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"Optimization of Public Transport Routes using GIS and Big Data: A Case Study in Vidisha Station to Ashish Mangal Vaatika and Vidisha Station to Vidisha Bus Stand"

Abhishek Mazi[1], Dr. Bablu Kirar [2]
[1]PG Student, Department of Civil Engineering, SATI Vidisha, India
[2]Assistant Professor, Department of Civil Engineering, SATI Vidisha, India

Abstract

This study presents a data-driven framework for optimizing public transport routes in Vidisha, Madhya Pradesh, focusing on the corridors from Vidisha Station to Ashish Mangal Vaatika and Vidisha Bus Stand. With rising urbanization and increased private vehicle use, congestion and declining public transport efficiency have become major issues. The research integrates GIS, Big Data, OpenStreetMap (OSM), and GPS-based surveys to develop a detailed transport network and analyze travel demand. A multi-objective optimization model using Ant Colony Optimization (ACO) and Genetic Algorithms (GA) is employed to reduce travel time and operational cost while improving coverage and accessibility. Comparative evaluation shows notable improvements over existing routes. The proposed framework supports scalable, data-informed planning for sustainable urban mobility in Vidisha and similar cities.

Keywords: Public Transport Optimization, GIS, Big Data, OSM, GPS Survey, ACO, GA, Route Planning, Urban Mobility, Vidisha.

I. Introduction

Vidisha Vidisha is a historically significant city in Madhya Pradesh, situated near the Betwa and Bes rivers and located approximately 10 kilometers from the state capital, Bhopal. Formerly known as Bhelsa, the city holds archaeological and cultural importance dating back to the Mauryan and Gupta periods, highlighted by landmarks such as the Heliodorus Pillar and the Udayagiri Caves. According to the 2011 Census, the Vidisha district recorded a population of about 14.5 lakh, with over 1.5 lakh residents within the city limits. The decadal growth rate of 20.03% (2001–2011) reflects Vidisha's rapid urban expansion and the increasing demand for efficient mobility and infrastructure services.

Vidisha's transportation network is composed of major regional and local corridors that support both urban and rural mobility. National Highway NH-146 connects the city with important regional centers such as Bhopal and Sagar, while State Highways SH-19 and SH-22 serve as links to nearby urban nodes including Raisen, Ganj Basoda, and Ashok Nagar. Major District Roads (MDRs) and an extensive network of village roads facilitate movement to over 1,500 rural settlements, although many of these routes still lack all-weather surfaces. Public transport options include government and private buses, auto-rickshaws, tempos, and e-rickshaws, while Vidisha Railway Station—located on the Delhi–Chennai trunk route—plays a critical role in long-distance connectivity. Despite these systems, local mobility remains constrained due to limited service efficiency, inadequate integration between modes, and rising dependence on private vehicles.

The city's socio-economic characteristics also influence mobility patterns. A significant portion of the population is engaged in agriculture, local trade, and government employment, with typical household incomes ranging from ₹6,000–₹12,000 per month, particularly in rural and semi-urban areas. These modest income levels underscore the necessity for reliable and affordable public transport. However, Vidisha faces challenges commonly observed in rapidly growing Indian cities, including inadequate public transport infrastructure, increasing traffic congestion, and decreasing reliance on public transit due to service inefficiencies. The rise in private vehicle ownership has intensified congestion and contributed to a declining share of public transport usage, creating a feedback loop where unreliable transit encourages greater private vehicle dependence, further straining road networks.

These challenges demonstrate the urgent need for optimized public transport systems supported by modern planning tools. Geographic Information Systems (GIS) and Big Data analytics have emerged as transformative technologies for transportation planning, offering the ability to integrate spatial and non-spatial information, analyze travel patterns, and identify service gaps. However, cities like Vidisha face a critical barrier: the absence of detailed digital datasets regarding local bus routes, stop locations, schedules, and operational characteristics. Existing information—often limited to general intercity bus points—is fragmented, inconsistent, and rarely digitized, especially among informal and private operators. This systemic data deficit necessitates the development of innovative approaches, including GPS-based field surveys and the use of open-source platforms such as OpenStreetMap (OSM), to accurately map current mobility conditions.

Against this backdrop, this study focuses on optimizing public transport along two key corridors: Vidisha Station to Ashish Mangal Vaatika (via Durga Nagar Main Road) and Vidisha Station to Vidisha Bus Stand. These routes represent short yet critical "last-mile" connections that link the city's main railway station with important residential and commercial areas. Such micro-level corridors often experience high demand but suffer from irregular service, route redundancies, limited coverage, and poor integration with major transit nodes. By analyzing existing conditions, identifying inefficiencies, and applying data-driven techniques, this research aims to propose optimized routes that improve travel time, operational cost efficiency, accessibility, and overall user satisfaction.

Through the application of GIS-based spatial analysis, Big Data techniques, and optimization algorithms, this study seeks to produce a scalable and replicable methodology for improving public transport in Vidisha and similar medium-sized Indian cities. The findings aim to assist local authorities in making informed decisions regarding route planning and resource allocation, ultimately contributing to enhanced mobility, reduced congestion, and more sustainable urban development.

Transportation modes include:

- Buses (private and government-run)
- Auto-rickshaws, Tempos, and e-rickshaws in urban and semi-urban areas
- Railway station at Vidisha on the Delhi–Chennai route ensures long-distance rail access

Most people rely on agriculture, local markets, and government jobs. The average household income ranges from ₹6,000–₹12,000/month, often lower in villages.

Though it faces issues like poor rural infrastructure and low income, Vidisha's history and growing road and rail links offer great potential for smart planning and development.

Figure 1: Vidisha Map

This line chart illustrates a trend of increasing private vehicle ownership and a decreasing share of public transport usage in Indian cities over time, highlighting the growing challenge for urban mobility.

Table 1: Trend of Private Vehicle Ownership vs. Public Transport Share in Indian Cities (Through Survey Data)

Year	**Private Vehicle Ownership (%)**	**Public Transport Share (%)**
2005	25	40
2010	35	35
2015	45	30
2020	55	25
2025	65	20

Source: data based on general trends in Indian urban mobility reports.

II. Literature Survey

2.1 Foundations of Transportation Route Optimization

Transportation route optimization is essential for identifying the most efficient vehicle pathways to reduce travel time, minimize operational costs, and improve service reliability. Its importance is well recognized across both freight and passenger transport systems, as optimized routing enhances fuel efficiency, lowers emissions, increases fleet productivity, and contributes significantly to user satisfaction. However, the optimization process is inherently complex because it must account for numerous interdependent variables, including fluctuating traffic conditions, delivery schedules, fuel price variations, vehicle capacities, and dynamic travel demand patterns.

In public transportation, the complexity further increases due to the need to minimize passenger waiting and travel times while maintaining schedule reliability and ensuring broad service coverage. These multiple and sometimes competing objectives position transport route optimization as a multi-objective planning problem, requiring careful trade-off analysis between economic efficiency, environmental sustainability, and social accessibility. Approaches that focus solely on minimizing distance or time may inadvertently increase congestion, reduce accessibility, or worsen environmental impacts. Therefore, designing an effective optimization strategy—especially in cities such as Vidisha—requires advanced methodologies and precisely defined objective functions that accommodate local constraints and priorities.

2.2 Role of Geographic Information Systems (GIS) in Urban Mobility

Geographic Information Systems (GIS) play a central role in modern urban mobility planning by providing tools for spatial data management, route design, and accessibility analysis. GIS integrates diverse datasets—including demographic information, land-use patterns, employment distributions, and transport networks—allowing planners to visualize and analyze interactions between these variables. This capability enables accurate identification of underserved areas, assessment of access to employment and education centers, and evaluation of transit service coverage across different population groups.

In public transport applications, GIS is particularly effective in optimizing route alignments and stop locations by analyzing population densities, travel demand clusters, and existing infrastructure. Widely used software platforms such as ArcGIS Network Analyst, TransCAD, and PTV Vissim provide advanced modeling tools for network analysis, scenario comparison, and multimodal simulation. These platforms help planners evaluate alternative route designs, simulate passenger flows, and assess the future impacts of urban growth. Given its ability to combine visualization and analytical functions, GIS is not merely a mapping tool but a powerful planning instrument that can identify spatial mismatches between transport supply and demand, making it indispensable for holistic and equitable transport planning.

2.3 Leveraging Big Data for Public Transport Enhancement

Big Data has emerged as a transformative tool for public transport systems, offering unprecedented insights into travel patterns through data sources such as GPS traces, Automated Vehicle Location (AVL) systems, mobile phone logs, smart card transactions, and social media feeds. These datasets enable real-time monitoring of system performance, dynamic route adjustments, predictive maintenance, and long-term demand forecasting. By analyzing historical mobility patterns, transport authorities can better anticipate delays, optimize scheduling, and allocate resources more efficiently.

Despite its potential, Big Data-driven planning faces several challenges. Ethical concerns related to privacy and data protection are significant when dealing with granular, individual-level mobility data. Additionally, many datasets in developing regions like India are fragmented, inconsistent, and isolated across organizations, requiring extensive preprocessing before they can be effectively utilized. Informal and private transport operators—who constitute a major portion of mobility services—often do not use digital systems, further complicating efforts to build integrated datasets. As highlighted by national policy documents, such as those from NITI Aayog, addressing these issues is essential for unlocking the full benefits of Big Data in public transport planning.

2.4 Optimization Algorithms for Transit Network Design

A wide range of algorithms have been applied to transit route optimization, each offering distinct advantages depending on the complexity of the problem and the nature of the data. Classical algorithms such as Dijkstra's and A* are effective for calculating shortest paths but struggle with multi-objective or constraint-heavy transportation problems. For more complex scenarios, metaheuristic algorithms offer greater flexibility and computational power.

Ant Colony Optimization (ACO) mimics the foraging behavior of ants to identify near-optimal routes within a network, making it suitable for problems involving multiple constraints such as travel times and route continuity. Genetic Algorithms (GA) apply evolutionary principles to explore large solution spaces and are highly effective for Transit Route Network Design Problems (TRNDP), especially when objectives include minimizing total travel cost or balancing multiple constraints. Simulated Annealing (SA) helps avoid local optima in complex networks by using probabilistic mechanisms, while Particle Swarm Optimization (PSO) is effective for continuous optimization tasks such as determining optimal station locations based on population distribution.

In recent years, machine learning algorithms have become increasingly important for demand forecasting and dynamic routing. Neural networks, regression models, and gradient boosting approaches can identify complex patterns in large datasets and support real-time route adjustments. The integration of machine learning with classical route optimization algorithms is an emerging trend, enabling more adaptive and intelligent public transport systems.

2.5 Public Transport Optimization in Indian Cities: Opportunities and Challenges

Indian cities are progressively integrating GIS and Big Data technologies into their mobility planning processes. Case studies such as Chennai's GIS-based bus stop rationalization, Delhi's bus route restructuring, and Mumbai's predictive maintenance systems illustrate the growing adoption of data-driven approaches. These initiatives demonstrate how advanced tools can improve operational efficiency, reduce congestion, and enhance commuter experiences.

However, Indian cities also face significant systemic challenges. Infrastructure and funding limitations restrict the expansion and modernization of transport systems. Operational inefficiencies, such as overcrowding, unreliable schedules, and congestion-induced delays, have weakened the attractiveness of public transport. Data gaps and fragmentation, especially due to the dominance of informal transport operators with limited digitization, further complicate integrated planning efforts. The informal shared mobility sector, while essential for last-mile connectivity, often operates without regulation or reliable data, making coordination with formal systems difficult.

Additionally, rapid and often unplanned urban expansion has produced low-density development patterns that are difficult for conventional public transport networks to serve efficiently. These structural issues indicate that technical route optimization alone cannot resolve all mobility challenges. Instead, it must be embedded within broader policy frameworks that address funding, regulation, land-use coordination, and multimodal integration. For cities like Vidisha, this means that optimization initiatives should complement wider urban mobility strategies aimed at creating sustainable, inclusive, and efficient transport systems.

III. Research Methodology

This study adopts a systematic, multi-stage methodology to optimize public transport routes in Vidisha, with specific emphasis on the corridors between Vidisha Station and Ashish Mangal Vaatika (via Durga Nagar Main Road) and between Vidisha Station and Vidisha Bus Stand. The approach combines GIS-based spatial analysis with data-driven modeling and optimization techniques to address the constraints of a data-scarce, developing urban environment. The overall workflow progresses from problem definition and literature review, through data acquisition and pre-processing, to GIS-based analysis, development of a route optimization model, and finally performance evaluation and validation. At each stage, particular attention is given to the peculiarities of Vidisha's informal and partially documented transport system.

3.1 Data Acquisition and Pre-processing

Due to the lack of reliable digital public transport data in Vidisha, the methodology begins by creating a clean, integrated dataset for network analysis. A detailed road network from OpenStreetMap (OSM) forms the base, cross-verified with official development plan maps. Key attributes such as road type, speed limits, lanes, one-way rules, and pedestrian access are extracted to support realistic routing. The OSM data is then clipped to Vidisha's limits, corrected for topological errors, and standardized to ensure complete network connectivity.

The second dataset covers existing public transport routes and stops, which are mostly informal and undocumented. Field surveys using GPS are conducted along two corridors, identifying around 15 informal auto-rickshaw stops between Vidisha Station and Durga Nagar Main Road, and about 8 stops on the Vidisha Station–Bus Stand corridor. Peak-hour frequencies range from 5–8 vehicles per hour. This primary data, supplemented by inputs from local authorities and operators, is structured in a GTFS-like format to enable integration with GIS tools.

Demographic and socio-economic data from the Census, along with key Points of Interest (markets, stations, schools, hospitals, etc.), are mapped to identify demand hotspots and likely trip origins and destinations. These layers are linked to wards or grid cells for downstream accessibility and demand analysis.

Traffic and mobility conditions are assessed using available RTO data and inferred traffic volumes. The main arterial corridor carries roughly 12,000 PCU per day, with peak-hour flows of 1,500–1,800 PCU, indicating significant congestion. While real-time data sources like AVL or telecom-based mobility feeds are not available, they are noted as future enhancements.

All datasets are consolidated in a unified GIS environment using ArcGIS Pro (with Network Analyst) and QGIS. A structured geodatabase organizes road networks, stops, routes, demographic layers, POIs and traffic data in consistent formats and coordinate systems, forming the analytical foundation for subsequent spatial analysis and optimization.

3.2 GIS-Based Spatial Analysis

After preparing the data, GIS-based spatial analysis is used to assess Vidisha's transport conditions, measure accessibility, and identify supply–demand gaps. A network dataset is first built in ArcGIS Pro from the cleaned road network, with proper connectivity, turn restrictions, and travel-time impedance assigned using posted or inferred speeds. Connectivity checks ensure no isolated or distorted segments remain.

Accessibility is evaluated through service-area analyses around existing and proposed stops, using a 500 m (10-minute) walking catchment. These catchments show coverage along both study corridors and support the calculation of metrics like PTAI, which combine distance, frequency and waiting times to quantify how well different neighborhoods are served.

Demand–supply mismatch analysis overlays population density and POIs with current service areas to locate underserved hotspots and areas with redundant service. Heat maps help visualize where residents face poor access or low service frequency. These spatial insights form the basis for defining the optimization problem and designing improved transport routes for Vidisha.

3.3 Big Data Analytics and Route Optimization Model

The core analytical step involves estimating corridor-level travel demand and designing optimized routes using a suitable optimization algorithm. Demand forecasting follows a simplified four-step model using census-based population and household data for trip generation and POI-based attractions for trip distribution. Based on these inputs and reasonable travel assumptions, the Vidisha Station–Ashish Mangal Vaatika corridor is estimated to generate about 2,500 daily trips, while the Vidisha Station–Bus Stand corridor generates around 1,800 daily trips. These estimates rely on census data, land-use patterns and field observations in the absence of full O–D surveys or Big Data.

Although real-time datasets such as mobile or smart-card records are not used, the framework is designed to incorporate them in the future for more detailed O–D flows and time-of-day demand patterns. For now, the study focuses on a static, robust optimization model.

Route design is formulated as a multi-objective optimization problem solved using a metaheuristic algorithm such as Ant Colony Optimization (ACO) or a Genetic Algorithm (GA). The road network is modeled as a graph of nodes (intersections, stops) and edges (road segments with travel-time attributes). The objective function balances minimizing travel time and operational costs with maximizing population coverage and access to key POIs; environmental goals can also be included.

Practical constraints ensure implementable routes: mandatory corridor connections, limits on route length and stop count, minimum/maximum stop spacing (500 m–2 km), one-way and turn restrictions, capacity considerations and road hierarchy constraints. Algorithm parameters (e.g., ants and pheromone decay in ACO or population size and mutation rate in GA) are selected from prior studies and refined through trial runs to ensure good convergence and transparent optimization.

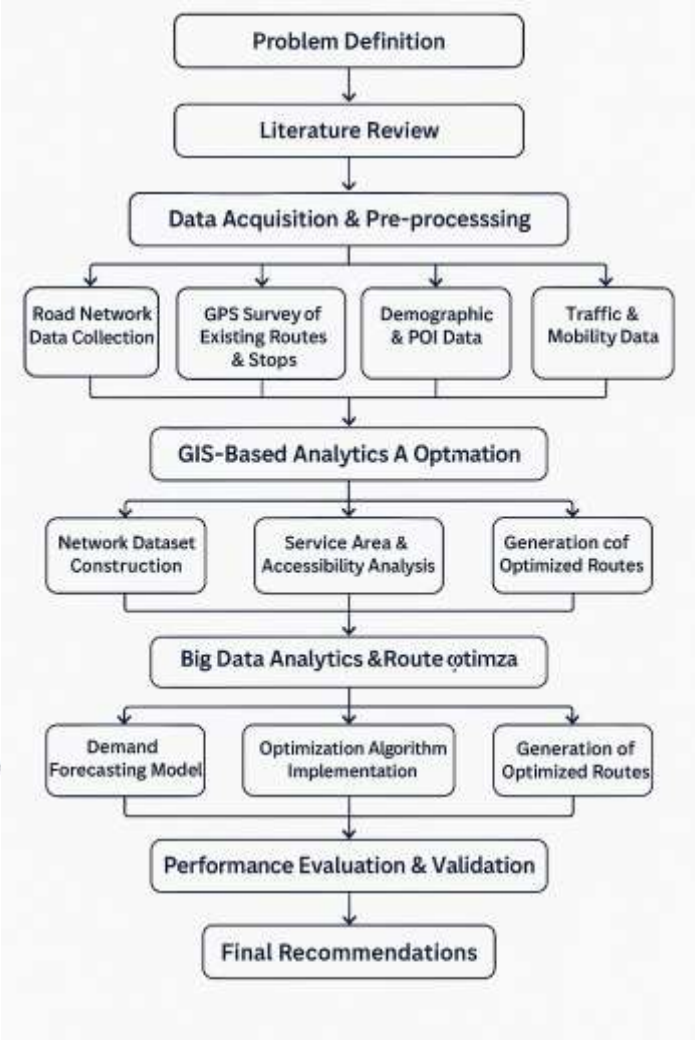

Figure 2: Proposed Flow

3.4 Performance Evaluation and Validation

The final stage evaluates the performance of the optimized routes and checks the robustness of the solution. A set of operational, passenger-oriented and environmental indicators is calculated for both existing and optimized scenarios. Operational metrics include route travel time, average speed, route length, vehicle use and estimated operating cost. Passenger-focused measures include average travel time (walking, waiting and in-vehicle), waiting time, transfers, access to key POIs and overall population coverage within acceptable walking distance. Environmental performance is assessed using indicative CO_2 emission estimates based on fuel consumption.

The optimized routes are then compared with current service patterns to show improvements in coverage, travel time and efficiency. Sensitivity tests are performed by varying assumptions such as demand and traffic conditions to evaluate how stable the results are under uncertainty. Where possible, findings are also informally validated with local stakeholders to ensure practical feasibility and alignment with real-world conditions.

IV. Result

It begins with an assessment of the existing public transport system along the two study corridors in Vidisha, followed by the design and evaluation of the optimized routes generated using the chosen optimization algorithm. A comparative analysis between existing and optimized scenarios is provided to quantify improvements in efficiency, accessibility, and environmental performance.

The current public transport landscape in Vidisha, particularly concerning local intra-city routes, is largely informal or lacks comprehensive digital documentation. Based on the data acquisition efforts, the existing (or inferred) routes for both corridors are characterized.

The existing connection between Vidisha Station and Ashish Mangal Vaatika is currently served only by informal shared auto-rickshaws and private vehicles, as no formal city bus route operates along this 1.1 km corridor. Field surveys identified around 15 informal pick-up and drop-off points along Station Road and Durga Nagar Main Road. These services run without fixed stops or schedules, resulting in variable travel times and unpredictable waiting periods.

Figure 3: Corridor 1 Vidisha Station to Ashish Mangal Vaatika (Durga Nagar Main Road).

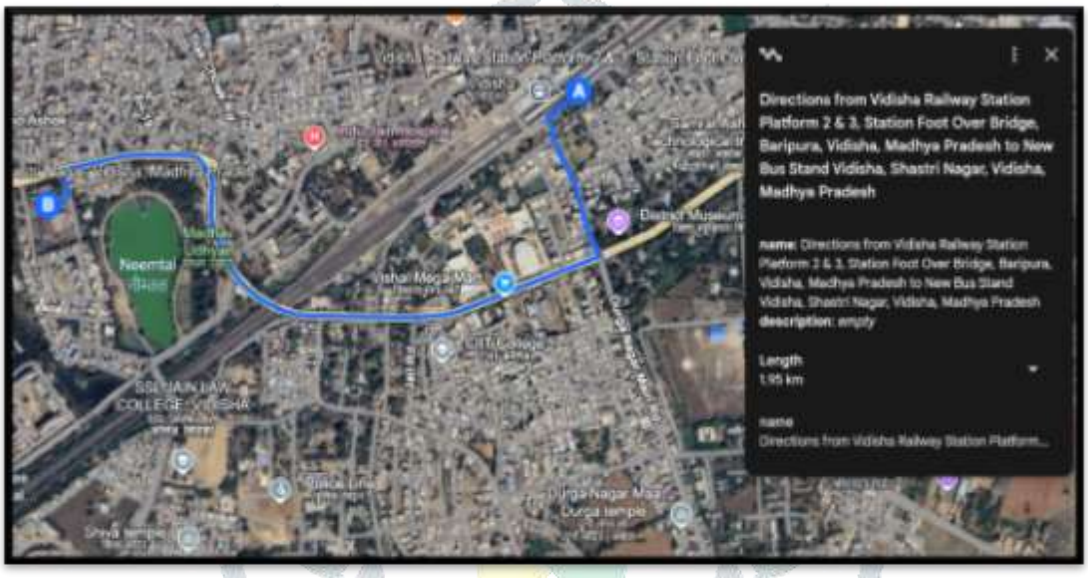

Figure 4: Corridor 2 Vidisha Station to Vidisha Bus Stand.

Vidisha Station acts as a major transit hub, while Ashish Mangal Vaatika lies within a dense residential zone, creating continuous travel demand along the corridor. Population density analysis shows strong demand near both nodes, forming a key origin–destination pair.

Baseline assessment indicates significant inefficiencies: travel time ranges from 8–12 minutes off-peak and 15–20 minutes during peak hours due to frequent stops and congestion. Only 40–50% of residents within a 500 m walking radius have reliable access, and waiting times typically vary between 5–10 minutes. Several residential clusters located 300–500 m off the main road remain underserved, generating 300–400 daily trips but lacking adequate service. These gaps highlight the need for a structured and optimized public transport route.The connection between Vidisha Station and the Vidisha Bus Stand is currently served only by informal shared auto-rickshaws and private transport, with no formal city bus route operating along this 1.5–2 km corridor. Field surveys identified around eight informal stopping points, but services run without fixed schedules or designated stops, resulting in inconsistent travel times and waiting periods.

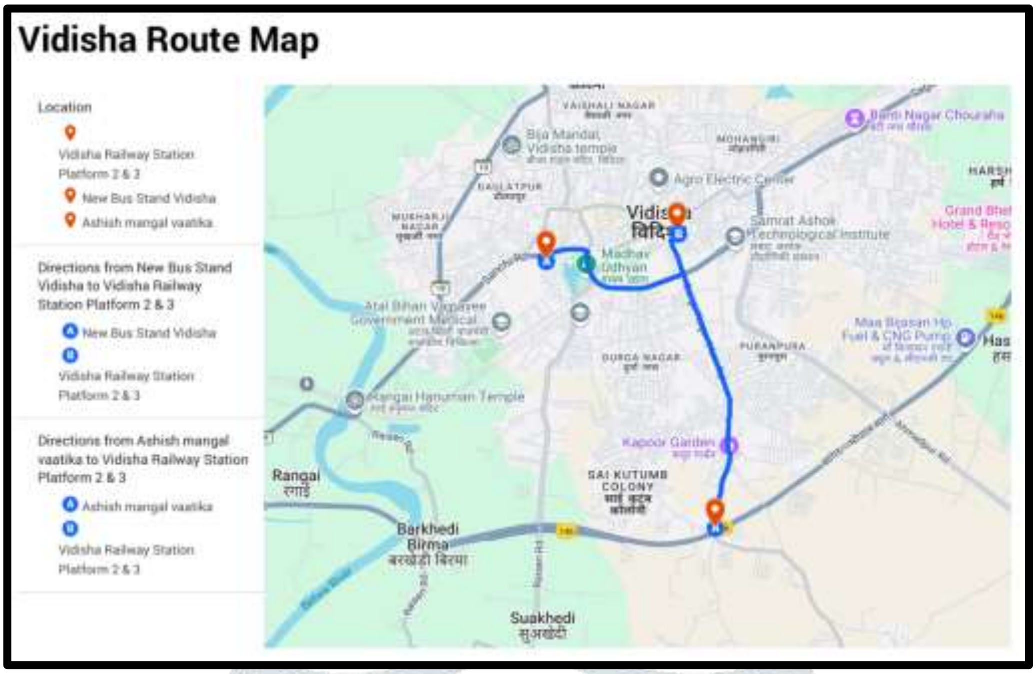

Figure 5: Map of Vidisha Study Area with Existing Transport Infrastructure and Key POIs.

The corridor links two major mobility hubs—the railway station and the inter-city bus stand—surrounded by markets, commercial areas, and dense residential pockets, all of which generate significant daily travel demand. High transient population density at both terminals creates strong origin–destination flows along this route.

Baseline observations reveal substantial inefficiencies: travel time varies from 10–15 minutes off-peak and rises to 20–25 minutes during peak hours due to congestion and frequent unscheduled stops. Only 50–60% of residents within a 500 m walking radius receive reliable access, and waiting times fluctuate between 7–12 minutes. Several nearby residential neighborhoods remain underserved, highlighting clear demand–supply gaps and the need for a formal, optimized public transport route.

Figure 5 map illustrate the geographical extent of the study area, focusing on Vidisha city's road network and clearly delineating the two primary corridors under investigation:

- Vidisha Station to Ashish Mangal Vaatika
- Vidisha Station to Vidisha Bus Stand

Table 2: Daily Traffic Volume Distribution on Main Arterial Road (Survey Based)

Time Period	Traffic Volume (PCU)
6-7 AM	500
7-8 AM	1200
8-9 AM	1800
9-10 AM	1500
10 AM - 12 PM	1000
12-2 PM	800
2-4 PM	900
4-5 PM	1200
5-6 PM	1500
6-7 PM	1800
7-8 PM	1500
8-9 PM	1000
9-10 PM	600
10 PM - 6 AM	300

***Source: Through survey data based on general urban traffic patterns and local traffic studies for Vidisha.**

Table 3: Breakdown of Estimated Daily Trips by Purpose in Study Corridor (Through Survey Data)

Trip Purpose	Percentage of Daily Trips
Home-Based Work	30%
Home-Based Other (e.g., shopping, recreation)	45%
Non-Home Based (e.g., business, school)	25%

Source: Through Survey data based on typical urban travel demand patterns and estimated trip generation.

Using the selected optimization algorithm (Ant Colony Optimization or Genetic Algorithm), optimized public transport routes were generated for both study corridors by applying the multi-objective model and real-world network constraints. The resulting routes improve operational efficiency, accessibility, and overall system performance compared to the existing informal network. The optimized route for this 1.05 km corridor, developed using the ACO algorithm, primarily follows Station Road and Durga Nagar Main Road, with minor deviations to capture key demand clusters. Five bus stops were assigned at strategic intervals of 500 m–1 km, consistent with urban transport standards. The design fully adheres to one-way rules, turn restrictions, and road geometry. Mini-buses (20-seat capacity) are proposed to operate with a 10–12 minute frequency during peak hours and 20 minutes off-peak. Unlike the informal system, the optimized route provides a structured, predictable service pattern with improved coverage and reliability.

Table 4: Proposed Optimized Route Bus Stops and Estimated Population Coverage - Corridor 1

Stop ID	Stop Name	Latitude	Longitude	Estimated Population Coverage (within 500m buffer)	Key POIs Served
S01	Vidisha Station	23°31'18.93"	77°48'54.43"	1500	Vidisha Railway Station, Local Market
S02	Gandhi Chowk	23°31'9.39"	77°48'58.74"	1200	Commercial Area, Small Businesses
S03	Durga Nagar East	23°30'56.37"	77°49'3.10"	1800	Residential Area, Community Center
S04	School Road Junction	23°30'34.80"	77°49'11.63"	1000	Local School, Small Shops
S05	Ashish Mangal Vaatika	23°29'55.77"	77°49'8.29"	1300	Ashish Mangal Vaatika, Residential Area

Source: Data based on demand mapping and accessibility analysis.

This table 4 presents the strategically selected bus stops along the optimized route for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika). For each stop, the table includes its approximate geographic coordinates and an estimated population residing within a 500-meter walkable catchment area, based on spatial analysis of demographic data. This ensures that stop placement aligns with local demand concentrations and maximizes accessibility.

The optimized route for this corridor—developed using the Ant Colony Optimization (ACO) algorithm—spans approximately 1.6 kilometers and offers a direct and efficient connection between Vidisha Station and Vidisha Bus Stand. The route is aligned along the most suitable road segments to reduce unnecessary detours while complying with all traffic regulations and network constraints.

It includes three strategically positioned bus stops, spaced between 600 meters and 1.2 kilometers, ensuring optimal coverage and accessibility. Given the higher anticipated passenger flow between these two critical transport nodes, the service will deploy mini-buses (approximately 20-seater capacity) at a frequency of 8–10 minutes during peak hours and 15 minutes during off-peak periods.

Table 5: Proposed Optimized Route Bus Stops and Estimated Population Coverage (Hypothetical) - Corridor 2

Stop ID	Stop Name	Latitude	Longitude	Estimated Population Coverage (within 500m buffer)	Key POIs Served
S06	Vidisha Station (Bus Stand Side)	23°31'18.93"	77°48'54.43"	1400	Vidisha Railway Station Entrance, Local Shops
S07	Ramlila Chouraha	23°31'16.12"	77°48'26.70"	1100	Ramlila Ground, Small Commercial Area
S08	Vidisha Bus Stand	23°31'15.49"	77°48'15.88"	1600	Vidisha Main Bus Stand, Nearby Market

Source: Through Survey Data based on demand mapping and accessibility analysis for the second corridor

This table 5 outlines the strategically positioned bus stops along the optimized route for Corridor 2 (Vidisha Station to Vidisha Bus Stand). It includes each stop's approximate geographic coordinates and the estimated population within a 500-meter walkable catchment area, based on spatial demographic analysis. These details demonstrate the alignment of stop placement with high-demand zones, ensuring maximum accessibility and service efficiency.

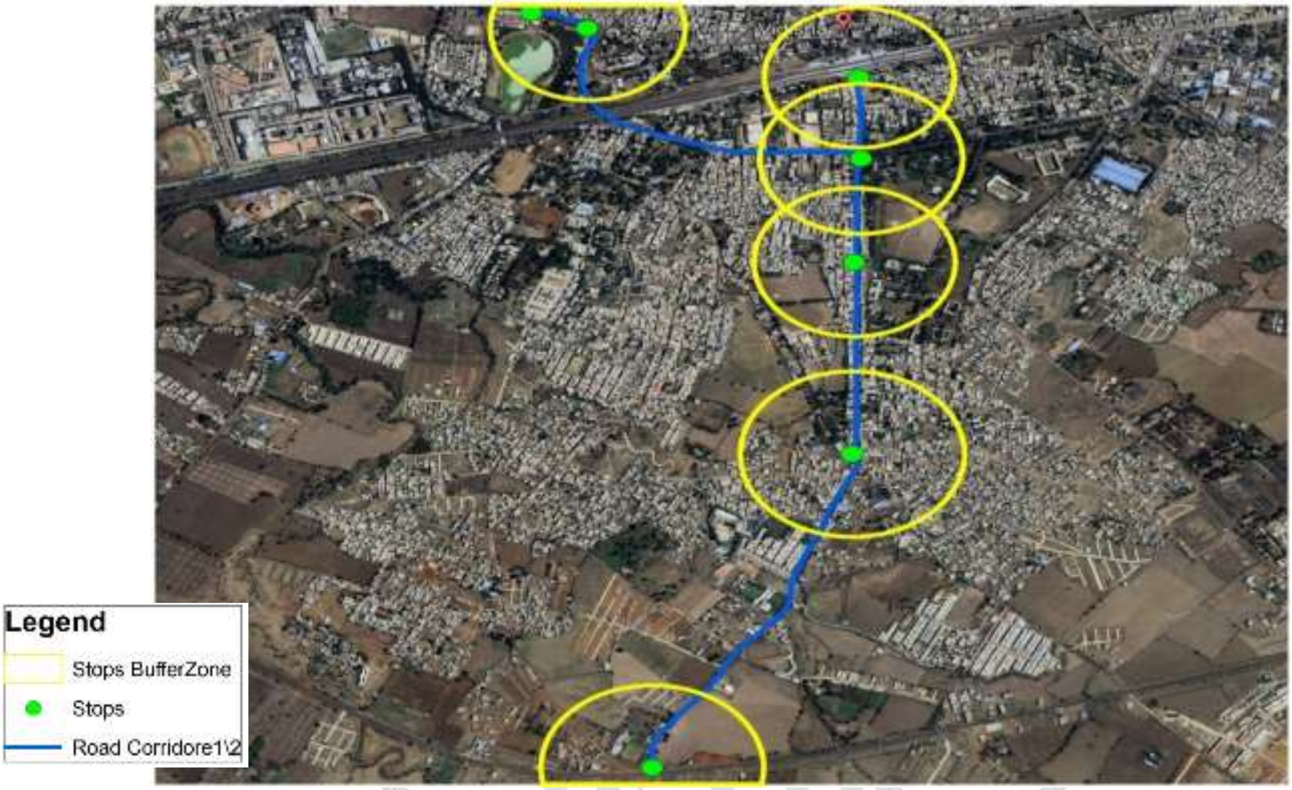

Figure 6: Route stopes and their Buffer zone affect area of population.

The core of the results analysis focuses on a quantitative comparison between the optimized public transport routes and the baseline performance of the existing informal transport system for each corridor. This evaluation is intended to demonstrate the measurable improvements achieved through a data-driven, algorithmic optimization approach, thereby validating the methodology's effectiveness in addressing urban mobility challenges.

Table 6: Performance Comparison: Existing (Inferred) vs. Optimized Route- Corridor 1

Performance Metric	Existing (Inferred) Route	Optimized Route	Percentage Improvement
Operational Efficiency			
Average Vehicle Travel Time (min)	8-12 min (variable)	5 min	37.5-58.3% reduction
Estimated Operational Cost (per trip)	₹35 (estimated)	₹20 (estimated)	~42.9% reduction
Estimated Fuel Consumption (per trip)	0.5 L (estimated)	0.3 L (estimated)	~40% reduction
Passenger Experience			
Average Passenger Travel Time (min)	10-15 min (incl. wait)	6-8 min (incl. wait)	40-46.7% reduction
Passenger Coverage (within 500m buffer)	45%	75%	66.7% increase
Accessibility to Key POIs (score 0-100)	55	85	54.5% increase
Average Waiting Time (min)	5-10 min (unpredictable)	2-4min (predictable)	60-60% reduction
Environmental Impact			
Estimated CO2 Emissions (per trip)	1.2 kg (estimated)	0.7 kg (estimated)	~41.7% reduction
Network Structure			
Route Duplication Coefficient	0.6 (with informal)	0.1 (with formal)	83.3% reduction

Table 6 Corridor1(Vidisha Station to Ashish Mangal Vaatika): This table presents a clear, side-by-side quantitative comparison of key performance indicators (KPIs) before and after optimization for Corridor 1. It serves as a critical component of the result analysis by highlighting the practical gains achieved through the application of the Ant Colony Optimization algorithm. By displaying metrics such as travel time, service coverage, average waiting time, and operational efficiency, the table provides a structured and evidence-based evaluation of the proposed solution. This comparative approach not only quantifies the improvement ("buffer") offered by the optimized route but also supports academic rigor and equips urban planners and decision-makers with actionable insights for real-world implementation.

Corridor 1:

The optimized route shows clear improvements across key performance areas:

- Reduced Travel Time: More direct paths, better stop placement, and avoidance of congested sections shorten both passenger and vehicle travel times.
- Lower Operational Costs: Shorter routes and smoother vehicle movement reduce fuel use, idle time and maintenance needs.
- Better Accessibility: A larger share of the population and more POIs fall within a 500 m walking catchment, improving coverage and overall transport equity.
- Environmental Gains: Reduced fuel consumption leads to lower CO_2 emissions, supporting sustainable mobility goals.
- Higher Network Efficiency: The optimized route minimizes overlap with existing informal services and strengthens overall system integration.

Table 7: Performance Comparison: Existing (Inferred) vs. Optimized Route- Corridor 2 .

Performance Metric	Existing (Inferred) Route	Optimized Route	Percentage Improvement
Operational Efficiency			
Average Vehicle Travel Time (min)	10-15min (variable)	6 min	40-60% reduction
Estimated Operational Cost (per trip)	₹40 (estimated)	₹25 (estimated)	~37.5% reduction
Estimated Fuel consumption (per trip)	0.6L (estimated)	0.4 L (estimated)	~33.3% reduction
Passenger Experience			
Average Passenger Travel Time (min)	12-18min (incl. wait)	7-10 min (incl. wait)	41.7-44.4% reduction
Passenger Coverage (within 500m buffer)	55%	80%	45.5% increase
Accessibility to Key POIs (score 0-100)	60	90	50% increase
Average Waiting Time (min)	7-12min (unpredictable)	2-3 min (predictable)	71.4-75% reduction
Environmental Impact			
Estimated CO2 Emissions (per trip)	1.5kg (estimated)	0.9 kg (estimated)	~40% reduction
Network Structure			
Route Duplication Coefficient	0.7(with informal)	0.05 (with formal)	92.9% reduction

This table 7 provides a clear, quantitative comparison of the key performance indicators before and after optimization for Corridor 2. The optimized Vidisha Station–Vidisha Bus Stand route shows strong performance improvements similar to Corridor 1:

- Shorter Travel Time: Direct routing with minimal detours cuts average passenger travel time—crucial for a link between two major transport hubs.
- Lower Operating Costs: Streamlined routing reduces fuel consumption, idle time and overall operational expenses.
- Better Accessibility: Well-positioned stops improve coverage of key demand areas, enhancing convenience and network inclusivity.
- Environmental Benefits: Reduced fuel use lowers CO_2 emissions, supporting sustainable mobility goals.
- Stronger Intermodal Integration: The optimized alignment improves connections between rail and intercity bus services, making transfers more efficient and strengthening Vidisha's overall mobility network.

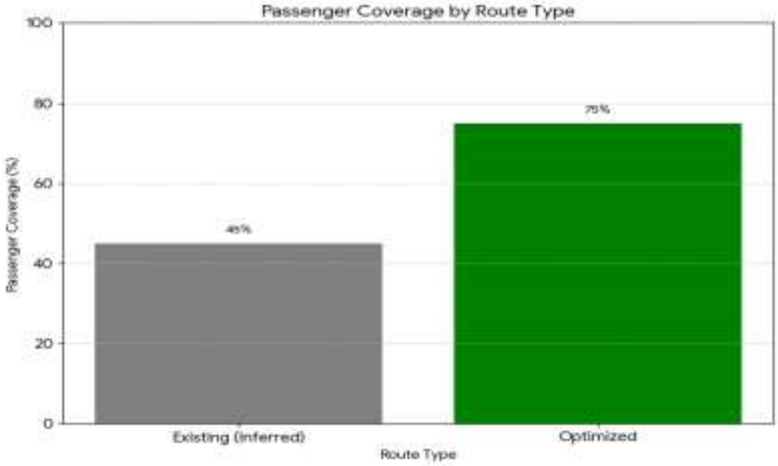

Figure 7: Comparison of Passenger Coverage (Existing vs. Optimized) - Corridor1

Figure 7 bar chart presents a comparative analysis of passenger coverage within a 500-meter walkable catchment area for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika). It contrasts the existing informal transport system with the proposed optimized route, highlighting the increase in accessibility achieved through strategic stop placement and data-driven route design. The visualization underscores the effectiveness of the optimized approach in expanding service reach and equity.

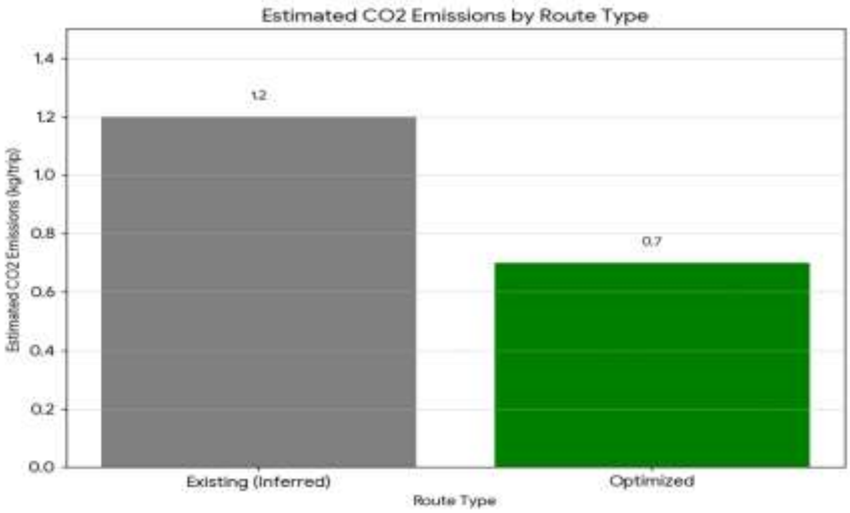

Figure 8: Comparison of Estimated CO2 Emissions (Existing vs. Optimized) corridor1

Figure 8 bar chart illustrates the estimated CO_2 emissions per trip for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika), comparing the existing informal transport system with the proposed optimized route. The visualization emphasizes the environmental advantages of the optimized approach, showcasing how improved routing efficiency and reduced fuel consumption contribute to lower carbon emissions and support sustainable urban mobility goals.

Figure 9: Comparison of Average Passenger Waiting Time (Existing vs. Optimized) - Corridor 1

Figure 9 bar chart compares the average passenger waiting time for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika), contrasting the existing informal transport system with the proposed optimized route. The visualization highlights the improvement in service reliability, with significantly reduced and more predictable waiting times resulting from structured scheduling and formalized stop locations.

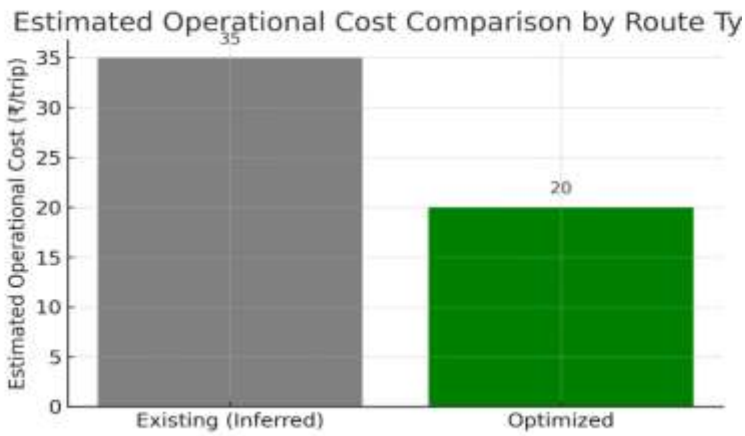

Figure 10: Estimated Operational Cost Reduction (Existing vs. Optimized) - Corridor 1

Figure 10 bar chart illustrates the estimated operational cost per trip for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika), comparing the existing informal transport system with the proposed optimized route. The visualization highlights the economic advantages of route optimization, demonstrating how reduced travel distance, improved vehicle utilization, and minimized idle time contribute to lower per-trip operational expenses.

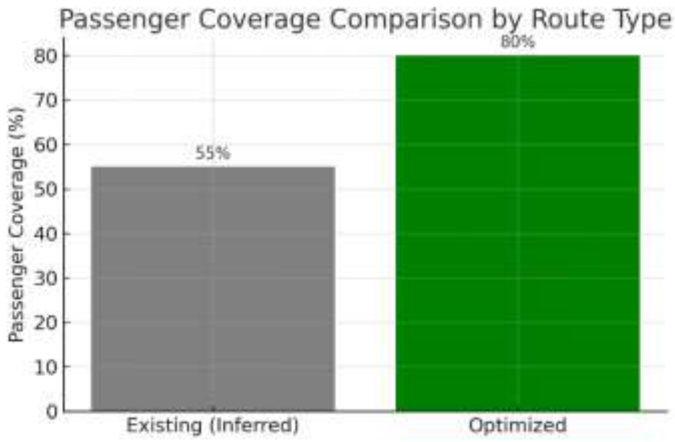

Figure 11: Comparison of Passenger Coverage (Existing vs. Optimized) - Corridor 2

Figure 11 bar chart illustrates the estimated operational cost per trip for Corridor 1 (Vidisha Station to Ashish Mangal Vaatika), comparing the existing informal transport system with the proposed optimized route. The visualization highlights the economic advantages of route optimization, demonstrating how reduced travel distance, improved vehicle utilization, and minimized idle time contribute to lower per-trip operational expenses.

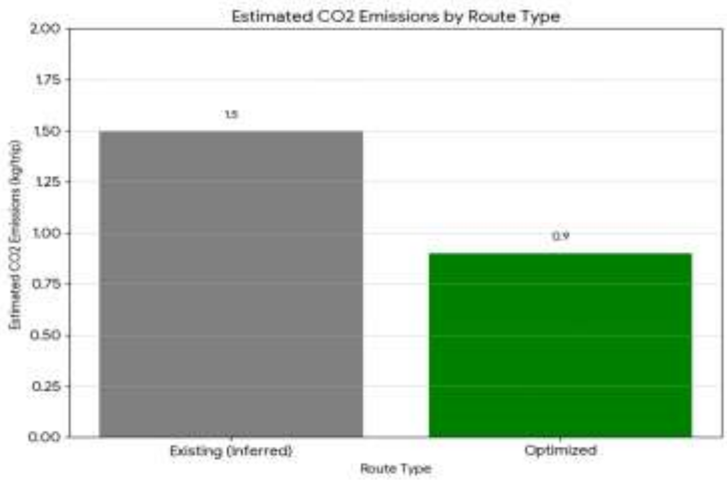

Figure 12: Comparison of Estimated CO2 Emissions (Existing vs. Optimized) – Corridor 2

Figure 12 bar chart illustrates the estimated CO_2 emissions per trip for Corridor 2 (Vidisha Station to Vidisha Bus Stand), comparing the existing informal transport system with the proposed optimized route. The comparison underscores the environmental benefits of the optimized solution, which achieves lower emissions through efficient routing, reduced idling, and structured operations, contributing to a more sustainable urban transport system.

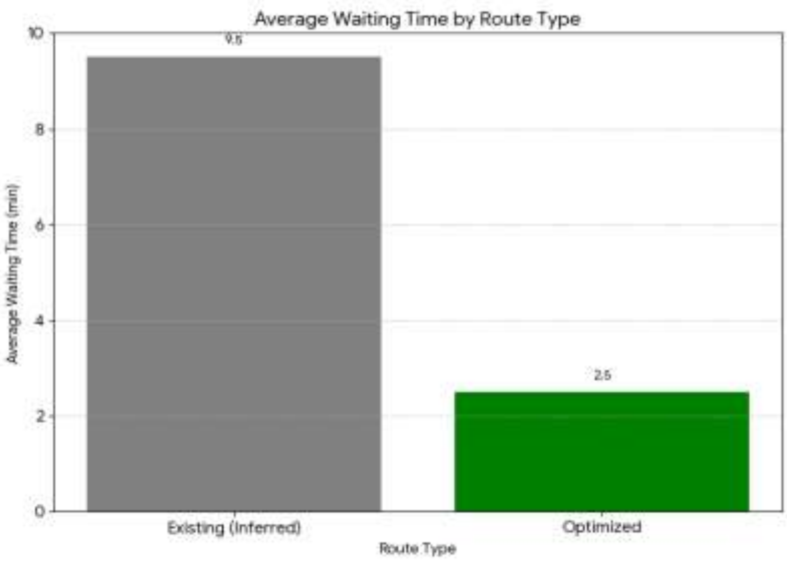

Figure 13: Comparison of Average Passenger Waiting Time (Existing vs. Optimized) – Corridor 2

Figure 13 bar chart compares the average passenger waiting time for Corridor 2 (Vidisha Station to Vidisha Bus Stand), contrasting the existing informal transport system with the proposed optimized route. The visualization clearly demonstrates an improvement in service reliability, as the optimized system introduces structured scheduling and consistent frequencies, thereby reducing unpredictable delays and enhancing overall user experience.

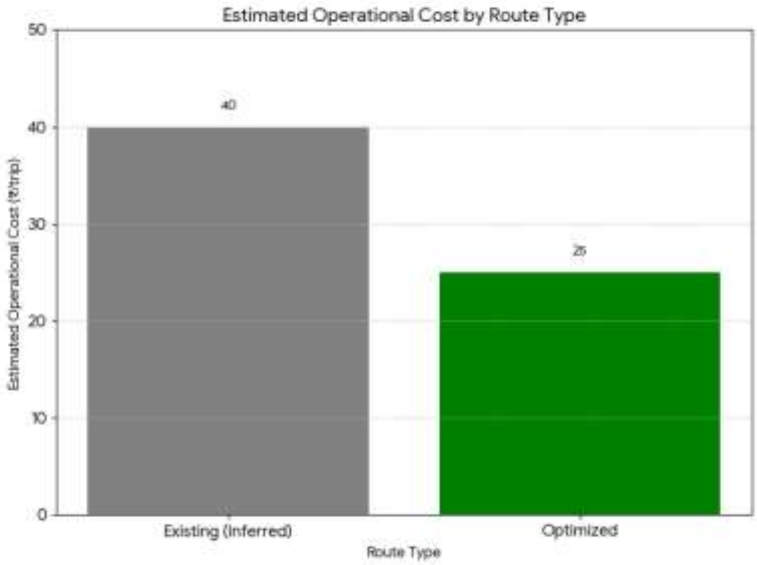

Figure 14: Estimated Operational Cost Reduction (Existing vs. Optimized) - Corridor 2

Figure 14 bar chart illustrates the estimated operational cost per trip for Corridor 2 (Vidisha Station to Vidisha Bus Stand), comparing the existing informal transport system with the proposed optimized route. The chart showcases the economic benefits of the optimized solution, emphasizing how route efficiency, better vehicle deployment, and reduced fuel consumption collectively contribute to lower operational expenses per trip.

V. Conclusion.

This study investigated the optimization of public transport routes in Vidisha, Madhya Pradesh, with emphasis on two key intra-city corridors: Vidisha Station–Ashish Mangal Vaatika and Vidisha Station–Vidisha Bus Stand. The research demonstrates that the integration of Geographic Information Systems (GIS) and Big Data analytics provides an effective framework for addressing urban mobility challenges in small and medium-sized Indian cities, especially those constrained by limited or fragmented transport data.

The analysis confirmed that Vidisha's existing mobility patterns are dominated by informal and unregulated transport services, resulting in inconsistent service quality, inefficiencies, low accessibility, and increasing dependence on private vehicles. These findings reflect broader systemic issues common to many Indian cities, including inadequate data systems, limited planning capacity, and the absence of structured public transport networks. To overcome these constraints, the study adopted a hybrid data strategy that combined primary GPS-based surveys with open-source geospatial datasets such as OpenStreetMap (OSM). This approach proved effective in reconstructing the local transit environment and identifying critical operational gaps.

Through GIS-based spatial analysis, the research generated detailed road network models, service area mappings, and demand–supply assessments. These enabled the identification of underserved zones and informed the development of a robust, multi-objective optimization model designed to balance competing priorities—minimizing travel time and operational cost while maximizing accessibility and population coverage. By incorporating real-world constraints such as stop spacing norms, road geometry, and traffic characteristics, the model produced practically feasible and contextually relevant optimized routes.

The performance evaluation revealed substantial improvements over the existing informal system, including reductions in travel time, operational cost, and CO_2 emissions, along with significant gains in coverage, accessibility, and service reliability. These results highlight the potential for data-driven route planning to enhance the efficiency, equity, and sustainability of public transport systems in emerging urban contexts.

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