Periodica Polytechnica Transportation Engineering, 53(4), pp. 462–471, 2025

Evaluating the Sustainability of Metro and Feeder Bus Integration: A Bengaluru Metro Case Study in India

Veeresh Kori[1], Seelam Srikanth[1*]

[1] School of Civil Engineering, REVA University, Rukmini Knowledge Park, Kattigenahalli, Yelahanka, 560064 Bangalore, Karnataka, India
[*] Corresponding author, e-mail: srikanths.reddy@reva.edu.in

Received: 23 August 2024, Accepted: 30 July 2025, Published online: 07 August 2025

Abstract

Rapid urbanization and an increase in private vehicle ownership in India's major cities have contributed to increased traffic congestion, pollution, and accidents. These challenges could be addressed in part by encouraging commuters to use public transport instead of private vehicles. The integration of different transport systems would be essential for increasing the utilization and efficiency of public transportation. It is essential to evaluate the existing level of integration among various transport systems to improve it. Consequently, the objective of this research is to adapt a methodology for evaluating the existing level of integration between metro and feeder buses while keeping sustainability as a goal. For evaluation, 18 sustainable transportation indicators were considered. To estimate the Sustainability Integration Index (SII) value, data were collected from transport hubs and nearby bus stops in Bengaluru, India. The multi-criteria method was used for the homogenization of transportation indicators. Based on the expert opinion survey, additional appropriate weights were obtained for each indicator, and the final SII value for selected metro stations was estimated in the range of 0 to 100. The adapted methodology was used to evaluate three transport policies in Bengaluru city relating to the integration of metro and feeder bus services. According to the analysis, the policy of increase in bus frequencies had the highest SII value, with an average increase of 4.97%, followed by policies of relocating bus stops and single ticketing systems, which had average increases of 3.49% and 4.58%, respectively.

Keywords

sustainability, metro station, feeder buses, transport policies

1 Introduction

1.1 General

The rapid urbanization of developing countries is posing a variety of challenges, particularly in the sector of transportation, such as adverse environmental effects caused by increasing vehicle emissions, excessive consumption of fossil fuels, and so on. These challenges could be addressed in part by encouraging commuters to use public transport instead of private vehicles. Due to concerns about transport utilization, all developing countries are adopting a new trend for planning and implementing an integrated public transport system. Global trends toward planned and integrated public transport system development have been influenced by promoting public transportation as a viable alternative to private vehicles (Matas, 2004; Ülengin et al., 2007). In general, integration refers to having the ability to use a local or regional public transportation network regardless of mode of transportation, tariffs, fares, timetables, ticketing procedures, and so on. Integration of transportation systems is required to enhance comfort, travel cost, and trip time (Kutz, 2004). Transportation systems can be integrated in terms of operational, physical, and fare aspects (Dhingra, 2008). As part of operational integration, routing, itineraries, and frequencies must be coordinated. Fare integration refers to the use of the same media (such as paper or electronic fare cards) to authenticate payment. Due to institutional, legal, and economic constraints, the transport service is provided without coordination by various government agencies (such as buses, trains, and metros), commercial operators, and private operators. From this perspective, making public transportation more accessible may induce some people to use it. Consequently, increasing the use and effectiveness of public transportation would rely greatly on the integration of various transport systems. Understanding and

Cite this article as: Kori, V., Srikanth, S. (2025) "Evaluating the Sustainability of Metro and Feeder Bus Integration: A Bengaluru Metro Case Study in India", Periodica Polytechnica Transportation Engineering, 53(4), pp. 462–471. https://doi.org/10.3311/PPtr.38158

evaluating the integration between these systems, as well as examining the practicality of new plans for integrating existing public transportation systems, are critical for resolving integration difficulties between mass transit systems (Errampalli et al., 2020).

The integration of different public transport modes, including metro systems, buses, trams, and feeder services, is a widely documented challenge experienced by cities around the world. Rapid urban development and the growing use of private vehicles have contributed to fragmented networks that often lack effective connections in terms of operations, infrastructure, and fare systems. For example, studies in Europe have pointed out that inconsistent scheduling and the absence of unified ticketing continue to limit seamless travel across modes (Kolak et al., 2011). In Latin America, research in São Paulo revealed that adopting integrated fare policies led to significant increases in public transport ridership, demonstrating the value of coordinated planning (Hidalgo, 2009). North American evidence also indicates that multimodal integration improves access and supports sustainability objectives by decreasing dependence on private cars (Mihyeon Jeon and Amekudzi, 2005). Within India, similar patterns have been observed, with cities such as Delhi encountering challenges like weak coordination among operators and limited last-mile connectivity between metro stations and buses (Errampalli et al., 2020). These examples make clear that transport integration is not solely an issue in India but rather a global concern requiring locally tailored strategies. The present research contributes to this international discourse by examining integration in Bengaluru as an illustrative case of a growing metropolitan area working toward more sustainable mobility.

1.2 A sustainable perspective on public transportation

The sustainable development concept gained popularity in the 1970s due to extensive media coverage (Beatley, 1995). The commonly used definition emphasizes transportation that meets current needs without compromising the ability of future generations to meet their own needs. This concept emphasizes the significance of considering the present and the future, as well as the long-term consequences of current actions that might not be immediately obvious. Sustainability is the study of the interaction between social, economic, and environmental systems at various spatial scales, either benefiting or harming one another. Sustainable planning involves finding long-term solutions to achieve economic, social, and environmental goals by enhancing system efficiency, without necessarily requiring trade-offs between these objectives (Litman and Burwell, 2006). When comparing door-to-door mobility between private and public transport, public transport is clearly at a disadvantage. The present status of transportation, particularly the widespread usage of private vehicles in cities, creates difficulties in achieving long-term levels of economic, social, and environmental resilience. As a result, one of the key sustainability goals is to reduce the usage of private vehicles in urban areas (Batterbury, 2003). Public transportation emerges as a potential alternative for achieving sustainability, as it offers higher occupancy rates for energy consumption and generates lower overall emissions compared to private vehicles. Enhancing the operational efficiency of public transportation and encouraging greater utilization can contribute to sustainability goals (Vassallo et al., 2012).

The primary objective of this study is to apply an existing methodology with modified indicators for evaluating the existing level of integration between metro rail and feeder buses to achieve sustainability. For assessing and evaluating the integration of feeder buses and metro rail, a total of 18 sustainable transportation indicators were used. The existing sustainability index of integration levels between the metro rail and feeder bus services in Bengaluru city has been analyzed using the adopted methodology. The evaluated integration levels are presented by Sustainability Integration Index (SII) values ranging from 0 to 100. Bengaluru city transportation hubs such as Baiyappanahalli Metro Station, Mejastic Metro Station, and Yeswantpur Metro Station operated by Bangalore Metro Rail Corporation Limited (BMRCL), and nearby feeder bus stops operated by Bengaluru Metropolitan Transport Corporation (BMTC) were chosen as study area for data collection.

2 Literature review

2.1 Public transport sustainable indicators

Researchers suggested the concepts of a sustainable transport and land use system, as well as the goals that would serve as a framework for selecting relevant performance indicators, after a thorough review of the literature (Black et al., 2002). The paper enlisted several indicators that contribute to less sustainable growth in developing countries, including shifting urban patterns, motorization, global urbanization trends, dependency on personal vehicles, and declining public transportation. In addition, researchers investigated the relationship between sustainability and transportation as well as the contribution of technological innovation. The study found a fundamental connection between sustainability, transportation, land use, and technology (Sinha, 2003). The authors synthesized various sustainability concepts, with a focus on the transportation sector. The commonly used definition emphasizes transportation that meets present and future needs without compromising the ability (Carey, 2004). The authors performed a multi-criteria assessment of selected European countries' transport networks and provided a framework for assessing the transport network's sustainability (Kolak et al., 2011). Sustainable transportation management considers economic, environmental, and resource consumption, and assists in increasing the efficiency of the transportation system and improving social life (Amirazodi, 2012). Researchers investigated the impact of urban mobility patterns on energy consumption and emissions in Indian cities and made solutions to minimize transport energy consumption and emissions (Sudhakara Reddy and Balachandra, 2012). Authors explored individual attitudes of experts and non-experts towards sustainable transportation, and the parameters that impact these attitudes (Xenias and Whitmarsh, 2013). Researchers presented assessments of public transport sustainability principles, with an emphasis on enhancing investigations of holistic composite sustainability indices. Some of these indices are to study the performance of public transport systems and for worldwide comparative performance assessment (De Gruyter et al., 2017; Miller et al., 2016a; Miller et al., 2016b). The authors proposed a set of public transport sustainability indicators that can be used to examine sustainability using an indicator-based approach (Karjalainen and Juhola, 2019). The authors investigated transport indicators for developing countries, concentrating on the Jakarta metropolitan region. According to the findings, quality service of public transportation, safety, travel cost, pollution, and accessibility are contextual factors for use in developing nations (Shiddiqi et al., 2022).

2.2 Evaluation of public transportation system

Public transport evaluation framework was developed by incorporating cost-benefit analysis and multi-criteria analysis, to assess public transportation projects. User-friendly spreadsheet-based tool was applied for regular and comprehensive evaluation of initiatives (Lake and Ferreira, 2002). Multi-criteria method was used to evaluate alternative transportation options in Delhi, India (Yedla and Shrestha, 2003). Delhi metro rail system was evaluated concerning capacity, travel duration, and accessibility. The authors developed evaluation indices based on commuters' opinions and identified the importance of a feeder system to address transfer wait times and expenses. The authors recommended the purchase of an integrated ticket valid for both bus and metro travel (Advani and Tiwari, 2005). The researchers developed a methodology for the evaluation of transportation systems based on six criteria: information, amenities, security and safety, access, connection, and reliability. The authors surveyed transit users, assessing the significance and satisfaction levels of various service features. The study also examined the association between transit stops/station attributes and user satisfaction (Iseki et al., 2007).

Multi-criteria analysis is used for evaluating the sustainability of urban rail. By comparing different scenarios (with and without the project), the methodology calculated the benefits and aggregated the percentage variations with weights assigned to indicators (Cascajo, 2005). The authors analyzed the transit integration in Sao Paulo, Brazil. Boarding increased by 49% and transit trips increased by 15% between 2002 and 2006 (Hidalgo, 2009). Researchers conducted research in 30 Indian cities to evaluate public transportation systems and selected indicators and assigned weights to assess the overall effectiveness of each city's transportation system (Wilbur Smith Associates, 2008). The authors studied the smart card system, analyzing its challenges, solutions, and impact. The study found that smart card system enhances the share of public transportation (Yedla and Shrestha, 2003). The public transportation system was evaluated using GIS in Jaipur. The authors highlighted the effectiveness of GIS as a user-friendly tool for evaluating public transit options (Vimal et al., 2011). A capacity and quality-based performance measurement approach was proposed for the Zurich public transportation system. Critical performance indicators were evaluated at different levels: individual elements, route segments, and the entire network (Orth et al., 2012). A comprehensive literature review on public transportation quality criteria was conducted to attract drivers. Service reliability and frequency are crucial factors in this regard (Redman et al., 2013).

Based on public demand and the public transport network, an optimization algorithm for the maximum profit optimal approach was proposed. In addition, the regional public transit network was optimized, and the operation was financially sustainable (Guzman et al., 2018; Wen et al., 2020). The authors presented guidelines to improve the frequency of metro systems to deliver more benefits to users and transportation agencies (Wen et al., 2020). The researchers developed a method for optimizing bus lines based on metro and bus integration. A qualitative relationship between bus and metro lines was introduced by considering the geographical location and service range. Changsha Metro Line was used as a case study for model validation. There is no global set of standards that would be adequate to evaluate the performance of a metro system, requiring further investigations in this area of study (Wei et al., 2020).

The discussion above illustrates the many studies that have been conducted worldwide to evaluate transportation infrastructure using a range of approaches with sustainability as a goal. But there is no set of standard sustainable indicators and methodology to evaluate the performance of transportation systems and further research is required in this area. The indicators are identified and measured using a wide range of methods. Consequently, a multi-criteria method has been appropriate for the sustainability analysis of public transport systems in India. The outcome of the study will be significantly affected by the evaluation perspective.

3 Methodology

3.1 Study methodology and indicators

In the present study, the methodology is applied for the calculation of SII value between metro rail and nearby feeder buses in Bengaluru city. The applied methodology was similar to that proposed by Errampalli et al. (2020). However, the indicator list was different. BMRCL and BMTC are Bengaluru's two primary public transport providers. To improve the city's overall public transport mode share, route integration is essential. One method would be for BMTC to provide feeder service to metro. The multi-criteria analysis method was employed for evaluating the present level of integration between metro rail and feeder buses. The study methodology is depicted in Fig. 1. For the evaluation, eight dimensions such as service availability, travel time, ticketing, customer services, comfort level, safety, hygiene, and image were considered. The 18 indicators representing these dimensions were selected based on an extensive literature review and expert consultations to ensure relevance and suitability for the Bengaluru context. Previous studies (Advani and Tiwari, 2005; Errampalli et al., 2020; Kolak et al., 2011) have highlighted similar factors as critical for evaluating integration effectiveness. Additionally, feedback from transport professionals and preliminary user discussions confirmed that these indicators reflect the operational characteristics and user priorities of the local metro and feeder bus system. Cleanliness and safety of metro stations

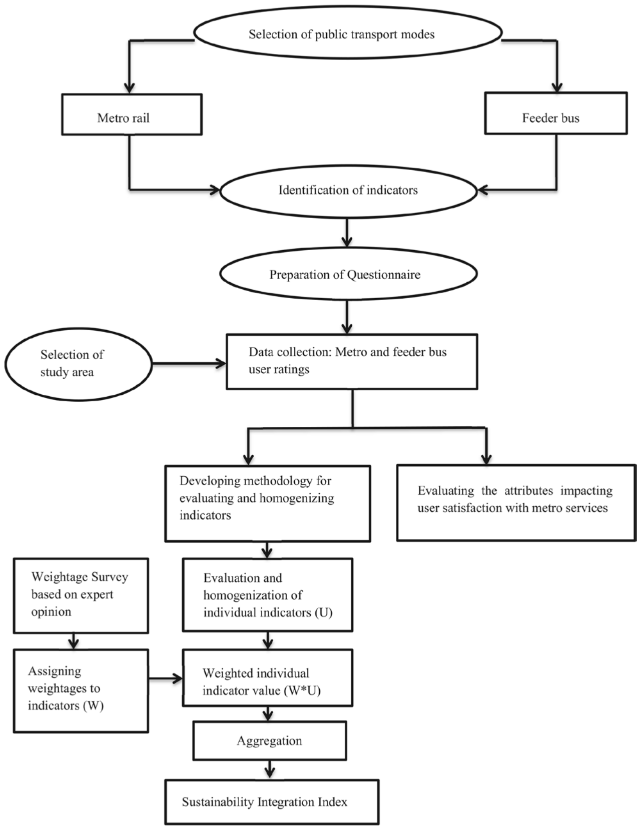

Fig. 1 Study methodology (Errampalli et al., 2020)

were included because they serve as enclosed, high-volume transfer hubs, while feeder bus stops are primarily open-air facilities where aspects like frequency, transfer distance, and accessibility were considered more important. All indicators were assessed through data collection via surveys and were normalized to a standardized scale from 0 to 1. The final SII value was calculated by aggregating the normalized indicator scores weighted according to expert evaluations (Table 1).

3.2 Homogenization

Homogenization is a mathematical method that transforms all indicators into standardized values for comparison to other variables. In the present study, some of the sustainable indicators would have a positive impact, while others would have a negative impact. For instance, the SII value is influenced negatively by the transfer time indicator. Hence, it is necessary to describe a method for turning all indicator variations into a common homogenized number that is typically between 0 and 1. To homogenize an indicator, for example, the ratio of users who use the metro and bus together to complete their journey was compared to those who use any other mode to continue their journey after using the bus or metro. When the data is compared, a fraction between 0 and 1 is obtained.

Table 1 Indicators for the estimation of SII value

Factors	Indicators
Availability of service	Frequency
	Speed
	Reliability
	Parking facility
Travel time	Transfer- time
	Transfer-distance
Ticket	Ticket prices
Customer services	On-board information
	Information at stations
Comfort level	Seating capacity inside metro
	Waiting conditions at metro
	Crowding
	Temperature and ventilation conditions at metro stations
Safety	Safety measures adopted inside metro
	Safety measures adopted at metro stations
Hygiene	Level of cleanliness in metros
	Level of cleanliness at the station
Image	Users' willingness to use Integrated metro and feeder bus services

A score of "1" implies that everyone uses the bus or metro, whereas a value of "0" suggests that everyone uses other modes after taking the bus or metro. The following Eq. (1) is used to calculate the homogenized value of an indicator for positive impact indicators, whereas Eq. (2) is applied for negative impact indicators:

$$u_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}}, \quad (1)$$

$$u_i = \frac{R_{\max} - R_i}{R_{\max} - R_{\min}}, \quad (2)$$

where u_i is the normalized value of the i-th indicator, R_i denotes the average rating assigned by survey respondents to the i-th indicator, $R_{\min}$ is the minimum possible rating score, and $R_{\max}$ is the maximum possible rating score.

3.3 Weightage and aggregation

The weighting procedure includes emphasizing data indicators' contributions to a final impact or decision. That is, instead of each indicator having an equal impact on the outcome, indicators have been adjusted to have greater significance. This was achieved by surveying transport expert professionals working at private companies with a predesigned questionnaire. The indicators are rated from 0 to 10, with 10 being the most important in terms of assessing integration. To determine the individual weightage for each indicator as given in Eq. (3), a weighted average was taken. The aggregate weighted individual indicators in the range of 0 to 100 are aggregated to provide the final SII value as given in Eq. (4), which represents the present level of integration. With a fully integrated system, the value can reach a maximum of 100 and a minimum of 0 with no integration.

$$\text{Individual weightage indicator} = w_i \times u_i \quad (3)$$

$$\text{SII} = \sum_{i=1}^{n} w_i \times u_i \quad (4)$$

3.4 Applicability of the methodology

The methodology presented in this study – including the formulation of sustainability indicators, the normalization of parameters, and the multi-criteria evaluation framework – is designed to be broadly transferable beyond metro and feeder bus integration in Bengaluru. Previous research has demonstrated that comparable assessment frameworks are effective in various transport planning contexts. For instance, Errampalli et al. (2020) implemented a similar multi-criteria indicator approach to evaluate multimodal integration between metro and bus operations in Delhi, while Kolak et al. (2011) applied related methods to assess the performance of integrated transport networks in several European cities, encompassing tramways and suburban rail services. The methodology is inherently modular, enabling transport planners and practitioners to customize the indicator set to align with the operational characteristics, policy objectives, and user priorities of the study area. Additionally, the weighting of indicators can be calibrated through expert elicitation techniques to reflect local governance structures, regulatory frameworks, and stakeholder preferences in different countries or regions. This adaptability ensures that the framework can be utilized to analyze a range of multimodal integration scenarios, such as coordinating metro systems with tram corridors, commuter rail, or Bus Rapid Transit networks, provided that context-specific adjustments are made to indicator selection and weighting. Consequently, the approach offers a robust and replicable tool for transportation engineers, urban mobility researchers, and policymakers aiming to assess and enhance public transport integration in diverse metropolitan environments.

4 Study area and data collection

Bengaluru city acts as a benchmark for other cities in developing countries that are constructing metro train systems. Bengaluru has a population of almost 12 million people spread throughout a 741 km^2 municipal region and the surrounding metropolitan area. The city now has 48.69 km of operational metro rail network spread across two lines, with 42.3 km of that network which began operations in June 2017. Another 127 km of metro network is being constructed and will be operational by 2025. The system is owned and operated by the BMRCL. After the launch of the Bengaluru metro reach in 2011, the BMTC launched a few feeder bus services. With the completion of metro Phase-I in 2017, BMTC added new feeder bus services. The existing feeder services connect areas to neighboring metro stations as well as metro stations themselves. The existing metro feeder routes have an average route length of 15 km and a frequency of 10–20 min. In comparison, Bengaluru Metro services operate at higher frequencies, with headways typically ranging from 4–6 min during peak hours and 8–10 min during off-peak periods. This frequent metro schedule means that the waiting time for transferring passengers is mainly determined by the feeder bus arrival intervals. Bengaluru city transit hubs (Baiyappanahalli Metro Station, Mejastic Metro Station, and Yeshwanthpur Metro Station) and bus stops within walking distance of the transit hubs were chosen to collect data. Transit hubs are locations that provide access to various modes of public transport in the area.

A perception survey was conducted to measure the selected indicators, and data was collected using a questionnaire survey at transportation hub stations and nearby bus stops. On a five-point Likert scale, commuters were asked to rate metro and bus facilities and infrastructure. A passenger survey was conducted at each study location. An adequate sample size was found using a simple random sampling approach at each metro station and nearby bus stop. Interviews would begin at each station during a morning commute time of 8:30 a.m. to 10:30 a.m. at bus stops, and a full-day commute schedule of 8:30 a.m. to 5:30 p.m. at metro stations. The survey samples collected at metro stations and feeder bus stations are shown in Table 2.

Table 2 Survey samples collected at metro stations and nearby bus stops

Sl. No.	Location	Survey samples size		
		Metro stations	Bus stations	Total
1	Baiyappanahalli metro station	388	411	799
2	Mejastic metro station	382	415	797
3	Yeshwantpur metro station	385	412	797

5 Evaluation of SII

5.1 Computation of weightage of indicators

The methodology used to homogenize each indicator is explained in the preceding sections. By using the homogenization method, each indicator value was converted in the range of 0 to 1. The results of an expert survey conducted among transport expert professionals working at private companies used to assign weights to the indicators. The primary objective of this study was to calculate the SII value for the study locations, which indicates the level of existing integration. Table 3 shows a summary of the sustainability indicators calculated from survey data at metro stations and near bus stops. The values of each indicator are shown as out of 1. As there are 18 indicators, the total value is out of 18. Based on these findings, the Mejastic metro station has the highest sustainability value when all factors are given equal weight.

5.2 Computation of SII value

The SII value is calculated for all metro stations and nearby bus stops, such as Baiyappanahalli, Mejastic, and Yeshwantpur. The weighted value of each indicator is calculated by multiplying its homogenized value by the indicator's expert survey weight. The weighted value of each indicator is then combined to obtain the final SII value of metro stations, which is shown in Table 4. Fig. 2 presents a visual representation of the SII values between metro rail and nearby bus stops. It can be observed that Baiyappanahalli metro station and nearby bus stops have a sustainability index of 72.11%, Mejastic metro station and nearby bus stops have a sustainability index of 77.16%, and Yeshwantpur metro station and nearby bus stops have a sustainability index of 64.11%. Several reasons contribute to the highest sustainability index reported at Mejastic metro station. To begin, there are multiple bus stations around the station, as well as many bus fleets operating in the vicinity. In addition, adequate connections, such as underpasses and footpaths, have been created to allow access to these bus stations. On the other hand, the lowest index value reported at Yeshwantpur metro station can be attributed to specific limitations in connectivity between the metro station and bus stop. In this scenario, the bus stations are located a long distance from the metro station and lack adequate facilities to allow access. Furthermore, the metro station is served by a small number of bus fleets. These issues all contribute to Yeshwantpur metro station's lower sustainability index value. As there are no

Table 3 Sustainability indicators obtained from perception and expert surveys

Indicators	Ratings from an expert survey	Homogenization of individual indicators		
		Baiyappanahalli metro station	Mejastic metro station	Yeshwantpur metro station
Frequency	8.9	0.88	0.94	0.86
Users' willingness to use Integrated metro and feeder bus services	5.2	0.96	0.92	0.88
Reliability	8.1	0.92	0.85	0.82
Seating capacity inside metro	5.2	0.83	0.86	0.86
Level of cleanliness in metros	7.1	0.89	0.87	0.73
Ticket prices	6.2	0.75	0.8	0.77
Safety measures adopted at metro stations	7.2	0.56	0.7	0.43
Waiting conditions at metro	4.1	0.76	0.45	0.4
Level of cleanliness at the station	4.0	0.95	0.88	0.78
Parking facility	6.1	0.31	0.55	0.3
Temperature and ventilation conditions at metro stations	6.4	0.22	0.45	0.3
Transfer distance	3.1	0.46	0.55	0.35
Crowding	6.0	0.77	0.89	0.65
Transfer time	3.4	0.93	0.78	0.79
Speed	3.6	0.47	0.96	0.75
Information at station	3.2	0.79	0.88	0.66
Onboard information	3.1	0.79	0.87	0.56
Safety measures adopted inside metro	9.1	0.74	0.69	0.65
Total value	100	12.98	13.89	11.54

Table 4 SII values of selected metro stations and nearby bus stops

Indicators	Weighted value		
	Baiyappanahalli metro station	Mejastic metro station	Yeshwantpur metro station
Frequency	7.83	8.366	7.654
Users’ willingness to use Integrated metro and feeder bus services	4.99	4.784	4.576
Reliability	7.45	6.885	6.642
Seating capacity inside metro	4.32	4.472	4.472
Level of cleanliness in metros	6.32	6.177	5.183
Ticket prices	4.65	4.96	4.774
Safety measures adopted at metro stations	4.03	5.04	3.096
Waiting conditions at metro	3.12	1.845	1.64
Level of cleanliness at the station	3.80	3.52	3.12
Parking facility	1.89	3.355	1.83
Temperature and ventilation conditions at metro stations	1.41	2.88	1.92
Transfer distance	1.43	1.705	1.085
Crowding	4.62	5.34	3.9
Transfer time	3.16	2.652	2.686
Speed	1.69	3.456	2.7
Information at station	2.53	2.816	2.112
Onboard information	2.45	2.697	1.736
Safety measures adopted inside metro	6.73	6.279	5.915
Final SII value	72.42	77.23	65.04

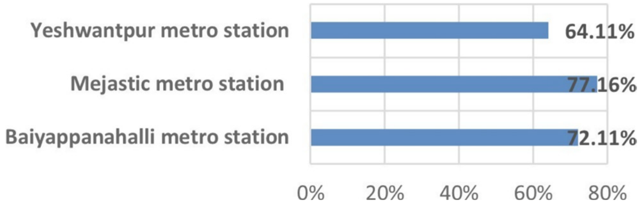

Fig. 2 Estimated SII values for different metro stations and nearby bus stops

universally accepted thresholds for categorizing SII values, interpretation in this study was based on relative comparison among the three stations and reference to similar research (Errampalli et al., 2020). In this context, SII values above approximately 75% can be considered indicative of strong integration performance, while values below 60% reflect notable deficiencies in coordination and user satisfaction. Scores in the range of 60–75% suggest moderate integration with areas for improvement. Accordingly, Mejastic station demonstrates relatively good integration, Baiyappanahalli station reflects moderate integration, and Yeshwantpur station indicates the need for targeted enhancements in service connectivity and infrastructure.

6 Evaluation of transport policies

The following three policies regarding the integration of the metro and feeder bus services in Bengaluru city were evaluated using the methodology that was used in this study:

1. Single ticketing system: a mechanism for collecting bus and metro fares together using an electronic card.
2. Bus stop relocation: moving the bus stops near the metro stations and building a direct link there will make switching between the metro and the bus easier.
3. Increasing bus frequency: waiting times are decreased by increasing the frequency of buses at the bus stops near metro stations.

The impact of the transport policies was evaluated for the selected indicators as well as the level of integration between metro rails and feeder buses as indicated by the sustainability index value. Table 5 shows the SII value for the metro station and nearby bus stops after the deployment of a single ticketing system, bus stop relocation, and increase in bus frequency. The SII value has increased by 4.73%, 4.38%, and 5.09%, respectively, because of the single ticketing system policy, bus stop relocation, and increase in bus frequency. Fig. 3 depicts a comparison of the average increase of the SII value of the three proposed transport policies. The policy of increasing bus frequency has the greatest impact on the SII value, followed by the policy of a single ticketing system and, finally, the policy of bus stop relocation.

Table 5 Evaluation of SII value for different policies

Metro stations	SII value			
	Existing condition	Single ticketing system	Bus stops relocation	Increase in bus frequency
Baiyappanahalli metro station	72.11%	77.08%	75.99%	77.47%
Mejastic metro station	77.16%	81.97%	81.51%	82.16%
Yeshwantpur metro station	64.11%	68.53%	69.01%	69.03%

Metro stations	Percentage increase in SII value			Average increase in SII value
	Single ticketing system	Bus stops relocation	Increase in bus frequency	
Baiyappanahalli metro station	4.97%	3.88%	5.36%	4.73%
Mejastic metro station	4.81%	4.35%	5.00%	4.38%
Yeshwantpur metro station	4.42%	4.90%	4.92%	5.09%

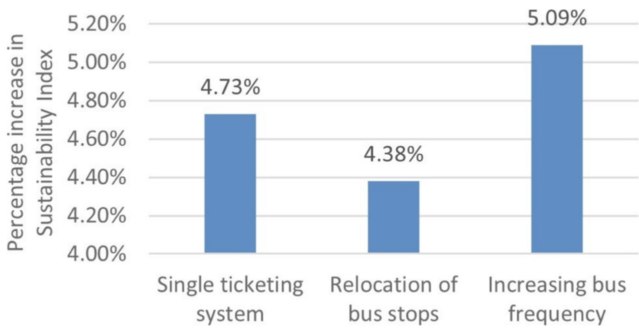

Fig. 3 Average percentage increase in SII value under various transport policies

7 Conclusions

The current study applied a methodology for evaluating integration between metro and feeder buses while keeping sustainability in view. For the evaluation of existing integration, a total of 18 sustainable transport indicators were considered. Data were collected from three transport hubs and nearby bus stops in Bengaluru city, India, to estimate SII value. The study methodology was used to assess three transport policies in Bengaluru city concerning the integration of metro and feeder bus services. The following conclusions were drawn from the present study:

- A total of 18 indicators have been identified to evaluate existing integration between metro rail and feeder bus services in developing countries. They are frequency, speed, reliability, parking facility, transfer-time, transfer-distance, ticket prices, on-board information, information at stations, seating capacity inside the metro, waiting conditions at metro, crowding, temperature and ventilation conditions at metro stations, safety measures adopted inside metro, safety measures adopted at metro stations, level of cleanliness in metros, level of cleanliness at the station and users' willingness to use integrated metro and feeder bus services.

- According to the findings, Mejastic metro station and its nearby bus stops have a sustainability index of 77.16%, Baiyappanahalli metro station and its nearby bus stops have a sustainability index of 72.11%, and Yeshwanthpur metro station and its nearby bus stops have a sustainability index of 64.11%. The Mejastic metro station is more integrated than the other two metro stations.
- The highest SII value for Mejastic metro station can be attributed to various bus stops surrounding the station, as well as many bus fleets operating nearby. Furthermore, suitable connections, such as underpasses and footpaths, have been built to provide access to these bus stops. The lowest SII value for Yeshwanthpur metro station can be attributed to specific limitations in connectivity between the metro station and the bus stop. The bus stations are located a long distance from the metro station and lack adequate facilities to allow access. Furthermore, the metro station is served by a small number of bus fleets.
- The SII value has increased by 4.73%, 4.38%, and 5.09% for the policy of a single ticketing system, bus stops relocation, and increase in bus frequency, respectively. The highest SII value can be observed for the policy of increase in bus frequency.

The adopted methodology can help planners and policymakers with city-wide planning and integration of public transport systems. The current study is primarily concerned with public transportation service indicators, with no monetary benefits considered for system evaluation. To enhance the accuracy of findings, the number of indicators might be increased further.

Acknowledgement
The authors would like to thank REVA University for their assistance during the data collection.

References

Advani, M., Tiwari, G. (2005) "Evaluation of public transport systems: Case study of Delhi Metro", In: Proceeding of International Conference on Structural and Road Transportation Engineering (START-2005), Kharagpur, India, pp. 3–5. ISBN 81-88901-14-8

Amirazodi, T. (2012) "Sustainable Urban Transport Management and Its Strategies", International Journal of Transport and Vehicle Engineering, 6(5), pp. 881–884. https://doi.org/10.5281/zenodo.1331453

Batterbury, S. (2003) "Environmental Activism and Social Networks: Campaigning for Bicycles and Alternative Transport in West London", The Annals of the American Academy of Political and Social Science, 590(1), pp. 150–169. https://doi.org/10.1177/0002716203256903

Beatley, T. (1995) "The Many Meanings of Sustainability: Introduction to a Special Issue of JPL", Journal of Planning Literature, 9(4), pp. 339–342. https://doi.org/10.1177/088541229500900401

Black, J. A., Paez, A., Suthanaya, P. A. (2002) "Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches", Journal of Urban Planning and Development, 128(4), pp. 184–209. https://doi.org/10.1061/(ASCE)0733-9488(2002)128:4(184)

Carey, M. (2004) "What is Sustainable?", presented at Post-Conference Workshop of the 9th Conference of Hong Kong Society for Transportation Studies-Sustainable Urban Transportation: Concepts, Policies and Methodologies, Hong Kong, China, Dec. 13.

Cascajo, R. (2005) "Assessment of economic, social and environmental effects of rail urban projects", presented at Young Researchers Seminar 2005, The Hague, Netherlands, May 11–13. [online] Available at: https://www.researchgate.net/publication/237576161_ASSESSMENT_OF_ECONOMIC_SOCIAL_AND_ENVIRONMENTAL_EFFECTS_OF_RAIL_URBAN_PROJECTS [Accessed: 29 July 2025]

De Gruyter, C., Currie, G., Rose, G. (2017) "Sustainability Measures of Urban Public Transport in Cities: A World Review and Focus on the Asia/Middle East Region", Sustainability, 9(1), 43. https://doi.org/10.3390/su9010043

Dhingra, S. L. (2008) "Integrated Urban Mass Transit System for Sustainable Development", presented at the First Indo-US Symposium on Advances in Mass Transit and Travel Behavior Research (MTTBR-08), Guwahati, India, Feb. 12–15.

Errampalli, M., Patil, K. S., Prasad, C. S. R. K. (2020) "Evaluation of integration between public transportation modes by developing sustainability index for Indian cities", Case Studies on Transport Policy, 8(1), pp. 180–187. https://doi.org/10.1016/j.cstp.2018.09.005

Guzman, L. A., Oviedo, D., Cardona, R. (2018) "Accessibility Changes: Analysis of the Integrated Public Transport System of Bogotá", Sustainability, 10(11), 3958. https://doi.org/10.3390/su10113958

Hidalgo, D. (2009) "Citywide Transit Integration in a Large City: The Interligado System of São Paulo, Brazil", Transportation Research Record: Journal of the Transportation Research Board, 2114(1), pp. 19–27.
https://doi.org/10.3141/2114-03

Iseki, H., Ringler, A., Taylor, B. D., Miller, M., Smart, M. (2007) "Evaluating Transit Stops and Stations from the Perspective of Transit Users", [pdf] California Department of Transportation, Sacramento, CA, USA. Available at: https://www.its.ucla.edu/wp-content/uploads/sites/6/2014/06/Appendix-C.pdf [Accessed: 29 July 2025]

Karjalainen, L. E., Juhola, S. (2019) "Framework for Assessing Public Transportation Sustainability in Planning and Policy-Making", Sustainability, 11(4), 1028.
https://doi.org/10.3390/su11041028

Kolak, O. İ., Akın, D., Birbil, Ş. İ., Feyzioğlu, O., Noyan, N. (2011) "Multicriteria Sustainability Evaluation of Transport Networks for Selected European Countries", Lecture Notes in Engineering and Computer Science, 2190(1), pp. 117–122. [online] Available at: https://research.sabanciuniv.edu/id/eprint/17867/1/WCE2011_pp117-122.pdf [Accessed: 29 July 2025]

Kutz, M. (ed.) (2004) "Handbook of Transportation Engineering", McGraw-Hill. ISBN 0-07-139122-3

Lake, M., Ferreira, L. (2002) "Towards A Methodology To Evaluate Public Transport Projects", Physical Infrastructure Centre, School of Civil Engineering, Queensland University of Technology, Brisbane, Australia, Rep. 02-03. [online] Available at: https://www.researchgate.net/publication/27464625_Towards_A_Methodology_To_Evaluate_Public_Transport_Projects [Accessed: 29 July 2025]

Litman, T., Burwell, D. (2006) "Issues in sustainable transportation", International Journal of Global Environmental Issues (IJGENVI), 6(4), pp. 331–347.
https://doi.org/10.1504/IJGENVI.2006.010889

Matas, A. (2004) "Demand and Revenue Implications of an Integrated Public Transport Policy: The Case of Madrid", Transport Reviews, 24(2), pp. 195–217.
https://doi.org/10.1080/0144164032000107223

Mihyeon Jeon, C., Amekudzi, A. (2005) "Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics", Journal of Infrastructure Systems, 11(1), pp. 31–50.
https://doi.org/10.1061/(ASCE)1076-0342(2005)11:1(31)

Miller, P., de Barros, A. G., Kattan, L., Wirasinghe, S. C. (2016a) "Public transportation and sustainability: A review", KSCE Journal of Civil Engineering, 20(3), pp. 1076–1083.
https://doi.org/10.1007/s12205-016-0705-0

Miller, P., de Barros, A. G., Kattan, L., Wirasinghe, S. C. (2016b) "Analyzing the sustainability performance of public transit", Transportation Research Part D: Transport and Environment, 44, pp. 177–198.
https://doi.org/10.1016/j.trd.2016.02.012

Orth, H., Weidmann, U., Dorbritz, R. (2012) "Development of Measurement System for Public Transport Performance", Transportation Research Record: Journal of the Transportation Research Board, 2274(1), pp. 135–143.
https://doi.org/10.3141/2274-15

Redman, L., Friman, M., Gärling, T., Hartig, T. (2013) "Quality attributes of public transport that attract car users: A research review", Transport Policy, 25, pp. 119–127.
https://doi.org/10.1016/j.tranpol.2012.11.005

Sinha, K. C. (2003) "Sustainability and Urban Public Transportation", Journal of Transportation Engineering, 129(4), pp. 331–341.
https://doi.org/10.1061/(ASCE)0733-947X(2003)129:4(331)

Shiddiqi, A. A. A., Sutjiningsih, D., Tjahjono, T., Darmajanti, L., Suprayoga, G. B. (2022) "Evaluating Sustainable Transport Indicators for Metropolitan Areas in Developing Countries: The Case of Greater Jakarta", The Open Transportation Journal, 16(1), e187444782206130.
https://doi.org/10.2174/18744478-v16-e2206130

Sudhakara Reddy, B., Balachandra, P. (2012) "Urban mobility: A comparative analysis of megacities of India", Transport Policy, 21, pp. 152–164.
https://doi.org/10.1016/j.tranpol.2012.02.002

Ülengin, F., Önsel, Ş., Topçu, Y. İ., Aktaş, E., Kabak, Ö. (2007) "An integrated transportation decision support system for transportation policy decisions: The case of Turkey", Transportation Research Part A: Policy and Practice, 41(1), pp. 80–97.
https://doi.org/10.1016/j.tra.2006.05.010

Vassallo, J. M., Di Ciommo, F., García, Á. (2012) "Intermodal exchange stations in the city of Madrid", Transportation, 39(5), pp. 975–995. https://doi.org/10.1007/s11116-011-9377-2

Vimal, G., Swami, B. L., Parida, M., Jain, S. S., Kalla, P. (2011) "GIS based evaluation of public transit system", Urban Transport Journal, 10, pp. 17–28.

Wei, J., Long, K., Gu, J., Ju, Q., Zhu, P. (2020) "Optimizing Bus Line Based on Metro-Bus Integration", Sustainability, 12(4), 1493.
https://doi.org/10.3390/su12041493

Wen, Y., Leng, J., Shen, X., Han, G., Sun, L., Yu, F. (2020) "Environmental and Health Effects of Ventilation in Subway Stations: A Literature Review", International Journal of Environmental Research and Public Health, 17(3), 1084.
https://doi.org/10.3390/ijerph17031084

Wilbur Smith Associates (2008) "Traffic & Transportation Policies and Strategies in Urban Areas in India", [pdf] Ministry of Urban Development, New Delhi, India. Available at: https://mohua.gov.in/upload/uploadfiles/files/traffic_transportation(1).pdf [Accessed: 29 July 2025]

Xenias, D., Whitmarsh, L. (2013) "Dimensions and determinants of expert and public attitudes to sustainable transport policies and technologies", Transportation Research Part A: Policy and Practice, 48, pp. 75–85.
https://doi.org/10.1016/j.tra.2012.10.007

Yedla, S., Shrestha, R. M. (2003) "Multi-criteria approach for the selection of alternative options for environmentally sustainable transport system in Delhi", Transportation Research Part A: Policy and Practice, 37(8), pp. 717–729.
https://doi.org/10.1016/S0965-8564(03)00027-2