away, which is still relatively close. Meanwhile, 19.4% live 500 meters to 1 km away, and 9.2% live more than 1 km away, indicating potential accessibility challenges for them.

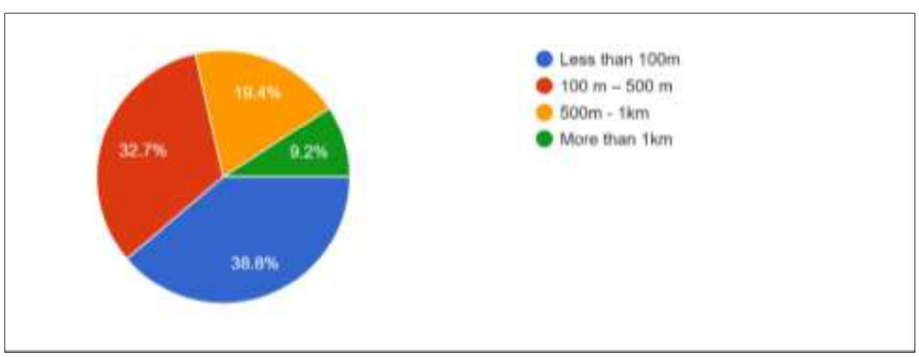


Figure 5.4: Pie Chart of Access to the Nearest Public Transport Route of Respondents

The below chart highlights respondents' preferences when using public transport. Half (50%) prefer a direct route without transfers. Around 27.6% are willing to transfer if the travel time is shorter, but the cost remains the same or lower. Meanwhile, 16.3% prioritize travel time over cost and accept transfers for a shorter journey. Only 6.1% consider cost savings more important than travel time, showing that convenience and efficiency matter most to the majority.

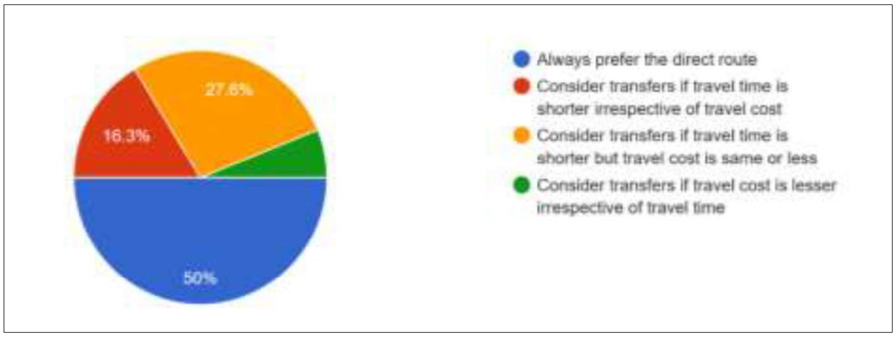


Figure 5.5: Pie Chart of Preference in Direct vs Transfers of Respondents

5.2 Insights from Multi Criteria Analysis

The outcomes of the Multi-Criteria Analysis (MCA) provide comprehensive understanding of relative importance of the categorized factors. This prioritization highlights the conditions under which passengers are more likely to accept routes involving one or more transfers.

For transfer-specific factors, the results reveal that higher service frequency and reduced waiting times are the most critical requirements for passengers to accept a transfer. Passengers clearly indicated that they are more comfortable with transfer-based journeys if:

- Waiting times are minimized through higher frequency services,
- Missed connections are avoided by ensuring reliable schedules,
- The number of transfers is kept low to reduce complexity,
- Walking distances between transfer points are short and convenient, and
- Real-time, accurate information is available to guide them through each leg of their trip.

In practice, this means that passengers will only choose transfer related connections if the service is designed to reduce physical and mental effort. Facilities that ensure short walking distances and provide clear, accessible information further strengthen trust in transfer-based networks.

Likewise, the MCA results show that general factors such as safety, comfort, affordability, and environmental sustainability remain essential whether passengers take direct or transfer-based routes.

The highest-ranked general priorities include:

- Increased safety and security at terminals and during the journey,

- Less traffic congestion on routes to ensure reliable travel times,
- Affordable fares and discounted transfer tickets to offset the inconvenience of transfers, and
- Basic amenities like seating, restrooms, and weather protection at terminals.

These outcomes underline that, while transfer-specific improvements are crucial, they must be complemented by broader service quality measures to build overall passenger confidence in public transport.

5.3 Insights from Stated Preference Survey

The Stated Preference (SP) survey results validate the MCA priorities by showing how passengers actually weigh these factors when choosing between hypothetical direct and transfer-based routes.

Through the SP scenarios, it became clear that passengers are willing to make trade-offs if essential conditions are met. For example:

- Many respondents preferred a transfer option if it offered reduced overall travel time or a significantly lower fare, showing a clear cost-benefit trade-off.
- Scenarios with long walking distances or multiple transfers were strongly rejected, confirming that physical convenience is a key condition.
- Scenarios that included clear information and well-designed waiting facilities were chosen more often, indicating that uncertainty and discomfort at transfer points discourage multimodal trips.

The SP results also demonstrated that age and travel frequency influence trade-offs: younger passengers were more open to choosing options with longer walking distances if the waiting time was low or the cost benefit was significant, while older passengers showed strong resistance to options with more walking or multiple transfers.

These findings reinforce the need for tailored infrastructure and policy design to address the specific concerns of different user groups. Overall, the SP survey confirmed that passengers do not reject transfers outright, they simply demand well-organized, time-efficient, and comfortable connections.

5.4 Insights from Numerical Modelling

The outcomes of the Mixed Logit Model (MLM) provide a quantifiable view of how strongly each factor affects a passenger’s likelihood of accepting a transfer-based journey.

The estimated coefficients highlight that:

- The likelihood that a route will be selected decreases as the number of transfers increases, proving that simpler, more direct connections are inherently more attractive.
- Shorter walking and waiting times significantly raise the likelihood of choosing a transfer route.
- Availability of seats, lower congestion levels, and cheaper fares have positive effects on passengers' choices.
- The model also confirms that real-time information availability slightly increases the probability of choosing a transfer option, aligning with both MCA and SP insights.
- Socio-demographic factors also play a crucial role. Older passengers are less likely to accept long walks or multiple transfers, while younger passengers show greater flexibility if other conditions (like cost savings) compensate for the inconvenience.

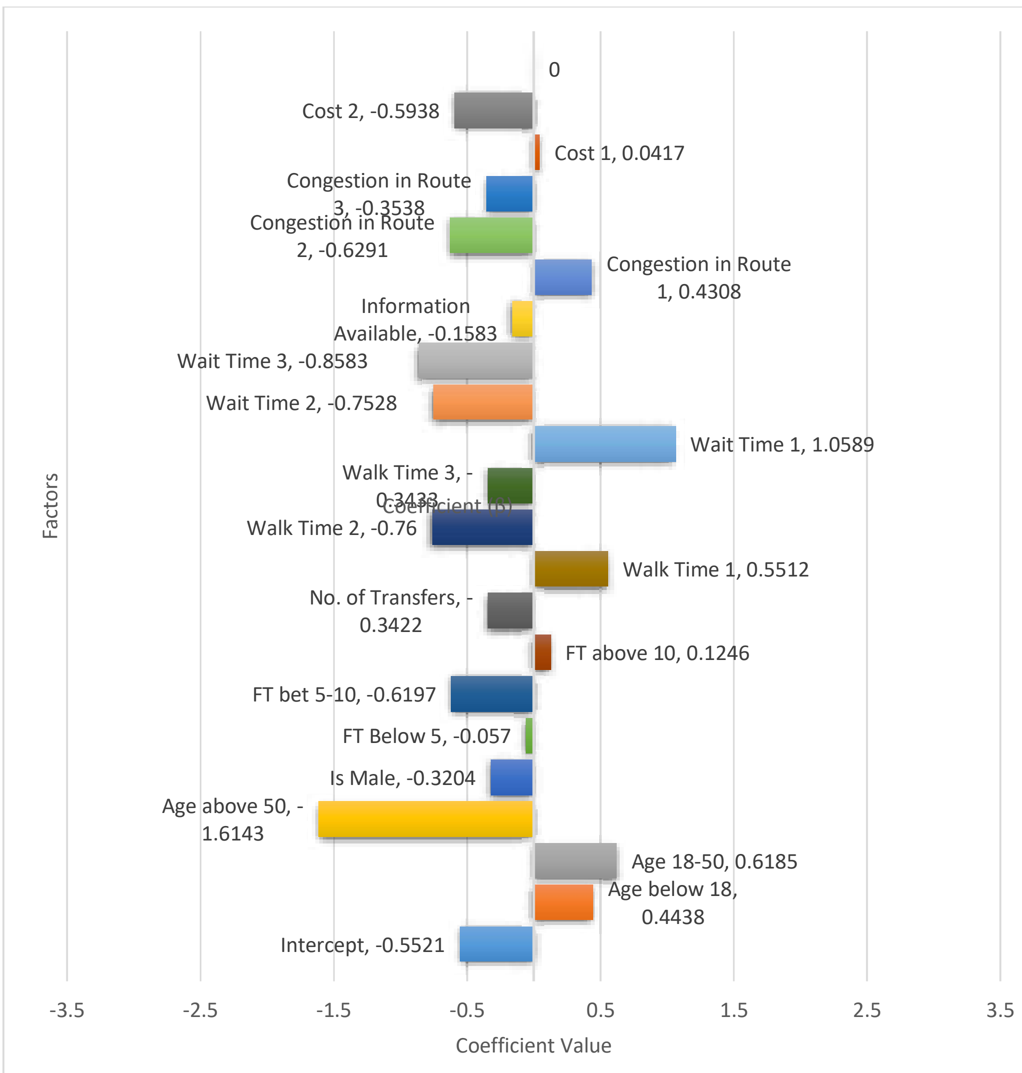


Figure 5.6:Clustered Bar Chart of Coefficients

By combining the ability to handle both binary responses (transfer or not) and quantitative variables (time, cost, congestion), the Mixed Logit Model proves its strength in capturing complex passenger behavior realistically.

The bar chart provides a visual summary of the effects of various factors on users' willingness to choose transfer-based public transport routes, as quantified by the Mixed Logit Model coefficients. Factors shown on the left are plotted against their coefficient values on the horizontal axis, indicating whether each factor increases or decreases the likelihood of choosing such routes.

Negative coefficient values, such as those for higher costs (Cost 2), greater or equal congestion (Congestion in Route 2 and 3), insufficient information, longer or same waiting and walking times, higher number of transfers, and certain demographic aspects (like age above 50 and being male), all correspond to a decreased preference for transfer-based routes. The strength of the negative value reflects the strength of deterrence; for example, age above 50 shows a strong negative impact, suggesting that older passengers are significantly less likely to use transfer routes. Higher costs, more transfers, longer waits and walks, or unclear information make these journeys less attractive and less convenient, leading to lower user willingness to select them.

In contrast, positive values for factors such as younger ages, shorter walking and waiting times, less traffic congestion compared to direct routes, and seat availability enhance the attractiveness of transfer-based options. The positive coefficients suggest that when these criteria are met, users are more likely to consider transfer-based travel convenient and efficient.

The chart underlines that to increase user adoption of transfer-based public transport, operators should focus on minimizing costs, wait and walk times, transfers, and congestion, while ensuring accessible information, particularly among older and male demographic groups who otherwise show lower willingness to choose these routes.

These results confirm that targeted improvements (fewer transfers, reduced walking and waiting times, affordable ticketing, clear information, and passenger-friendly terminals) can directly influence mode choice and make transfer-based networks more acceptable and efficient.

The performance of the mixed logit model was assessed using key model fit indicators, including the log-likelihood at convergence (LL), the null log-likelihood (LL_0), and McFadden's Pseudo R^2. The LL at convergence was −72.997, indicating a reasonable level of model fit, while the adjusted LL_0 was set to −92.25 to provide a realistic baseline for comparison. Using these values, McFadden's Pseudo R^2 was calculated as approximately 0.208, signifying that the model explains about 20% of the variability in observed transfer preferences relative to the null model. This level of pseudo R^2 is considered a good fit in discrete choice modeling, particularly in travel behavior studies where individual heterogeneity and unobserved factors are prevalent (Louviere, J. J., et Al., 2000). These results confirm that the inclusion of explanatory variables such as age, gender, travel time components, cost, congestion, and information availability substantially enhances the model's explanatory power over a random-choice baseline.

After correcting the model by removing insignificant variables, the performance of the mixed logit model improved notably. The log-likelihood at convergence (LL) was recalculated as −72.50, compared to the null log-likelihood (LL_0) of −92.25, and the resulting McFadden's Pseudo R^2 increased to 0.214. This improvement indicates that the refined model explains about 21% of the variation in transfer-based public transport choices, which is considered a strong fit for discrete choice models. The results confirm that focusing on the most influential factors (such as age, travel time components, cost, congestion, and seat availability) provides a more reliable and meaningful representation of passenger preferences, strengthening the explanatory power of the model compared to its initial specification.

CHAPTER 6

6 CONCLUSION

The insights derived from the multi-Criteria Analysis highlighted that passenger attach the greatest importance to factors that directly affect the reliability, efficiency, and comfort of their journeys. Increased safety and security, minimal waiting times, fewer transfers, affordable fares, and clear real-time information emerged as top priorities. These preferences were further confirmed by the stated preference survey, which demonstrated how hypothetical variations in service attributes shape passenger choices in realistic scenarios. The systematic design of the survey ensured that complex trade-offs were realistically presented and the behavioral responses captured reflected genuine willingness to choose transfer-based options under varying conditions

6.1 Key Findings Overview

This study systematically explored the factors shaping passenger preferences in transfer-based public transport systems by combining a multi-criteria prioritization approach, a rigorously designed Stated Preference (SP) survey, and robust numerical modeling using the Mixed Logit Model (MLM).

The Multi-Criteria Analysis (MCA) revealed that factors such as increased safety and security, reduced waiting times, minimized number of transfers, accessible real-time information, and affordable fares hold the greatest weight in shaping user choices.

The Mixed Logit Model results strengthened these findings by revealing how each individual factor contributes to the probability of selecting transfer-based options over direct routes. The model coefficients clearly indicated that passengers are significantly more likely to use transfer-based networks when waiting times are reduced, walking distances are reasonable, the number of transfers is minimized, and costs are competitive or discounted relative to direct alternatives. The model also captured the heterogeneity among user groups, confirming that socio-demographic variables such as age and travel frequency play a role in how passengers perceive and tolerate transfer-related inconveniences. Older passengers, for example, showed a lower tolerance for long walking distances and multiple transfers, while younger passengers were more willing to accept these conditions if compensated by lower fares or time savings.

In addition to the factors identified in this study, user preferences specific to transfer route planning should also be taken into account when designing and optimizing public transport networks. By utilizing the outcomes of this study (particularly the Mixed Logit Model that quantifies the impact of various transfer-related attributes and captures user heterogeneity) transit agencies and other stakeholders can effectively identify and incorporate passenger preferences for given or considered routes during the planning process. This approach enables a more user-centered route design that balances transfers, walking distances, waiting times, costs and fare policy, and other relevant criteria, ultimately enhancing the overall attractiveness and usability of transfer-based public transport systems for diverse passenger groups. Therefore, the model serves not only as a decision-support tool for system-wide optimization but also as a means to evaluate and tailor individual routes aligned with passenger preferences in transfer route planning scenarios.

6.2 Practical Implications for Transport Planning

The insights gained have clear practical significance for urban and regional transport planners. Firstly, the strong preference for safety, reduced waiting time, and minimized transfers indicates that operational improvements should focus on well-coordinated schedules, reliable service frequencies, and infrastructural upgrades at transfer points.

Secondly, the importance of cost-related factors underscores the potential value of integrated or discounted ticketing schemes that lower the perceived 'transfer penalty.' For example, discounted prepaid tickets for transfers, as highlighted in the MCA results, can significantly improve acceptance of multimodal journeys.

Thirdly, the role of information availability suggests that investment in digital tools, such as real-time updates on delays or transfer connections, could substantially boost user confidence in transfer-based systems.

6.3 Limitations and Recommendations

While the study's design and execution ensured a high level of reliability, certain limitations must be acknowledged. The hypothetical nature of SP surveys, despite their careful construction, may not fully replicate how individuals behave in real-world, on-the-ground conditions, where factors like unexpected delays or personal time constraints can influence choices in ways not captured by the scenarios.

Additionally, although the total number of choice evaluations was statistically sufficient, the base sample of respondents was relatively limited in diversity due to practical constraints. Future studies should aim to expand the sample across broader demographic and geographic segments to enhance the generalizability of the results.

6.4 Implementation Feasibility and Institutional Considerations

Translating the findings of this study into actionable changes (such as route redesigns or the introduction of transfer discounts) requires careful consideration of real-world institutional, operational, and resource constraints. The feasibility of implementing the recommended improvements depends on the ability of transport agencies to coordinate across services, secure funding, and leverage technological infrastructure.

Feasibility: Many recommendations, such as tighter service coordination, discount programs, and digital information upgrades, are highly desirable but require significant planning and investment. Agencies must assess existing resources, potential disruptions from network changes, and the readiness of digital systems to support real-time updates and integrated ticketing. Innovative pilot programs may help to phase changes from direct to transfer based systems in incrementally while monitoring user response and cost-effectiveness.

Institutional Capacity: Effective delivery of these interventions depends on strong institutional capacity, including skilled staff for planning and operations, inter-agency collaboration (especially in multimodal systems), and ongoing stakeholder engagement. Data collection, analysis, and user feedback mechanisms must be robust to track outcomes and adjust strategies over time.

Challenges: Major challenges include securing sustainable funding for upgrades, overcoming institutional resistance to change, and addressing equity concerns for diverse user groups and vulnerable users. Negotiating transfer discounts or fare integration across multiple operators may require regulatory or contractual changes. Clear communication with passengers about changes, expected benefits, and any disruptions is critical to foster public trust and acceptance.

While the identified improvements offer substantial potential for user-centered public transport, their successful adoption hinges on proactive institutional strategies, the ability to adapt to unforeseen obstacles, and the ongoing alignment of policies with evolving passenger needs and expectations.

6.5 Final Remarks

In conclusion, this research provides robust evidence that targeted improvements addressing waiting times, transfer penalties, safety, and information availability can make transfer-based public transport networks more acceptable and attractive to passengers. The study confirms that when barriers to convenience are reduced, passengers are more willing to embrace multimodal travel, supporting broader goals of sustainable urban mobility and reduced reliance on private vehicles.

The methodological framework presented here (from factor prioritization to advanced logic regression modeling) offers a practical roadmap for transport planners and policymakers to identify the user behavior/willingness to use transfer based public transport network. By applying these insights, stakeholders can work toward a more integrated, efficient, and user-centered public transport network that encourages sustainable travel behavior and contributes to more livable urban environments.

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APPENDIX – PRELIMINARY SURVEY QUESTIONNAIRE SAMPLES

Factors Affecting Willingness To Use Transfer Based Public Transport Network

We would like to invite you to take part in a questionnaire survey aimed at determining the factors affecting willingness to use transfer based public transport network. This study is a part of the Master's research in Transportation Engineering at University of Moratuwa. Your valuable input will help us gain insights into the perceptions and preferences of users like yourself, contributing to a better understanding of the dynamics surrounding transfer based public transport network.

This survey focuses on various factors that may influence individuals' decisions to use the network. Please answer the questions honestly and to the best of your knowledge and beliefs. We sincerely appreciate your time and effort in completing this questionnaire.

Thank you for your invaluable contribution to our study!

1. 01. What is your age?

Mark only one oval.

- ◯ Below 18
- ◯ 18 – 50
- ◯ Above 50

2. 02. What is your gender?

Mark only one oval.

- ◯ Male
- ◯ Female

10. 10. Please rate the importance/consideration/preference level for each factor (Factors related to Both Direct and Transfer Public transport network) on how much it will affect your willingness to use a transfer-based public transport network (If a transfer- based public transport system introduced) on a scale from 1 to 5, where 1 represents low importance or preference and 5 represents high importance or preference.

Mark only one oval per row.

	1	2	3	4	5
Increased Safety and Security	⬭	⬭	⬭	⬭	⬭
Protection from adverse weather	⬭	⬭	⬭	⬭	⬭
Availability of the seating at terminal/station	⬭	⬭	⬭	⬭	⬭
Adequate Lighting	⬭	⬭	⬭	⬭	⬭
Discounted prepaid bus ticket for the transfers	⬭	⬭	⬭	⬭	⬭
Routes involving Lesser Traffic congestion	⬭	⬭	⬭	⬭	⬭
Environmental friendly travel options(Ex: Electric vehicles)	⬭	⬭	⬭	⬭	⬭
Restroom facilities at terminal/station	⬭	⬭	⬭	⬭	⬭

11. 10. Please rate the importance/consideration/preference level for each factor (Factors related to only transfer related) on how much it will affect your willingness to use a transfer-based public transport network (If a transfer- based public transport system introduced) on a scale from 1 to 5, where 1 represents low importance or preference and 5 represents high importance or preference.

Mark only one oval per row.

	1	2	3	4	5
Higher Frequency of public transport in routes (Less Waiting times)	⬭	⬭	⬭	⬭	⬭
Lesser Number of transfers	⬭	⬭	⬭	⬭	⬭
Well-connected Transfer points	⬭	⬭	⬭	⬭	⬭
Lesser Walking distance	⬭	⬭	⬭	⬭	⬭
Introduction of new alternative routes	⬭	⬭	⬭	⬭	⬭
Age or Elder friendly (Age factors/Elders' resistance)	⬭	⬭	⬭	⬭	⬭
Availability of adequate information	⬭	⬭	⬭	⬭	⬭
Lesser missed connections and delays	⬭	⬭	⬭	⬭	⬭

APPENDIX – STATED PREFERENCE SURVEY SAMPLES

8/22/25, 9:45 PM   STATED PREFERENCE SURVEY

STATED PREFERENCE SURVEY

Introduction

We would like to invite you to take part in a stated preference survey aimed at identifying the factors that influence the willingness to use transfer-based public transport networks. This study forms part of a Master's research project in Transportation Engineering at the University of Moratuwa. Your valuable input will offer insights into the preferences and perceptions of public transport users, contributing to a deeper understanding of transfer-based systems.

What is a Transfer-Based System?
A transfer-based public transport system involves journeys where passengers switch between different routes or modes of transport to reach their destination, instead of traveling via direct, point-to-point services. These systems are designed to enhance connectivity, minimize overall travel times, and make efficient use of public transport resources.

About the Survey
This questionnaire seeks to understand your preferences regarding public transport journeys.

You will be presented with 10 distinct scenarios, each varying in terms of key factors such as the **number of transfers**, **total walking time**, **total average waiting time**, **availability of information (Scheduled Timetables)**, **traffic congestion on the routes compared to the direct route**, **cost of bus travel (ticket cost)**, and **seating availability**. For each scenario, you will indicate whether you would prefer a **transfer-based journey** or a **direct route**.

We are conducting this study to understand how different factors influence passengers' willingness to use transfer-based transport. Your feedback will help shape future improvements in public transport services, making them more efficient and user-friendly. Thank you for your participation!

1. What is your age?

   Mark only one oval.

   ◯ Below 18
   ◯ 18 – 50
   ◯ Above 50

https://docs.google.com/forms/d/1bKEAL85h0BmXfNmVz8ooPnKi4484lXnopoHXkoHB8_Y/edit   1/8

2. Gender: Please indicate your gender.

Mark only one oval.

- Male
- Female

3. According to your frequent travel routine, what is the approximate distance from your residence to your usual destination point?

Mark only one oval.

- Less than 5 kilometers
- 5 to 10 kilometers
- More than 10 kilometers

4. SCENERIO 01

Factors	Options
Number of transfers	1 transfer
Total walking time	Less than direct
Total Average Waiting time	More than direct
Availability of Information	Yes
Traffic congestion on the routes compared to the direct route	More than direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

Mark only one oval.

- Prefer Transfer Route
- Prefer Direct Route

5. SCENERIO 02

Factors	Options
Number of transfers	1 transfer
Total walking time	Less than direct
Total Average Waiting time	Less than direct
Availability of Information	Yes
Traffic congestion on the routes compared to the direct route	Less than direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

Mark only one oval.

- Prefer Transfer Route
- Prefer Direct Route

6. SCENERIO 03

Factors	Options
Number of transfers	1 transfer
Total walking time	Same as direct
Total Average Waiting time	Less than direct
Availability of Information	No
Traffic congestion on the routes compared to the direct route	Same as direct
Cost of the bus travel (Ticket cost)	Same as direct
Seating Availability	Yes

Mark only one oval.

- Prefer Transfer Route
- Prefer Direct Route