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Research Article

Assessment of the Impact of a Newly Operated Mass Rapid Transit System on Multimodal Transportation System Performance in the Indian Context

Rupam Sam[1*], Dr. Sudip Kumar Roy[2]

[1*]Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah, West-Bengal, India, Pin: 711103 2020cep007.rupam@students.iiests.ac.in

[2]Department of Civil Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah, West-Bengal, India, Pin: 711103 sudip.civil@faculty.iiests.ac.in

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ABSTRACT

This research study examines the effects of a new metro system implementation on various performance indicators along with the determination of service quality components of a multimodal transportation network. The objectives of the study are twofold: firstly, to compare the performance indicators before and after the metro system implementation, and secondly, to conduct a principal component analysis of the service quality assessment related to the multimodal transportation system. The data, based on individual multimodal trip characteristics (before metro and after metro scenario) and multimodal service quality ,were collected from 400 commuters experiencing the newly operated mass rapid transit system (MRTS) using a revealed preference survey approach in multimodal transport system. Impact on the both of the quantitative (such as performance indicators, including travel time index, interconnectivity convenience ratio, journey speed etc.) and qualitative (such as modal service quality) multimodal performance indicators, were analysed using parametric and non-parametric statistical tests to compare the changes on these indicators in before and after metro scenario. These findings suggest that the metro system has positively influenced the overall efficiency of the multimodal transportation performance, may involve trade-offs by compromising few indices, highlighting the need for comprehensive and sustainable mobility planning. The findings of this research contribute to the understanding of sustainable mobility and its implications for urban transportation planning in terms of significance of the metro system in improving commuter experience, optimizing resources, and promoting the use of public transportation.

Keyword: Metro system, Multimodal transportation, Performance indicators, Sustainable mobility, Public transit, Principal component analysis.

Introduction:

Public transport systems are an important part of urban development by providing daily movement between places of residence and work, as well as other practices and activities [1]. In urban areas, multimodal transportation systems play a crucial role by ensuring efficient, reliable, and sustainable mobility for commuters. Multi Modal Transportation System (MMTS) can be defined as the applications of technological and scientific principle to the planning, design, operation and management of service facilities, combining two or more transport modes to provide utility and service for safe, rapid, convenient and environmentally compatible movement of the people. Two or more different modes are used for single trip in MMTS, between which the traveller has to make a transfer [2]. Transfer is an essential part of multimodal trip and travellers have to change modes at transfer nodes. Hence seamless travel is an important requirement of any multimodal system. Metro provides the optimum solution of mass transportation problems [3]. The introduction of new transportation infrastructure, presents an opportunity to enhance the performance of the transportation

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network and improve the overall travel experience for passengers. Thus, the introduction of metro systems requires careful planning and design to ensure their effectiveness. Evaluating the impact of such interventions is vital to understanding their effectiveness and guiding future transportation planning and policy decisions. In order to explore the mechanisms to improve connectivity by improving multimodal transit service, a systemic approach is required mainly in the developing countries.

Multimodal transportation system indices are closely related to sustainability as they provide valuable insights into the performance and effectiveness of transportation systems in achieving sustainable outcomes. Multimodal transportation system indices assess the efficiency of resource utilization in a transportation network. By evaluating the seamless integration and connectivity between different modes of transportation (e.g., metro, train, bus, auto, walking), these indices help optimize the use of existing infrastructure and resources. These performance indices provide quantitative measures to assess the efficiency, convenience, and reliability of the transportation system. Multimodal transportation system indices provide a comprehensive framework for assessing and improving the sustainability of transportation systems. As most of the public transport trips are multimodal, it is necessary to evaluate the performance of multimodal transportation systems. Comparing multimodal performance indicators, before and after the implementation of a new metro system can provide valuable insights into how transportation infrastructure affects sustainable development goals. By focusing on the factors that have the most significant impact on user satisfaction, the transportation system can be tailored to meet the needs and expectations of commuters by enhancing user experience and providing seamless experience encourages people to opt for public transportation, reducing the reliance on private vehicles and contributing to a more sustainable urban transport system. The new metro system helps reduce traffic congestion, it can lead to time savings for commuters. This not only enhances the overall transportation experience but also leads to increased productivity and better work-life balance for individuals, supporting sustainable development goals.

The structure of the public transit system has a significant effect on its performance and services. The primary objective of this research aims to analyse the impact of the newly implemented mass rapid transit system (MRTS such as metro system) on both quantitative and qualitative multimodal performance indicators, such as travel time index, interconnectivity convenience ratio, journey speed, and modal service quality etc. This study can identify areas of efficiency and resource optimization in order to build well-functioning multimodal transportation system by analysing and comparing the performance indicators. The robustness of the results was determined by applying both parametric and non-parametric tests and discussing the implications of using different test approaches. The secondary objective of the study is to conduct Principal component analysis (PCA) for modal service quality assessment (as perceived by the commuters) influencing the performance of multimodal transportation system. Understanding the underlying structure of service quality through PCA allows for long-term planning making the transportation system more resilient and adaptable to changing demands. Conducting PCA to analyse the service quality assessment in the context of multimodal transportation can provide valuable insights and recommendations to improve the system's sustainability. This study can guide the policymakers and transportation planners in creating sustainable transportation networks that prioritize environmental protection, social equity, and economic vitality.

Literature Review:

Majority of studies use network distance—which is determined by origin and destination location data—to calculate access and egress times. According to Blom (1982), people are often prepared to accept greater access distances when the major mode distance increases. However, the egress distance stays the same as the main mode distance increases [4]. However, there are conflicting results about the associations between the choice of access (and egress) mode and individual and land-use variables. According to the findings of Krygsman et al. (2004), trip direction, access and egress mechanisms, rather than socio-demographic traits, determine access and egress timings [5]. All studies, however, agree that travel time to (from) transfer points is the most critical consideration when choosing an access or egress route and is likely the greatest deterrent to use public transportation. According to Keijer and Rietveld (2004) and Rietveld (2000), the distance for access and egress together makes for 15% of the overall journey distance. According to Rietveld (2000), longer multimodal trips

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are more desirable than shorter multimodal trips because the ratio of access and egress distance to the main mode distance is smaller and the negative effects of access and egress stages are lessened when the main stage distance is long (Keijer and Rietveld, 2004). To quantify and assess the effectiveness of the transportation system, connectivity is one of the index metrics that can be utilized (Borgatti, 2005). The effectiveness of the transit system can be assessed using network connectivity (Hadas and Ceder, 2010) as a measure to help decision makers prioritize transit investments and determine which stops and lines require immediate attention in terms of operation and maintenance. This is essential for these service providers to demonstrate their strength in business performance in a competitive business environment, numerous service providers have commissioned numerous studies on commercial service quality (Azar 2007; Badri, Abdulla & Al-Madani 2005; Mazzeo 2004; Sivadas & Prewitt-Baker 2000) [7,8]. Framework (SERVQUAL model) with five dimensions of service quality including reliability, assurance, tangibility, empathy, and responsiveness, have been used to assess the passengers' needs [9].

There is a significant research gap regarding the assessment of their impact on multimodal transportation system performance, particularly in the Indian context. While few studies have explored the effects of MRTS implementation and assessment of performance indicators separately, there is a lack of comprehensive research that specifically examines the overall impact of a newly operated MRTS on the multimodal transportation performance in Indian context.

Performance Indicators:

Performance-based planning is the application of performance management within the planning and programming processes of transportation agencies to achieve desired performance outcomes for the multimodal transportation system. The multimodal performance indicators, often referred to as measures of effectiveness (MOEs), which enable the evaluation of specific and measurable outcomes in relation to established goals and objectives of this study by providing quantitative evidence of how well the transportation system is functioning. Based on the previous literature [9, 10, 11] the following indicators are considered for this study:

- **The Travel Time Index (TTI):** TTI represents the ratio of the average travel time after the metro system implementation to the average travel time before the metro system implementation. The TTI aids in estimating travel times for different routes or transportation modes. By knowing the free flow time and using the TTI value, it is possible to estimate the expected travel time during peak periods. This information is valuable for trip planning, allowing commuters to allocate appropriate travel durations and make informed decisions.
- **Interconnectivity convenience ratio (ICR):** This index takes into account both access time and egress time in relation to the total journey time. ICR assesses the convenience and ease of intermodal transfers within the transportation network. A lower ratio indicates better interconnectivity and smoother transitions between modes, which enhances the overall multimodal transportation experience. The ratio often falls within the moderate range of 0.2-0.5 for multimodal excursions. Improved interconnectivity convenience ratio indicates a more seamless and efficient transfer experience for passengers, facilitating smoother multimodal journeys and encouraging greater uptake of public transportation.
- **Non-vehicular to Vehicular Travel Time Ratio (IVTT to OVTT):** This ratio is a measure that compares the time spent outside the vehicle to the time spent inside the vehicle. It provides insights into the balance between the different components of a trip, highlighting the relative importance of out-vehicle travel time compared to in-vehicle travel time. A higher Out-In Ratio suggests that a significant portion of the total travel time is spent outside the vehicle, indicating a greater emphasis on activities such as walking or waiting. This may be the case in scenarios where the transportation system relies heavily on walking or where there are lengthy waiting times for transfers.
- **Walking Time Ratio & Waiting Time Ratio:** The Waiting Time Ratio provides insights into the proportion of the total travel time that is spent on waiting during a journey and the Walking Time Ratio is a

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measure of the proportion of time spent on walking as a share of the total travel time. After the metro implementation, improvement or change in the waiting times and walking time, experienced by passengers.

- **Journey speed (JS) & Running speed (RS):** Journey speed considers the entire trip from the origin to the destination, including both the time spent in motion (running speed) and any waiting time at stops or stations. By comparing the before and after the metro implementation, improvement or change in the journey speed and running speed can be determined.

By considering Public Transit Service Level (PTSL) as a qualitative performance indicator, valuable insights can be gained regarding the overall satisfaction and experience of commuters using the public transportation system before and after the metro system implementation. This qualitative aspect complements the quantitative indicators and provides a more comprehensive understanding of the impact of the new metro system on the multimodal transportation system's performance. By employing performance measures, transportation authorities can monitor system performance over time, gaining valuable insights into the effectiveness of their initiatives.

Study Area:

Travel characteristics vary with city size, city structure and available transport infrastructure. By distinguishing between inter- and intra-urban travel, Wardman and Tyler (2000) contend that accessibility to railway stations (distance) is not the main factor influencing inter-urban demand. The length of the trip and the users' prior rail experience have a greater impact on the demand for inter-urban travel (Wardman and Tyler, 2000). The study area should represent a relevant urban region where the metro system has recently been introduced and where multimodal transportation networks are significant.

Kolkata, also known as the "City of Joy," holds significant historical, cultural, and economic

importance in India. As the capital of the state of West Bengal, Kolkata is one of India's major metropolitan cities and a vital commercial and industrial hub. The city has witnessed significant growth and development over the years, which has led to challenges in its transportation infrastructure. Kolkata has a diverse multimodal transportation system that caters to its large population and the influx of commuters. The city's transportation network includes various modes such as buses, trams, taxis, suburban trains, and river ferries.

Howrah and Sealdah Railway Station, the largest railway station in India, holds immense importance in Indian transportation system due to its historical significance, role as a major transportation hub, high passenger footfall, efficient connectivity, contribution to Kolkata's economy, heritage architecture and intermodal connectivity. It continues to play a crucial role in India's railway network and remains an integral part of Kolkata's urban transportation infrastructure. This city has been focusing on the development and implementation of mass rapid transit system (MRTS) in the form of an underground metro rail for many years, providing efficient connectivity to various parts of the city.

The Kolkata Metro was the first metro railway in India. The first operational line, known as the North- South corridor, was inaugurated in 1984. The newly implemented East-West Corridor of the Kolkata Metro is a vital transportation link that connects the eastern and western parts of the city. Kolkata metro network has achieved a milestone when Kolkata Metro (East-West corridor) runs first underwater passenger trial run this year in the month of April between Howrah Maidan and Esplanade under the river bed of Ganga (first underwater metro corridor and the deepest metro in India) and soon the Howrah city (also known as twin city of Kolkata) is going to be connected when this East-West corridor will be fully operational (Figure 1). This East-

West corridor is one of the two major metro corridors of the Kolkata Metro system, the other being the North-South Corridor. In present scenario, the East-West Corridor is partially operational Sealdah railway station (started from July, 2022) and Karunamoyee and Salt Lake Sector V (known as IT hub of Kolkata) CBD areas.

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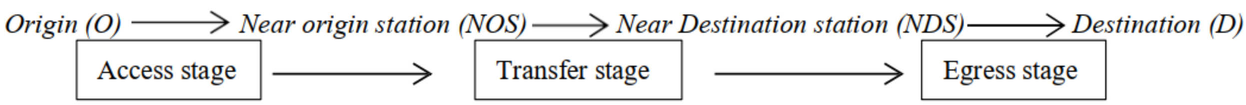
Figure 1: East-west metro corridor, Kolkata city

Kolkata exhibits diverse characteristics that make it representative of other urban cities in Indian context facing similar transportation situation. For this research, the study area has focused on the city Kolkata due to its recent implementation of a metro system, making it an ideal case study for assessing the impact of this new infrastructure on performance indices. Firstly, the newly implementation of the East-West metro system in Sealdah area represents a significant intervention in the existing transportation network. Secondly, this tier-I city is characterized by a multimodal transportation system that includes various modes such as buses, autos, taxis, and other forms of public transportation and such complexity allows for a comprehensive assessment of intermodal connectivity and the potential synergistic effects between the metro system and other modes of transportation. Sealdah metro station located in close proximity to the Sealdah railway station, passengers (commuting from sub-urban areas towards the Salt Lake) can easily switch to the new mass rapid transit service to reach their destination and provide commuters with additional transportation options, making it easier for them to reach their destinations and therefore this corridor are selected for this research. The selection of Kolkata as the study area for this research provides an ideal context to assess the impact of the newly implemented metro system on performance indices in multimodal transportation. The area's recent introduction of the metro system, its multimodal transportation network, representative characteristics, and data availability make this city a suitable study area for gaining insights into the effectiveness of the metro system in enhancing transportation performance.

Data Collection:

Most appropriate data collection methodology is determined based on the research objectives and available resource including surveys, field observations, interviews, and existing data sources. To ensure a comprehensive analysis, various types of data need to be collected and therefore the following outlines the process of data collection and the types of data that are required for this study:

Identification of Study Participants: The target population for data collection is identified, which has included the daily commuters who utilize both of the transportation system in Kolkata city: The newly operated Sealdah metro and Sealdah railway station and therefore, the following multimodal trip pattern (Mixed-Train- Mixed) of the commuters has been considered:



- **Origin (O):** The spot from where the journey is started (i.e. Home).
- **Near origin station (NOS):** Nearest rail transit station from the origin (i.e. Sub-urban rail stations) and also considered as initial transfer point of this trip for individual commuters.
- **Near destination station (NDS):** Nearest rail transit station from the destination (i.e. Urban rail station, Sealdah railway station) and also considered as final transfer point of this multimodal trip pattern.
- **Destination (D):** The spot where the journey ends (i.e. CBD area Salt-lake in Kolkata city)

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- **Access stage:** The first stage of multimodal trip is from Origin to NOS is the Access stage. This stage may consist the combination of modes such as walking and auto rickshaw, walking and bus etc. used by the newly shifted commuters.
- **Transfer stage:** The second trip stage is from NOS to NDS is the Transfer stage in this study. Local train is considered as common transfer mode for all the newly shifted commuters.
- **Egress stage:** This last stage of the trip reaching destination from the NDS point. This stage mainly gets influenced as the newly implemented metro service has been considered in this stage for the newly shifted metro commuters.

In order to have the comprehensive details of the individual commuter trip details, next this study moves on the collection of the required data for this study.

Survey Data Collection: The relevant questionnaires are designed for the newly shifted commuters and surveys were conducted through in-person or telephonic interviews to gather information from commuters and other relevant participants during morning peak hour and off-peak hour. The sampling strategy used here was random sampling strategy. Data (including measurements both before and after the metro system implementation) for the mentioned performance indicators, is collected from a representative sample of commuters and the dataset is organized with separate ate columns for each performance indicator denoting the scenarios (e.g., "Before-Metro" and "After-Metro"). As the decisions of the newly shifted metro commuters (chosen alternative over the rejected alternatives) are revealed in the commuter's behaviour, this is called as

Revealed Preference (RP) survey. Using a revealed preferences survey can lead to more reliable and actionable findings, as it reflects actual behaviours and experiences of commuters in real-world conditions. This RP survey has captured data on various aspects related to performance indices in context to new metro system, based on travel times, satisfaction levels in context to new metro system implementation in multimodal urban transport system. This also helps to understand the holistic effect of the metro system on commuters' satisfaction and experience with the transportation system in context to before and after metro scenario. Table 1 helps in assessing the changes in the perceived modal service quality parameters before and after the metro system implementation. This table presents the ratings (5 point scale) given by commuters for each parameter in both scenarios (BM and AM).

Table 1: Modal service quality

<table>
<tr><th>Sl no</th><th>Modal service quality Parameters</th><th>Rating (BM)</th><th>Rating (AM)</th></tr>
<tr><td>1</td><td>Waiting comfort</td><td rowspan="10" colspan="2">1: Worst
2: Bad
3: Mediocre
4: Good
5: Best</td></tr>
<tr><td>2</td><td>Journey Comfort</td></tr>
<tr><td>3</td><td>Waiting Safety</td></tr>
<tr><td>4</td><td>Journey Safety</td></tr>
<tr><td>5</td><td>Ease of access in digital information</td></tr>
<tr><td>6</td><td>Frequent is the modal service</td></tr>
<tr><td>7</td><td>Easy to access from the previous mode</td></tr>
<tr><td>8</td><td>Cleanness service</td></tr>
<tr><td>9</td><td>Service during bad weather or any special event</td></tr>
<tr><td>10</td><td>Mental and physical fatigue using modal service</td></tr>
</table>

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By comparing the aggregated scores before and after the metro system implementation, significant improvements or changes in the overall multimodal service quality can be determined with the qualitative approach based on Trip characteristics of the newly shifted commuters in based on Table 2. The commuters were asked about their revealed preference regarding their trip characteristics by considering the distance, trip time, Out-Vehicle travel time (OVTT) and In-vehicle travel time for each stage and satisfaction regarding modal service quality egress stage of their individual trip.

Table 2: Trip characteristics

	O-D	Distance		Mode		Journey time				Egress mode Satisfaction level	
						BM		AM			
		BM	AM	BM	AM	IV TT	OV TT	IV TT	OV TT	BM	AM
	Home (Origin) – Near origin station (NOS)									NA	NA
	Near origin station (NOS)- Near destination station (NDS)									NA	NA
	Near destination station (NDS)- Destination										

Sample Size Determination: Considering the following assumptions as, desired confidence level of 95% (corresponding to a two-tailed test Z-score of approximately 1.96), the expected proportion (p) to estimate or assume the proportion of the population (assuming 0.5 for this study) that exhibits the characteristic of interest and margin of error (E) to determine the maximum tolerable error (corresponding to 5% margin of error) or level of precision in results, required sample size is calculated using the formula: $Sample\ size = (Z^2 * p * q) / E^2$. Based on this formula, the required sample size would be approximately 385. A total of 400 sample data has been considered for this study.

Field Observations: Field observations were conducted by self-commuting in local train by making a trip to collect real-time data on transportation operations, infrastructure utilization, and commuter behaviour by involving observing boarding and alighting patterns, mode choices, and other factors that contribute to performance indices. Field observations can provide valuable insights into the actual implementation and functioning of the metro system.

Ensure Data Quality and Reliability: quality control measures were implemented to ensure the accuracy and reliability of the collected data by consideration of the data validation, cleaning, and addressing any missing data or inconsistencies to maintain the integrity of the dataset. Ethical Considerations: Ethical considerations when collecting data, such as obtaining informed consent from participants, ensuring anonymity and confidentiality, and complying with relevant data protection and privacy regulations.

By employing a combination of survey data, field observations, interviews, and existing data sources, a comprehensive dataset was gathered in order to assess the impact of the metro system on performance indices in multimodal transportation. The collected data should encompass the performance indices under

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investigation, including travel time data, interconnectivity convenience ratios, multimodal level of service measurements, and any other relevant indicators specific to the research objectives.

Methodology:

It is essential to consider the characteristics of the data, such as normality, sample size, and distribution, before choosing the appropriate test. Additionally, demographic information, mode choices, trip characteristics, and commuter preferences can provide valuable context for the analysis. By gathering real-world data from commuters, the study can obtain accurate and objective information to analyse and compare the transportation system's performance before and after the metro implementation. Before conducting statistical tests, the distribution of each performance indicator is examined separately for the before and after metro scenarios.

The paired t-test is applied to compare the values of various performance indicators or variables before and after the implementation of a metro system (BM: Before Metro and AM: After Metro). Along with the parametric tests like paired t-tests are used and non-parametric tests like the Wilcoxon signed-rank test are employed to ensure the validity of the results. It is recommended to perform both tests (parametric and non-parametric) as a sensitivity analysis to assess the robustness of the findings and to ensure that the conclusions are not dependent on the assumptions of a particular test. When both tests provide similar results, it suggests that the findings are not sensitive to the normality assumption and are more reliable. By using a combined approach of parametric and non-parametric tests, this research ensures a robust and rigorous evaluation of the impact of the newly operated Mass Rapid Transit System on multimodal transportation system performance in an Indian context. This methodological rigor enhances the validity of the study's conclusions and provides valuable insights for policymakers, urban planners, and transportation authorities to make informed decisions for future infrastructure development and public transit enhancement.

Data standardization is performed by subtracting the mean and dividing by the standard deviation for each variable to give equal weight to all variables during PCA. The covariance or correlation matrix is computed based on the standardized data, with the correlation matrix preferred when variables are measured on different scales. Eigenvalues and eigenvectors of the covariance or correlation matrix are then calculated to determine the variance explained by each principal component and their corresponding directions and weights.

Demographic Analysis:

Understanding the socio-economic characteristics of the commuters can help in analysing how different groups of people perceive and use the transportation system before and after the metro implementation. The Table 3 provides socio-economic information about percentage of commuters, including their gender, age, occupation, income, trip purpose, and frequency of using the transportation system.

Table 3: Demographic Information

Sl. no.	**Socio-economic**	Category	% of commuters
1	Gender	Male	72
		Female	28
2	Age	<20	15
		21-30	32
		31-40	22
		41-50	11
		51-60	18
		>60	2
3	Occupation	Working staff	43

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		Business	15
		Student	32
		Others	4
4	Income	<10k	31
		10k-25k	16
		25k-40k	17
		40k-55k	18
		55k-70k	12
		>70k	6
5	Trip purpose	Home-based work (HBW)	67
		Home-based education (HBE)	28
		Home-based others (HBO)	5
6	Frequency	1 day/week	2
		2-3 days/week	18
		4-5 days/week	72
		6-7 days / week	8

This indicates that a higher proportion of commuters are male compared to female. Home-based work (HBW) is the primary purpose for commuting, representing 67% of commuters. The percentage of commuters based on the frequency of their trips which shows mostly (72%) travel 4-5 days a week. Working staff represents the largest group, making up 43% of the commuters and students account for 32% of the commuters in this study.

Results and Discussion:

The performance indices: To evaluate the significance of the differences between the performance indices in the before and after scenarios, both parametric and non-parametric tests were performed. The results will shed light on the overall effectiveness of the metro system implementation and its impact on the multimodal transportation system's performance. The utilization of these tests aimed to ensure the validity and reliability of the findings. The paired samples t-test was applied to determine the changes in various performance indicators, and the SPSS output viewer was used to obtain the results.

The result of the paired samples t-test has been determined using the SPSS output viewer. The results from the paired samples statistics suggest improvements of the indicators based on the change of mean score obtained on Table 4. The mean values of each performance indicator are provided for both the "Before Metro" (BM) and "After Metro" (AM) scenarios, along with the corresponding sample sizes (N), standard deviations (Std. Deviation), and standard errors of the mean (Std. Error Mean).

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Table 4: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Travel Time Index BM Travel Time Index AM	1.079	400	.069	.0073
		1.028	400	.044	.0046
Pair 2	ICRBM ICRAM	.508	400	.078	.0083
		.452	400	.077	.0082
Pair 3	OVTT to IVTTBM OVTT to IVTTAM	.397	400	.112	.0119
		.383	400	.131	.0140
Pair 4	IVTT Ratio BM IVTT Ratio AM	.720	400	.0517 .060	.0055
		.728	400		.0064
Pair 5	OVTT Ratio BM OVTT Ratio AM	.279	400	.052	.0055
		.271	400	.060421	.0064
Pair 6	Walking Time Index BM Walking Time Index AM	.143	400	.03099	.0033
		.118	400	.02720	.0029
Pair 7	Waiting Time Index BM Waiting Time Index AM	.136	400	.0315	.0033
		.119	400	.0272	.0029
Pair 8	JSBM JSAM	16.389 18.420	400	3.354 3.509	.3575
			400		.3740
Pair 9	RSBM RSAM	22.038	400	3.721	.3967
		24.336	400	3.792	.4041
Pair 10	BMPTSL AMPTSL	3.248	400	.201	.0225
		4.894	400	.0817	.0091

The consistency among each pair indicators in context of before and after the metro system implementation is determined based on the output of the Table 5.

Table 5: Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Travel Time Index BM & Travel Time Index AM	400	.356	.001
Pair 2	ICRBM & ICRAM	400	.991	.000
Pair 3	OVTT to IVTTBM & OVTT to IVTTAM	400	.910	.000
Pair 4	IVTT Ratio BM & IVTT Ratio AM	400	.897	.000
Pair 5	OVTT Ratio BM & OVTT Ratio AM	400	.897	.000
Pair 6	Walking Time Index BM & Walking Time Index AM	400	.751	.000
Pair 7	Waiting Time Index BM & Waiting Time Index AM	400	.388	.000
Pair 8	JSBM & JSAM	400	.966	.000
Pair 9	RSBM & RSAM	400	.961	.000
Pair 10	BMPTSL & AMPTSL	400	.234	.037

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The t-values represent (Table 6) the magnitude of the differences between the means of the paired data, while the p-values indicate the probability of observing such differences by chance. A small p-value (usually less than 0.05) indicates that the difference between the BM and AM scenarios is statistically significant. This means that the metro system implementation has a significant impact on the respective performance indicator.

Table 6: Paired sample test

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pair 1 TTIBM - TTIAM	.051	.067	.007	.036	.065	7.133	399	.000
Pair 2 ICRBM - ICRAM	.057	.011	.001	.054	.058	50.084	399	.000
Pair 3 OVTT to IVTT BM - OVTT to IVTT AM	.013	.055	.005	.002	.024	2.274	399	.000
Pair 4 IVTT Ratio BM - IVTT Ratio AM	-.008	.027	.003	-.014	-.003	-2.952	399	.000
Pair 5 OVTT Ratio BM - OVTT Ratio AM	.008	.027	.003	.003	.014	2.952	399	.000
Pair6WalkingTimeIndexBM - Walking Time Index AM	.025	.021	.002	.021	.029	11.202	399	.000
Pair7WaitingTimeIndexBM - Waiting Time Index AM	.017	.033	.003	.010	.024	4.989	399	.000
Pair 8 Journey Speed BM - JSAM	-2.031	.909	.097	-2.224	-1.839	-20.963	399	.000
Pair 9 Running Speed BM - RSAM	-2.298	1.051	.112	-2.520	-2.075	-20.511	399	.000
Pair 10 BMPTSL - AMPTSL	-1.646	.198	.022	-1.690	-1.602	-74.106	399	.000

The variation of t-values among the paired indicators in a paired t-test is significant because it indicates the degree of difference or similarity between the two scenarios being compared. The t -value represents the strength and direction of the difference between the means of the two scenarios (before metro - BM and after metro - AM). The indicators such as ICR, PTSL show negative t-value as this indicates a more significant increase in the performance indicator in the after metro (AM) scenario compared to the before metro (BM) scenario. Smaller t-values, close to 0, suggest a smaller or negligible difference between the two scenarios. It implies that the metro system implementation has less impact on the performance indicator. The significance of the pairs of the t-values is determined by the p-value (Sig. (2-tailed)) associated with each t-value. A smaller p- value (usually less than the chosen significance level, often 0.05) indicates a statistically significant difference between the two scenarios corresponding all the paired indicators.

Conducting nonparametric tests in addition to paired t-tests enhances the reliability and validity of the study's findings, especially when dealing with real-world data that may not always conform to the assumptions of

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parametric tests. It allows researchers to draw more robust and well-supported conclusions about the impact of the metro system on the performance indicators in the before and after scenarios. The assumption of normality was formally checked using the Shapiro-Wilk test, which indicated a significant departure from normal distribution ($p < 0.05$).

Table 7: Non-parametric test

	Pair 1	Pair 2	Pair 3	Pair 4	Pair 5	Pair 6	Pair 7	Pair 8	Pair 9	Pair 10
Z	-17.876	-17.876	-19.417	-5.856	-16.232	-10.171	-5.856	5.856	17.876	19.417
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

The results (Table 7) also signify that after the metro system implementation, there were notable improvements in various performance indicators related to travel time, interconnectivity, walking, waiting, and journey speed. Commuters experienced reduced travel times and improved intermodal transfer convenience, leading to a more seamless and efficient multimodal transportation system. Additionally, walking and waiting times decreased for most of the cases, enhancing the overall commuting experience. Few paired indicators, such as, OVTT Ratio, Walking time index show a slight change comparing to the significant changes of other indicators such as ICR, Journey speed etc. which indicates a potential trade-off between efficiency and convenience. Although there is a slight improvement in travel time, it comes at the expense of increased walking time in some cases. Improving or enhancing one aspect of the transportation system (reflected by the parameter with higher z-score/t-value) might come at the expense of compromising other aspects (reflected by parameters with lower z-scores/t-values). In this study, a "trade-off" refers to the fact that improving or enhancing one specific aspect of the transportation system (measured by a parameter with a lower z-score/t-value) may lead to compromises or negative impacts on other aspects of the system (measured by parameters with higher z-scores/t-values). Overall, the metro system had a positive impact on transportation efficiency and commuter satisfaction. In summary, the Z-scores and p-values from this non-parametric test provide additional support for the significant differences observed in the paired t-tests conducted previously.

Factor Analysis: All the commuters using the mentioned trip pattern (Mixed-Train-Mixed) are the public transport users which indicate the shift from another road public transport system mainly in Egress stage in this study. This phenomenon of users shifting from one public transport mode to another is commonly referred to as the "effect of cannibalization." Cannibalization, in this context, means that the new MRTS is "eating into" the market share of existing public transport systems by attracting their users. As more commuters opt for the faster, more efficient and comfortable MRTS, the demand for traditional road-based public transport may decrease, leading to a decrease in its ridership and revenue. Factor analysis allows the study to reduce the complexity of the original variables by grouping them into coherent and interpretable factors, providing a more insightful understanding of the underlying dimensions of multimodal transportation performance and improvement of the determined components of road-based public transport system in order to maintain a balance in ridership.

Before undertaking factor analysis, it is necessary to calculate sampling adequacy by performing Kaiser-Meyer-Olkin (KMO) measure of Sampling Adequacy test. This study has obtained KMO value of 0.821 (close to 1) which suggests strong and significant (Sig. <0.05) sampling adequacy for performing the Principle component analysis.

Higher communalities indicate that the extracted factors explain a larger proportion of the variance in the original variables, while lower communalities suggest that the extracted factors do not account for much of the variance in the original variables. Table 8 shows the communalities for each variable before and after the extraction using Principal Component Analysis (PCA).

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Table 8: Communalities

	Initial	Extraction
Waiting Comfort	1.000	.596
Journey Comfort	1.000	.820
Waiting Safety	1.000	.565
Journey Safety	1.000	.773
Information	1.000	.592
Frequency	1.000	.584
Easeo faccess	1.000	.906
Cleanniness	1.000	.655
Bad weather	1.000	.906
Mental Fatigue	1.000	.611

Extraction Method: Principal Component Analysis.

From Table 8, the communalities range from 0.565 to 0.906, indicating that the factors extracted from

the data explain a significant portion of the variance in each variable. Higher communalities suggest that the identified factors capture a substantial amount of the variability in the data, indicating the robustness of the factor structure.

The total variance explained shows the cumulative percentage of variance accounted for by each principal component (factor). In this study (Table 9), the first four components explain approximately 72.36% of the total variance. This suggests that these four factors are sufficient to represent a large portion of the variability in the original variables, making them meaningful constructs that can be further analysed and interpreted.

Table 9: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.339	33.389	33.389	3.339	33.389	33.389
2	1.653	16.531	49.921	1.653	16.531	49.921
3	1.145	11.447	61.367	1.145	11.447	61.367
4	1.099	10.991	72.358	1.099	10.991	72.358
5	.946	9.458	81.817			
6	.706	7.059	88.876			
7	.523	5.234	94.110			
8	.388	3.884	97.994			
9	.181	1.809	99.803			
10	.020	.197	100.000			

Extraction Method: Principal Component Analysis.

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Figure 2: Scree plot

From the scree plot (fig: 2) the first 4 components have Eigenvalues over 1 and can be consider these

"strong factors" which suggests that 4 factors underlie in this research. The component matrix displays the factor loadings of each variable on each principal component. A factor loading represents the correlation between a variable and a specific principal component. Higher absolute factor loadings indicate a stronger association between the variable and the component.

The component matrix displays (Table 10) the factor loadings of each variable on each principal component. A factor loading represents the correlation between a variable and a specific principal component.

Higher absolute factor loadings indicate a stronger association between the variable and the component. Variables with high factor loadings on a particular component are considered to be well-represented by that component and are more likely to be included in that component.

Table 10: Component Matrix[a]

	Component			
	1	2	3	4
BM Waiting Comfort	.568	-.387	-.268	.425
BM Journey Comfort	.692	.275	-.488	.311
BM Waiting Safety	.393	.237	.046	.726
BM Journey Safety	.233	.353	.473	.578
BM Information	.291	.679	-.086	-.427
BM Frequency	-.389	.043	.650	-.130
BM Easeofaccess	.359	.566	.269	.059
BM Cleaniness	.759	-.156	.272	.308
BM Bad weather	.455	.251	.764	.324
BM Mental Fatigue	.624	.829	-.313	.027

Extraction Method: Principal Component Analysis. a. 4 components extracted.

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Based on the substantial proportion of the variability in the original variables, suggesting that four parameters (components) capture essential aspects of multimodal transportation performance impacted by the metro system implementation. From the Component table based on the obtained scores these four components can be named as: Comfort, Convenience, Reliability and Safety. This suggests these four components majorly influenced the commuters satisfaction level to selection of newly implemented modal service (metro over existing road transport modes) and therefore, have strong impact on the qualitative performance indicator (i.e. Public transit satisfaction level) as mentioned previously.

Conclusion and Discussion:

The collected data serve as the foundation for subsequent analyses and provide valuable insights into the effectiveness and implications of the newly implemented metro system. Both parametric and non-parametric tests show a significant difference in the dataset, it provides strong evidence that there is a significant effect or change between the two groups being compared (e.g., before and after metro scenarios). The findings of this research indicate that the implementation of the new metro system has a significant positive impact on the various multimodal performance indicators, such as the travel time index, interconnectivity convenience ratio etc. The new metro system has made it easier for commuters to transfer between different modes of transportation, which has reduced the overall travel time and inconvenience of multimodal trips. The implications of this finding for the planning and operation of multimodal transportation systems are that metro systems can be an effective way to improve the performance of multimodal transportation as this newly implemented metro system can make it easier for the commuters to transfer between different modes of transportation, which can reduce the overall travel time and inconvenience of multimodal trips. The study has provided strong evidence that the new metro system has contributed to reducing travel times, enhancing intermodal connectivity, and improving the overall efficiency and convenience of the transportation network. By analysing the results and identifying potential trade-offs, policymakers can devise strategies that prioritize the improvement of specific parameters while minimizing negative impacts on others, ultimately leading to a well- balanced and efficient multimodal transportation system. Besides, the qualitative analysis by performing PCA helps to identify the components of modal service quality which can also suggest to focus on these components for enhancing the attractiveness road public transit system to maintain proper balance on all types of existing public transit modes to achieve the goal of Sustainable multimodal public transport system by reduction of cannibalization effect and enhancing the attractiveness of road based transport modes as well. This comprehensive analysis has provided valuable insights on the impact on the performance indicators of the multimodal transportation due to newly operated metro service in Kolkata city (connecting important railway station to CBD areas) and the factors influencing the public transit service perceived quality.

The study's sample size might be limited, which could affect the generalizability of the results to a larger population. The research might have been conducted over a specific period, which might not capture long-term trends and variations in transportation performance. Some performance indicators, such as journey speed and running speed, might have been derived from depending upon commuter’s perspective rather than actual observations. While these models are widely used in transportation research, they may introduce uncertainties in the results.

By studying the impact of the metro system in this area, the research findings can potentially be extrapolated to other cities or regions with similar transportation characteristics and contexts. Evaluating the impact of the metro system in this context will provide insights into the overall multimodal travel experience and the potential for modal shift among commuters. The research findings from this study area can contribute to broader discussions on urban transportation planning, policy development, and the optimization of multimodal transportation systems in similar urban regions worldwide. This study's results can be utilized by policymakers, urban planners, and transportation authorities by providing valuable insights into the effectiveness of the new metro system in enhancing multimodal transportation performance to make informed decisions for future infrastructure development and public transit enhancement.

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