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Emerging Commuters' Perception of First and Last-Mile Connectivity around Metro Stations

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Abstract

First and Last Mile Connectivity (FLMC) is the connection between primary public transportation and the beginning and end of an individual's trip. Globally, FLMC is considered an essential tool in sustainable transportation development. Through sustainable transportation measures, it manages major trip concerns faced through environmental, social, and economic factors. Researchers in several studies have highlighted several apprehensions to be considered while planning for FLMC in an area. Comprehension of the outcome depends on various intrinsic factors of the study area. For instance, the character of the place, users of the study area, regional setting of the area, local climate, infrastructural need and demand, environmental status of the site, and so on. This paper aims to identify the parameters for appraising FLMC, classify the associated indicators, and characterize the indicators in a defined parameter for the study area. The methodology includes documentation of the parameters through a systematic literature review and validation by stakeholders through a primary survey. The interpretation of the data received is analysed through exploratory factor analysis (EFA) and fuzzy logic (FL) to create the final weight of the parameters. Thus, a framework for identifying and analysing the parameters for a specific area in a developing context with similar socio-economic status is created.

Keywords: Fuzzy Analytical Hierarchy Process (FAHP), FLMC, Parameters, Perception, Principal Component Analysis (PCA).

Introduction

FLMC, in the context of urban passenger transportation, refers to the connectivity between the doorsteps of the trip ends (origins or destinations) and the nearest public transit stations (such as railway stations, bus stops, and metro-rail stations). Historically, after industrialization in the late 18th century, cities were oriented in a car-driven pattern and increasingly relied upon fossil-fuel-driven private modes. In the late 20th century, experts, namely Calthorpe, Cervero, and Bernick, apprehended the adverse consequences that were likely to happen due to the unsustainable transportation patterns in the then cities and recommended several measures imperative for sustainability (1–5). Sustainable Development Goals (SDGs), initiated by the United Nations (UN) as a global concern (6), were adopted as a mission by several countries (7, 8). Following this mission, numerous development policies have been initiated during the last two decades to improve environmental quality, destination accessibility, and quality of life in urban areas. The keystones of the policies relating to the transportation systems sustainability include shifting destination choices, combining trips to minimize travel, and switching to fewer pollutant vehicles (9). One of the significant implementation strategies for the said sustainable transportation policies, adopted by several countries across the globe, includes the introduction and augmented use of rapid transit (RT), such as Mass Rapid Transit Systems (MRTS) and Bus Rapid Transit Systems (BRTS), with a target for compact and integrated urban planning in line with the Transit Oriented Development (TOD) principles. As the RTs cannot connect the doorsteps of the trip ends, the need for a well-developed FLMC arises. Walking, non-motorized transit (NMT) modes and other Intermediate Public Transport (IPT) are favourably considered for the FLMC. While the need for FLMC arises from global sustainability concerns, it's planning calls for a context-specific approach. For the developed nations, FLMC planning frequently focuses on walking, supported by well-laid pedestrian infrastructure and urban design that encourages

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pedestrian movement. Contrarily, for a developing scenario, FLMC planning is a more complex problem with a host of challenges and elements, including the dearth of pedestrian-friendly walkways, the existence of diverse modes (bicycle and IPTs, namely rickshaws and e-rickshaws) and service providers, the multiplicity of regulatory, legislative and financial institutions; upcoming high-end technology driven control systems and varied land use patterns. In addition, the most important challenge arises from the commuters' wide-ranging responses and varied preferred choices for accessing the transit hubs emerging from their heterogeneous demographic and socio-economic characteristics. Thus, to address the contextual needs, the FLMC problem-solving demands befitting approaches involving public participation to ensure parity of long-term impacts with short-term benefits towards attaining the sustainability goals (10). The reported literature discusses the infrastructural status by users' perceptual ratings, which is basically a top-down approach; this study focuses on a bottom-up approach by understanding the users' needs and then determining the parameters for the infrastructural implementation. Thus, it ultimately contributes to a sustainable approach by promoting environmental, economic, and social preservation.

The current article suggests a framework for appraising the FLMC parameters based on commuters' perceptions. FLMC parameters, in the current study, refer to those that are perceptual in nature (as perceived by the commuters) and can determine the demand for FLMC. The specific scope of the appraisal includes identifying the FLMC parameters along with their indicators, which are the elements of the built environment and transportation supply that build up the commuters' perception regarding the respective FLMC parameters in an area. The finalization of the built environment indicators is adopted by conducting a PCA. Finally, the weights for the parameters and the indicators are estimated, emphasizing expert opinion on the finalized indicators. The 'FAHP' has been used for data analysis since it is considered an ideal tool for studies dealing with human perceptions, eliminating biases and uncertainties (11).

The suggested framework has been demonstrated for the case of Esplanade, a significant transportation node in Kolkata, India. Esplanade is a well-connected locality in central Kolkata and is known for its busy surroundings with prevalent retail-commercial, institutional, and recreational land uses. The study area consists of an existing MRTS corridor connecting the north-south alignment of the city since the 1980s, which primarily connects the neighbourhood localities (residential zones) with the advent of the new east-west alignment, which primarily connects the Central Business Districts (CBDs) and the major Eastern Railway zones of the city. This, in turn, will invite a new trend of commuters in the zone and ultimately anticipate a shift in commuters' patterns.

Following the introduction of the National Urban Transport Policy (NUTP), the majority of the Indian cities' endeavours have been in favour of embracing sustainable transportation options, such as improving and augmenting MRTS services, promoting NMT modes, EVs, and the like, to reduce the use of private modes and transport induced carbon footprints. Nevertheless, there has been an immense increase in the dependence on motorized private vehicles; one reason is the need for more attention to the stakeholders' opinions regarding FLMC, which is the primary link between commuters and public transportation. Studies in Indian cities revealed dissatisfaction among public transport users due to intimidating issues related to poor accessibility to the nearest public transit mode and the assisted infrastructure, which are the key reasons, among others, for not using public transportation, as stated by a section of the commuters (12). Implementing strategies, policies, and design solutions based on context-specific dimensions through a bottom-up approach can only bring a thriving outcome to the on-going endeavour for sustainability. Thus, the need to undertake studies focused on FLMC in India's developing scenario based on commuters' needs is undeniable.

The authors trust that similar studies are limited and raise the need for the suggested framework to be a prerequisite for planning FLMC in the developing scenario, particularly in India.

Reviews from the Secondary Sources

The literature review for the current study comprises two subsections: the first one summarizes the parameters determining the FLMC status and the analytical techniques used, as reported in previous studies, policy documents, and work manuals sourced from indexed journals published during 2000-2024 (CE), compendiums and websites of the government and government undertaking organizations. The second subsection provides an overview of the theoretical foundation of FL, the analytical tool selected for this study, and its rationale.

FLMC Parameters

The need for investigations into the various aspects of FLMC is well-recognized in the literature (13). A well-developed FLMC is considered to have enormous potential for increasing the ridership of public transit systems and enhancing the commuters' service quality experience. Discourses suggest that a deficiency of good connectivity between mass transit (MT) stations and the trip-end points may discourage commuters from using public transit and thus adversely affect ridership (4, 14). The experience before, during, and after walking can impact long-term psychological health and is a major determinant of travel behaviour in the urban environment. Thus, the perceptions of various citizen groups should be characterized by laws, policies, and practices while planning FLMC (15). The FLMC problem is more complex and acute in developing countries, where MT systems are frequently observed to be poorly integrated with other transport modes. The problem is further compounded by several issues such as the absence of appropriate pedestrian and NMT infrastructure, distinct geographic and climatic conditions, diverse demographic and socio-economic characteristics of commuters, dearth of planning database, lack of data-driven planning practice relying on convention, assumptions, and planning standards adapted from developed nations, absence of coordination between planning authorities, and the such like.

While India has been attempting to increasingly rely on mass transit systems, like other developing scenarios, the aspects of FLMC remain neglected in Indian cities (16). A trip-characteristics survey for commuters by Delhi Metro revealed that the first- and last-mile segments account for about 40% of the travel time and 48% of the travel cost while comprising only 18% of the total travel distance (17). Diverse modes are used in Indian cities for the FLMC. While walking is a popular access mode in Indian cities, informal modes of transportation, such as bicycles, cycle rickshaws, shared auto-rickshaws, feeder services, etc., cater to many transit users in their first and last mile, particularly in areas with limited and unfriendly pedestrian facilities. These informal modes also provide flexible options to meet specific mobility requirements and thus are highly acclaimed. Consequently, the conventional TOD zones of 800 meters, primarily based on walking as the main access mode, may not be applicable as a standard and may not accurately reflect the diverse FLMC needs in Indian cities (18). Given the focal intent of the current study, the selected FLMC-related discourses were grouped into two categories: first, those done in the developing context of India, and second, the studies with geographical references representing scenarios of developed countries. All the studies identify and suggest FLMC parameters based on stakeholders' perceptions, expert wisdom, or both across all the FLMC verticals. FLMC vertical is referred to as the selected four sections of access modes of FLMC, consisting of walking, NMT (bicycle, e-rickshaws, cycle rickshaws), Multimodal Integration (MMI), and IPT (auto-rickshaws, cabs, shuttles). The varied FLMC verticals are important in the Indian context due to their organic spatial distribution. Table 1 indicates the parameters and the associated indicators reported in several literatures.

The shared focal intent of the reviewed discourses has been to achieve an in-depth understanding of the influence of the built environment and transportation services on the commuters' satisfaction and preference for the FLMC to transit stations; the studies are scatted over varied specific objectives and geographical locations deploying an array of analytical tools ranging from qualitative and descriptive thematic reviews to quantitative statistical techniques (15). Nevertheless, the need for further systematic studies to appraise the FLMC parameters and their indicators is undeniable, particularly considering the developing scenario's complex issues and challenges with the biases and uncertainties associated with the commuters' perception.

Table 1: FLMC Parameters Reported in the Literature

Parameters	Indicator	Reference
Indian Context		
Accessibility	Access to the pathways	
	Accessibility of pathways/ walkways	(6, 19)
	Access to feeder services	
	Universal accessibility through Barrier-free / Inclusive design	
Availability	Supporting infrastructure and facilities	(19–21)
	Shading devices	
	Street geometry	
	Vegetation and orientation	
Comfort	Footpath width	(19, 21–24)
	Footpath height	
	Cleanliness and maintenance of the footpath	
	Facility of amenities	
	Provision of inclusive infrastructure	
	Barrier-free ways	
	Signage	
Safety	Road intersections	(22, 24–28)
	Buffer zone/ segregation of the footpath from the road	
	Type of crossing (traffic calming devices slow traffic)	
	Difficulty in crossing/ time taken for crossing	
	Time taken to cross the access routes	
	Light after dark	
	Land use along the footpath	
Security	Police patrolling	(19, 28–30)
	Digital surveillance CCTV installation	
In a Developed and Developing Scenario Outside of India		
Accessibility and Proximity	Supporting the infrastructure of pathways	(31–36)
	Ease of access	
	The effective width of footpaths	
	Walking time	
	Detour factors	
Safety	From Road accidents	(37–41)
	Pedestrian-vehicular conflict	
	Road crossing safety	
Security	Perception of security from crime	(37,41)
	Motorist behavior characteristics	
	Commercial settlements	
	Housing density	
Convenience	Presence of street furniture	(32, 37, 40)
	Presence of toilets	
	Universal access	
	Designated crossings, and	
	Eliminated obstacles	
Attractiveness	Frequent maintenance	(37, 40)
	Keeping the place clean	

FL and FAHP: Theoretical Foundation and Rationale for the Current Study

FL is an extension form of the Boolean logic by Lofti Zadeh in 1965 on the mathematical theory of fuzzy sets - a generalized form of the existing classical set theory. It enables flexibility for reasoning, which helps manage inaccuracies and uncertainties. Its further advantage is that it formalizes human reasoning in natural language. FL is widely used for its high power of precisiation and, therefore, to assist as a conterminous model of reality, particularly in human-centric fields (42). FL elements includes Fuzzy Sets, Linguistic variables, Fuzzy operators, reasoning in FL, and crisp output through defuzzification (43).

FL has been applied to many mathematical branches. In addition, combined with classical approaches, it has been used in practice across various disciplines, such as control, decision support, data processing, engineering, management, urban sustainability analysis, logistics, medicine, and so on (44–46). The two main advantages of this method are that it can use the existing linguistic knowledge successfully and treat uncertainty appropriately. FL has been used in several transportation studies, such as modelling and simulating pedestrian dynamic behaviour (47), congestion pricing in urban networks based on its level of service (48) and the identification of hazardous zones as regional transportation corridors (49). FL promises to enhance the practicality of traffic and transportation planning, particularly when stakeholders' opinion plays a significant role in decision-making (11).

Literature indicates that appraising FLMC parameters entails analysing data based on stakeholders' perceptions. Human perceptions are associated with the properties of intrinsic vagueness, inconsistency, qualitative, and subjective. Thus, obtaining the actual perception requires Precisiated Natural Language (PNL) rather than bivalent mathematical interpretation (50). The input and the output variables are in linguistic terms rather than in the form of any numerical variables. Thus, the rationale for the FL application in the current study prevails (50).

The Analytic Hierarchy Process (AHP) is a decision-making tool that assists in prioritizing alternatives by analysing multiple criteria. Individuals and organizations use a decision-making method to rank alternatives they are considering based on pairwise comparisons (51, 52). FAHP is an extension of AHP that was developed with the FL theory. The FAHP method is similar to the AHP, where the AHP scale is set into the fuzzy triangle scale. The typical steps involved in the FAHP are: Generating the comparison matrix, examining for consistency, 3. Incorporating Triangular Fuzzy Number (TFN), 4. Evaluating the weight value for the fuzzy vector, and 5. Ranking of the criteria (53).

Methodology

Table 2 describes the steps in the methodological framework and the data collection techniques of the current study:

Table 2: Methodological Framework

A. Literature-Based Compilation of FLMC Indicators as Variables: This step entails a Systematic Literature Review (SLR) based on previous studies (54, 55) as indicated in the literature. The SLR steps include a) defining the goal, b) searching the literature based on the defined goal, c) refining the search through preliminary elimination and confirmation, d) analysing the confirmed documents with the keywords, the expected outcome of the study, and interrelationship with the study's main objectives, and e) finally presenting the findings in a structured format.

B. Identifying the Significant Indicators for each Parameter using EFA: It comprises the following steps:

B.1 Design of Survey Questionnaire: A structured questionnaire was designed to collect primary data on the commuters' perception of FLMC in the study area. The questionnaire consists of statements describing the indicators of the FLMC parameters (as compiled in Step A). The respondents are to be asked to rate attributes on a five-point Likert scale (56, 57) based on its importance in the respective FLMC parameter using the following set of linguistic variables comprising five elements, namely 'very high' (5), 'high' (4), 'medium' (3), 'low' (2), and 'negligible' (1). The respondents are characterized explicitly as the daily commuters representing the working-age population and are selected based on random sampling. The perception data has been collected through a primary survey conducted from December 2022 to April 2023 at the Esplanade station gates. The other associated mandate involved with the respondents was that they must be regular users of the metro rail (at least three days a week), taking a work or educational trip. The survey was conducted during peak and off-peak hours on weekdays.

B.2 To Examine the Questionnaire Reliability: A pilot study was carried out among 30 commuters to examine the reliability and identify the possible errors of the survey questionnaire (stated in B.1) using Cronbach's Alpha. Cronbach's alpha is a measure of internal consistency and is also considered a measure of scale reliability. It can be expressed as:

$$\alpha = \frac{n\bar{r}}{1+\bar{r}(n-1)}$$

Where n represents the number of items, and $\bar{r}$ is the mean correlation between the items. Cronbach's alpha ranges between 0 and 1. Generally, a Cronbach's alpha value of more than 0.7 is considered acceptable. A high alpha level shows that the test items are highly correlated (58).

B.3 EFA: It entails the following steps:

B.3.1 Assessment of Data Suitability: The Kaiser-Meyer-Olkin (KMO) test (58, 59) was carried out to check the sampling adequacy in the Statistical Package for Social Sciences (SPSS) statistical tool. Similarly, Barlett's test of Sphericity (58, 59) was computed to assess the appropriateness of the dataset. PCA is considered a suitable technique for dimension reduction after conducting the KMO and Bartlett's test of sphericity with values of greater than 0.5 and less than 0.05, respectively. The expression for KMO is:

$$MO_j = \frac{\Sigma_{i \neq j} r_{ij}^2}{\Sigma_{i \neq j} r_{ij}^2 + \Sigma_{i \neq j} u} \quad (59)$$

Where R = $[r_{ij}]$ is the Correlation Matrix, U = $[u_{ij}]$ is the Partial Covariance Matrix, and Bartlett's test of sphericity is:

-((n-1) - (2*p-5)/6) * log(det(R)) (59)

Where n is the number of observations, p is the number of variables, and R is the correlation matrix. The chi-square test is then performed on (p2-p)/2 degrees of freedom (59).

B.3.2 Factor Extraction: The significant indicators (variables) under each FLMC parameter were extracted using two techniques, namely the Kaiser (Eigenvalue) Criterion and the Screen test based on principal component analysis (58, 60). The indicators in the dataset are observed and appraised through factor analysis and, based on the Eigenvalues greater than 1 in the scree plot, are categorized under the identified parameter with factor loadings greater than 0.5. The factor loadings of less than 0.5 are eliminated, and the elimination is based on the sample size (60).

B.3.3 Factor Optimization and Interpretation: Determining the factor loading based on the sample size and applying the dimension reduction based on user responses. The total number of indicators integrated is 34; thus, the sample size should ideally range between 136 and 170. A sample size of 200 is considered for this study, along with considering an eigenvalue greater than one and a factor loading greater than 0.5. Thus, the number of indicators that summed up to 34 in numbers was reduced to 20.

C. Appraising the Weights of the FLMC Parameters and the Identified Significant Parameters using the FAHP: It entails the following steps:

C.1 **Generating Comparison Matrix:** The pairwise comparison matrix has been developed with respect to each pairwise indicator under each parameter in the form 4X4, 3X3, 4X4, 3X3, 6X6, and the parameter in the form 5X5, respectively. The pairwise comparison matrix is generated in connection with the formula aij = wi/wj, where i, j represent 1,2,3 ……n and n represents the number of criteria to be compared, w represents the weights, and a represents the ratio of the weights.

C.2 **Examining for Consistency:** The matrices' consistency is checked using the formula CR = CI/RI, where CR is the consistency ratio, CI is the consistency index, and RI is the ratio index. If the CR of the smaller matrix is less than 10% (0.1), then the data is considered to be acceptable for using the FAHP. The CR for all the matrices is framed in Table 6.

C.3 **Fuzzification:** Conversion of Linguistic Variables into Triangular Fuzzy Numbers (TFN) (*Table 3*) (53). Three points define the TFN as A = (a,b,c), and the expression μA(x) gives the membership function. The intermediate scales defined between the Linguistic Variables are given by Intermediate TFN (1, 2, 3), (3, 4, 5), (5, 6, 7), (7, 8, 9), referring to the intensity of interest identified as 2, 4, 6, and 8, respectively (Figure 1).

C.4 **Fuzzy Inference Rules:** In this stage, the setup of fuzzy rules, membership functions, and input variables to infer the output variables is established (53, 61). The FAHP method for weight calculation is executed using the Geometric Mean Method. The expression gives the fuzzified pairwise comparison matrix:

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \odot \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} \quad (53)$$

Where, M_{gi}^{l}, M_{gi}^{2}, ... M_{gi}^{m}, be values of extent analysis of i^{th} objects for 'm' goals. Then, the value of fuzzy synthetic extent with respect to the i^{th} object is defined.

C.5 **Defuzzification:** The crisp result is obtained using the weighted average defuzzification method, which is computed as:

$$x^* = \frac{\sum_{i=1}^{n} \mu_{\bar{C}_i}(x_i).(x_i)}{\sum_{i=1}^{n} \mu_{\bar{C}_i}(x_i)} \quad (62)$$

Table 3: Relation of Linguistic Data with TFN (53, 63)

Linguistic Variable	TFN	Intensity of Interest
Very High	(9,9,9)	9
High	(6,7,8)	7
Medium	(4,5,6)	5
Low	(2,3,4)	3
Negligible	(1,1,1)	1

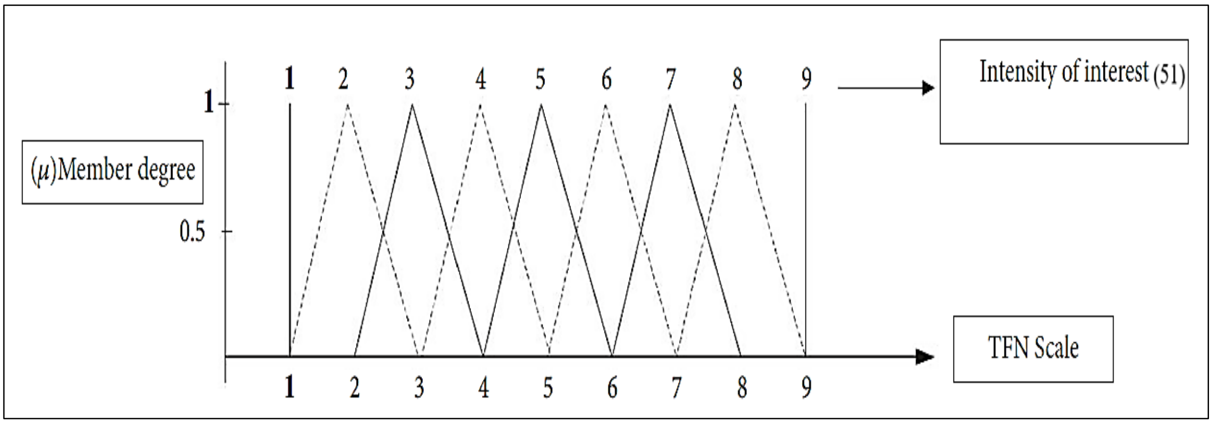

Figure 1: Graph for TFN set

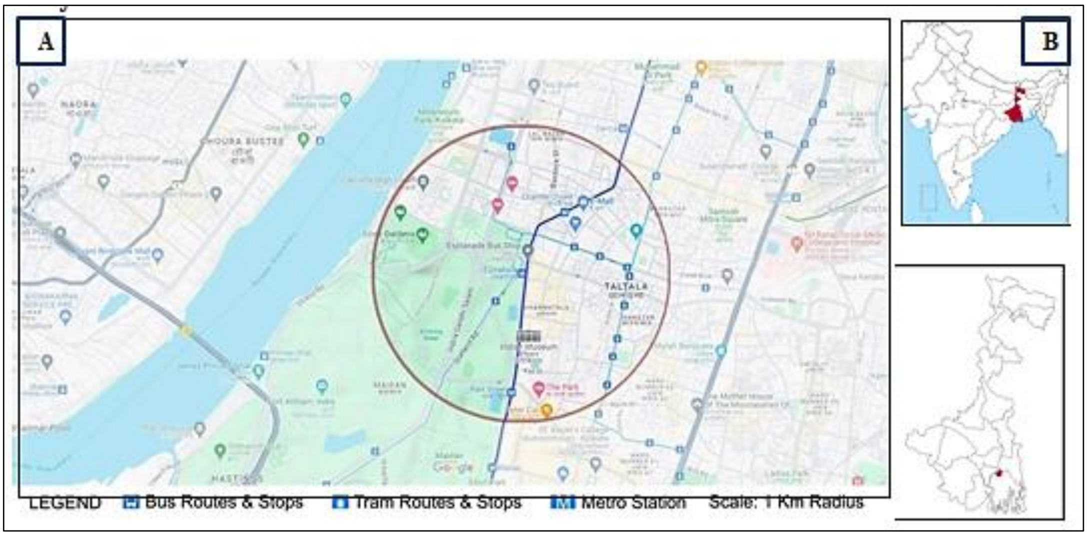

Figure 2: A) Delineating the Study Area in a Circle of 1 Kilometre Radius, B) Locating the Study Area in India and the State of West Bengal

Study Area and Context

The expanse within a one-kilometer radius from the existing station gate (marked M Esplanade in Figure 2A) of the Esplanade metro-rail station (Kolkata) delineates the study area for the current investigation. The rationale for the study area selection is that the Esplanade metro station is the only intersection of the North-South alignment of Kolkata Metrorail, providing service for the last three decades, and the East-West corridor has been put into operation recently (64). The daily footfall of the Esplanade metro station recorded in 2017 (pre-COVID-19 scenario) was about 85,000 (65) and was about 61608 on 17.03.2024 after the partial commencement of the East-West metro line. It is assumed to increase significantly with the commencement of the entire operation of the East-West metro corridor. The existing North-South MRTS corridor connects the old city (in the north) and new city extensions (in the south), and the new East-West corridor connects from Howrah Maidan, passing through one of the major suburban railway terminals (Howrah) to the Esplanade Station and will extend till Sector V, Saltlake (which is the new administrative zone of the metropolitan region). With intrastate and interstate bus depots, one tram depot, retail markets, offices, institutions, organized open spaces, and a host of landmark buildings, Esplanade is a part of the Business District in the central part of Kolkata, which is the largest metro city in the eastern part of India. It has a significant potential for emerging as a multimodal hub.

Besides the metro rail, several modes currently operate in this area, including 2-wheelers, 4-wheelers, buses, bicycles, trams, para-transits, and shuttle cabs. The passenger flow in the Esplanade station indicates two peaks in a typical weekday – morning peak (09:30 – 11:00 a.m.) and evening peak (06:30 - 07:30 p.m.), while an overall peak time of the day is noted in the evening. The peak hour demand accounts for approximately 15% of the day's volume. The weekday peak hour volume averages about 7819 passengers, with 43% outgoing and 57% incoming. This implies that around 125 passengers leave or enter the station every minute during peak hours, seeking FLMC (65). Analysis of the incoming and outgoing station access mode composition in the Esplanade station (Table 4) reveals the FLMC demand in the station area. Whereas, accessing the trip diary, 38.4% of passengers choose paratransit, 15.3% choose buses, 7.9% choose bicycles, 7.7% choose other motorized vehicles before using the metro rail, followed by 30.7% walking from their origin. 23.3% of passengers choose paratransit, 15.3% choose buses, 23% choose other motorized vehicles before using the metro rail, followed by 38.4% walking to their destination. Assessing the trip diary, it is observed that around 23.6% of commuters are generated to and from the peri-urban areas, and the remaining 76.4% are the urban residents themselves.

Table 4: Incoming and Outgoing Station Access Modes Composition in Esplanade Station

	Motorized vehicle (%)				Non-motorized vehicle (%)		
	Bus	**Tram**	**Cab service (Ola/Uber)**	**Taxi**	**Rickshaw**	**Bicycle**	**Pedestrian**
Incoming	56	2	12	9	N.A.	N.A.	21
Outgoing	44	0	7	16	N.A.	N.A.	33

Table 5: Compiled list of FLMC Parameters and Indicators

Sl. No.	Parameter	Indicator	Variance Code	FLMC Vertical
01	Accessibility (Physical)	1.1 Ease of access from the main road to the walking/ cycling pathway – curb height/ramp/grade-separated walkway/tactile flooring	VAR00001	Walk, NMT
		1.2 Natural terrain condition suitability – plain surface/ sloped/semi–sloped/ steep/ slippery/ likewise	VAR00002	Walk, NMT
		1.3 Distance from MRTS station to parking/ shared mode/ bus stops/ IPT – distance to and from the parking facility or bicycle-shared points	VAR00003	Walk, NMT
		1.4 Number of road crossings between bus stops/ IPT – the importance of barrier less connectivity to and from the MRTS to the next mode for accessing FLMC	VAR00004	MMI, IPT
		1.5 Continuity of walkway/ bicycle track – an uninterrupted pathway for a particular/ specified stretch	VAR00005	Walk, NMT, MMI, IPT
		1.6 Adequacy of width of pedestrian/cycling way – clear width for walking/ cycling without any hindrance at peak hours	VAR00006	Walk, NMT, MMI, IPT
		1.7 Encroachment by vending/ similar activities/ parking – obstructive to the clear width of walking/ cycling	VAR00007	Walk, NMT, MMI, IPT
02	Attractivity and Comfort (desirable)	2.1 Assisted Street furniture at suitable locations – ensuring comfort and convenience along with the visual element in the way of walking/ cycling	VAR00008	Walk, NMT, MMI, IPT
		2.2 The character of the abutting-built form creating pleasant views/ vistas – enabling and attracting users to walk and cycle in the area	VAR00009	Walk, NMT
		2.3 Presence of commercial and recreational activity in the place without hindering commuters – to ensure eyes on the street, eliminating discomfort by users, especially females and seniors	VAR00010	Walk, NMT
		2.4 Presence of natural landscape as a visual element – use of any existing trees/ water bodies as an element of attraction and comfort for the users	VAR00011	Walk, NMT
		2.5 Presence of trees and vegetation as a shade/ vista - creating visual balance and comfort in the summer/ sun	VAR00012	Walk, NMT,

Sl. No.	Parameter	Indicator	Variance Code	FLMC Vertical
				MMI, IPT
		2.6 Paving materials encouraging walking and cycling – ensuring convenience to walk/ cycle, non-skid, not broken, and likewise	VAR00013	Walk, NMT
		2.7 Presence of shading device (natural/ artificial) in the walkway/ cycle track/ waiting area – to act as a barrier during the scorching sun/ rain	VAR00014	Walk, NMT, MMI, IPT
		2.8 Presence of essential public amenities in the vicinity/ terminus area – like public toilets, drinking water facilities	VAR00015	Walk, NMT, MMI, IPT
03	Availability of essential support infrastructure	3.1 Availability of modes at the required frequency and Level of Service (LoS) – readiness of modes like bus/ tram/ cab/ shuttle/ to the required direction/ zone	VAR00016	MMI, IPT
		3.2 Availability of shared cycle facility/ parking in the MRTS zone – enabling required options for users to assess the FLMC	VAR00017	NMT
		3.3 Availability of information/signage to and from the MRTS station and indicating the location map of the vicinity – assisting in reaching the essential services without loss of time and resources	VAR00018	Walk, NMT, MMI, IPT
		3.4 Availability of ticket counter/inquiry/ unified payment system – assisting to board any suitable mode available without interruption	VAR00019	MMI, IPT
		3.5 Availability of IT infrastructure - Wi-Fi facility, charging stations, ATM, and likewise	VAR00020	MMI, IPT
		3.6 Availability of fare and real-time information on modes – enabling the users to decide on the mode and time management	VAR00021	MMI, IPT
		3.7 Availability of inclusive parking/ bays/ boarding/ dropping points – assisting the different types of users of the spaces to access without hesitation	VAR00022	MMI, IPT
04	Environmental Suitability	4.1 Noise quotient of the micro-region – affecting the walking/ cycling users	VAR00023	Walk, NMT
		4.2 Air quality of the microclimate – suitable for waiting/ accessing the area	VAR00024	Walk, NMT
		4.3 Prevalent microclimatic conditions affecting commuters – rain/ heat/ extreme temperatures/ stormy/ likewise	VAR00025	Walk, NMT
		4.4 Cleanliness of the pedestrian walkway/ cycling track – ensuring health status through solid waste management of the area/ pathways	VAR00026	Walk, NMT

Sl. No.	Parameter	Indicator	Variance Code	FLMC Vertical
05	Safety and Security	5.1 Presence of abutting-built form/ land use during several hours of the day – ensuring roadside activities and eyes on the street	VAR00027	Walk, NMT, MMI, IPT
		5.2 Presence of designated separated lanes for designated users – separate lanes/ stretch for separate users (walkways for pedestrians/ cycling tracks for cyclists, roadway for vehicles)	VAR00028	Walk, NMT, MMI, IPT
		5.3 Presence of commercial and recreational activity in the place to ensure certain footfall – ensuring the utility of the way and eyes on the street	VAR00029	Walk, NMT, MMI, IPT
		5.4 Presence of natural/ artificial surveillance to ensure perceived safety – presence of guards/ police at the junctions, installation of CCTV, likewise	VAR00030	Walk, NMT, MMI, IPT
		5.5 Traffic speed and volume at the crossings/ junctions and the number of crossings – presence of zebra crossing/ signals/ subways/ walkable over bridges	VAR00031	Walk, NMT, MMI, IPT
		5.6 Use of bollards and railings to ensure the designated space for different users – if the designated lanes are on the same plane	VAR00032	Walk, NMT, MMI, IPT
		5.7 Visual connectivity ensuring the look away to certain distances – a clear view of the stretch of walking and cycling way to ensure the safety and security of the users	VAR00033	Walk, NMT, MMI, IPT
		5.8 Presence of lights during the night hours – to eliminate any negative actions (robbery, physical harm) and ensure the safety and security of users	VAR00034	Walk, NMT, MMI, IPT

Results

Comprehending the methodological framework, this section expresses the analysis and results of the process in the sequence mentioned in the Methodology Section.

Literature-based Compilation of FLMC Parameters and Indicators

Table 5 indicates the compiled list of parameters and indicators reported in the literature and structured through an observational study. The compiled list integrates the studies across the FLMC verticals, consisting of the Walk, NMT, MMI, and IPT, to support the overall system

Questionnaire Reliability: Using Cronbach's Alpha

The Cronbach's Alpha is tested in the statistical tool SPSS for the identified indicators as reported in the literature for a pilot sample size to confirm the questionnaire's reliability and as observed and reported in Figure 3. It can be confirmed from the test that the considered indicators are all reliable, as they correspond to values greater than 0.7.

Reliability Statistics

Cronbach's Alpha	N of Items
.890	34

Figure 3: Questionnaire Reliability as Reported by Cronbach's Alpha Test for the List

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.571
Bartlett's Test of Sphericity	Approx. Chi-Square	5522.333
	df	378
	Sig.	.000

Figure 4: Indicating the Values for the KMO and Bartlett's Test of the Parameters

EFA to Identify Significant Factors

The factor analysis executed has been demonstrated in the following steps:

Assessment of Data Suitability

As reported in studies and mentioned in the Methodology section, if the KMO and Barlett's test of Sphericity have a value greater than 0.5 and less than 0.05, respectively, it can be considered suitable for performing PCA for that dataset. Thus, the dataset can be considered for using PCA shown in Figure 4.

Factor Extraction

This step explicitly performs the EFA using the PCA. In this step, the parameters' indicators are considered independent variables in the SPSS tool to execute the EFA. The dimension of the indicators has been reduced from 34 to 20 in this case. Through EFA, it can be concluded that the assumed indicators under each parameter are retained or reduced, and finally, the derived output (the final list of indicators under each parameter) for the study area. As indicated in Figure 5, the Scree plot in Figure 6 defines the number of components to be identified as 5 (similar to the observation in the literature) with eigenvalues greater than 1.

Factor Optimization and Interpretation

This step determines the final list of indicators categorized by their factor loadings shown in Figure 5 and under each parameter with FLMC Verticals, in Table 7.

	Component				
	1	2	3	4	5
VAR00001		.776			
VAR00003		.793			
VAR00005		.903			
VAR00006		.927			
VAR00009			.930		
VAR00010			.832		
VAR00011			.945		
VAR00016					.786
VAR00017					.738
VAR00018					.628
VAR00020					.686
VAR00024				.764	
VAR00025				.900	
VAR00026				.830	
VAR00028	.781				
VAR00029	.657				
VAR00030	.868				
VAR00032	.837				
VAR00033	.833				
VAR00034	.740				

Figure 5: The Final List of Reduced Indicators with Factor Loadings that are constituted by Dimension Reduction

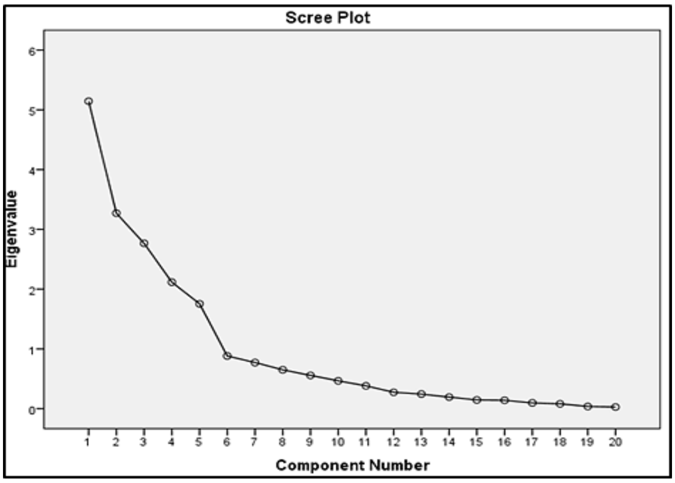

Figure 6: Scree Plot Determining the Number of Factors Greater than 1

Appraising the Weights of the FLMC Parameters and the Identified Significant Parameters using FAHP

This step is commenced under the purview of five experts on the importance of the finalized indicators under each parameter and the individual parameter itself, using the linguistic variables defined in the Methodology. The five experts are an urban planner, an environmental planner, an urban designer, a transport planner, and a geographer who uses the MRTS system for commuting or is exposed to the study area.

Examining for Consistency

The CR for all the matrices is framed in Table 6.

Defuzzification

The TFN weights are defuzzified using the weighted average centroid defuzzification method, and the global weights normalized out of 100 for the Parameters and Indicators are obtained in Table 7.

Table 6: CR Table for the Parameter-Indicators and the Parameters

Matrix Name	Accessibility Indicators (4X4)	Attractivity and Comfort Indicators (3X3)	Availability Indicators (4X4)	Environmental Suitability Indicators (4X4)	Safety and Security Indicators (6X6)	Parameters (5X5)
CR	0.07	0.02	0.04	0.05	0.06	0.02

Table 7: The Estimated Global Weights of the Parameters and Indicators

Sl. No.	Parameter	Variance Code	Global Weight			
			Walk	NMT	MMI	IPT
1	Accessibility (Physical)	VAR00001	11.92	11.92	-	-
		VAR00003	1.89	1.89	-	-
		VAR00005	5.23	5.23	13.20	13.20
		VAR00006	7.14	7.14	18.03	18.03
		Total	26.18	26.18	31.20	31.20
2	Attractivity and Comfort (desirable)	VAR00009	0.46	0.46	-	-
		VAR00010	4.01	4.01	-	-
		VAR00011	1.80	1.80	-	-
		Total	6.27	6.27	-	-
3	Availability of essential support infrastructure	VAR00016	-	-	13.52	13.52
		VAR00017	-	6.69	-	-
		VAR00018	16.28	9.59	4.43	4.43
		VAR00020	-	-	1.46	1.46
		Total	16.28	16.28	19.40	19.40
4		VAR00024	2.18	2.18	-	-

Sl. No.	Parameter	Variance Code	Global Weight			
			Walk	NMT	MMI	IPT
	Environmental Suitability	VAR00025	6.79	6.79	-	-
		VAR00026	0.93	0.93	-	-
		Total	9.90	9.90	-	-
5	Safety and Security	VAR00028	17.78	17.78	21.22	21.22
		VAR00029	2.25	2.25	2.68	2.68
		VAR00030	12.17	12.17	14.51	14.51
		VAR00032	4.09	4.09	4.89	4.89
		VAR00033	1.18	1.18	1.40	1.40
		VAR00034	3.9	3.9	4.65	4.65
		Total	41.37	41.37	49.40	49.40
		Grand Total	100	100	100	100

Discussion

The study outcome indicates that safety and security are ranked highest, followed by accessibility, availability, environmental suitability, and attractively and comfort in the study area. The built environment indicators are sensitive to the study area. This can be referred to by comparing the list of indicators in *Tables 5 and 6*. For instance, VAR00002 refers to the suitability of natural terrain conditions; since the selected study area is in plain land, it is not that relevant in the scenario and is accordingly optimized in the final list. Similarly, it can be stated that any optimized indicator indicates its relevance in the area. The finalization of the parameters indicates the intrinsic demand for infrastructure in the area, thus creating a scope for a sustainable approach. The selected study area is an existing Central Business District (CBD) and a hub of several Mass Transits Hub like Tram Depot and Bus Depot, thus has high demand for MMI and IPT (also can be interrelated with the incoming and outgoing access modes by the users in Table 4) indicating its weight across the parameters and associated indicators.

This paper presents a data-driven methodological framework to appraise the weights of the FLMC parameters, an amalgamation of the evidential features of the infrastructure (indicators) and the specific features of the user's perception of it. The sample collected is a proportionate representation of the distributed age and gender of the overall population; thus, it can be characterized as an almost accurate illustration of the study area. Several pieces of literature focus explicitly on the parameters relating to a particular FLMC vertical (walk, NMT, MMI, and IPT). Thus, to address this scenario, this study includes all the FLMC verticals, which have comprehensive practical implications in any developing context (specifically India). The varied responses across different cities in India can be compared as reported in several literature references in this study (16-27). The use of FL through FAHP has been fruitful in achieving crisp results, affirming the global weights of the parameters and their indicators.

Conclusion

The study area has been presented as a supportive illustration of the proficiencies of the methodological framework. Thus, it can be considered a tool for investigating the weights of the applicable indicators in any given context. The list of parameters and indicators is confirmed based on the need for a developing scenario structure with similar socio-economic status and urban morphology; it might vary in the case of other contextual demands. The perception of the commuter is dependent on the localized scenario; thus, it impacts the final output.

The framework advocates proficient and sustainable policy implications concerning FLMC planning. Additional formulae implementation to examine the status of identified parameters in the localized scenario for all the FLMC verticals, the effect of variation of perception based on the typology of the connectivity and modes on sustainable transportation can be characterized as a further research scope.

Abbreviation

None.

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Author Contributions

Abhinanda Chatterjee: Writing (Original Draft), Conceptualization, Investigation, Methodology, Data Curation, Formal analysis. Subrata Kr. Paul: Writing (Review and Editing), Project administration, Supervision.

Conflict of Interest

No potential conflict of interest was reported by the author(s).

Ethics Approval

Informed Consent: The survey participants have been informed about the use of the data.

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