Scholar's Digest- Journal of Multidisciplinary Studies
Volume 02, Issue 12, December, 2023
ISSN (E): 2949-8856
Scholarsdigest.org

SYNERGIZING GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND MULTICRITERIA DECISION MAKING ANALYSIS (MCDA) FOR PUBLIC TRANSIT NETWORK OPTIMIZATION: A REVIEW

Barham Salah Nsaif ,
Nihad Davut Hassan ,
Qais F Hasan
Technical Engineering College, Northern Technical University, Kirkuk, Iraq
* Corresponding author's e-mail : Barham.Salah@ntu.edu.iq

Abstract
This paper provides a detailed overview of the integration of Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP) approaches in the optimization of public bus transport networks. The review includes a comprehensive analysis of the literature as well as a discussion of the major findings, computing effectiveness, utility, and possible directions for future research. Because it smoothly blends multi-criteria decision-making and spatial analysis, the combination of GIS and AHP shows to be a useful tool in handling the complexities inherent in public transportation planning. The study investigates the use of GIS in integrating optimization models, expressing network data, performing geographical and temporal analysis, and assisting in decision-making. It looks at studies that have utilized GIS to optimize routes in an efficient manner, showcasing the many approaches and methods that have been used in the literature. The report also identifies the primary findings and constraints of GIS and AHP integration research. The benefits of using GIS-AHP models in decision support systems for companies involved in urban planning and transportation are highlighted in the discussion. The study concludes with a prospective exploration of possible directions for future research, including the addition of new data sources, flexible demand modeling, and state-of-the-art optimization techniques.

Keywords: Geographic Information Systems (GIS), Multi-Criteria Decision-Making (MCDA), Analytical Hierarchy Process (AHP), Public Bus Transport, Route Optimization, Spatial Analysis.

Introduction

1.1. Public transport network route selection importance

For metropolitan populations worldwide, public transportation networks are essential infrastructure that offer accessibility and mobility (Cheng & Chen, 2015). As cities deal with the issues of expansion, shifting land use patterns, and increased transportation requirements, the design, planning, and optimization of bus networks is becoming an increasingly important field of research and policy. Because public transportation organizations must balance a number of conflicting goals while working under operational, budgetary, and schedule restrictions, choosing the best routes may be challenging (Ahmed et al., 2019; Arbex & da Cunha, 2015; Laporte et al., 2017). The established routes serve as the foundation for determining the system's overall sustainability, efficacy, and efficiency.

Incorporating bus rapid transit (BRT) system elements is a crucial contemporary factor in public bus route planning. According to Shojaei Baghini et al. (2014), BRT seeks to deliver effective, high-capacity urban mobility through dedicated lanes, off-board fare collecting, level boarding, and other improvements. Because specialized infrastructure requires large capital expenditures, BRT networks need to carefully plan their routes (Warren & Ortega-Sanchez, 2016; Walteros et al., 2015; Owais et al., 2016). The routes have to strike a compromise between the overall network coverage and accessibility goals and the speed advantages from busway parts. BRT systems and the specific models required to quantify the travel time savings from dedicated lanes have been the subject of several recent studies. However, the inability to accurately express the advantages inside standard planning frameworks is still hampered by data restrictions. As a result, there is a current research deficit for quickly establishing BRT networks, particularly in megacities in developing nations that are proposing new systems. In order to simulate the time savings and reliability improvements from building integrated BRT corridors, the route selection rules need to take into account connection measures that go beyond those of traditional bus networks.

Effective networks may encourage the use of public transportation, lessen the impact on the environment, and ease traffic congestion as a result of people transferring from private automobiles (Cheng et al., 2016; Bagoee et al., 2017). They can also help underprivileged people who have no other options by enhancing access and vital connectivity. Improved analysis is now possible thanks to sophisticated data sources and computational methods. With multi-criteria tradeoffs, however, it is still challenging to identify solutions that provide sufficient service coverage and quality.

1.2. GIS applications in solving this complex problem

To address the complex problem of choosing the best route for public transportation networks, GIS offer essential spatial analytic skills (Faroqi & Sadeghi niaraki, 2015; Toms & Song, 2016). With the use of GIS, integrated data management is made easier by visualization that takes into account the topography of coverage, demand levels in different metropolitan zones, journey durations that represent traffic, and infrastructure limitations. In order to evaluate accessibility gaps, find possible new connections, and evaluate benefits from route alterations, network analysis tools representationally model transportation graphs (Mishra et al., 2015). These functions allow model results to be interpreted in the context of their geographic location, which is a powerful supplement to optimization techniques when comparing alternatives.

1.3. Significance of using AHP in decision-making

In order to define the best routes for public transportation networks, it is necessary to balance the opinions of many stakeholders and frequently at odds criteria (Laporte et al., 2017; Dib et al., 2017). Such complicated multi-criteria judgments can be addressed using an organized framework called the AHP (Ghaderi & Pahlavani, 2015; Oswald Beiler & Treat, 2015). With the use of AHP, the problem may be hierarchically divided into smaller issues that can be compared pairwise to determine priority weights on a ratio scale, allowing for a systematic evaluation. This method assists in gathering empirical data and subjective expert opinions in order to evaluate trade-offs between criteria such as operational difficulties, budgetary restrictions, environmental efficiency, and rider coverage in a comprehensive manner. AHP-based route selection conclusions can resist examination and re-evaluation, which is crucial for long-term infrastructure planning, because they permit inconsistent judgments and sensitivity analysis (Güner, 2018).

2. Challenges of Public Transport Route Optimization

2.1. Multiple objectives - cost, accessibility, coverage, demand levels

When defining the best routes for public transportation networks, transit authorities must balance a number of intricate and sometimes at odds objectives (Baaj and Mahmassani, 1995; Chakroborty and Wivedi, 2002). The combination of these conflicting goals and intrinsic data ambiguities presents considerable analytical challenges for route selection based on models. Table 1 illustrates how, with constrained operational resources, important outcomes pertaining to cost, connection, coverage, and rider demand compete.

The route topology should ideally maximize public transportation and environmental advantages while maintaining the agency's financial sustainability (Ceder, 2007). Nonetheless, it might be difficult to create tradeoff functions and hierarchies between such incompatible objectives (Friman and Fellesson, 2009). Consistent decision-making for route selection challenges is further complicated by the existence of diverse stakeholder interests.

Table 1. Major objectives in transit route optimization.

Objective	Example Metrics
Operational cost efficiency	Total fleet size, Deadhead kilometers, Fuel consumption
Network connectivity	Transfer points/nodes, Maximum transfers, Network diameter
Demand served	Total ridership, Household, or job accessibility
Service coverage	% of stops within distance threshold, Low-income areas covered
Travel and wait times	Route directness, Headway frequency

2.2. Lack of integration between data and methods

The disconnection between data sources and analytical methodologies impedes not only the pursuit of various goals but also the identification of optimal paths (Peng and Dueker, 1995). For ridership statistics, transit agencies typically use antiquated surveys, census demographics, and smartcard archives; geographic datasets show the limitations of the network infrastructure. It has been challenging to meaningfully incorporate such data into mathematical models (Baaj and Mahmassani, 1991). It's possible that the results of route generating algorithms don't match the real-world temporal, geographical, or demand flows. Furthermore, creating unique interfaces and measurements is necessary to visualize results so that planners may evaluate options within geographic settings. Planning is hampered by a lack of coherence across data, computational techniques, and decision support graphics. Integration of GIS has evolved, although this still requires highly skilled technical knowledge. A simpler toolkit could encourage the use of a method.

2.3. Dynamics of urban systems and demand patterns

Transit service design is typically stagnant, with route adjustments occurring over extended periods of time, despite the fast evolution of urban areas and transportation requirements (Lee and Vuchic, 2005). Before implementation, changes in land use, demography, and transport patterns may cause the underlying assumptions of modeled optimizations to become out of date. For example, brand-new housing complexes may change network-wide predicted ridership numbers. An analytical problem arises from dynamic demand-supply interactions when crowding and congestion also affect route selection (Szeto and Jiang, 2014). Planning frameworks that are responsive are necessary to capture such cyclic linkages. Forecasting is quite challenging because of uncertainty surrounding new transportation choices (like ridesharing) and economic shocks. Effective route designs must therefore strike a compromise between adaptability to accommodate variations and efficiency for present trends.

3. GIS Application in Transportation Network Analysis

3.1. Network data representation and modeling

Transit planning requires the ability to store, visualize, and evaluate transportation infrastructure restrictions. Geographic information systems offer particular capabilities for this purpose (Peng and Dueker, 1995). Transport networks are represented digitally as topological graphs with segments and junctions that have capabilities restricted, transit lanes, directionality, and speed limitations. Multimodal connections, lines, routes, pauses, and timetables are included in advanced data models (Curtin et al. 2013). Travel impedances and accessibility levels may be accessed on a system-wide basis thanks to the integrated representation that takes geography and hierarchy into consideration. Before creating optimal improvements, planners might use visual map analytics to identify gaps or inadequacies. When compared to more abstract mathematical formulations, these realistic representations help to explain why most practical initiatives are supported by GIS. In order to capture congestion, the attention has recently switched to dynamically segmenting networks by time period.

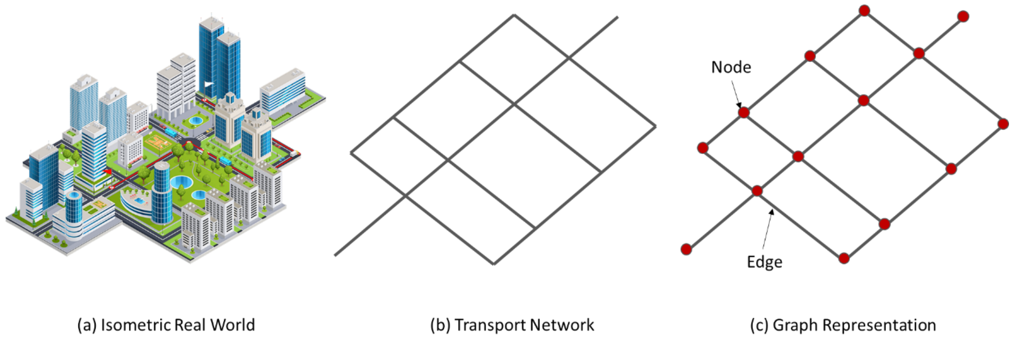

Figure 1. Illustration of transport network representation from real world to a graph representation.

3.2. Spatial and temporal analysis capabilities

GIS systems offer flexible toolkits of statistical methods, overlay operations, and proximity analysis that produce essential inputs for transportation planning (Peng and Dueker, 1995). Demand may be estimated using catchment zones surrounding stations that are based on walk access thresholds. At underserved areas, ridership prediction is provided by mapping demographic characteristics. Network distribution gaps are analyzed using features including clustering, interpolation, and buffer creation. Modeling time-variant flows with historical or simulated traffic datasets is made possible by temporal capabilities. Animation visualizations evaluate the effects of congestion, delays, and wait times on various transportation lines (Zhou et al. 2014). Rather than using static models to detect problematic routes, these spatiotemporal analytics evaluate network performance.

3.3. Integration with optimization models

GIS and mathematical programming integration has improved transit assessments to create better networks (Baaj and Mahmassani, 1995). Optimization models lack the geographical data base and representational flexibility that GIS offers. Combining methods allows modeled route maps derived from GIS platforms to be assigned optimal vehicle schedules or stop patterns. Then, the geographic representation aids in determining if optimal theoretical designs are feasible. The integrated models are further improved by input on shortcomings. Recent developments in GIS also make it possible to execute simple optimization queries for transit allocation issues natively. However, creating embeddable algorithms, effective solvers, and techniques for parameter adjustment inside recognizable GIS interfaces for planners is still an active research area.

3.4. Overview of GIS-based route optimization studies

3.4.1. Applications of GIS in Public Transport Studies

Rui and Haihong (2010) concentrated on improving shortest path algorithms, network modeling, and topology construction in a touch-screen public transportation system in Wuxi, China. They demonstrated enhanced overall performance through the implementation of GIS and relational database management system (RDBMS) integration. This report offers information on how GIS is really used in public transportation. Using GPS and GIS, Devlin, McDonnell, and Ward (2008) carried out a thorough investigation of the routing of timber hauling in Ireland. Finding the best routes based on road class, distance, speed, and travel time was their goal. According to the study, GIS by itself could assess lumber truck route rather well, particularly when taking road classifications into account. The transportation network's overall efficiency was improved by the real-time tracking and monitoring capabilities that the GPS integration brought. Zhu, Zou, and Xu (2006) used GIS and Global System for Mobile Communication (GSM) technology in another study to present an integrated solution to the public transit guiding problem. With an emphasis on reaction speed in a real-time system, the goal was to route travelers to their destinations as quickly as possible. The study illustrated how a productive algorithm was implemented in a GIS in Guangzhou, proving the usefulness of the suggested model and algorithm for guiding public transportation. With an emphasis on urban bus routes, Akgol et al. (2020) presented a unique technique for evaluating the rationality of transit route plans. The study optimized Istanbul Metropolitan City's bus route design by measuring geometric elements. A visual depiction of illogical bus routes was made possible by the use of GIS in geocoding the "digital rationality map," which helped to influence future changes in public transportation route design based on more than a million trips. Chao (2011) made a significant contribution to the subject by introducing a model for the intelligent monitoring and real-time regulation of Tangshan's urban public traffic. The project created a framework for real-time control and monitoring of bus operations by simulating urban public transportation operation using GIS. An intelligent monitoring and scheduling system for public transportation in metropolitan areas was developed with the help of GPS and GIS integration, demonstrating the potential for sophisticated traffic management systems.

3.4.2. GIS-based route optimization studies

Heuristic optimization and shortest path algorithms are two methods that are frequently used to optimize public transportation networks using GIS. Arunadevi et al. (2007) and Deshmukh et al. (2019) both provided evidence of the value of GIS in route design and optimization. Shortest route algorithms for transit networks have been developed and evaluated in several research, improving user convenience and routing efficiency (Su et al. 2005; Bielli et al. 2006; Ming-qu 2007; Wenyuan 2011; Hai 2013; Xu et al. 2017). Additionally, heuristic algorithms have been successfully applied to objectives including minimizing transfers, establishing resilient routes, and decreasing parking congestion (Jerby and Ceder 2006; Yan-yan Chen and Dong-zhu Wang 2009). (Koszelew and Ostrowski 2013).

Bus network dynamic optimization has shown results when genetic algorithms and GIS are used. Fan and Machemehl (2006) generated the best bus routes under varying demand by combining network analysis and evolutionary algorithms. A hybrid genetic and simulated annealing technique was presented by Majima et al. (2008) for the construction of earthquake-resistant bus networks. Genetic algorithm implementation for routes that evolve based on urban shape was made possible by GIS-based frameworks (Huang et al. 2010; Zhang and Huang 2011). Shatnawi et al. (2020) optimized bus stop location using genetic algorithms and particle swarm optimization, whereas Heyken Soares et al. (2019) proposed network scaling to enable genetic algorithms to function. Wei et al. (2022) created an ant colony optimization method to expand upon current bus routes in order to satisfy passenger demand.

Bielli et al. (2006) took into account the limits of various forms of transportation when designing their suggested system for multimodal networks. A real-time model that generates time-dependent best routes across several modes and criteria was reported by Li et al. (2011). An effective method for both private and public transportation was proposed by Khani et al. (2012). Integrating geospatial data across modalities to enable analysis for better mobility was demonstrated by Ismail and Said (2014). Using Google Maps, Kang and Youm (2017) created an application with an easy-to-use interface for searching multimodal routes. Table A1 summarizes key information from studies on GIS-based route optimization studies.

4. AHP and Decision Making in Route Optimization

4.1. Principles of AHP

A organized framework for complex judgments including several criteria, parties, and intangible aspects is offered by the Analytical Hierarchy Process (Saaty, 1980). Hierarchies are used to break down problems, each consisting of a goal, criteria, sub-criteria, and options. Priority vectors for the ratio scale are derived by pairwise comparisons of components at each level. To get weights, for example, professionals analyze route length vs transfers. Uncertainty in judgment is managed via consistency validation. Synthesis determines ranks by applying criterion priority among options. Sensitivity analysis measures how resilient results are to modifications. In order to make optimal selections, AHP integrates both qualitative and quantitative data.

4.2. Key criteria and indicators used

AHP has used a variety of hierarchical criteria as a decision aid for route planning, depending on the specific settings and data availability limits in each situation (Schoon et al., 1988). However, anticipated demand, operating expenses, fleet size needs, and network integration concerns are frequently important considerations (route directness, transfers etc.). The overall trip time, transfer nodes, vehicle kilometers, stop coverage, and load factors are all reflected in the metrics for alternate routes. In data-rich implementations, input criteria for ranking route possibilities might come from GIS-based accessibility measurements or urban transport models (Eboli and Mazzulla, 2012).

4.3. Review of Integrated GIS-AHP Route Studies

GIS and AHP approaches are used in a number of studies to prioritize transportation infrastructure with an emphasis on sustainability metrics, as well as to optimize route alignment, bus route efficiency, and optimal route selection in highway networks. Singh et al. (2019) provides a solid method for planning route alignment by combining fuzzy AHP with a multi-criteria decision-making framework based on geographic information systems. The research efficiently handles uncertainty by including environmental, social, economic, and technological variables, and it uses Least-Cost Path (LCP) analysis to determine the best course of action. In addition, Shi et al. (2021) provide a thorough assessment model based on multi-source data and AHP with an emphasis on bus route optimization. Using a variety of data sources, their analysis highlights the significance of a well-optimized public transportation network and suggests an assessment indicator system. As the actual examination of the Beijing bus network shows, the model works well for objectively evaluating and optimizing bus routes.

A "User-System" decision-making theory is introduced by Xiang et al. (2007) as they explore the best route selection in highway networks. They convert the "Optimal Route Problem" into the traditional "Shortest Path Problem" by establishing an index system for link impedance evaluation using AHP theory. Insights into dynamic route optimization in highway networks are provided by the suggested theory, which has been verified by a testing system. AHP and GIS are used in a strategy presented by Oswald Beiler and Treat (2015) to prioritize transportation infrastructure based on sustainability parameters. The report tackles the dangers associated with climate change and offers policymakers an extensive framework for project prioritization that takes into account social, economic, and environmental aspects. In another paper, Kaewfak et al. (2021) make a contribution to the field of multimodal transportation by emphasizing the optimization of freight routes with multiple objectives. Their study takes into account variables including travel cost, duration, and inherent hazards to identify the best multimodal transportation routes using AHP and zero-one goal programming. In complex transportation networks, the integrated approach aids in decision-making and improves logistical performance. A Multimodal Multi-Criteria Route Planning (MMRP) model combining fuzzy Analytical Hierarchy Process and simulated annealing is proposed by Ghaderi and Pahlavani (2015). The model considers factors like fee, time, user inconvenience, and path length when combining public and private transportation options efficiently. Tehran serves as a demonstration of the method's resilience and offers insightful information for optimizing urban transportation.

Moreover, Rahman et al. (2022) use AHP and GIS geoprocessing techniques to strategically allocate new bus stop locations in Shah Alam. Their research provides useful insights for improving public transportation infrastructure by highlighting the significance of location, functionality, safety, and aesthetic appearance in meeting the changing demands of urban populations. Yildirim and Bediroglu (2019) integrate GIS-based network analysis with AHP to provide a substantial contribution to high-speed railway (HSR) route identification. Their hybrid route optimization model, which takes into account both environmental and economic factors, demonstrates a thorough methodology and emphasizes the significance of sustainable infrastructure development within the framework of intricate transportation networks. The problem of effectively capturing real-world road networks in GIS for route planning analysis is discussed by Sadeghi-Niaraki et al. (2011). In order to provide more accurate and realistic route planning outcomes, the study incorporates actual aspects like weather, sight-seeing information, and road type into its introduction of an impedance model (IM) based on AHP. Pahlevani et al. (2019) make a substantial contribution to multimodal transportation planning with their Multi-modal Multi-criteria Personalized Route Planning (MMPRP) model. The paper presents a customized method to optimize transportation options, integrating TOPSIS, quantifier-guided Ordered Weighted Averaging (Q-OWA) operators, and fuzzy AHP. This practical tool is intended for planners and users. The safety and appropriateness of bicycle routes are examined by Saplıoğlu and Aydın (2018) in their investigation of the integration of riding with public transportation. Their study offers a thorough method to resolve safety problems and enhance the efficacy of cycling integration through the use of GIS, AHP, and a questionnaire survey. A new city major road bus signal priority model is presented by Da-Ming et al. (2011). It uses GIS for micro-traffic simulation and AHP for priority factor determination. Their model shows a workable way to increase the efficiency of public transportation in metropolitan areas by reducing the total delay for buses and other priority vehicles. Sattayaprasert et al. (2008) use AHP for multiple criterion analysis to optimize logistics routes for hazardous materials (HazMats). The risk-based route network offers policymakers and practitioners a methodical and risk-based strategy to handling the complex problems related to HazMat transportation. Elangovan (2021) chooses the metro route location in Madurai city using remote sensing, GIS, and AHP. The paper presents a progressive method for planning urban transportation, taking into account variables such as land use, traffic, and population density. It also highlights the significance of sophisticated technology in the decision-making process. Table A2 summarizes key information from studies on optimal routing of public transit networks and infrastructure, including the research aim, data inputs, methodology, outcomes, limitations, and bibliographic details.

5. Conclusions

The optimization of public bus transit routes through the integration of GIS and AHP has shown to be a potent synergy. Research demonstrated the advantages of merging multicriteria decision-making procedures with spatial analytic capabilities, providing a comprehensive method for route selection that takes into account both qualitative and quantitative aspects. The creation of efficient decision support systems for transportation agencies and urban planners is greatly aided by GIS-AHP models. The literature study indicates that by taking a wide range of factors into account, GIS-AHP models significantly aid in the discovery of the best bus transit routes.

Notwithstanding, certain challenges continue to exist, such as those concerning data precision, computational effectiveness, and the dynamic characteristics of urban transportation networks. It is vital for scholars and professionals to maintain a watchful eye on these obstacles in order to guarantee the sustained resilience and applicability of GIS-AHP techniques. With the introduction of new technologies, real-time monitoring, and data source developments, the integration of GIS and AHP is anticipated to continue to develop. Route optimization techniques will probably become more flexible, responsive, and context-aware as a result of this progress. More collaboration between GIS specialists, data scientists, transportation engineers, and urban planners is probably in store for future studies. The improvement of GIS-AHP procedures is expected to be greatly aided by interdisciplinary approaches that use machine learning, sophisticated optimization techniques, and stakeholder engagement tactics.

6- Supplementary materials for the paper :

Table A1. Summary of GIS-based public transport route optimization methods.

Research Aim	Input Data	Methods	Results	Limitations	Reference
Ant colony optimization for bus network improvement	Road network data, passenger demand data	ACO with transfer rules and constraints	Feasible bus network optimization	Specific to urban context	Wei et al. (2022)
Multimodal route search algorithm	Public transport data, user needs	Android application with Google Maps API	Improved quality of service and efficiency	Specific to South Korean transport	Kang & Youm (2017)
Integrate multi-mode transport for mobility/accessibility improvements	Transport network data for various modes	ArcGIS Network Analyst, abstract connector approach	Integrated transport model enabling optimal path analysis	Limited to case study area	Ismail & Said (2014)
Design GIS-based transit data model as foundation for planning/management	Spatial and non-spatial transit data	Arc-node network model with point, link, polygon features	Flexible model supporting network functions	Maintenance and scalability not discussed	Zeng et al. (2010)
Enable multi-destination route queries in public transit	Public transportation network data	Enhanced A* and greedy algorithms	Feasible and quick optimal route recommendation	Focused only on computational performance	Xu et al. (2017)

Expand bus routes using fuzzy optimal path algorithm	Geospatial data of transport network	Fuzzy optimal path algorithm in GIS	Potential bus stop and route identification	Route implementation not discussed	Duong et al. (2016)
Transit route optimization using genetic algorithms	Ridership demand data, route data	Genetic algorithm	Effective methodology tested across scenarios	No real-world validation	Fan & Machemehl (2006)
Improve bus-subway transfers and residents' accessibility	Subway service area data, resident travel data	GIS analysis, NSGA-II optimization, TOPSIS	Enhanced bus stop locations and resident accessibility	Specific to case study	Wang et al. (2023)
Develop GIS-based demand responsive transit system	Public fleet data, passenger demand data	GIS dynamic routing optimization	Improved operational efficiency	Limited technical details	Faroqi & Sadeghi-Niaraki (2015)
Develop dynamic optimal traffic route finder	Transport network data, traffic patterns	GIS integrated routing algorithm	Effective incorporation of real-time traffic data	Limited details on data sources	Monica Bhavani & Valarmathi (2020)
Real-time multimodal route optimization across transport modes	Transport network data, traffic data	GIS integration with traffic simulation, AHP	Dynamic least cost routing across modes	Limited factors and modes included	Li et al. (2011)
Optimize public transport using vehicle routing problem	Transport network data, timetables	GIS network analysis, VRP tool	Insights on spatial analytics for transport optimization	Limited case study focus	Borowska-Stefanska & Wisniewski (2017)
GIS-based bus transfer query system	Public transit network data	GIS network modeling, visual programming	Decision support for travelers	Basic prototype functions	Fei (2009)
Optimize bus networks using GIS and genetic algorithms	Bus route, rail route data	GIS platform, genetic algorithms	Improved bus route design aligned with rail routes	Limited validation	Zhang & Huang (2011)
Bridge public transit gap in weak-demand areas via ant colony optimization	Transport network data, ridership data	GIS, ant colony optimization	Optimal feeder routes improving coverage	Unable to validate in real-system	Calabrò et al. (2020)
Campus bus route optimization	Transport needs survey data	GIS, Dijkstra algorithm	Enhanced utilization and accessibility	Narrow scope	Ru (2015)
GIS and genetic algorithm-based bus network optimization	Population, land use, transport data	GIS, genetic algorithms, accessibility models	Improved and robust bus route design	Parameter sensitivity not analyzed	Huang et al. (2010)
Optimize bus stop locations using GIS and algorithms	Transport network and ridership data	GIS, PSO, genetic algorithms	Reduced travel times and improved access	Specific to case study area	Shatnawi et al. (2020)
Develop computer algorithm for transit route choice	Public transit network, passenger data	GIS, psychological analysis	Algorithm optimizing connections, reducing transfers	No computational testing	Bo-tao (2010)
Optimal path finding using bipartite graph model	Public transit network data	Iterative penalty method for multi-path selection	Efficient algorithm considering transfers, distance	Limited testing	Yan & Shang (2010)
Planning method for optimal bus routes	Road network, passenger capacity data	k shortest path algorithm	Provided insights on improving public transit routes	Narrow focus, no limitations	Wenyuan (2011)
Optimal design of electric bus systems minimizing total cost	Transport network data, costs	Mixed integer linear programming	Versatile optimization model tested across scenarios	Focused only on cost factors	Lotfi et al. (2020)
Bus route optimization using trajectories	Mobility pattern, bus demand data	MkNNHC algorithm	Efficient route planning and capacity estimation	Only computational testing	Gupta & Yadav (2018)
Explore GIS and remote sensing for route planning	Transport network data	Network analysis in ArcGIS	Framework for travel time and cost reduction	Qualitative analysis	Deshmukh et al. (2019)
Hybrid metaheuristic for robust transit route design	Transport network data, seismic history	Network evolution, simulated annealing	Fault-tolerant and eco-friendly route generation	Domain-specific assumptions	Majima et al. (2008)
Intelligent route planning using parallel genetic algorithms	Transport network data	Parallel genetic algorithms on HPC cluster	Efficient route finding avoiding local optima	Focused on static environment	Arunadevi et al. (2007)

Efficient Pareto-optimal route computation	Public transit network data	Round-based routing algorithm	Faster processing without preprocessing needs	Limited testing	Delling et al. (2015)
GIS-based public transit query system	Public transport network data	Shortest path algorithm, MapInfo	Decision support for travelers	Basic prototype functions	Ming-qu (2007)
Integrate geometry and semantics for public transit transfers	Public transit network data and properties	Spatial analysis of topology and traffic rules	Enhanced precision of transfer algorithms	Not computationally validated	Shao-pei & Jian-jun (2010)
Bus transit optimization using tabu search algorithms	Transit demand, route data	Tabu search heuristics	Outperformed genetic algorithm method	No real-world validation	Fan & Machemehl (2008)
Enhanced shortest path algorithm for bus networks	Bus transport network data	Topology matching, database storage	Improved computational efficiency	Specific to public bus networks	Su et al. (2005)

Table A2. Review of research literature on public transportation route optimization.

Research Aim	Input Data	Methods	Results	Limitations	Reference
Enhance route alignment planning through multi-criteria decision analysis	Environmental, social, economic, technical spatial data	GIS, spatial multi-criteria analysis, fuzzy AHP, least-cost path method	Identification of optimal route alignment from alternatives	Limited to case study area	Singh et al. (2019)
Develop evaluation model for bus route optimization using multi-source data	Bus smart card, location, attribute data	Indicator system, AHP	Quantitative grading method for bus optimization scheme evaluation	Requires extensive data collection	Shi et al. (2021)
User-system optimal route searching incorporating multi-goals	Highway network GIS data	AHP, Dijkstra algorithm	Feasible testing system identifying optimal route	Limited factors considered	Xiang et al. (2007)
Integrate GIS and AHP for transportation project prioritization	Sustainability metrics for projects	GIS spatial analysis, AHP	Framework for decision-makers to holistically prioritize projects	Specific to rail/bus networks	Oswald Beiler & Treat (2015)
Multi-objective optimization of freight route choices	Transport cost, time and risk data	AHP, ZOGP	Model generating optimal routes considering multiple factors	Focused on coal manufacturing	Kaewfak et al. (2021)
Develop efficient multimodal route planning model	Transport network connectivity, criteria data	Fuzzy AHP, simulated annealing	Efficient model providing optimal routes	Limited transport modes	Ghaderi & Pahlavani (2015)
Allocate potential bus stop locations using AHP	Criteria data (location, safety etc.)	AHP, GIS geoprocessing	Identification of preferred criteria and locations	Specific to case study area	Rahman et al. (2022)
GIS and AHP based railway route determination	Economic, environmental, social criteria data	GIS network analysis, AHP	Optimal route with reduced cost and environmental impact	Focused on one route segment	Yildirim & Bediroglu (2019)
Enhance route planning through realistic impedance modeling	Road network, weather, sightseeing data	AHP-based impedance modeling	Alignment of planned routes with real-world paths	Limited testing over time	Sadeghi-Niaraki et al. (2011)
Personalized multimodal route planning integrating fuzzy AHP, Q-OWA, and TOPSIS	Criteria weights, transport connectivity	Fuzzy AHP, Q-OWA operators, TOPSIS	85% user acceptance of proposed optimal routes	Limited transport modes considered	Pahlevani et al. (2019)
Examine parameters influencing cycling route integration with public transport	Accident data, survey data	GIS, AHP, survey analysis	Identification of crucial safety/suitability factors for integration	Focused only on cycling routes	Saplıoğlu & Aydın (2018)
Develop signal priority model to reduce bus delay	Traffic flow data, GIS data	AHP, traffic simulation	Delay reduction for priority vehicles and overall traffic	Limited to simulation testing	Da-Ming et al. (2011)
Risk-based hazmat route optimization	Shipping data, risk criteria data	AHP route prioritization	Shortest risk-based route network for hazmat logistics	Focused solely on gasoline shipping	Sattayaprasert et al. (2008)
Metro route selection using GIS and AHP	Population, land use, transport data	GIS, remote sensing, AHP weighted overlay analysis	Optimal metro routes and stations	Limited to case study area	Elangovan (2021)

References

1. Ahmed, L., Mumford, C., & Kheiri, A. (2019). Solving urban transit route design problem using selection hyper-heuristics. European Journal of Operational Research, 274(2), 545–559. https://doi.org/10.1016/j.ejor.2018.10.022
2. Akgol, K., Gunay, B., Eldemir, F., & Samasti, M. (2020). A new method to measure the rationalities of transit route layouts. Case studies on transport policy, 8(4), 1518-1530.
3. Arbex, R. O., & da Cunha, C. B. (2015). Efficient transit network design and frequencies setting multi-objective optimization by alternating objective genetic algorithm. Transportation Research Part B: Methodological, 81, 355–376. https://doi.org/10.1016/j.trb.2015.06.014
4. Arunadevi, J., Johnsanjeevkumar, A., & Sujatha, N. (2007, December). Intelligent transport route planning using parallel genetic algorithms and MPI in high performance computing cluster. In 15th International Conference on Advanced Computing and Communications (ADCOM 2007) (pp. 578-583). IEEE.
5. Baaj, M.H., Mahmassani, H.S., 1995. An AI-based approach for transit route system planning and design. Journal of Advanced Transportation 25 (2), 187–210.
6. Bielli, M., Boulmakoul, A., & Mouncif, H. (2006). Object modeling and path computation for multimodal travel systems. European Journal of Operational Research, 175(3), 1705-1730.
7. Ceder, A., 2007. Public transit planning and operation: Theory, modelling and practice. CRC Press.
8. Chakroborty, P., Wivedi, T., 2002. Optimal route network design for transit systems using genetic algorithms. Engineering Optimization 34 (1), 83–100.
9. Chao, C. (2011). System of the Urban Public Traffic Intelligent Monitoring and Real-time Control Based on GIS 、GPS. Journal of Hebei Polytechnic University.
10. Cheng, H., Madanat, S., & Horvath, A. (2016). Planning hierarchical urban transit systems for reductions in greenhouse gas emissions. Transportation Research Part D: Transport and Environment, 49, 44–58. https://doi.org/10.1016/j.trd.2016.08.033
11. Cheng, Y.-H., & Chen, S.-Y. (2015). Perceived accessibility, mobility, and connectivity of public transportation systems. Transportation Research Part A: Policy and Practice, 77(0), 386–403. https://doi.org/10.1016/j.tra.2015.05.003
12. Curtin, K.M., Vo, T., Choi, J., 2013. Metropolitan area transit routing model for public-transit analysis and planning. Transportation Research Record 2351(1), 111-119.
13. Da-Ming, L. I., Xin-Liang, Z. H. A. O., & Qi, S. U. N. (2011). Signal Priority Model for Buses and Other Priority Vehicles. Journal of Transportation Systems Engineering and Information Technology, 11(2), 119.
14. Delling, D., Pajor, T., & Werneck, R. F. (2015). Round-based public transit routing. Transportation Science, 49(3), 591-604.
15. Deshmukh, P., Rao, D. S. P., Botale, R., & Pwade, P. Y. (2019). Remote Sensing and Geographic Information System-Based Route Planning. In Smart Technologies for Energy, Environment and Sustainable Development: Select Proceedings of ICSTEESD 2018 (pp. 299-314). Springer Singapore.

16. Devlin, G. J., McDonnell, K., & Ward, S. (2008). Timber haulage routing in Ireland: an analysis using GIS and GPS. Journal of Transport Geography, 16(1), 63-72.
17. Di, H., Yusong, Y., Shoujing, G., & Guang, H. (2007). Optimal routing algorithm for public traffic network based on matrix analysis. 西南交通大学学报, 20(3), 315-319.
18. Dib, O., Moalic, L., Manier, M. A., & Caminada, A. (2017). An advanced GA–VNS combination for multicriteria route planning in public transit networks. Expert Systems with Applications, 72, 67–82. https://doi.org/10.1016/j.eswa.2016.12.009
19. Eboli, L., & Mazzulla, G. (2012). Performance indicators for an objective measure of public transport service quality. European Transport-Trasporti Europei, (51).
20. Elangovan, K. (2021, December). Metro Route Site Selection for Madurai City Using Remote Sensing and GIS. In Proceedings of the First International Conference on Combinatorial and Optimization, ICCAP 2021, December 7-8 2021, Chennai, India.
21. Fan, W., & Machemehl, R. B. (2006). Optimal transit route network design problem with variable transit demand: genetic algorithm approach. Journal of transportation engineering, 132(1), 40-51.
22. Faroqi, H., & Sadeghi-Niaraki, A. (2015). Developing gis-based demand-responsive transit system in tehran city. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1-W5, 189–191. https://doi.org/10.5194/isprsarchives-XL-1-W5-189-2015
23. Friman, M., Fellesson, M., 2009. Frequency of rationales in transit network design. Journal of Transport Geography 17 (1), 19–29.
24. Ghaderi, F., & Pahlavani, P. (2015). A new multimodal multi-criteria route planning model by integrating a fuzzy-ahp weighting method and a simulated annealing algorithm. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1-W5, 203–209. https://doi.org/10.5194/isprsarchives-XL-1-W5-203-2015
25. Güner, S. (2018). Measuring the quality of public transportation systems and ranking the bus transit routes using multi-criteria decision making techniques. Case Studies on Transport Policy, 6(2), 214–224. https://doi.org/10.1016/j.cstp.2018.05.005
26. Hai, W. (2013). Bus Transport Transfer Algorithm. Computer Systems and Applications.
27. Heyken Soares, P., Mumford, C. L., Amponsah, K., & Mao, Y. (2019). An adaptive scaled network for public transport route optimisation. Public Transport, 11(2), 379-412.
28. Huang, Z. D., Liu, X. J., Huang, C. C., & Shen, J. W. (2010). A GIS-based framework for bus network optimization using genetic algorithm. Annals of GIS, 16(3), 185-194.
29. Ismail, M. A., & Said, M. N. (2014, June). Integration of geospatial multi-mode transportation Systems in Kuala Lumpur. In IOP Conference Series: Earth and Environmental Science (Vol. 20, No. 1, p. 012027). IOP Publishing.
30. Jerby, S., & Ceder, A. (2006). Optimal routing design for shuttle bus service. Transportation Research Record, 1971(1), 14-22.
31. Kaewfak, K., Ammarapala, V., & Huynh, V. N. (2021). Multi-objective optimization of freight route choices in multimodal transportation. International Journal of Computational Intelligence Systems, 14(1), 794-807.

32. Kang, Y., & Youm, S. (2017). Multimedia application to an extended public transportation network in South Korea: optimal path search in a multimodal transit network. Multimedia Tools and Applications, 76, 19945-19957.
33. Khani, A., Lee, S., Hickman, M., Noh, H., & Nassir, N. (2012). Intermodal path algorithm for time-dependent auto network and scheduled transit service. Transportation Research Record, 2284(1), 40-46.
34. Koszelew, J., & Ostrowski, K. (2013). Evolutionary algorithm with geographic heuristics for urban public transportation. In Transactions on Computational Collective Intelligence XII (pp. 191-207). Springer Berlin Heidelberg.
35. Laporte, G., Ortega, F. A., Pozo, M. A., & Puerto, J. (2017). Multi-objective integration of timetables, vehicle schedules and user routings in a transit network. Transportation Research Part B: Methodological, 98, 94–112. https://doi.org/10.1016/j.trb.2016.12.018
36. Lee, Y.J., Vuchic, V.R., 2005. Transit network design with variable demand. Journal of transportation engineering 131(1), 1-10.
37. Li, Y. T., Huang, B., & Lee, D. H. (2011). Multimodal, multicriteria dynamic route choice: A GIS-microscopic traffic simulation approach. Annals of GIS, 17(3), 173-187.
38. Majima, T., Takadama, K., Watanabe, D., & Katuhara, M. (2008, August). Generation of public transit network by network evolution model. In 2008 SICE Annual Conference (pp. 964-971). IEEE.
39. Ming-qu, F. (2007). Design and Realization of City Public Transportation Query System Based on MapInfo. Traffic & Transportation.
40. Mishra, S., Welch, T. F., Torrens, P. M., Fu, C., Zhu, H., & Knaap, E. (2015). A tool for measuring and visualizing connectivity of transit stop, route and transfer center in a multimodal transportation network. Public Transport, 7(1), 77–99. https://doi.org/10.1007/s12469-014-0091-2
41. Oswald Beiler, M. R., & Treat, C. (2015). Integrating GIS and AHP to prioritize transportation infrastructure using sustainability metrics. Journal of Infrastructure Systems, 21(3), 04014053. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000245
42. Owais, M., Osman, M. K., & Moussa, G. (2016). Multi-Objective Transit Route Network Design as Set Covering Problem. IEEE Transactions on Intelligent Transportation Systems, 17(3), 670–679. https://doi.org/10.1109/TITS.2015.2480885
43. Pahlevani, P., Ghaderi, F., & Bigdeli, B. (2019). Modeling different decision strategies in a time tabled multimodal route planning by integrating the quantifier-guided OWA operators, fuzzy AHP weighting method and TOPSIS. International Journal of Transportation Engineering, 7(1), 35-56.
44. Peng, Z.R., Dueker, K.J., 1995. Spatial data integration in route-level transit demand modeling. Journal of the Urban and Regional Information Systems Association 7(1), 26-36.
45. Peng, Z.-R., Kang, L., Chen, G., 2011. Schedule coordination control for public transit network based on enhanced adaptive genetic algorithm. Journal of Transportation Systems Engineering and Information Technology 11 (2), 106–112.

46. Rahman, A. A. A., Majid, N. A., Ramlan, M. H., & Hakim, M. A. (2022, July). Allocating Of New Potential Bus Stop Location Using Analytical Hierarchy Process (AHP) technique. In IOP Conference Series: Earth and Environmental Science (Vol. 1051, No. 1, p. 012016). IOP Publishing.
47. Ru, X. (2015). The Optimal Path Planning Algorithm for Campus Bus. Journal of Chongqing University of Science and Technology.
48. Rui, X., & Haihong, X. (2010, August). Application of GIS in Wuxi touch-screen public transportation system. In 2010 Second IITA International Conference on Geoscience and Remote Sensing (Vol. 1, pp. 250-253). IEEE.
49. Saaty, T.L., 1980. The analytic hierarchy process: planning, priority setting and resource allocation. McGraw-Hill, New York.
50. Sadeghi-Niaraki, A., Varshosaz, M., Kim, K., & Jung, J. J. (2011). Real world representation of a road network for route planning in GIS. Expert systems with applications, 38(10), 11999-12008.
51. Saplıoğlu, M., & Aydın, M. M. (2018). Choosing safe and suitable bicycle routes to integrate cycling and public transport systems. Journal of Transport & Health, 10, 236-252.
52. Sattayaprasert, W., HANAOKA, S., TANEERANANON, P., & Pradhananga, R. (2008). Creating a risk-based network for hazmat logistics by route prioritization with AHP: case study: gasoline logistics in Rayong, Thailand. IATSS research, 32(1), 74-87.
53. Schoon, J.G., van der Wijk, M.C., van Persijn, C.T., 1988. Analytical Hierarchy Process for transit service criteria. Transportation Research Record 1197, 12–20.
54. Shatnawi, N., Al-Omari, A. A., & Al-Qudah, H. (2020). Optimization of bus stops locations using GIS techniques and artificial intelligence. Procedia Manufacturing, 44, 52-59.
55. Shi, Q., Zhang, K., Weng, J., Dong, Y., Ma, S., & Zhang, M. (2021). Evaluation model of bus routes optimization scheme based on multi-source bus data. Transportation research interdisciplinary perspectives, 10, 100342.
56. Shojaei Baghini, M., Ismail, A., Hesam Hafezi, M., Kohzadi Seifabad, O., & Alezzi Almansob, R. (2014). Bus rapid transit (BRT) system impacts to environmental quality. Research Journal of Applied Sciences, Engineering and Technology, 7(7), 1344–1350. https://doi.org/10.19026/rjaset.7.400
57. Singh, A.K., Pal, S., Thakur, N., 2017. GIS-based approach for delimitation of bus routes: a case study of Dhanbad City, India. Journal of Urban Management 6 (2), 116–124.
58. Singh, M. P., Singh, P., & Singh, P. (2019). Fuzzy AHP-based multi-criteria decision-making analysis for route alignment planning using geographic information system (GIS). Journal of Geographical Systems, 21, 395-432.
59. Su, Y., Wang, Y., & Yu, Z. (2005). A new updated shortest path algorithm for urban public bus network. Geo-information Science, 7(002), 099-104.
60. Szeto, W.Y., Jiang, Y., 2014. Transit route and frequency design: Bi-level modeling and hybrid artificial bee colony algorithm approach. Transportation research part B: methodological 67, 235-263.

61. Toms, K., & Song, W. (2016). Spatial analysis of the relationship between levels of service provided by public transit and areas of high demand in jefferson county, kentucky. Papers in Applied Geography, 2(2), 147–159. https://doi.org/10.1080/23754931.2015.1115365
62. Walteros, J. L., Medaglia, A. L., & Riaño, G. (2015). Hybrid algorithm for route design on bus rapid transit systems. Transportation Science, 49(1), 66–84. https://doi.org/10.1287/trsc.2013.0478
63. Wang, S., Zuo, Z., & Liu, Y. (2023). Study on Location of Bus Stop in Subway Service Area Based on Residents' Travel Accessibility. Sustainability, 15(5), 4517.
64. Warren, J. P., & Ortegon-Sanchez, A. (2016). Designing and modelling Havana's future bus rapid transit. Proceedings of the Institution of Civil Engineers - Urban Design and Planning, 169(2), 104–119. https://doi.org/10.1680/jurdp.15.00015
65. Wei, Y., Jiang, N., Li, Z., Zheng, D., Chen, M., & Zhang, M. (2022). An improved ant colony algorithm for urban bus network optimization based on existing bus routes. ISPRS International Journal of Geo-Information, 11(5), 317.
66. Wenyuan, L. (2011). Planning Method Based on Bus Route. Journal of Chinese Computer Systems.
67. Xiang, Q. J., Ma, Y. F., & Lu, J. (2007, June). Optimal route selection in highway network based on travel decision making. In 2007 IEEE Intelligent Vehicles Symposium (pp. 1266-1270). IEEE.
68. Xu, C., Shi, Y., & Tao, N. (2017, March). The Research Of Multipath Query Implementation Based On The City's Public Transportation System. In 2017 7th International Conference on Education, Management, Computer and Society (EMCS 2017) (pp. 536-538). Atlantis Press.
69. Yan-yan, C. H. E. N., & Dong-zhu, W. A. N. G. (2009). Heuristic Algorithm for Searching Public Transit Paths Based on Reliability Analysis. Journal of Transportation Systems Engineering and Information Technology, 9(3), 98.
70. Yildirim, V., & Bediroglu, S. (2019). A geographic information system-based model for economical and eco-friendly high-speed railway route determination using analytic hierarchy process and least-cost-path analysis. Expert Systems, 36(3), e12376.
71. Zhang, N., & Huang, Z. (2011). Evaluation and optimization of bus route network in Wuhan China.
72. Zhou, G., Yan, X., Dang, Y., Wu, Y.J., 2014. Effectiveness of bus priority lane based on GPS data. Transportation Research Record 2417(1), 44-52.
73. Zhu, L., Zou, L., & Xu, J. (2006, June). Integrating GSM technology for the public transportation guidance system. In 2006 6th World Congress on Intelligent Control and Automation (Vol. 2, pp. 8550-8553). IEEE.
74. Arunadevi, J., Johnsanjeevkumar, A., & Sujatha, N. (2007, December). Intelligent transport route planning using parallel genetic algorithms and MPI in high performance computing cluster. In 15th International Conference on Advanced Computing and Communications (ADCOM 2007) (pp. 578-583). IEEE.

75. Borowska-Stefanska, M., & Wisniewski, S. (2017). Vehicle routing problem as urban public transport optimization tool. Computer Assisted Methods in Engineering and Science, 23(4), 213-229.
76. Bo-tao, L. (2010). Route Choice in Urban Transit Network Computer Algorithm. Computer Knowledge and Technology.
77. Calabrò, G., Inturri, G., Le Pira, M., Pluchino, A., & Ignaccolo, M. (2020). Bridging the gap between weak-demand areas and public transport using an ant-colony simulation-based optimization. Transportation Research Procedia, 45, 234-241.
78. Da-Ming, L. I., Xin-Liang, Z. H. A. O., & Qi, S. U. N. (2011). Signal Priority Model for Buses and Other Priority Vehicles. Journal of Transportation Systems Engineering and Information Technology, 11(2), 119.
79. Delling, D., Pajor, T., & Werneck, R. F. (2015). Round-based public transit routing. Transportation Science, 49(3), 591-604.
80. Deshmukh, P., Rao, D. S. P., Botale, R., & Pwade, P. Y. (2019). Remote Sensing and Geographic Information System-Based Route Planning. In Smart Technologies for Energy, Environment and Sustainable Development: Select Proceedings of ICSTEESD 2018 (pp. 299-314). Springer Singapore.
81. Duong, T. M. T. O., Phuong, H. N., & Duong, T. M. (2016). Application of fuzzy optimal path algorithm for bus route expansion in Thai Nguyen City. International Journal of Computer Engineering and Information Technology, 8(12), 226.
82. Elangovan, K. (2021, December). Metro Route Site Selection for Madurai City Using Remote Sensing and GIS. In Proceedings of the First International Conference on Combinatorial and Optimization, ICCAP 2021, December 7-8 2021, Chennai, India.
83. Fan, W., & Machemehl, R. B. (2006). Optimal transit route network design problem with variable transit demand: genetic algorithm approach. Journal of transportation engineering, 132(1), 40-51.
84. Fan, W., & Machemehl, R. B. (2008). Tabu search strategies for the public transportation network optimizations with variable transit demand. Computer-Aided Civil and Infrastructure Engineering, 23(7), 502-520.
85. Faroqi, H., & Sadeghi-Niaraki, A. (2015). Developing gis-based demand-responsive transit system in tehran city. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1-W5, 189–191. https://doi.org/10.5194/isprsarchives-XL-1-W5-189-2015
86. Fei, L. (2009). Bus Transfer Query System Based on GIS. Journal of Shandong Jiaotong University.
87. Friman, M., Fellesson, M., 2009. Frequency of rationales in transit network design. Journal of Transport Geography 17 (1), 19–29.
88. Ghaderi, F., & Pahlavani, P. (2015). A new multimodal multi-criteria route planning model by integrating a fuzzy-ahp weighting method and a simulated annealing algorithm. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1-W5, 203–209. https://doi.org/10.5194/isprsarchives-XL-1-W5-203-2015

89. Gupta, V., & Yadav, S. (2018). Route Searching using Modified k-Nearest Neighbor with Hill Climbing over Trajectories. International Journal of Advanced Research in Computer Science and Software Engineering. https://doi.org/10.23956/ijarcsse.v8i5.718.
90. Huang, Z. D., Liu, X. J., Huang, C. C., & Shen, J. W. (2010). A GIS-based framework for bus network optimization using genetic algorithm. Annals of GIS, 16(3), 185-194.
91. Ismail, M. A., & Said, M. N. (2014, June). Integration of geospatial multi-mode transportation Systems in Kuala Lumpur. In IOP Conference Series: Earth and Environmental Science (Vol. 20, No. 1, p. 012027). IOP Publishing.
92. Kaewfak, K., Ammarapala, V., & Huynh, V. N. (2021). Multi-objective optimization of freight route choices in multimodal transportation. International Journal of Computational Intelligence Systems, 14(1), 794-807.
93. Kang, Y., & Youm, S. (2017). Multimedia application to an extended public transportation network in South Korea: optimal path search in a multimodal transit network. Multimedia Tools and Applications, 76, 19945-19957.
94. Li, Y. T., Huang, B., & Lee, D. H. (2011). Multimodal, multicriteria dynamic route choice: A GIS-microscopic traffic simulation approach. Annals of GIS, 17(3), 173-187.
95. Lotfi, M., Pereira, P., Paterakis, N. G., Gabbar, H. A., & Catalao, J. P. (2020). Optimal design of electric bus transport systems with minimal total ownership cost. IEEE Access, 8, 119184-119199.
96. Majima, T., Takadama, K., Watanabe, D., & Katuhara, M. (2008, August). Generation of public transit network by network evolution model. In 2008 SICE Annual Conference (pp. 964-971). IEEE.
97. Ming-qu, F. (2007). Design and Realization of City Public Transportation Query System Based on MapInfo. Traffic & Transportation.
98. Oswald Beiler, M. R., & Treat, C. (2015). Integrating GIS and AHP to prioritize transportation infrastructure using sustainability metrics. Journal of Infrastructure Systems, 21(3), 04014053. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000245
99. Pahlevani, P., Ghaderi, F., & Bigdeli, B. (2019). Modeling different decision strategies in a time tabled multimodal route planning by integrating the quantifier-guided OWA operators, fuzzy AHP weighting method and TOPSIS. International Journal of Transportation Engineering, 7(1), 35-56.
100. Rahman, A. A. A., Majid, N. A., Ramlan, M. H., & Hakim, M. A. (2022, July). Allocating Of New Potential Bus Stop Location Using Analytical Hierarchy Process (AHP) technique. In IOP Conference Series: Earth and Environmental Science (Vol. 1051, No. 1, p. 012016). IOP Publishing.
101. Ru, X. (2015). The Optimal Path Planning Algorithm for Campus Bus. Journal of Chongqing University of Science and Technology.
102. Sadeghi-Niaraki, A., Varshosaz, M., Kim, K., & Jung, J. J. (2011). Real world representation of a road network for route planning in GIS. Expert systems with applications, 38(10), 11999-12008.

103. Saplıoğlu, M., & Aydın, M. M. (2018). Choosing safe and suitable bicycle routes to integrate cycling and public transport systems. Journal of Transport & Health, 10, 236-252.
104. Sattayaprasert, W., HANAOKA, S., TANEERANANON, P., & Pradhananga, R. (2008). Creating a risk-based network for hazmat logistics by route prioritization with AHP: case study: gasoline logistics in Rayong, Thailand. IATSS research, 32(1), 74-87.
105. Shao-pei, C., & Jian-jun, T. (2010). Public transportation transfer based on integration of geometric and semantic rules applied on transportation networks. Science of Surveying and Mapping, 35, 159-161.
106. Shatnawi, N., Al-Omari, A. A., & Al-Qudah, H. (2020). Optimization of bus stops locations using GIS techniques and artificial intelligence. Procedia Manufacturing, 44, 52-59.
107. Shi, Q., Zhang, K., Weng, J., Dong, Y., Ma, S., & Zhang, M. (2021). Evaluation model of bus routes optimization scheme based on multi-source bus data. Transportation research interdisciplinary perspectives, 10, 100342.
108. Singh, M. P., Singh, P., & Singh, P. (2019). Fuzzy AHP-based multi-criteria decision-making analysis for route alignment planning using geographic information system (GIS). Journal of Geographical Systems, 21, 395-432.
109. Su, Y., Wang, Y., & Yu, Z. (2005). A new updated shortest path algorithm for urban public bus network. Geo-information Science, 7(002), 099-104.
110. Wang, S., Zuo, Z., & Liu, Y. (2023). Study on Location of Bus Stop in Subway Service Area Based on Residents' Travel Accessibility. Sustainability, 15(5), 4517.
111. Wei, Y., Jiang, N., Li, Z., Zheng, D., Chen, M., & Zhang, M. (2022). An improved ant colony algorithm for urban bus network optimization based on existing bus routes. ISPRS International Journal of Geo-Information, 11(5), 317.
112. Wenyuan, L. (2011). Planning Method Based on Bus Route. Journal of Chinese Computer Systems.
113. Xiang, Q. J., Ma, Y. F., & Lu, J. (2007, June). Optimal route selection in highway network based on travel decision making. In 2007 IEEE Intelligent Vehicles Symposium (pp. 1266-1270). IEEE.
114. Xu, C., Shi, Y., & Tao, N. (2017, March). The Research Of Multipath Query Implementation Based On The City's Public Transportation System. In 2017 7th International Conference on Education, Management, Computer and Society (EMCS 2017) (pp. 536-538). Atlantis Press.
115. Yan, X., & Shang, Y. (2010). Path-finding algorithm of public transport networks based on bipartite graph model. Computer Engineering and Applications, 46(5), 246-248.
116. Yildirim, V., & Bediroglu, S. (2019). A geographic information system-based model for economical and eco-friendly high-speed railway route determination using analytic hierarchy process and least-cost-path analysis. Expert Systems, 36(3), e12376.
117. Zeng, W., Chang, X., & Lv, J. (2010). Design of data model for urban transport GIS. Journal of Geographic Information System, 2(2), 106.

118. Zhang, N., & Huang, Z. (2011). Evaluation and optimization of bus route network in Wuhan China.