

Review of public transportation integration and modeling strategies: Toward seamless urban mobility



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Abstract To solve the issues of expanding urbanization, traffic congestion, and environmental sustainability, public transportation system integration has become a crucial area of concern for urban planners and legislators. This paper discusses the concept of integrating different modes of transportation and the necessity of using a reliable modeling strategy to enhance and optimize urban mobility networks generally. The implementation and efficiency of integrated public transportation systems in several cities are examined in this research paper. The study focuses on a number of notable case studies of various cities that have made substantial efforts to integrate multiple modes of transportation to enhance urban mobility. This study provides a thorough overview of the advantages, difficulties, and potential solutions associated with integrated public transportation as it exists today and as it is currently being modeled. The research also examines several modeling strategies for integrated transport system design and optimization. This study seeks to provide significant insights into the current status of integrated public transportation, identify research gaps, and propose viable pathways for future research and development by synthesizing literature and case studies. Information for the analysis was gathered from the Web of Science, Scopus, Science direct, MDPI Publisher database spanning the years 2000 to 2024. The article collected a total of 624 bibliometric records of publications. Both quantitative and qualitative analyses were conducted as part of the study. This paper conducts a literature review focusing on the latest research concerning the Integration of public transportation-related subjects. It employs scientific databases, a specified list of keywords, and established inclusion criteria to gather data, assess content, and conduct a bibliometric analysis.

Keywords: integrated public transportation, integrated system design, optimization, literature review

1. Introduction

India has been rapidly urbanizing, with a sizeable portion of the country's population migrating there in search of better job prospects and better living conditions. Numerous issues have been caused by this urbanization trend, including an increase in the demand for infrastructure and transportation. By 2036, urban growth is anticipated to account for 73% of the population increase overall (MoHFW, 2019). Indian cities today make up approximately 30% of the country's total population. Accordingly, India's urban population is predicted to increase from 285 million in 2001 to approximately 473 million in 2021 and 820 million by 2051. Therefore, cities must accommodate not only the current population's transportation demands but also those of people who may eventually move into metropolitan areas.

The need for transportation services has increased as a result of the expansion of the urban population. Traffic jams, longer commutes, rising pollution, and inadequate road networks are just a few of the problems cities are currently dealing with (Thondoo et. al, 2020; Verma et. al, 2021). Providing effective and sustainable mobility solutions is essential as urban populations rise. Reliable public transportation networks are a crucial component of urban design since dependence on private vehicles can worsen congestion and pollution (Papadakis et al., 2024)

These issues could be partially resolved by encouraging commuters to use public transportation rather than private vehicles. Cities are now attempting to promote nonmotorized and public modes of transportation as alternatives (Abdulrazzaq et al., 2020). To encourage mode transition, services must be accessible, effective, and appealing. Integrated multimodal transport planning is a method of planning that takes into account all modes of transportation to address these problems (Schwedes & Hoor, 2019). From this perspective, making public transit more accessible might persuade select passengers to use it, in which case bus services might serve as feeders to larger transportation networks such as the metro. According to data from the International Association of Public Transport (UITP), the network length of metro rail systems increased quickly from 222 km in three cities in 2011 to 810 km in 15 cities by 2022. (Article published in January 2023 in Swarajya). 'More for People and Less for Cars' is the motto of NUTP (2006), which promotes city development with an



emphasis on increasing the number of people who use the public transit system. According to NTDPC (2014), 38% of large cities' mode shares are for public transportation. The major research objectives of the study include the following considerations:

- To review existing public transport scenarios in terms of the integration of the metro, BRTS, AMTS, and para-transit modes of Ahmedabad city.
- To analyze user preferences and expectations related to the integration of Metro with other modes.
- To develop a travel demand model using VISUM to estimate the base-year travel demand.
- To assess and compare various integration alternatives/variants on the basis of the application of the transport model designed and simulated in VISUM.

2. Need for Study

The largest city in Gujarat and the seventh-largest metropolis in all of India is Ahmedabad. The current estimate for Ahmedabad city's population in 2023 is 7,692,000, whereas the estimate for the population of the Ahmedabad metropolitan area is 8,772,000. There are 2,600 kilometers of roads in the Indian city of Ahmedabad. Approximately 1.5 million automobiles were registered in the city overall during the 2007 fiscal year; by 2019, that number had climbed to more than twice that amount. Early on, there were more four-wheelers in the city, but since the middle of the 2000s, there has been a dramatic increase in the number of two-wheelers. More than 70% of the city's registered automobiles in 2019 were two-wheelers.

Ahmedabad city is experiencing significant problems as a result of urbanization and population growth, including traffic jams on roads that cause delays, larger blocks that make it harder to reach, a lower level of public transportation service, and a lack of integration between public transportation modes and intersecting routes.

According to research by CEPT University in Ahmedabad, only 12% of city residents currently use public transportation, whereas 27% choose two-wheelers. However, it is predicted that by 2041, the use of public transportation will increase from 12% to 30% with the introduction of the metro system, among other things, according to a report titled "Improving Public Transport in Ahmedabad" by Shravya N [1]. This forecast shows how the metro system can increase Ahmedabad's reliance on public transportation.

The Ahmedabad Municipal Transport Services (AMTS), the Bus Rapid Transit System (BRTS), and the Metro are the three main public transportation options in the city. The Ahmedabad BRTS provides public transportation bus services in the Ahmedabad metropolitan area and is run by Ahmedabad Janmarg Limited (AJL). As of March 2018, the BRTS operated a fleet of 315 buses and carried an average of 1.60 lakh passengers daily as part of its mission to improve connectivity and mobility. The BRTS, which has 14 lines and 162 stations (as of June 2018), is a key component of Ahmedabad's transportation system.

The metro rail public transportation system in Ahmedabad is run by Gujarat Metro Rail Corporation Limited. The East–West Corridor, which runs from Vastral Gam to Thaltej Gam (18 stations) and covers a distance of 21.16 km, and the North–South Corridor, which runs from Motera Stadium to APMC Vasna (15 stations) and covers a distance of 18.87 km, make up the first phase of metro operations.

According to the report and study conducted by the CEPT University statistics, in terms of the public transport level of service, city os is only 3, which indicates a poor supply of public transport facilities and a lower frequency and greater headway.

The city of Ahmedabad continues to struggle with transportation problems, and the current transportation system is unable to keep up with rising demand, despite significant investments in road and transit infrastructure. Therefore, the integration of these public transit systems (Metro with BRTS and AMTS) would become a key factor in increasing public transit usage and would solve this problem to some extent. This resulted in improved efficiency of usage and increased city LOS in terms of public transport facilities and accessibility.

3. Methodology

Various studies conducted in different cities have been considered to develop methodologies and identify various elements that influence the degree of integration between the various means of public transportation that are currently in use. An entire framework for building and evaluating transportation solutions will be developed on the basis of case studies and critical reviews conducted around the world, with the goal of integrating an existing metropolitan public transit system for Ahmedabad city.

3.1. Materials and methods

The primary sources utilized for this literature review include scientific papers, books, journals, and technical reports. Initially, a broad exploration was conducted via search engines and databases, including Science Direct and Scopus, as well as supplementary tools, such as Mendeley Desktop and Web of Science, to gather and filter resources. These resources were managed via a reference manager. Subsequently, VOS Viewer software facilitated the visualization of overarching themes,

facilitating an initial bibliometric analysis. Additional web-based tools, such as co-citations and cross-referencing, are occasionally employed to refine resource selection.

During the initial phase of gathering textual materials, our selection process focused primarily on publications dated 2000–2024 as the year of publication. In the process of retrieving records, a key challenge lies in identifying keywords deemed pertinent to the analyzed issue. Five primary research domains within the realm of public transport integration were identified as follows:

- Seamless Intermodal Connectivity
- Intelligent transportation system (ITS) integration
- Multimodal Transportation Planning and Management
- Public–private partnership models for transport integration
- Sustainable urban mobility solutions

The main domains selected for the initial search considered multimodal transportation planning and transport integration. As a result, a set of 9296 publications was subjected to additional selection criteria.

Additionally, we ensured that each record contained at least one of the specified keywords within any part of its text along with earlier selection criteria applied. Furthermore, we limited our consideration to texts written in the English language.

List of keywords considered:

- Integration of public transportation
- Multimodal integration of public transportation
- Sustainable transportation
- Evaluation of multimodal transportation
- Integrated transport modeling
- Integration via VISUM

Consequently, the initial investigation produced 232 records for the keyword “Integration of Public Transportation” 38 records for the keyword “Multimodal integration of Public Transportation” 45 records “Evaluation of Multimodal Transportation” 306 records for the keyword “Integrated Transport “Modeling” 3 records on the keyword “Integration of public transportation using VISUM”. Figure 1 shows the PRISMA flowchart that was developed for the literature review.

In the second and third phases of the methodology, the focus shifted toward refining the research. In the second phase, we employed the Mendeley Desktop tool to identify records that incorporated two or more of the keywords listed above, thereby creating a more concise list from the initial research findings. Figure 2 illustrates the distribution of publication dates, indicating a notable surge in interest in the field of the integration of public transportation. Figure 3 shows the number of publications related to transport integration in the period 2000–2024.

In the fourth and concluding stage, we employed the VOS viewer for the final bibliometric analysis. This phase aimed to confirm that even after refining the initial pool of 624 resources to the final ones cited, we adequately covered the entire scope and objective of our comprehensive literature review. Through this tool, we analyzed co-citation and co-occurrence patterns, thereby reinforcing the significance and comprehensiveness of our chosen materials. The outlined tasks of the methodology and the utilized materials are depicted in Figure 4.

The co-word analysis was conducted through the following steps:

- Searching for records in the database on the basis of the criteria outlined in detail in the methodology section.
- Exporting data, which include author name(s), title, abstract, keywords, and sources.
- Generate relationship maps to identify thematic clusters. A frequency analysis was carried out for a set of 2476 keywords, 97 of which met the threshold.
- Analysis of the obtained results.

Figure 4 shows a visualization of the keywords and cword analysis for the topic area integration of transportation. The most frequent keywords were “Public Transportation/Public transport/Public Transit” (115), “Model” (122), “Sustainable transport” (97), “Multimodality” (15), “Accessibility” (34), and “Shared Mobility” (14).

Co-word analysis identified five research clusters related to the theme of sustainable transport:

Cluster 1 (red) represents sustainable urban/public transport and mobility; Cluster 2 (green) represents transportation modeling; Infrastructure Cluster 3 (blue) represents customer satisfaction and transport network planning; Cluster 4 (yellow) represents multimodal planning and optimization; and Cluster 5 (purple) represents mobility and service quality.

Figure 5 highlights density based keyword analysis to understand domains of further research on the topic of integration of transportation modes.

Major papers were selected on the basis of their relevance according to the methodology. A detailed review of the work in those papers is presented in the next section. Major factors and methods were identified through a literature review, which was used to develop methodologies for the integration of public transportation in Ahmedabad city.

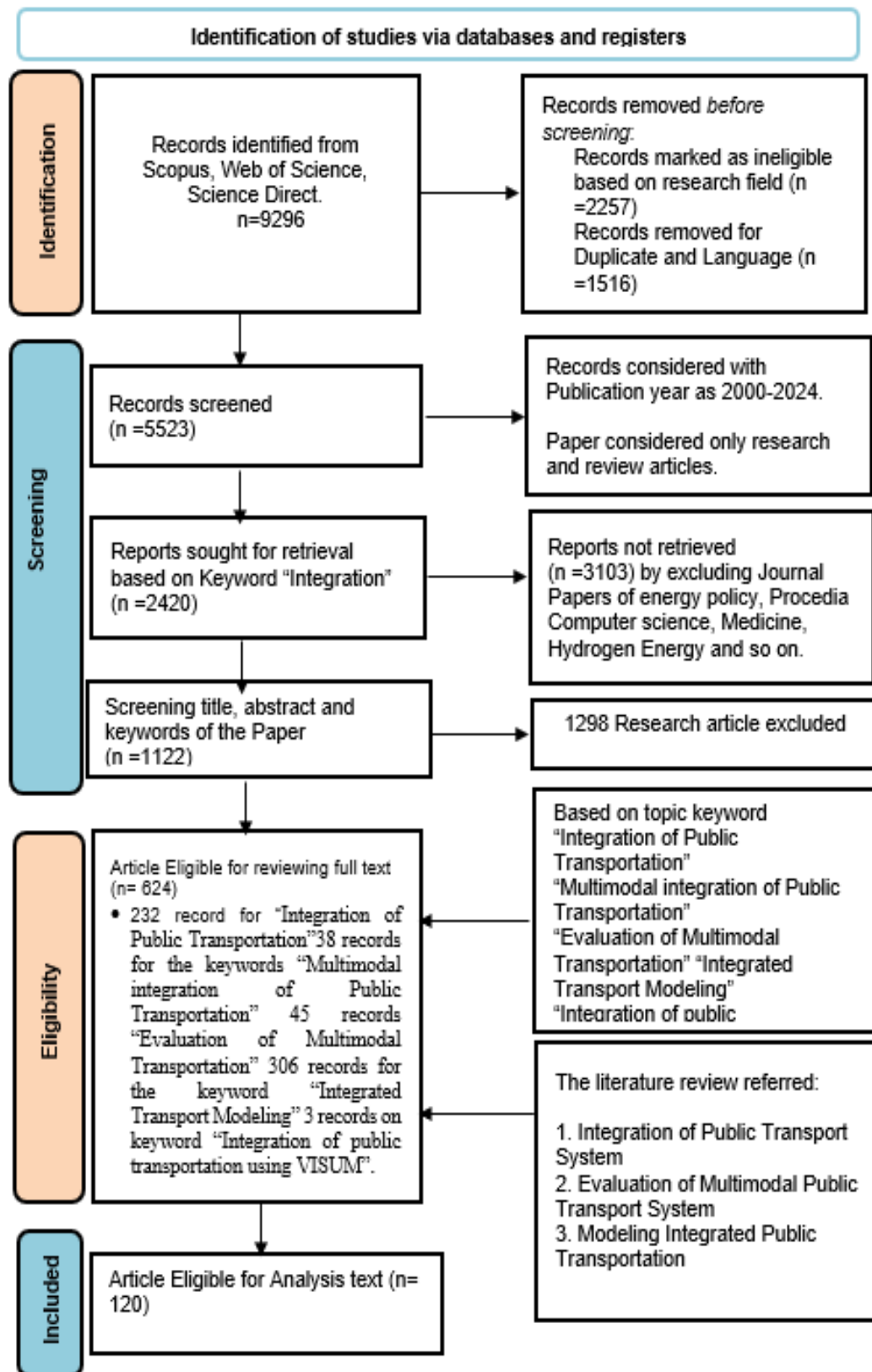


Figure 1 PRISMA flowchart used for the literature review.

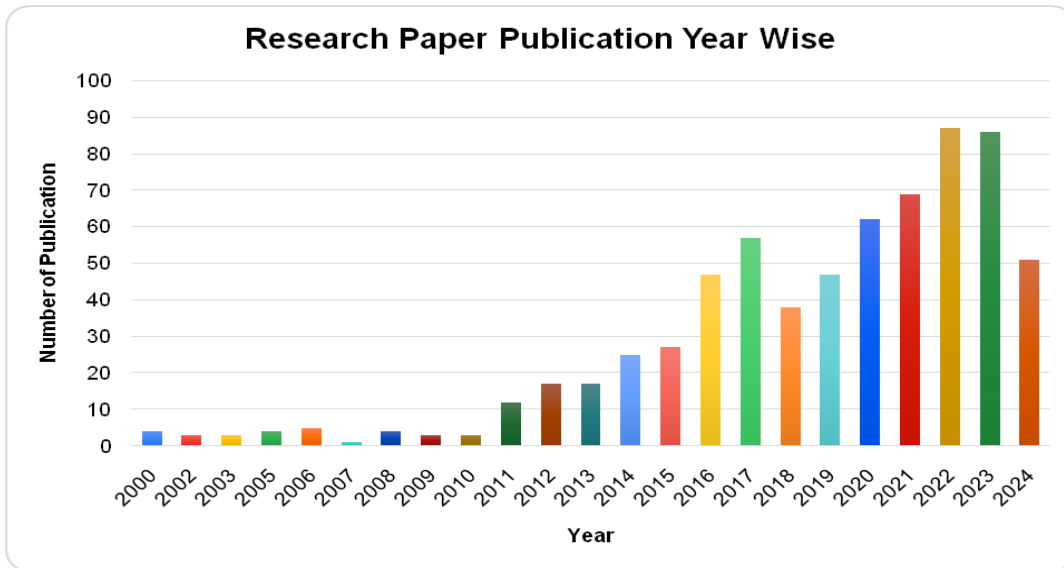


Figure 2 Research papers published in the field of public transport integration annually.

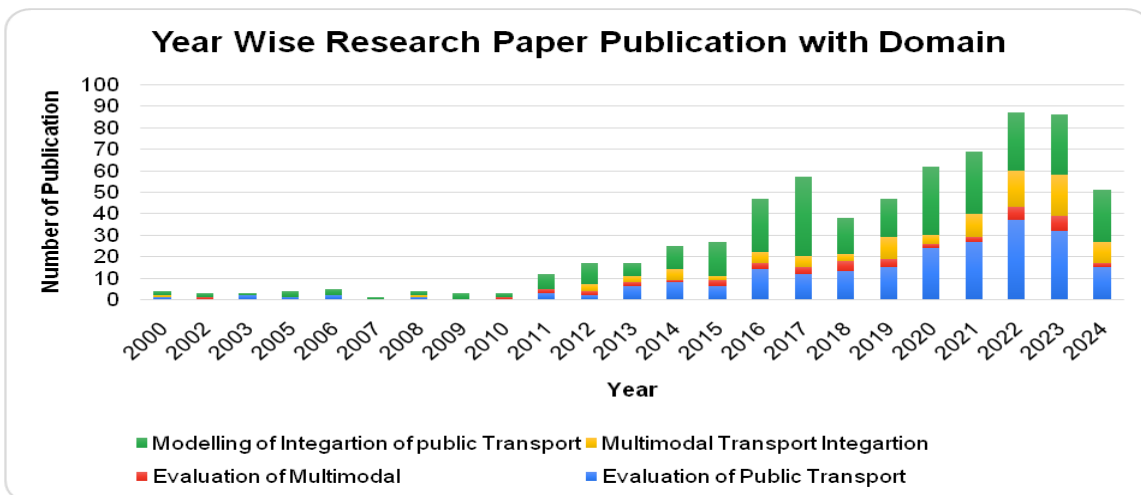


Figure 3 Research paper publication domain in the field of public transport integration annually.

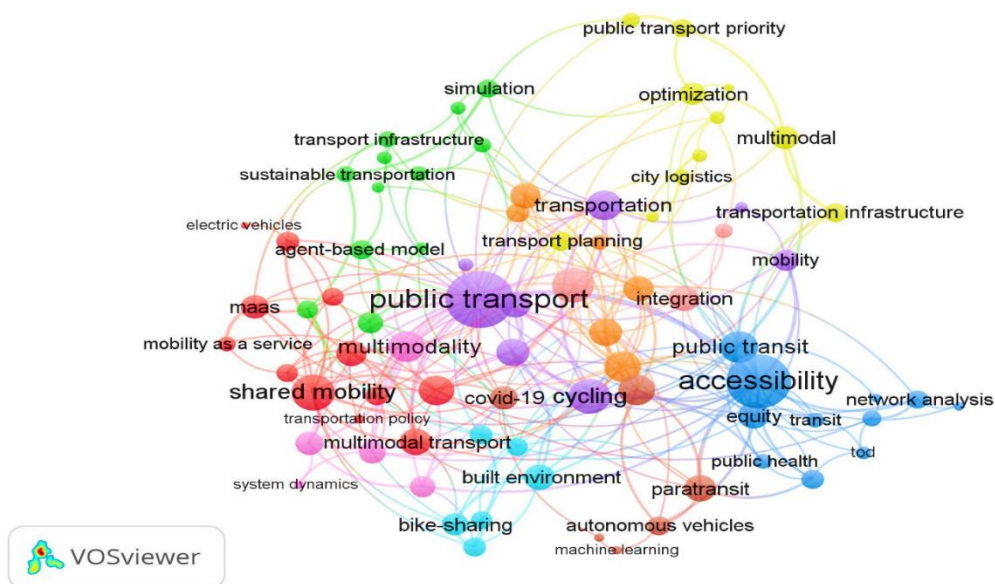


Figure 4 VOS viewer co-word analysis for research papers published in the field of transport integration. Source: (VOS viewer tool).

result, shortcomings in layout integration are found after an analysis of the current transit service. To create a new network plan with distinct functions and an organized hierarchy, a new bus system with a thorough design is ultimately suggested. To provide optimal connectivity and coordination between the modes and lines, the new configuration is a three-level network with distinct functions and performance characteristics for each level.

The concept of integration is defined across multiple levels—operational (fare and ticket integration, scheduling, information), physical, organizational, and fare/ticket integration. The second section outlines a case study in Thessaloniki, transitioning from a bus-only system to a bimodal transit network with a new metro line. An integration strategy is proposed for future operations, emphasizing the need for coordination and collaboration among multiple agencies involved in managing the two modes and their respective lines.

Jasti and Ram (2016) developed an extensive evaluation program that assesses the performance of a transport system using a suitable set of environmental, economic, financial, and social indicators, which is crucial for sustainable transport planning. This research provides information about indicator groups that are acceptable for assessing intra city urban bus transportation while keeping in mind the more general goal of social sustainability. By creating 8 performance indicators with 30 evaluators, a framework for the evaluation of the public transportation system is constructed. To rank the entire metropolitan bus system, a weighted ranking system is used. Service availability, comfort, fare, passenger information systems, environmental sustainability, economic sustainability, and social systems are among the several performance indicators utilized for evaluation.

The study shows that the urban bus system in Hyderabad is operating at 70% efficiency, which suggests that the overall quality of service provided by the bus system is OQOS 3, indicating that the performance is average and reflects the need for improvement in the area of public integrated systems and social sustainability. The study focused on evaluating the public transportation system while only considering one mode and a variety of performance measures. Therefore, the parameters for integration between various modes differ. Additionally, different weights are assigned to the integration criterion of the sustainability index. It is possible to create an evaluation methodology similar to that used by Ahmedabad to assess the city's current level of integration with various forms of public transportation.

Bernal (2016) evaluated eight effective global intermodal facilities, focusing on accuracy, information, travel and waiting times, facility availability, and security. It emphasizes the importance of park and ride and kiss and ride infrastructures, considering walking flows, transit usage, and sustainability-related issues. This study highlights the need for efficient and safe intermodal facilities.

By using Ahmedabad and Delhi as a study region, this article Sharma (2017) on sustainable urban transport provides an overview of a comprehensive set of indicators that are used by planners and authorities to assist cities in establishing an integrated and sustainable transportation system. The following conclusions are drawn from this research to achieve sustainability in terms of urban public transportation. Prioritizing public transit is a good way to ensure mass mobility. A multimodal, integrated transit system that includes rail, buses, metro, bicycles, and pedestrians should be established. An integrated mass-transit system can be used as a planning tool to keep track of a city's sustainable growth, and more cost-effective, environmentally friendly, and sustainable technology can be used to address air quality issues (CNG cars, hybrids, electric cars, etc.). Thus, this paper clearly highlights the role of integrated modes of transportation in the sustainable growth of any city.

Winter et al. (2018) investigated the performance of an automated demand-responsive transport service (ADRTS) as a replacement for scheduled bus services, considering factors such as demand levels, vehicle capacity, and initial vehicle distribution. The case study reveals that ADRTS, a demand-responsive transport service, has operational costs between 0.84 and 1.22 Euros for a minimum fleet size, with an average passenger wait time of 2--6 minutes per trip.

Wei et al. (2020) address the challenge of optimizing and enhancing original bus lines following the construction of new metro systems in cities. The proposed approach emphasizes bus and metro integration, introducing a bus line optimization technique. The cooperation and competitive relationship between bus and metro lines is qualitatively introduced in the context of geographical space consideration on the basis of the locations and service areas of the bus (500 m radius) and metro (800 m radius) stations. The cooperation relationship between bus and metro lines is determined by applying cooperation and competition indices. The cooperation coefficient serves as the foundation for building the bus line optimization model.

The findings imply that integrating bus and metro services can reduce overall bus line length, repeat length, and trip costs while also greatly improving the public transportation service level and degree of cooperation performance. In addition to providing a sensible passenger distribution, the improved integration network also aids in reducing resource waste.

Theoretically, several variables, such as the distributions of passenger demand, transit capacity, and geographic space relationships, influence the degree to which metros and buses compete with one another. The competition and cooperation model proposed in this research is mostly spatially oriented and ignores the service capacity and passenger flow demand on bus lines.

Sarkar and Sheth (2021) this paper is an attempt to develop an integrated mass rapid transit system (MRTS) for a smart city project in western India. The methodology adopted for this study was primary data research through a

questionnaire survey. Furthermore, this study also focuses on developing a utility equation for respondents with the help of multiple linear regression analysis and its probability of shifting to public transport for certain factors. Multiple linear regression analysis was performed on the basis of the survey conducted. The results revealed that the most important factors for shifting to public transport were travel time, savings and comfort rating. The cost saving factor and accessibility were not important in terms of people shifting to using public transport systems. Parameter homogenization and weighting need to be specified. Multiple criteria analysis tools can provide more precise and optimized results.

Thao et al. (2021) explored the implementation and outcomes of integrating ridesharing with public transportation in four rural municipalities in central Switzerland. Using a mixed methods approach, the study reveals that the public transportation authority designed the integration to enhance public transportation with ridesharing. Key strategies include disseminating information about the ridesharing program, integrating notice boards into local bus stops and regional train stations, and implementing pricing tactics to signify contractual arrangements between drivers and riders while mitigating competition.

This paper's conclusions are supported by an exploratory study. Research on the relationships between built environment elements and ridesharing usage has only used spatial analysis. The inability to conduct regression models to verify this impact was caused by notice boards' poor level of observation and their associated final locations. Furthermore, three qualitative interviews were carried out with the relevant stakeholders. Therefore, these data constraints should be taken into account in any generalizations made from research findings.

Bi et al. (2021) In addition to integrating two modes—bike-sharing and ride-sourcing—this study aims to advance our understanding of the elements that influence the regularity with which shared mobility is used. The initial comparison between the two systems is based on the way they move. Next, to determine how trip parameters and travel environment variables affect the frequency of usage, a binary logistic model is utilized.

Researchers discovered that users' mode choices are significantly correlated with trip distance, suggesting that ride-sharing and bike-sharing cater primarily to short- and long-distance transfer users, respectively. The rivalry and complementarity of several shared mobility feeder modes were also influenced by time and weather, with the latter being more likely to change during weekends, during peak hours, and in the event of extreme weather. Furthermore, consumers of metro-shared mobility place a high value on the availability of two different types of transportation services, which are influenced by the metro station and the built environment around it. It is beneficial to embrace a sustainable mobility design from the general optimal in light of this study and the suggested policy consequences.

Ghasri et al. (2024) examined the effects of introducing an integrated transportation system on mode choice behavior by investigating travelers' preferences and assessing their willingness to pay for different attributes of such a system. Data were collected through an online stated preference survey conducted in July 2020 during the COVID-19 restrictions in Canberra, providing valuable insights into preferences during these unique circumstances. Using a latent class choice model, the analysis identified four latent segments within the sample, each characterized by distinct mode choice and mode shift behaviors, as well as sociodemographic attributes. The results indicated that younger age, higher educational attainment, part-time employment, lower vehicle ownership, and higher scooter ownership were associated with a greater likelihood of transitioning to the integrated system.

Anis and Sacco (2024) proposed the integration of public transit with cost-effective car-sharing systems to increase connectivity and accessibility, using the connectivity and accessibility index (CAI) for evaluation. The proposed approach offers an optimization-based design model for a hybrid CS system, evaluating its capabilities through a real-world case study of Trento's PT system. This paper introduces a mixed-integer linear programming (MILP) methodology to maximize the CAI across all zones by identifying optimal zone locations, vehicle allocation, and CS service activation types. The problem successfully maximizes the minimum total CAI across all zones in Trento, as demonstrated by the outcomes.

Melis et al. (2024) examined the integration of a large-scale on-demand bus system with a high-frequency fixed line public transport network in urban areas. It focuses on real-time requests, bus station locations, and fixed capacity minibuses. The goal is to decide trip types and route buses, assign bus stations, and assign transfer stations for metro legs. The heuristic compares integrated systems to on-demand buses and finds that integrated systems perform better in terms of the service rate, number of served requests, and average ride time per passenger.

Li et al. (2024) presented a comprehensive analysis of the integration of e-scooter sharing with public transit systems, addressing the first-and last-mile challenge. It examines the spatial and temporal integration patterns of e-scooter sharing with public transit across 124 European cities. Additionally, the study employs machine learning techniques and a model-agnostic interpretation method to investigate the nonlinear effects of various city-level factors on the integration ratio. The key findings include the following:

1. Significant variations exist in the integration ratio of e-scooter sharing with public transit among different cities in Europe, ranging from 5.59% to 51.40%, with a standard deviation of 8.47%.
2. Temporal patterns of integration ratios are analyzed, leading to the categorization of cities into four clusters via hierarchical clustering.

3. The nonlinear impacts of city-level factors such as socioeconomic indicators, road network characteristics, and public transit variables on the integration ratio are explored. This analysis highlights the factors influencing first-mile and last-mile transit (RFMT and RLMT) values, offering insights into strategies to enhance integration.

Overall, these findings provide valuable insights for city planners and policymakers in developing evidence-based policies for implementing micromobility solutions in various urban contexts. Table 1 highlights factors which are identified from various research papers that deals with integration of public transportation integration.

Table 1 Summary of factors identified from the literature review for the integration of the public transport system.

Reference	Approach/Tool	Parameters/Variables considered for integration																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Ibrahim (2003)	Improve access and connectivity operational and service levels integration	✓	✓	✓	✓															
Sun et al. (2012)	pivot-point modeling & Neural-fuzzy logic			✓	✓		✓	✓	✓	✓	✓									✓
Saliara (2014)	layout integration	✓	✓	✓	✓	✓														
Jasti and Ram (2016)	Weight Based Ranking System	✓	✓	✓	✓	✓						✓	✓	✓					✓	✓
Bernal (2016)	Case Study based on reports and research paper			✓		✓	✓		✓			✓				✓				✓
Sharma (2017)	overview an all-inclusive set of indicators for integration	✓	✓	✓	✓	✓														
Winter et al. (2018)	Multiple linear regression.	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Konstanze (2018)	Simulation (ADRTS)					✓	✓				✓									
Wei et al. (2020)	Bus line optimization model (Genetic Algorithm), TransCAD			✓	✓		✓				✓									
Sarkar and Sheth (2021)	Multiple linear regression.	✓	✓	✓	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Thao et al. (2021)	Mixed methods approach (Interviews, QGIS, Swiss statistics for the Swiss population (Statpop), POI application programming)			✓		✓				✓	✓								✓	✓
Bi et al. (2021)	Binary logistic model, (DBSCAN) clustering for points of interest (POIs) extraction											✓					✓		✓	✓
Ghasri et al. (2024)	Econometric Framework (latent class choice model) & (ANA behavior)	✓	✓	✓			✓						✓	✓					✓	



Anis and Sacco (2024)	Connectivity and accessibility index mathematical & Optimization model	✓	✓	✓	✓	✓		
Melis et al. (2024)	A mixed integer programming (MIP)	✓	✓	✓	✓		✓	✓
Li et al. (2024)	Temporal signature and clustering analysis	✓	✓				✓	

1-Fare integration; 2-Information integration; 3-Physical integration (proportion of area within the walking distance of a bus); 4-Network/operational integration (degree of bus/metro overlap); 5-Integrated planning; 6-Travel time; 7- Transfer times; 8-Peak period load factor; 9-Bus revenue kilometers; 10-Travel cost; 11-Service availability; 12-Service reliability; 13-Comfort; 14-Safety;15-Park; and riding; 16-Feeder service to the metro; 17-Waiting time; 18-Trip/Travel characteristic; 19-Environment

4.2. Review of the evaluation of a multimodal public transport system

Krygsman et al. (2004) reported that improving access to and egress from public transport can significantly reduce trip time and be cost-effective compared with expensive infrastructure and vehicle enhancements. A comprehensive travel-activity diary was used to estimate travel time, revealing that access and egress times are influenced by access and egress modes and trip orientation rather than sociodemographic characteristics. The interconnectivity ratio decreases as the trip time increases, with most multimodal trips falling within a modest range of 0.2--0.5.

Advani and Tiwari (2005) evaluated the Delhi Metro in terms of its capacity, trip duration, and accessibility. Evaluation indices were established to reflect commuters' perceptions of metro services. A recommendation for a combined ticket for bus and metro transportation was made. Systems of public transit have been designed to ease traffic congestion. However, systems designed in India demonstrate that capacity is underutilized and that costs are running over. It is necessary to build a methodology and arguments to support the effective use of this system. The total commuter journey, including access and transfer times, should be considered when estimating the demand for transit services. The degree of integration across these modalities should also be assessed for improved use of the ones already in place.

Tangphaisankun et al. (2010) Oneway to increase the use of mass transit is to provide paratransit as a feeder system for the system in developing cities (Akkarapol et al., 2010). Two hypotheses are proposed for investigation in this research. The first step is to ascertain how commuters' perceptions of paratransit—both flexible for-hire and fixed route services—affect their perceptions of mass transit accessibility. The second objective is to determine whether either attitude influences people's intentions to use paratransit or mass transit in the future. The influence of both service satisfactions on commuters' tendency to use paratransit as a feeder and the effects of paratransit service satisfactions on the overall satisfaction of mass transit access trips were estimated via the structural equation model.

This study aims to investigate the potential of paratransit and understand how commuter perceptions of the service impact attitudes toward mass transit connections and behaviors related to paratransit as a feeder system. Positive commuter satisfaction influences attitudes toward mass transit connections and the future use of both paratransit and mass transit. The findings suggest the need for well-crafted improvement policies for paratransit services to increase the overall efficiency of mass transportation.

Patnala et al. (2013) used New Delhi as a case study to assess the performance of a multimodal transportation system (MMTS), where the metro has replaced other modes of public transportation for everyday travel. Only if the access and egress distance is not too great is multimodal transportation a desirable choice. As excessive lengths are likely to diminish ridership, access and egress (together with waiting and transfer times) appear to be characteristics that have a greater impact on the effectiveness and performance of a multimodal transportation system. Reduced access, egress, and transfer times can be achieved by combining several modes at an interchange, which is a representation of an integrated MMTS. By offering better entry & egress, transfer, park & ride, and card access at public transit systems, OVTT & transfer times can be decreased. This paper provides a framework for assessing multimodal transportation systems. The factors that affect usage and efficacy are apparent. An evaluation of the current level of integration across various public transportation modes can be aided by research.

Nosal and Solecka (2014) explained the notion of travel demand management and the fundamentals of integrating urban public transportation. Urban transportation integration demands a thorough review of the methods used to measure activities. Cities frequently provide a variety of integration options, but choosing the right option might be challenging. Making an assessment of the many integrated systems of urban public transportation (ISUPT) types via multicriteria decision assistance methods (MCDA) might make this decision easier. The purpose of this paper is to outline the key components of the MCDA approach before discussing its potential for use in evaluating ISUPT variants. One of the MCDA approaches, the AHP ranking method, was applied to evaluate the ISUPT versions.



To select the best ISUPT solution, the authors suggested the use of a complex methodology consisting of the following 5 stages (Solecka, 2013):

- Stage 1: Diagnosis and assessment of the current status of the public transport system.
- Stage 2: Formulation of the concept of ISUPT evaluation as a multi criteria problem of the ranking of given variants.
- Stage 3. Review and evaluation of methods for multi criteria ranking of given options.
- Stage 4. Conducting computational experiments via selected options ranking methods.
- Stage 5. Summary of the computational experiments.

To assess the ISUPT, this paper highlights the use of a set of 10 criteria that consider technical, economic, social and environmental aspects. The variables considered for the evaluation of integration were travel time, the Journey standard, the Rolling stock use index, the environmentally friendly level of integration of the public urban transport system, the reliability of the urban public transport system, the safety of journeys (situations and traffic), the profitability of the urban public transport system, the availability of the urban public transport system, and investment costs. To assess the multicriteria evaluation of the ISUPT, the AHP method was used. The AHP approach involves combining various criteria into a single, improved additive utility function. The decision maker will always select a preference or will view each pair of variants as equivalent under the assumption that all the variants are comparable. Comparisons between similar pairs of variations, criteria, or subcriteria are used in preference modeling. Three approaches are tested computationally: one common ranking for all stakeholders and one distinct ranking for the decision maker. Distinct rankings are generated for all interested stakeholders and a decision maker to select the best used.

Goel and Tiwari (2016) conducted a 2011 study on 1112 metro commuters and reported significant associations between trip length, vehicle ownership, metro station location, and population density. Alternative modes depend on trip length and vehicle ownership. Up to 88% of metro trips have an interconnectivity ratio of 0.2–0.5, making it a robust parameter for assessing or forecasting the ridership of public transportation systems. The study demonstrated that trips in metro systems are longer than those in buses because of the interconnectivity ratio. A metro travels two times longer distances for a given travel time, making it more accessible. This results in fewer trips being catered to by metro systems, as access to a metro station in Delhi is longer than a bus stop.

Errampalli et al. (2020) in the present study, a system for assessing the levels of integration between two public transportation modes was established that incorporates the sustainability idea. To gauge the degree of integration between the three main sustainability domains—economic, social, and environmental—the study established 12 qualitative and quantitative indicators. This study takes into account multi criteria analysis, which involves homogenizing the chosen public transportation sustainability indicators and arriving at an aggregated final index value with suitable weights for each indicator. The established method was then used to calculate the current degrees of integration between buses and metro trains in South Delhi, India. The following findings can be drawn from the current study: the most appropriate indicators are found for determining the sustainability index's overall evaluation, with an emphasis on the integration of public transportation modes (bus and metro) in the Indian setting. Productivity, transfer time, mobility, accessibility, additional employment generated, bus and metro user ratings, safety and security, additional facilities, reliability, air pollution, land consumption, and NMT facilities are some of them. To help planners and policy makers with city-wide planning and public transportation integration, the technique used in the present study can be utilized to examine the levels of integration between various public transportation modes. The system was evaluated using solely the parameters of the public transportation system in the current study; no capital investments or financial gains were taken into account. To increase the accuracy of the outcomes, the number of indicators can be further increased.

Trivedi et al. (2020) assessed the current feeder system on a specific stretch of road in Ahmedabad, Gujarat, from Shivranjani Cross Road to Jivraj Cross Road. According to a thorough analysis and the responses of the local population, the current feeder system is insufficient to meet the needs of regular commuters. The overloaded rickshaws are proving to be harmful modes of transportation, so a well-designed feeder system must be used. The current state of the feeder system in the chosen study area is briefly discussed in this research. This paper provides a solid foundation for addressing the issue of an insufficient feeder system, which in turn highlights the requirements for feeder system development and integration among BRTS, AMTS, and METRO. Only one location was chosen for the investigation.

Torabi et al. (2022) investigated the acceptability and attractiveness of emerging transport modes for passengers at the Delft Campus train station in the Netherlands. The study revealed that travel costs are more important than time for accessing or egressing from a small hub, and autonomous vehicles (AVs) are highly valued as first/last mile transport. Table 2 highlights various approaches and tools that are considered for integrating various modes with each other. Various research work provide insights regarding variables that influences integration of public transportation.

Table 2 Summary of factors identified from the literature review of the evaluation of multimodal public transport systems.

Reference	Approach/Tool	Parameters/Variables considered for integration																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Krygsman et al. (2004)	comprehensive travel-activity diary			✓		✓	✓	✓			✓								✓	
Advani and Tiwari (2005)	Evaluation Indices Based on commuter’s perspective.	✓				✓	✓	✓		✓	✓					✓		✓	✓	
Tangphaisankun et al. (2010)	Commuter perceptions on paratransit service using Structural Equation Model					✓	✓	✓					✓	✓					✓	
Patnala et al. (2013)	Performance Measure Based on Commuter Survey			✓		✓	✓	✓			✓	✓	✓				✓	✓	✓	
Nosal and Solecka (2014)	MCDAs methods – the AHP ranking method					✓	✓		✓		✓	✓	✓	✓	✓				✓	
Goel and Tiwari (2016)	A sequential four-stage travel demand modeling using VISUM & ArcGIS						✓	✓			✓					✓	✓	✓	✓	
Errampalli et al. (2020)	Sustainability Integration Index multicriteria analysis (MCA) approach	✓	✓	✓	✓			✓				✓		✓	✓				✓	
Trivedi (2020)	commuters’ perception toward public transportation and available feeder system.			✓													✓		✓	
Torabi et al. (2022)	Stated Preference Experiment			✓	✓		✓		✓	✓	✓	✓	✓					✓		

1- Accessibility 2-Productivity 3-Users rating 4-Mobility 5-Level of Integration (Interconnectivity) 6-Travel Time (IVTT, OVTT) 7- Transfer times (Difficulty in transfer, Transfer type) 8-Investment Cost 9-Capacity 10- Travel Cost 11-Service Availability 12-Service Reliability 13-Comfort 14-Safety & Security 15 Additional Facilities (Park and ride) 16- Feeder service to the metro 17-Waiting Time 18-Trip/Travel Characteristic (Influence Zone, Access and Egress distance, Access and egress time) 19-Environment

4.3. Review modeling of an integrated transportation system

Shrivastava and O’Mahony (2010) presented a model for the operational integration of public buses and suburban trains, comprising the routing sub model and the scheduling sub model. The routing sub model employs a heuristic algorithm to generate feeder routes for buses originating at train stations. The scheduling sub model uses genetic algorithms to optimize coordinated feeder bus schedules on specified suburban rail timetables. The case study focuses on the DART station Dun Laoghaire, resulting in a designed feeder route network aligned with current DART schedules, demonstrating the effectiveness of the proposed model in achieving operational integration. The model developed in the study maintains a careful balance between the load factor and demand while keeping waiting times manageable. Therefore, from the perspective of users and operators, the model can produce results that are satisfactory (feeder routes and synchronized schedules). Therefore, the modeling exercise that has been suggested may add to realistic modeling of coordinated operations for passenger excursions.

Fierek and Zak (2012) focused on the integration of private and public transportation within a metropolitan area, employing the multiple criteria decision-making (MCDM/A) approach and macro simulation. Using the VISUM macro simulation program, various scenarios (IUTSs) are created and evaluated on the basis of a set of criteria reflecting stakeholder



interests. The assessment, conducted via the Electre III/IV technique, incorporates the preferences of city authorities determined through questionnaires and interviews. Computational experiments lead to the final ranking and selection of the most desirable integrated urban transportation systems (IUTSs). From a methodological point of view, the proposed approach for planning an integrated urban transportation system has a universal character and can be applied in a variety of transportation systems. Further research should be carried out in two directions: detailed analysis of the winning variant supported by microsimulation and application of different MCDM/A methods in the evaluation of variants.

Solecka and Zak (2014) presented the full design and evaluation process for transportation options, leading to the integration of an urban public transportation system. The suggested method is founded on the use of heuristic-expert design of an integrated metropolitan public transportation system, its modeling via a computer-based macrosimulation system called VISUM, and its multidimensional multiple parameter comparison with the current methodology. The article provides a thorough explanation of each step that must be followed to implement the suggested method, which results in the creation of an integrated public transportation system. Researchers have concentrated on the physical, infrastructural, organizational, economic, and informational components of integration while creating solutions for transport integration. A comparison of the proposed integration option with the current public transportation system is performed. They conducted a real-world case study to demonstrate the relationship between the integration of new railway-oriented transportation modes into the existing public transit network. The research compares two public transportation system variants—V0 and V1—multidimensionally and analyzes how they integrate. On the basis of a comparison of the existing public transportation system, variant V0, and its modification, variant V1, a discussion of transport integration and the overall standard of travel is presented. This study has two main outcomes: methodological and practical. The application of the macro simulation package VISUM to the design of transport integrating solutions and the creation of several measures/parameters that can be used in the evaluation of transport integration are included in the paper's methodological contribution. The comparison of two public transportation integration options is crucial from a practical standpoint. The authors demonstrate how to perform this comparison and which versions can be viewed as more or less integrated.

Chalumuri et al. (2017) reported that unbalanced modal splits are the outcome of commuters switching to private and intermediate transit because of the lack of effective public transportation. VISUM was used in a research study as a macro simulation tool. On the basis of a total of 7098 individual questionnaire responses gathered in Delhi, a sequential four-stage travel demand model was created. The created travel demand model was used to predict the base year traffic flows for private and public transportation trips, and field data were used to confirm the results. The benefits of park-and-ride facilities and multimodal integration of Delhi's metro rail systems with feeder modes were assessed at the network level to promote sustainable transportation. After developing multimodal integration, the results revealed an increase in metro train ridership. This research revealed that the metro share will expand from 32% in the current situation to a maximum share of 164% with the implementation of feeder modes and P&R facilities as separate variances of mode choice.

According to a quantitative assessment of P&R options, offering these facilities with parking fees of 5 INR/h (as opposed to 10 INR/h or above) would produce the most benefits at the network level of integration. This study's main outcome is a methodological analysis for creating and carrying out transport modeling and network integration via the macro simulation program VISUM. The approach takes into account the creation of a set of criteria that can be used to assess an integrated network and looks at its effectiveness in terms of passenger benefits.

Krishna and Chattaraj (2020) discussed the present public transportation network in Hyderabad city and proposed new lines to extend the present existing network via VISUM macro simulation software, which helps transportation planning improve the existing network of cities and uses GIS network software in this study. In this study, three modes of public transportation networks in Hyderabad are evaluated via VISUM software and transportation performance indices, such as the accessibility index, congestion index, safety index and travel time analysis. More parameters for performance indices based on physical and service integration, service reliability, and fare integration can be used to evaluate public transportation in Ahmedabad city.

Kłos and Sierpinski (2021) Due to the abundance of services offered and the lack of integration between them, city dwellers are forced to choose between one or more means of transportation to complete the necessary journey. This article's major objective is to offer a model for the integration of various transportation services that could aid persons who plan to travel in their decision-making. Consequently, a model of urban sharing service parameters was identified and categorized. Along with those elements relevant to the prospective region of operation, location-specific characteristics that influence the integration with public transportation have also been discovered. Location (four parameters), demographics (two parameters), travel (six parameters), economy (four parameters), quality (eight parameters), and lifestyle (six parameters) were the groups into which the parameters were separated. A multicriteria decision-making strategy has been suggested to consider all the important factors and find a solution to the current issue. To do this, scores and weights that affect the model are constructed.

Dawda et al. (2022) used a hybrid multi criteria decision-making approach (MCDM) that combines fuzzy delphi, interpretative structural modeling (ISM), and cross-impact matrix multiplication applied to classification (MICMAC) techniques. This study explores the development of India's urban transportation system, suggests ways to design an

"integrated multimodal" and "sustainable transport system," and models barriers to its implementation. Using fuzzy Delphi analysis, the study revealed 32 important hurdles to creating an IMTS, of which 21 were given higher priority. ISM-MICMAC analysis was also used to study how the barriers interact with one another. According to the investigation, the greatest hindrances were pro-mobility established powers and traditions, a lack of unified urban transport authority, a lack of integrated land use and transportation planning, and a lack of expertise in urban transport planning. The local government can successfully implement an integrated multimodal and sustainable transport system by overcoming barriers with the aid of the framework for identifying and prioritizing the barriers and policy actions suggested in the current study.

Yang et al. (2023) presented a two-phase decision–support optimization framework for anMaaS system involving metros and shared autonomous vehicles (SAVs). It uses a mixed integer programming model to optimize routes and schedule SAVs to minimize operation costs. The rolling horizon solution method is applied to real-time scenarios. The method shows that travelers become more sensitive to mode choice as the metro time increases.

Marinelli and Gallo (2024) explored the integration of Dial-a-Ride into a bus transit service, with a focus on improving transport flexibility. The problem is modeled as a dynamic Dial-a-Ride problem, with an integer linear programming model applied to reduce the computational effort. The optimization model, developed as a GIS-based tool, was applied to a bus transit service in Benevento, Italy, reducing computational effort and demonstrating benefits over fixed routes and micromobility. Table 3 gives summary of modeling techniques used for integration system in transportation planning.

Table 3 Summary of factors identified from a literature review modeling an integrated transportation system.

Reference	Approach/ Tool	Parameters/Variables considered for integration																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Shrivastava and O'Mahony (2010)	Heuristic algorithm. & genetic algorithms	✓	✓	✓																	
Fierek and Zak (2012)	MCDM/A approach and macro simulation (VISUM)					✓	✓	✓	✓						✓	✓	✓	✓	✓	✓	
Solecka and Zak (2014)	heuristic design of a concrete variant and macro simulation (VISUM)				✓		✓	✓		✓									✓	✓	
Chalumuri et al. (2017)	VISUM macro simulation software Four Stage Travel Model																				
Krishna and Chattaraj (2020)	VISUM macro simulation software		✓				✓	✓						✓	✓				✓	✓	✓
Kłos and Sierpinski (2021)	Multi criteria decision making model.							✓	✓		✓			✓	✓				✓	✓	✓
Dawda et al. (2022)	MCDM fuzzy Delphi, interpretative structural modeling (ISM), and Cross-Impact Matrix Multiplication		✓			✓									✓					✓	
Yang et al. (2023)	Mixed integer programming model,			✓	✓	✓	✓	✓													
Marinelli and Gallo (2024)	Integer linear programming model, optimization model using GIS tool	✓							✓	✓		✓									✓

1-Routing & Scheduling Sub Model 2-Accessibility 3-coordinated feeder bus schedule 4 Ridership 5-Level of Integration (Interconnectivity, Mobility) 6-Travel Time (IVTT, OVTT) 7- Transfer times (Difficulty in transfer, Transfer type) 8-Investment Cost 9- Average Passenger Speed 10- Travel Cost 11-Service Availability 12-Service Reliability 13-Comfort 14-Safety & Security 15 Additional Facilities (Park and ride) 16- Feeder service to the metro 17-Waiting Time 18-Trip/Travel Characteristic (Influence Zone, Access and Egress distance, Access and egress time) 19-Environment.

5. Conclusion

Public transportation system integration is a challenging and complicated project with enormous potential to improve urban mobility and address urgent urban concerns. This study has shed light on the numerous features of integration and provided insights into the modeling strategies used to optimize its implementation through a thorough analysis of the literature. The literature has emphasized the many advantages of integrating public transportation networks. Among the benefits that integrated systems provide to urban populations are improved connectivity, shorter travel distances, greater ridership, and environmental sustainability.

The integration of various modes of transportation and the use of advanced modeling techniques involve a variety of approaches, difficulties, and consequences that have been clarified through the synthesis of research findings, methodologies, and case studies. Modeling methods have proven to be extremely useful for planning, simulating, and improving integrated transportation systems. The analysis of studies reporting successful integration initiatives in various locations shows that community involvement, context-aware techniques, and customized approaches are crucial to obtaining results.

These reviews highlight the importance of adaptable modeling frameworks that can be tailored to particular urban situations, enabling decision-makers to assess the possible effects of integration and adjust their policies as necessary. The gaps found in the literature present promising directions for further study.



Ahmedabad city has recently introduced a metro system; thus, there is a need for comprehensive research on effective strategies for integrating the metro system with existing public transportation modes such as buses and auto rickshaws. It is vital to comprehend how to logically integrate various modes to enable simple transfers for commuters. To address the problems effectively and potential of integrating metros with other modes of transportation in cities, research on the integration of metro systems with other forms of public transportation in the context of Ahmedabad city requires further in-depth investigations. It is crucial to look into last-mile connectivity solutions from metro stations to different locations.

This review has laid a strong foundation for future research in this area, highlighting the value of interdisciplinary cooperation, cutting-edge modeling techniques, and a comprehensive strategy for urban transportation planning. The integration of multiple public transportation systems will surely play a crucial role in defining the city of the future, as Ahmedabad continues to develop and look for sustainable mobility solutions.

Acknowledgment

I would like to express my sincere gratitude to my guide, Dr. R. M. Jain, and the members of my doctoral progress committee, Dr. G. J. Joshi, and Dr. A. M. Jain, for their continuous support, valuable feedback, and insightful guidance throughout the course of this research. I am also thankful to Dr. T. H. Vyas for his constructive comments and encouragement. Finally, I would like to thank my family and friends for their unwavering support and understanding.

Ethical Considerations

This literature review on public transportation integration and modeling strategies was conducted following ethical research guidelines. All data and sources referenced in this paper were derived from publicly available academic journals, books, and credible online resources. Appropriate citations have been included to acknowledge the original authors and contributions. Since this study does not involve primary data collection, interviews, or interactions with human subjects, it did not require institutional ethical approval. The review aims to provide an unbiased and comprehensive overview of the current state of knowledge, ensuring that diverse viewpoints and research findings within the domain of urban mobility are accurately represented.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

References

- Abdulrazaq, L. R., Abdulkareem, M. N., Mat Yazid, M. R., Borhan, M. N., & Mahdi, M. S. (2020). Traffic Congestion: Shift from Private Car to Public Transportation. *Civil Engineering Journal*, 6(8), 1547–1554. <https://doi.org/10.28991/cej-2020-03091566>
- Advani, M. (2010). Demand estimation for public transport system: a case study of Delhi. unpublished thesis, Department of Civil Engineering, IIT, Delhi.
- Advani, M., & Tiwari, G. (2005). Evaluation of public transport systems: case study of delhi metro .
- Anis, S., & Sacco, N. (2024). Enhancing Public Transport Accessibility: Exploring Hybrid Car Sharing Systems for Improved Connectivity. *Transportation Engineering*, 16, 100255. <https://doi.org/10.1016/j.treng.2024.100255>
- Bapat, H., Sarkar, D., & Gujar, R. (2022). Application of multicriteria decision making for evaluation of key performance indicators of integrated project delivery and BIM model for an infrastructure transportation project in Western India. *International Journal of Construction Management*, 12, 2077–2086. <https://doi.org/10.1080/15623599.2022.2040077>
- Bernal, L. M. M. D. (2016). Basic Parameters for the Design of Intermodal Public Transport Infrastructures. *Transportation Research Procedia*, 499–508. <https://doi.org/10.1016/j.trpro.2016.05.104>
- Bhaskar, P. (2013). Methodology for assessing the social, economic and environmental effects of public transportation systems. M.tech. Thesis report.
- Bi, H., Ye, Z., & Zhang, Y. (2021a). Analysis of the Integration Usage Patterns of Multiple Shared Mobility Modes and Metro System. *Transportation Research Record: Journal of the Transportation Research Board*, 10, 876–894. <https://doi.org/10.1177/03611981211013351>
- Brand, J., Hoogendoorn, S., van Oort, N., & Schalkwijk, B. (2017). Modeling multimodal transit networks integration of bus networks with walking and cycling. 2017 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS). <https://doi.org/10.1109/mtits.2017.8005612>
- Chalumuri, R. S., Nath, R., & Errampalli, M. (2017 b). Development and evaluation of an integrated transportation system: a case study of Delhi. *Proceedings of the Institution of Civil Engineers - Transport*, 2, 75–84. <https://doi.org/10.1680/jtran.16.00003>
- Cheng, Y.-H., & Liu, K.-C. (2012). Evaluating bicycle-transit users' perceptions of intermodal inconvenience. *Transportation Research Part A: Policy and Practice*, 10, 1690–1706. <https://doi.org/10.1016/j.tra.2012.10.013>
- Cherry, C., & Cervero, R. (2007). Use characteristics and mode choice behavior of electric bike users in China. *Transport Policy*, 3, 247–257. <https://doi.org/10.1016/j.tranpol.2007.02.005>
- Dawda, N. H., Arkatkar, S. S., Joshi, G. J., & Litman, T. (2022). Prioritizing and Modeling the Interrelationship between the Barriers for Designing an “Integrated Multimodal” and “Sustainable” Urban Transport System for Developing Economies. *SSRN Electronic Journal*.

<https://doi.org/10.2139/ssrn.4214447>

Dhingra, S. L. (2008). Integrated urban mass transit system for sustainable development . *First Indo-US Symposium on Advances in Mass Transit and Travel Behavior Research*.

El Adli, K. Z., & Al-Attar, A. (2022). Mass Transit: An Integrated Approach to Sustainable Urban Development – The Case of Greater Cairo Region. In *Innovative Renewable Energy* (pp. 313–321). Springer International Publishing. http://dx.doi.org/10.1007/978-3-030-76221-6_39

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), 180–187. <https://doi.org/10.1016/j.cstp.2018.09.005>

Fielding, G. J., Glauthier, R. E., & Lave, C. A. (1978). Performance indicators for transit management. *Transportation*, 4, 365–379. <https://doi.org/10.1007/bf00168037>

Fierek, S., & Zak, J. (2012). Planning of an Integrated Urban Transportation System based on Macro – Simulation and MCDM/A Methods. *Procedia - Social and Behavioral Sciences*, 54, 567–579. <https://doi.org/10.1016/j.sbspro.2012.09.774>

Ghasri, M., Ardeshiri, A., Zhang, X., & Waller, S. T. (2024). Analyzing preferences for integrated micromobility and public transport systems: A hierarchical latent class approach considering taste heterogeneity and attribute nonattendance. *Transportation Research Part A: Policy and Practice*, 181, 103996. <https://doi.org/10.1016/j.tra.2024.103996>

Goel, R., & Tiwari, G. (2016). Access–egress and other travel characteristics of metro users in Delhi and its satellite cities. *IATSS Research*, 2, 164–172. <https://doi.org/10.1016/j.iatssr.2015.10.001>

gosetsuke. (n.d.). Integrated Urban Mass Transit System For Sustainable Development July 25, 2024, from <https://www.scribd.com/document/65506401/Integrated-Urban-Mass-Transit-System-for-Sustainable-Development>

Hasani Goodarzi, A., Jabbarzadeh, A., Fahimnia, B., & Paquet, M. (2024). Evaluating the sustainability and resilience of an intermodal transport network leveraging consolidation strategies. *Transportation Research Part E: Logistics and Transportation Review*, 103616. <https://doi.org/10.1016/j.tre.2024.103616>

Huang, Y., Ma, L., & De Vos, J. (2024). Travel behavior and multimodality: a conceptual framework and critical review of research. *Transport Reviews*, 3, 709–730. <https://doi.org/10.1080/01441647.2023.2300088>

Ibrahim, M. F. (2003). Improvements and integration of a public transport system: the case of Singapore. *Cities*, 20(3), 205–216. [https://doi.org/10.1016/s0264-2751\(03\)00014-3](https://doi.org/10.1016/s0264-2751(03)00014-3)

Jasti, P. C., & Ram, V. V. (2016). Integrated and Sustainable Service Level Benchmarking of Urban Bus System. *Transportation Research Procedia*, 17, 301–310. <https://doi.org/10.1016/j.trpro.2016.11.096>

Klos, M. J., & Sierpiński, G. (2021). Building a Model of Integration of Urban Sharing and Public Transport Services. *Sustainability*, 13(6), 3086. <https://doi.org/10.3390/su13063086>

Krishna, G., & G. C. (2020). Analysis Of Urban Public Transportation Network In Hyderabad: Telangana. In *International Conference on Civil Architectural and Environmental Sciences (ICAES-20)*.

Krygsmann, S., Dijst, M., & Arentze, T. (2004). Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio. *Transport Policy*, 11(3), 265–275. <https://doi.org/10.1016/j.tranpol.2003.12.001>

Kumar, P. P., Parida, M., & Swami, M. (2013). Performance Evaluation of Multimodal Transportation Systems. *Procedia - Social and Behavioral Sciences*, 795–804. <https://doi.org/10.1016/j.sbspro.2013.11.174>

Li, A., Gao, K., Zhao, P., & Axhausen, K. W. (2024). Integrating shared e-scooters as the feeder to public transit: A comparative analysis of 124 European cities. *Transportation Research Part C: Emerging Technologies*, 104496. <https://doi.org/10.1016/j.trc.2024.104496>

Ma, M., Zhang, F., Liu, W., & Dixit, V. (2022). A game theoretical analysis of metro-integrated city logistics systems. *Transportation Research Part B: Methodological*, 14–27. <https://doi.org/10.1016/j.trb.2021.12.005>

Marinelli, M., & Gallo, M. (2024). An integrated bus transit service for demand-responsive urban public transport. *Transportation Research Procedia*, 78, 327–334. <https://doi.org/10.1016/j.trpro.2024.02.042>

Melis, L., Queiroz, M., & Sörensen, K. (2024). The integrated on-demand bus routing problem: Combining on-demand buses with a high-frequency fixed line public transport network. *Computers & Operations Research*, 106554. <https://doi.org/10.1016/j.cor.2024.106554>

Nidhi R (2021). Public Transport System of Ahmedabad City Post Graduation Studio Report, CEPT University Ahmedabad <https://portfolio.cept.ac.in/2021/S/fp/strategic-plan-for-urban-transport-system-ut4000-spring-2021/improving-public-transport-system-in-ahmedabad-spring-2021-put20328>

Nosal, K., & Solecka, K. (2014). Application of AHP Method for Multicriteria Evaluation of Variants of the Integration of Urban Public Transport. *Transportation Research Procedia*, 3, 269–278. <https://doi.org/10.1016/j.trpro.2014.10.006>

Papadakis, D. M., Savvides, A., Michael, A., & Michopoulos, A. (2024). Advancing sustainable urban mobility: insights from best practices and case studies. *Fuel Communications*, 20, 100125. <https://doi.org/10.1016/j.jfueco.2024.100125>

Public Transport System of Ahmedabad City | CEPT Summer Exhibition 2021. (n.d.). CEPT Winter Exhibition 2022. Retrieved July 25, 2024, from <https://exhibition.cept.ac.in/se21/studio/strategic-plan-for-urban-transport-system-ut4000-spring-2021/public-transport-system-of-ahmedabad-city-spring-2021-put20220>

Rastogi, R. (2010). Willingness to Shift to Walking or Bicycling to Access Suburban Rail: Case Study of Mumbai, India. *Journal of Urban Planning and Development*, 1, 3–10. [https://doi.org/10.1061/\(asce\)0733-9488\(2010\)136:1\(3\)](https://doi.org/10.1061/(asce)0733-9488(2010)136:1(3))

Rothfeld, R., Straubinger, A., Paul, A., & Antoniou, C. (2019). Analysis of European airports' access and egress travel times using Google Maps. *Transport Policy*, 148–162. <https://doi.org/10.1016/j.tranpol.2019.05.021>

Saliara, K. (2014). Public Transport Integration: The Case Study of Thessaloniki, Greece. *Transportation Research Procedia*, 535–552. <https://doi.org/10.1016/j.trpro.2014.11.041>

Sarkar, D., & Sheth, A. (2021). Development of sustainable public–private partnership model for bus rapid transit system in Western India: a case study approach. *Innovative Infrastructure Solutions*, 1. <https://doi.org/10.1007/s41062-021-00612-y>

Schoeman. (2017). *Transportation, Land Use and Integration*. WIT Press.

Schwedes, O., & Hoor, M. (2019). Integrated Transport Planning: From Supply- to Demand-Oriented Planning. Considering the Benefits. *Sustainability*,



- 11(21), 5900. <https://doi.org/10.3390/su11215900>
- Sharma, P. (2017). A study of sustainable transportation system in Ahmedabad and Delhi. *Int. J. Adv. Res. Ideas Innov. Technol*, 3, 749-752.
- Shravya, N. (2021). Improving Public Transport System in Ahmedabad | CEPT - Portfolio. Home | CEPT - Portfolio; Portfolio of Urban Transportation Planning Cept Unniversity.
- Shrivastava, P., & O'Mahony, M. (2010). Integrated approach toward sustainable development. *World Review of Intermodal Transportation Research*, 3 (1/2), 26. <https://doi.org/10.1504/writr.2010.031578>
- Singh, Y. P. (2002). Performance of the Kolkata (Calcutta) metro railway. In *Urban Mobility for All. Proceedings Conference* .
- Solecka, K., & Žak, J. (2014). Integration of the Urban Public Transportation System with the Application of Traffic Simulation. *Transportation Research Procedia*, 3, 259–268. <https://doi.org/10.1016/j.trpro.2014.10.005>
- Sun, M., Song, L., Chen, F., & Xian, K. (2012). Bus and Metro Integration Improvements in Beijing. *Sustainable Transportation Systems*, 299-307. <https://doi.org/10.1061/9780784412299.0036>
- Tangphaisankun, A., Nakamura, F., & Okamura, T. (2010). Influences of Paratransit as A Feeder of Mass Transit System in Developing Countries Based on Commuter Satisfaction. *Journal of the Eastern Asia Society for Transportation Studies*, 1341–1356. <https://doi.org/10.11175/easts.8.1341>
- Thao, V. T., Imhof, S., & von Arx, W. (2021). Integration of ridesharing with public transport in rural Switzerland: Practice and outcomes. *Transportation Research Interdisciplinary Perspectives*, 100340. <https://doi.org/10.1016/j.trip.2021.100340>
- Thondoo, M., Marquet, O., Márquez, S., & Nieuwenhuijsen, M. J. (2020). Small cities, big needs: Urban transport planning in cities of developing countries. *Journal of Transport & Health*, 19, 100944. <https://doi.org/10.1016/j.jth.2020.100944>
- Torabi K, F., Araghi, Y., van Oort, N., & Hoogendoorn, S. (2022). Passengers preferences for using emerging modes as first/last mile transport to and from a multimodal hub case study Delft Campus railway station. *Case Studies on Transport Policy*, 10(1), 300–314. <https://doi.org/10.1016/j.cstp.2021.12.011>
- Trivedi, P. (2020). Evaluation of Feeder System between BRTS and Proposed Metro Station of Ahmedabad. *International Journal for Research in Applied Science and Engineering Technology*, 8(2), 601–606. <https://doi.org/10.22214/ijraset.2020.2091>
- Verma, A., Harsha, V., & Subramanian, G. H. (2021). Evolution of Urban Transportation Policies in India: A Review and Analysis. *Transportation in Developing Economies*, 7(2). <https://doi.org/10.1007/s40890-021-00136-1>
- 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>
- Winter, K., Cats, O., Correia, G., & van Arem, B. (2018). Performance analysis and fleet requirements of automated demand-responsive transport systems as an urban public transport service. *International Journal of Transportation Science and Technology*, 7 (2), 151–167. <https://doi.org/10.1016/j.ijst.2018.04.004>
- Yang, S., Wu, J., Sun, H., & Qu, Y. (2023). Trip planning for a mobility-as-a-service system: Integrating metros and shared autonomous vehicles. *Transportation Research Part E: Logistics and Transportation Review*, 176, 103217. <https://doi.org/10.1016/j.tre.2023.103217>
- Yap, M. D., Correia, G., & van Arem, B. (2016). Preferences of travelers for using automated vehicles as last mile public transport of multimodal train trips. *Transportation Research Part A: Policy and Practice*, 1–16. <https://doi.org/10.1016/j.tra.2016.09.003>