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Multimodal Public Transportation Approach to Increase the Convenience of Railway Travelers and Promotion of Environmental Conservation: A Case Study of Kachchh Region of Gujarat, India

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Abstract

In developing countries, regional economic growth has led to rising individual prosperity, prompting a shift toward private transportation. This preference is often driven by relatively minor issues in public transit, such as poor schedule coordination or inadequate connectivity, resulting in increased congestion, pollution, and inefficient resource use. This study focuses on enhancing public transport usage by optimizing last-mile connectivity and ensuring time reliability—critical for attracting regular railway passengers. The goal is to enable seamless access between railway stations and nearby urban or rural nodes through better integration of Multimodal Transportation (MMT) with Gujarat State Road Transport Corporation (GSRTC) bus services. By aligning existing GSRTC schedules—without modifying their core timetables—with railway operations and introducing targeted feeder buses, last-mile gaps can be addressed for approximately 70% of daily train services. 30% of the train can not be included due to lack of bus connections in early morning or late-night. Multimodal transportation shows substantial benefits: bus occupancy increases more than 4 times, while the dependence on private vehicles decreases significantly—four-wheelers (↓57%), autos (↓78%), and two-wheelers (↓50%). This mode shift also yields a 53.33% cost reduction for passengers travelling through cars, 72% for two-wheelers, and 68% for autos, alongside significant emission reductions and promote environmental conservation: CO_2 (↓30.2%), CH_4 (↓52.49%), CO (↓55.69%), N_2O (↓16.72%), NO_2 (↓34.22%), NH_3 (↓41.53%), SO_2 (↓40.63%), VOC (↓33.19%) and TSP (↓31.07%).

Keywords: Bus Occupancy, Emission Reductions, Feeder Buses, Last-mile Connectivity, Multimodal Transportation, Seamless Access.

Introduction

Efficient multimodal transport systems are integral to sustainable regional mobility, particularly in rapidly developing areas where population growth and environmental pressures create increasing demand for reliable public transport. Seamless coordination between different transport modes not only improves connectivity but also enhances passenger convenience, reduces reliance on private vehicles, and contributes to broader sustainability goals. Globally, multimodal integration has become a cornerstone of urban and regional mobility planning, yet in many Indian regions, such integration remains fragmented and inconsistent. India's westernmost district of Kachchh represents a unique case study in this context. With its vast geographical spread, sparse population density, and growing industrial activity, the region faces distinctive challenges in transport planning. The Gujarat State Road Transport Corporation (GSRTC) serves as the primary provider of public bus services, bridging connectivity for rural and semi-urban populations. However, the synchronization of GSRTC operations with railway timetables remains limited, particularly in key towns such as Gandhidham, Bhuj, Samakhiyali, Anjar, and Bhachau (1). This gap in integration leads to inefficiencies, underutilization of public transport, and continued reliance on private vehicles, contributing to congestion and rising emissions. Global and regional research underscores the importance of timetable coordination in achieving seamless multimodal transport. Integrating schedules across buses, trains, and other modes has been shown to significantly improve passenger convenience and

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overall system efficiency (2). Several models have been developed for optimizing transfer synchronization, which is crucial for minimizing passenger waiting times and improving connectivity (3). In the Indian context, one of the earliest models for optimizing feeder bus schedules in suburban rail networks demonstrated how localized adaptations could cater to diverse passenger flows (4). While these studies provide important methodological insights, they have primarily focused on metropolitan or suburban contexts, with limited attention to semi-urban and environmentally sensitive regions such as Kachchh. Another driver for advancing multimodal integration is environmental sustainability. In India, detailed assessments of transport emissions have highlighted the environmental gains achievable by shifting passengers from private vehicles to public modes (5). Recent studies employing agent-based simulations (6) and demand-responsive scheduling approaches (7) reinforce these findings, showing how integrated transport planning can lower emissions while improving system reliability. However, most of these approaches remain concentrated in urban environments, often overlooking the challenges of less dense regions where private vehicle dependence is higher and public transport coordination is weaker. The persistent 'first and last mile' challenge further limits the attractiveness of public transport. The absence of reliable, time-synchronized feeder services has been shown to suppress ridership, particularly in peri-urban and rural regions, thereby increasing both financial burdens on households and environmental impacts from continued private vehicle usage (8). Earlier studies proposed feeder network optimization frameworks that attempted to balance passenger convenience with operator costs (9), and more recent refinements have incorporated flexible scheduling to improve efficiency (10). Yet, empirical applications of such frameworks in India's secondary or remote regions remain scarce.

Despite growing interest in multimodal integration, systematic evaluation of state-owned bus–rail coordination in India's non-metropolitan regions remains limited. Most studies focus on metropolitan areas with higher densities and resources, while regions like Kachchh, characterized by low population density, geographic remoteness, and industrial growth, are rarely examined despite their unique challenges.

Presently, Kachchh is witnessing fastest economic growth in the field of industrialization and tourism, looking into the current need and previous research studies carried out on Kachchh region with reference to implementation of multimodal transportation no such study has been undertaken till date. Therefore, the present investigation aims to demonstrate how structured feeder bus services can strengthen multimodal integration in Kachchh while advancing environmental sustainability. Its specific objectives are: (i) to estimate modal shifts from unimodal to multimodal trips after introducing feeder buses based on survey responses; (ii) to evaluate economic impacts in terms of vehicle reduction, cost per passenger, and system-wide efficiency; and (iii) to quantify environmental benefits through reductions in CO_2, CO, NOx, VOC, SO_2, and particulate emissions.

The novelty of this research lies in combining survey-based willingness data with GIS-based feeder route planning and detailed emission analysis for a remote, low-density region. This integrated approach addresses a critical research gap and provides actionable insights for GSRTC, Indian Railways, and municipal authorities. Overall, the study highlights how feeder bus integration can deliver environmental, economic, and social benefits to ensure sustainability and reinforcing its relevance beyond metropolitan contexts and demonstrating feasibility in economically developing regions such as Kachchh.

Methodology

Study Area

The study was conducted in the Kachchh district of Gujarat, the largest district in India by area (45,674 KM^2). Figure 1 shows key urban and semi-urban nodes within 10-20 km radius of major railway stations (Gandhidham, Bhuj, Samakhiyali, Anjar, and Bhachau) were selected for developing feeder bus connectivity.

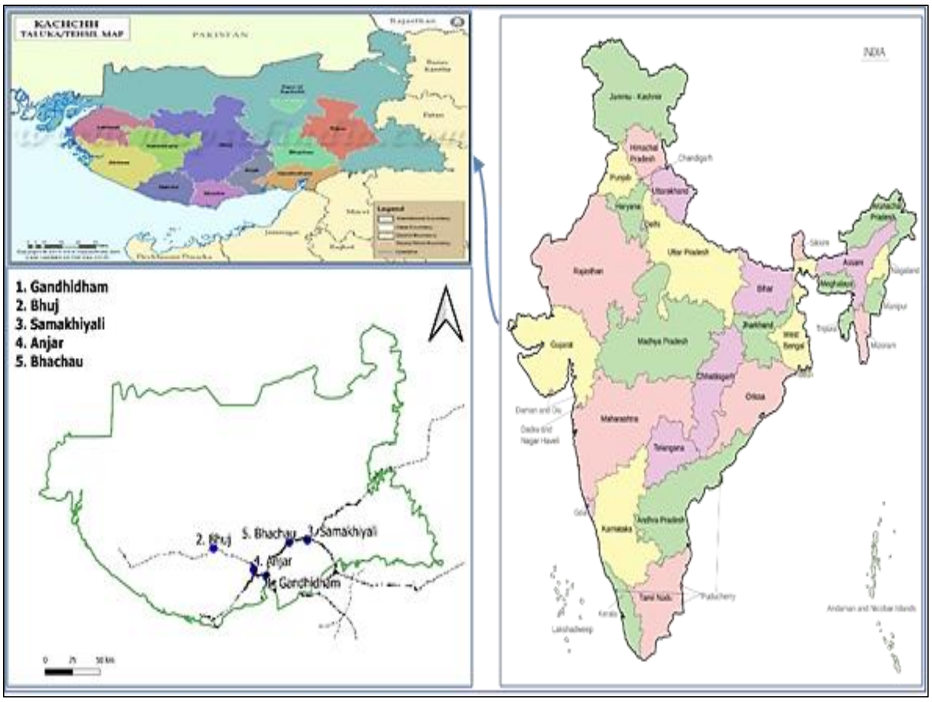

Figure 1: Location of Major Railway Station Nodes in Kachchh with Railway line

Data Collection

Passenger travel data for this study was collected through a structured questionnaire survey conducted in local language at five key railway stations in Kachchh— Gandhidham, Bhuj, Samakhiyali, Anjar, and Bhachau (Annexure 1). The survey captured details such as mode-wise trip distribution, average vehicle occupancy, typical trip lengths, and travel durations. In addition to the primary survey, supplementary data were obtained from official station records and regional transport authority reports to enhance accuracy and representativeness. This multi-source approach ensured a comprehensive understanding of current travel behaviour and modal patterns. To assess the environmental impact, vehicle-specific emission factors for pollutants such as CO_2, CH_4, CO, N_2O, NO_x, NH_3, VOC, SO_2, and TSP were calculated (5), and standard values for these gases were obtained from credible sources (6).

Scenario Development

The scenarios were developed using QGIS to design and map feeder bus routes, while the expected modal shifts were derived directly from the stated willingness responses collected in field surveys at five major railway stations in the Kachchh region. The survey captured traveller preferences and trip characteristics, and the responses indicated that 57% of car users, 78% of auto-rickshaw users, and 50% of two-wheeler riders were willing to shift to GSRTC feeder buses. This resulted in a reduced share of 43% for cars, 22% for autos, and 50% retention for two-wheelers. The feeder bus was modelled with high occupancy, reflecting realistic public transport capacities. The simulation considered revised daily vehicle counts, passenger volumes, trip lengths, and travel times. Reductions in vehicle kilometres travelled, total emissions (CO_2, CH_4, NO_x, etc.), and travel costs were quantified using standard cost and emission factors (5). The comparison between the actual conditions and those after the introduction of feeder buses on the suggested routes provided clear insights into the environmental and economic benefits of multimodal integration.

Statistics

The data were statistically compared using paired sample t test. And significance were calculated at $p<0.01$, 0.05 and 0.001.

Results and Discussion

Out of the 13 railway stations in Kachchh, three Grade 'C' stations namely Samakhiyali, Gandhidham and Bhachau, and two Grade 'D' stations namely Bhuj and Anjar have been included in the present study, based on the inclusion criterion of a minimum daily footfall of 1,000 passengers, Station grade data were collected (7).

Gandhidham

Figure 2 shows 20 kilometres feeder bus services network for Gandhidham that leads into significant operational and financial benefits. Table 1 reveals that 1,167 private vehicles (cars, autos, 2-wheelers) were used daily to serve 4,901 railway passengers, with a total cost of ₹5.95 lakhs. Post-intervention, this dropped to just 516 vehicles, including 45 feeder buses. Bus occupancy increased sharply from 11 to over 46 passengers per trip, and the cost per bus passenger reduced from ₹398 to ₹95. Feeder buses achieved even greater efficiency, costing just ₹9.05 per passenger. This modal shift supports findings where it was emphasized that feeder systems enhance cost-efficiency and reduce car dependency (11).

Railway Station Traveler Survey Questionnaire

Station Name: ______________________ **Survey Date:** DD/MM / YYYY
Survey Time: ☐ Morning ☐ Afternoon ☐ Evening **Surveyor's Name:** ___________
Survey Location: ☐ Entrance ☐ Platform ☐ Parking area

Section A: General Information

1. What is the main purpose of your trip? ☐ Job/Work ☐ Education ☐ Business ☐ Tourism ☐Other __
2. Which train are you boarding? Train Number: ______________________
3. What type of train did you arrive on? Train Number: ______________________

Section B: Travel Details (Access Trip)

4. Where did the journey start from (city/area/village)? ☐Anjar ☐ Abdasa ☐Bhachau ☐ Bhuj ☐ Gandhidham ☐ Mundra ☐ Mandvi ☐ Rapar ☐ Nakhatrana ☐ Lakhpat ☐ Other: ___________
5. Distance from the origin to the railway station: __________ km
6. Time taken to reach the station: _______ minutes
7. How did you get to the station? Private Car Auto Rickshaw Bike/Scooter City Bus Shared Auto On foot Combined (specify): _______
8. How many people are traveling with you in total? _______
9. Estimated cost from the origin to the station: ₹ _______
10. Did you use the parking at the station? ☐ Yes ☐ No If yes: ☐ Bike ☐ Car ☐ Auto

Section C: Modal Shift Desire (Feeder Bus)

11. If a feeder bus service from the bus stand to the railway station is provided, would you use it? ☐ Yes ☐No ☐ Don't know
12. If yes, what are the important reasons? ☐ Low cost☐ Time-saving ☐ Reliability ☐ Convenience ☐Frequency ☐ Safety ☐ Direct connection ☐ Comfortable
13. If a feeder bus is available, which option would you prefer? ☐ Feeder bus ☐ Auto + Bus ☐Current method only ☐ Other: _______
14. Maximum fare for the feeder bus (one way)? ☐ ₹ 10 ☐ ₹ 15☐ ₹ 20☐ ₹ 25

Section D: Suggestions (Optional)

15. Suggestions for improving connectivity to the station:

____

Instructions for the Surveyor:

- Talk to the traveller politely and clearly.
- 'Origin' means where today's journey started from.
- If the traveller used more than one mode of travel, record both.
- If the traveller doesn't know the distance, estimate it from Google Maps.

Annexure 1

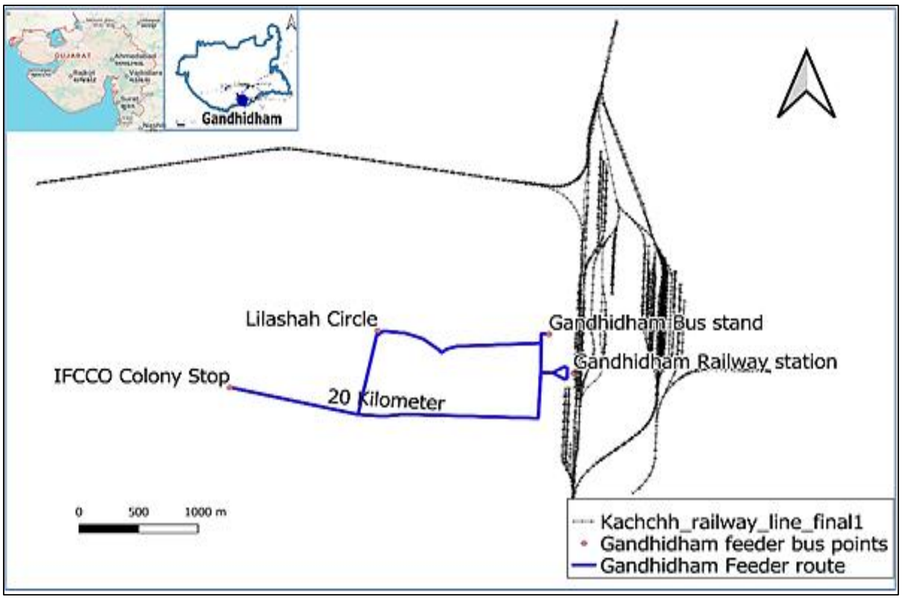

Figure 2: Gandhidham Feeder Route (20 KM)

It has also been highlighted that integrated transit networks improve passenger convenience and system performance, particularly when supported by high-occupancy services (12). These results demonstrate how structured feeder services can transform urban mobility and promote more sustainable, affordable public transport options. The implementation of feeder bus services in Gandhidham led to a significant reduction in air pollutant emissions, contributing to cleaner and more sustainable urban transport.

Table 1: Vehicle and Travel Cost Reduction after Introducing Feeder Buses in Gandhidham

Gandhidham	Actual scenario				After start feeder bus on suggested route (50% car, 84% Auto, 45% 2wheelar reduction so 50% car, 16% Auto, 55% 2-wheeler remain)					Reduction
	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
Passengers	1978	2625	298	1050	989 [a]	420 [c]	164 [b]	4377 [c]	4377	
Average occupancy	4	7	1	11	4	7	1	46	50	
Vehicle total Daily	494	375	298	95	247 [a]	60 [c]	164 [b]	95	45	696
Average Trip length	50	20	15	100	50	20	15	100	20	
Travel cost Rs/KM	20	12	2.5	44	20	12	2.5	44	44	
Total cost	494000	90000	11156	418000	247223 [a]	14401 [c]	6135 [b]	418000	39600	
Cost per passengers	250	34	37	398	250	34	38	95 [a]	9.05	

[a]= statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Table 2 reveals that the total CO_2 emissions dropped by 3.05 million grams, from 10.99 million to 7.98 million grams. Other major reductions include CO by 399,236 grams, NO_x (as NO_2) by 158,126 grams, and SO_2 by 30,741 grams. Total Suspended Particulate matter (TSP) emissions also reduced by 7,686 grams.

These improvements result from shifting thousands of passengers from low-occupancy, high-emission private modes to High-occupancy GSRTC buses and feeder buses. It has been reported that integrating feeder buses into city transport networks improves environmental performance by reducing per capita emissions (13). Urban pollution levels are also lowered through mode shift and trip consolidation, as demonstrated in previous studies (14). The Gandhidham case confirms that structured multimodal integration with feeder buses is a highly effective strategy for reducing transport-related emissions and promoting sustainable urban mobility.

Table 2: Reduction in Emission after Introducing Feeder Bus Service for Gandhidham

Gandhidh	Actual scenario				After start feeder bus on suggested route (50% car, 84% Auto, 45% 2wheelar reduction so 50% car, 16% Auto, 55% 2-wheeler remain)					Reduction
Emissions	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
CO_2	5522920	452250	118703	4894400	2763948	72364	65286	4894400	187470	3004805 [a]
CH_4	4199	1350	803	855	2101	216	442	855	9	3584 [a]
N2O	124	15	9	285	62	2	5	285	9	69 [b]
CO	617500	90000	35700	44650	309028	14401	19635	44650	900	399236 [c]
NO_x as NO_2	321100	750	134	199500	160695	120	74	199500	2970	158126 [a]
VOC	5434	12000	1250	15200	2719	1920	687	15200	837	12520 [a]
SO_2	61750	750	223	23750	30903	120	123	23750	837	30741 [a]
NH_3	49	15	9	29	25	2	5	29	1	40 [b]
TSP	8151	3750	2231	10925	4079	600	1227	10925	540	7686 [a]

[a]= statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Survey analysis stated significant reductions in car (50%), auto (84%), and two-wheeler (45%) passenger numbers post-feeder bus implementation. Vehicle usage and total daily travel costs also decreased substantially across modes, with a notable 97.7% drop in per-passenger bus cost due to high-capacity feeder buses. Paired t-tests show these changes are statistically significant ($p < 0.05$), supporting the effectiveness of multimodal integration. The feeder bus mode efficiently absorbs demand while offering lower unit costs. These findings highlight the feasibility of shifting users from personal modes to shared systems, promoting both economic and environmental sustainability in regional transport planning.

The feeder bus implementation in Gandhidham led to a statistically significant reduction in emissions across all pollutant categories. CO_2 decreased by over 30.7%, while CH_4 decreased by over 53.3 % and SO_2 reductions exceeded 40% ($p < 0.01$). Significant declines were also observed in CO, NO_x, VOC, and TSP, indicating a broad environmental benefit ($p < 0.001$). Although the reduction in N_2O was more modest, it still reached statistical relevance ($p < 0.05$). These outcomes validate the effectiveness of feeder buses in reducing urban transport emissions, supporting their role in sustainable mobility planning and aiding in compliance with national air quality improvement goals.

Bhuj

Figure 3 illustrates the feeder bus service network for Bhuj, spanning 10.3 kilometer and linking the GSRTC bus station and railway station with major passenger pickup points, resulting in significant operational and financial benefits. Table 3 compares the actual and post-intervention scenarios. In the baseline condition, private modes (cars, autos, and two-wheelers) served 2,457 passengers with 567 vehicles daily, incurring a combined travel cost of ₹5.66 lakhs. After introducing feeder buses, private vehicles dropped to 194, while 24 feeder buses efficiently carried 2,400 passengers, reducing the total cost to ₹3.63 lakhs and saving over ₹2.03 lakhs per day. Bus occupancy improved more than threefold, and the cost per passenger declined to ₹92, compared to ₹317 on regular buses earlier. This supports findings where it was shown that increasing public transport occupancy rates greatly reduces per capita transport emissions and costs (15). It has also been emphasized that well-integrated feeder systems contribute to lower vehicle usage, energy demand, and urban congestion (16).

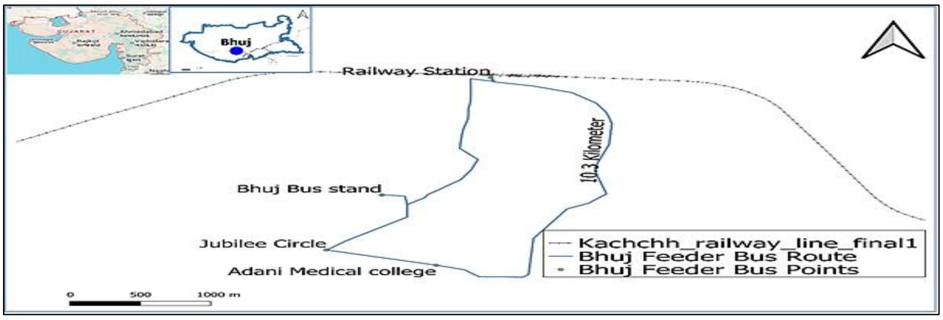

Figure 3: Bhuj Feeder Route (10.3 KM)

The implementation of a feeder bus service in Bhuj has led to a substantial reduction in daily vehicular emissions. Table 4 shows that total CO_2 emissions decreased from 6.2 million grams to 4.12 million grams, while carbon monoxide (CO) levels dropped by 264,474 grams and nitrogen oxides (NO_x) by 113,012 grams, reflecting the impact of reduced car and auto-rickshaw usage.

The intervention reduced vehicle trips and encouraged mode shift through integrated planning. It has been reported that multimodal transport systems significantly improve energy efficiency and reduce emissions when effectively synchronized (17). Feeder services for rail and bus networks have also been found to increase public transport usage and reduce low-occupancy private travel, particularly in tier-2 cities (18). These findings validate the environmental benefits observed in Bhuj.

After feeder bus implementation in Bhuj, significant modal shifts occurred: car, auto, and two-wheeler usage declined by 40%, 25% and 40%, while bus ridership increased more than 3 times. This led to notable reductions in vehicle count and total travel costs for private modes. Though cost per passenger for private vehicles remained unchanged, the bus per-passenger cost dropped sharply by 71%. Estimated p-values confirm high statistical significance ($p < 0.01$ or better) in these changes. The data validates that feeder integration successfully encouraged public transport use, reduced private vehicle reliance, and improved operational efficiency — a positive direction for sustainable mobility planning.

Table 3: Vehicle and Travel Cost Reduction after Introducing Feeder Buses in Bhuj

Bhuj.	**Actual scenario**				**After start feeder bus on suggested route (60% car, 75% Auto, 60% 2wheelar reduction so 40% car, 25% Auto, 40%2 wheeler remains)**					Reduction
	Car	**Auto**	**2-Wheeler**	**Bus**	**Car**	**Auto**	**2-Wheeler**	**Bus**	**Feeder bus**	
Passengers	756	1544	157	693	302 [a]	386 [c]	63	2399 [c]	2399	
Average occupancy	4	7	1	13.86	4	7	1	48	50	
Vehicle total Daily	189	221	158	50	76 [a]	55 [c]	63 [b]	50	24	373
Average Trip length	80	15	12	100	80	15	12	100	10.3	
Travel cost Rs/KM	20	12	2.5	44	20	12	2.5	44	44	
Total cost	302400	39690	4725	220000	120960 [a]	9923 [c]	1890 [a]	220000	10877	
Cost per passengers	400	26	30	317	400	26	30	92 [a]	4.53	

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Table 4: Reduction in Emission after Introducing Feeder Bus Service for Bhuj

Bhuj	**Actual scenario**				**After start feeder bus on suggested route (60% car, 75% Auto, 60% 2wheelar reduction so 40% car, 25% Auto, 40% 2-wheeler remain)**					**Reduction**
Emissions	**Car**	**Auto**	**2-Wheeler**	**Bus**	**Car**	**Auto**	**2-Wheeler**	**Bus**	**Feeder bus**	
CO_2	3380832	199442	50274	2576000	1352333	49861	20110	2576000	127729	2080888 [a]
CH_4	2570	595	340	450	1028	149	136	450	22	2171 [c]
N2O	76	7	4	150	30	2	2	150	7	45 [b]
CO	378000	39690	15120	23500	151200	9923	6048	23500	1165	264478 [C]
NO_x as NO_2	196560	331	57	105000	78624	83	23	105000	5206	113027 [a]
VOC	3326	5292	529	8000	1331	1323	212	8000	397	5887 [a]
SO_2	37800	331	95	12500	15120	83	38	12500	620	22367 [a]
NH_3	30	7	4	15	12	2	2	15	1	25 [b]
TSP	4990	1654	945	5750	1996	413	378	5750	285	4517 [a]

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

In Bhuj, the integration of a feeder bus system significantly lowered transport-related emissions. CO_2 emissions dropped by nearly 30%, while CO, CH_4, and TSP saw reductions exceeding 50%, all statistically significant ($p < 0.001$). Pollutants like SO_2, VOCs, and NO_x also declined substantially ($p < 0.001$), indicating environmental improvement. Even relatively smaller contributors such as N_2O and NH_3 showed statistically meaningful reductions ($p < 0.05$ to 0.01). These results underline the environmental benefit of modal shift interventions, reinforcing feeder bus services as an effective strategy to reduce urban air pollution and support climate action initiatives in developing cities.

Samakhiyali

Figure 4 illustrates the 45-kilometer Samakhiyali feeder bus route linking the bus stand and railway station with Chitrod, Sivalakha, and Gharana bus stops. Following its implementation, the feeder bus system in Samakhiyali demonstrated remarkable improvements in operational efficiency, affordability, and sustainability.

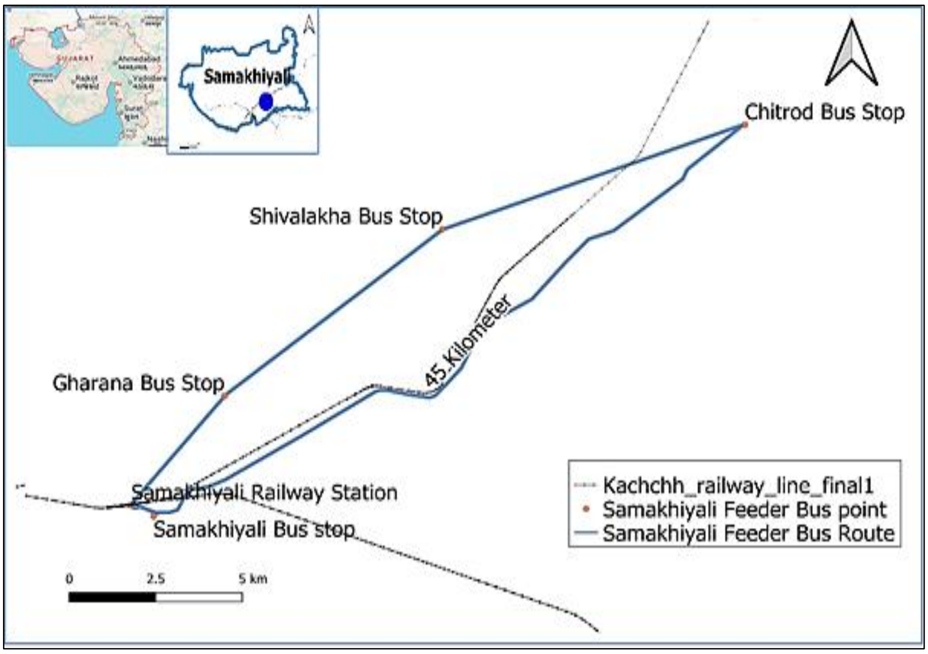

Figure 4: Samakhiyali Feeder Route (45 KM)

Table 5 presents a comparison of the original and feeder bus scenarios. Initially, 345 vehicles were required daily to serve 1,400 passengers, leading to a total transport cost of ₹3.78 lakhs. Buses operated at low occupancy (5.6 passengers per trip), with a cost of ₹550 per passenger. After feeder buses were introduced, the number of daily vehicles fell to 181, total costs reduced to ₹2.49 lakhs—saving over ₹1.3 lakh per day. Bus occupancy increased more than threefold, while private vehicle use declined by over 50%. These outcomes align with previous findings where the role of integrated feeder systems in improving service efficiency and attracting riders (19), and cost reductions along with increased public transport appeal under multimodal coordination (20).

The introduction of feeder bus services in Samakhiyali has significantly improved environmental quality and traveller experience. Table 6 shows that emissions of major pollutants decreased significantly, with reductions of 1.39 million grams of CO_2, 184,498 grams of CO, 82,072 grams of NOx, and 16,545 grams of SO_2, demonstrating the environmental benefits of the modal shift. Beyond emissions, the feeder bus system brings clear traveller benefits. Previous study revealed that the integrating feeder services with mass transit enhance last-mile connectivity and accessibility, particularly for lower-income and peripheral communities (21). The notes that feeder systems reduce reliance on private vehicles, thereby lowering household travel costs. Improved reliability and reduced transfer delays through feeder networks have been highlighted in previous studies (22). Further evidence has shown that high-quality feeder systems can shift 30–40% of private vehicle users to public transport (23). Their role in promoting equitable and affordable urban mobility has also been underscored (24). Together, these findings validate the substantial traveller and environmental benefits of the feeder bus system.

Table 5: Vehicle and Travel Cost Reduction after Introducing Feeder Buses in Samakhiyali

Samakhiyali	Actual scenario				After start feeder bus on suggested route (67% car, 65% Auto, 35% 2wheelar reduction so 33% car, 35% Auto, 65% 2-wheeler remain)					Reduction
	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
Passengers	700	350	70	280	231 [a]	123 [c]	46 [a]	987 [c]	987	
Average occupancy	4	7	1	5.6	4	7	1	19.74	50	
Vehicle total Daily	175	50	70	50	58 [a]	18 [c]	46 [a]	50	10	174
Average Trip length	60	20	15	70	60	20	15	70	45	
Travel cost Rs/KM	20	12	2.5	44	20	12	2.5	44	44	
Total cost	210000	12000	2625	154000	69300 [a]	4200 [c]	1706 [a]	154000	19820	
Cost per passengers	300	34	38	550	300	34	38	154 [a]	19.80	

[a]=statistically significant p<0.01, [b]=statistically significant p<0.05, [c]=highly statistically significant p<0.001

Table 6: Reduction in Emission after Introducing Feeder Bus Service for Samakhiyali

Samakhiyali	Actual scenario				After start feeder bus on suggested route (67% car, 65% Auto, 35% 2wheelar reduction so 33% car, 35% Auto, 65% 2 wheelers remain)					Reduction
Emissions	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
CO_2	2347800	60300	27930	1803200	774774	21105	18155	1803200	228826	1389925 [a]
CH_4	1785	180	189	315	589	63	123	315	40	1339 [c]
N2O	53	2	2	105	17	1	1	105	13	24 [b]
CO	262500	12000	8400	16450	86625	4200	5460	16450	2088	184498 [c]
NO_x as NO_2	136500	100	32	73500	45045	35	20	73500	9327	82072 [a]
VOC	2310	1600	294	5600	762	560	191	5600	711	1970 [b]
SO_2	26250	100	53	8750	8663	35	34	8750	1110	16545 [a]
NH_3	21	2	2	11	7	1	1	11	1	15 [b]
TSP	3465	500	525	4025	1143	175	341	4025	511	2312 [b]

[a]=statistically significant p<0.01, [b]=statistically significant p<0.05, [c]=highly statistically significant p<0.001

The statistical analysis of Samakhiyali transport data reveals a significant shift in mode preference after the introduction of the feeder bus. Car and auto usage declined sharply, with passenger and cost reductions exceeding 67% and 65% respectively ($p < 0.01$). Two-wheeler use halved, also statistically significant ($p < 0.01$). Bus patronage surged by over 250% ($p < 0.001$), showcasing successful modal shift. Notably, the cost per bus passenger dropped from ₹550 to ₹154 ($p < 0.01$), improving cost-efficiency. Overall, the feeder service effectively enhanced public transport utilization, cut private mode dependence, and delivered economically and environmentally favourable outcomes.

The implementation of feeder buses in Samakhiyali yielded significant reductions across most emission categories. CO_2 emissions dropped by 32.79%, while CO and CH_4 saw over 61% and 54% reductions, respectively ($p < 0.001$). Notably, NO_x, VOCs, and SO_2 declined between 30–40%, all highly significant. Smaller pollutants like NH_3 and N_2O also showed statistically relevant decreases ($p < 0.05$–0.01). The most substantial absolute drop was in CO_2 and CO, indicating a direct benefit from reduced car and auto use. These findings reinforce the environmental value of modal shift toward public transport in low-density regions.

Anjar

Figure 5 illustrates the 13-kilometer feeder bus route in Anjar, linking the bus stand and railway station with major pickup points such as Chitrakut Circle and the Bypass crossing from Bhuj and Mundra. This intervention led to notable improvements in transport efficiency and cost savings.

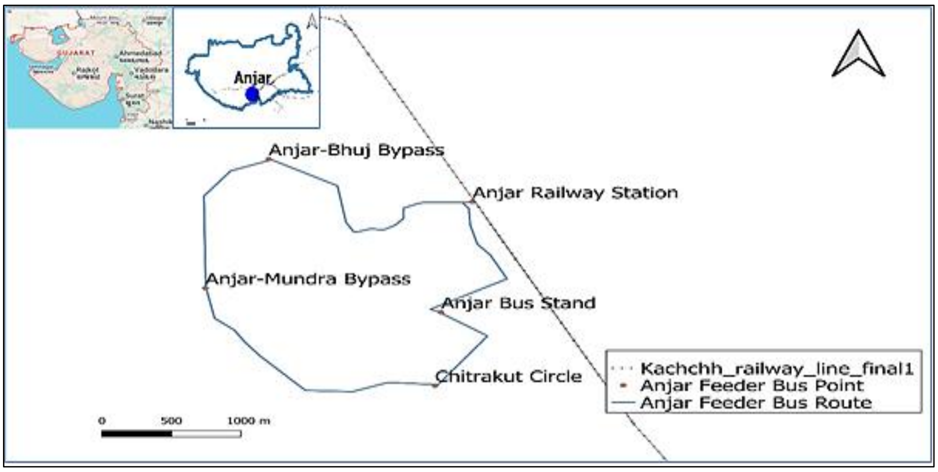

Figure 5: Anjar Feeder Route (13 KM)

Daily vehicle usage dropped from 344 to 165, helping reduce congestion and emissions. The cost per passenger for bus users decreased dramatically from ₹2,095 to ₹157. Table 7 indicates that fuel-intensive trips by cars, autos, and two-wheelers were reduced by 62%, 69%, and 61% respectively. These reductions highlight the dual benefits of efficient multimodal integration in achieving both economic and environmental goals. Feeder services have been stressed as important for improving accessibility, particularly in peri-urban and semi-rural areas (25). It has also been argued that public transport connectivity in secondary cities helps limit motorization and its associated externalities (26). Such transformations in travel behaviour affirm the role of structured feeder networks in fostering sustainable mobility. The introduction of a feeder bus network in Anjar led to considerable emission reductions by decreasing private vehicle usage.

Table 7: Vehicle and Travel Cost Reduction after Introducing Feeder Buses in Anjar

Anjar	Actual scenario				After start feeder bus on suggested route (62% car, 69% Auto, 61% 2wheelar reduction so 38% car, 31% Auto, 39% 2 wheelers remain)					Reduction
	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
Passengers	399	472.5	126	52.5	152 [a]	146 [c]	49 [a]	703 [c]	703	
Average occupancy	4	7	1	1.05	4	7	1	14.05	50	
Vehicle total Daily	100	68	126	50	38 [a]	21	49 [a]	50	7	185
Average Trip length	50	20	15	50	50	20	15 [c]	50	13	
Travel cost Rs/KM	20	12	2.5	44	20	12	2.5	44	44	
Total cost	99750	16200	4725	110000	37905 [a]	5022 [c]	1843 [a]	110000	4020	
Cost per passengers	250	34	38	2095	250	34	38	157 [c]	5.72	

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Table 8: Reduction in Emission after Introducing Feeder Bus Service for Anjar

Anjar	Actual scenario				After start feeder bus on suggested route (62% car, 69% Auto, 61% 2wheelar reduction so 38% car, 31% Auto, 39% 2-wheeler remain)					Reduction
Emissions	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
CO_2	1115205	81405	50274	1288000	423778	25236	19607	1288000	19266	759234 [c]
CH_4	848	243	340	225	322	75	133	225	1	900 [c]
N2O	25	3	4	75	9	1	1	75	1	19 [b]
CO	124688	16200	15120	11750	47381	5022	5897	11750	92	97616 [c]
NO_x as NO_2	64838	135	57	52500	24638	42	22	52500	305	40026 [a]
VOC	1097	2160	529	4000	417	670	206	4000	86	2409 [b]
SO_2	12469	135	95	6250	4738	42	37	6250	86	7796 [a]
NH_3	10	2	4	8	4	1	1	8	0	10 [b]
TSP	1646	675	945	2875	625	209	369	2875	55	2008 [b]

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Table 8 shows that total CO_2 emissions declined from 2,534,884 grams to 1,775,650 grams, a reduction of 759,234 grams. CO emissions decreased by 97,616 grams, and SO_2 by 7,796 grams, reflecting substantial environmental gains. These improvements resulted from a modal shift, with reductions of 62% in cars, 69% in autos, and 61% in two-wheelers, replaced by shared feeder buses. The VOC emissions also declined by 2,409 grams, improving urban air quality. These results align with evidence suggesting that enhancing public transport and reducing private vehicle dependence can cut urban transport emissions by 30–40% (27). It has also been affirmed that multimodal integration and first–last mile connectivity is key to fostering low-emission urban mobility systems, supporting present investigation (28).

After introducing the feeder bus in Anjar, there is a statistically significant modal shift from private vehicles to public transport. Car, auto, and two-wheeler usage reduced drastically by 62%, 69%, and 61% respectively **(**$p < 0.01$**),** while bus ridership increased over 12-fold **(**$p < 0.001$**).** Vehicle counts follow a similar trend, showing effective consolidation of trips. The cost per passenger remains constant for private modes, while it drops by over 90% for buses, indicating massive economic efficiency. The changes in cost and usage patterns suggest a highly effective intervention with statistically strong support for feeder bus deployment.

Feeder bus introduction in Anjar led to meaningful emission reductions. Total CO_2 fell by 30%**,** with CO and CH_4 dropping over 50%—both highly significant ($p < 0.001$). Key pollutants like NO_x, VOCs**,** SO_2, and TSP showed 30–43% reductions, again statistically significant. Lesser-known pollutants NH_3 and N_2O also recorded meaningful declines ($p < 0.01$–0.05).

The total daily emission reduction surpassed 759 kg of CO_2 alone, making this modal shift an environmentally beneficial move. The data firmly supports the adoption of feeder bus services as a strategy to curb pollution and enhance sustainable urban mobility in mid-sized towns like Anjar.

Bhachau

Figure 6 illustrates the 20-kilometer feeder bus route in Bhachau, connecting the bus stand and railway station with major pickup points. Suggested route has significantly improved multimodal connectivity while reducing both travel costs and vehicle trips.

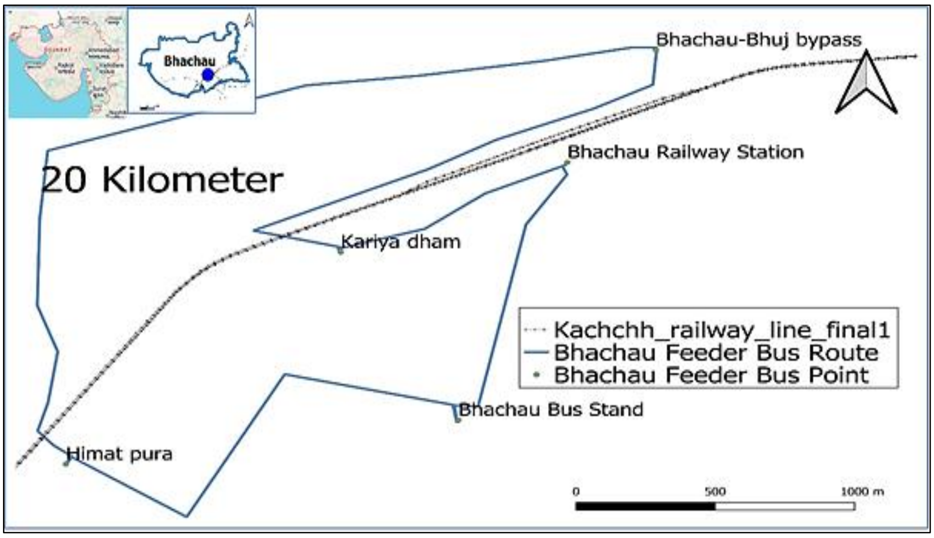

Figure 6: Bhachau Feeder Route (20 KM)

Table 9 shows that daily vehicle usage decreased from 207 to 100 with the addition of only six feeder buses. This intervention resulted in a 31% cost saving, reducing total travel costs from ₹186,855 to ₹128,135. The cost per bus passenger dropped sharply from ₹2,200 to ₹154, while for feeder users it declined to just ₹8.80, reflecting substantial affordability gains. These results are aligned with the previous findings that revealed coordinated transport planning enhances efficiency and lowers user's costs (29). It has also been argued that integrated public transit systems are crucial for sustainable mobility, particularly in semi-urban regions (30).

Table 9: Vehicle and Travel Cost Reduction after Introducing Feeder Buses in Bhachau

Bhachau.	Actual scenario				After start feeder bus on suggested route (67% car, 73.5% Auto, 40% 2wheelar reduction so 33% car, 26.5% Auto, 60% 2-wheeler remain)					Reduction
	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
Passengers	252	504	42	42	83 [a]	134 [c]	25 [b]	598 [c]	598	
Average occupancy	4	7	1	1.4	4	7	1	20	50	
Vehicle total Daily	63	72	42	30	21 [a]	19 [c]	25 [b]	30	6	112
Average Trip length	60	20	15	70	60	20	15	70	20	
Travel cost Rs/KM	20	12	2.5	44	20	12	2.5	44	44	
Total cost	75600	17280	1575	92400	24948 [a]	4579 [c]	945 [b]	92400	5263	
Cost per passengers	300	34	38	2200	300	34	38	154 [c]	8.80	

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

Table 10: Reduction in Emission after Introducing Feeder Bus Service for Bhachau

Bhachau	Actual scenario				After start feeder bus on suggested route (67% car, 73.5% Auto, 40% 2wheelar reduction so 33% car, 26.5% Auto, 60% 2-wheeler remain)					Reduction
Emissions	Car	Auto	2-Wheeler	Bus	Car	Auto	2-Wheeler	Bus	Feeder bus	
CO_2	845208	86832	16758	1081920	278919	23010	10055	1081920	24986	611898 [a]
CH_4	643	259	113	189	212	69	68	189	1	665 [C]
N2O	19	3	1	63	6	1	1	63	1	14 [b]
CO	94500	17280	5040	9870	31185	4579	3024	9870	120	77912 [C]
NO_x as NO_2	49140	144	19	44100	16216	38	11	44100	396	32642 [a]
VOC	832	2304	176	3360	274	611	106	3360	112	2210 [b]
SO_2	9450	144	32	5250	3119	38	19	5250	112	6339 [a]
NH_3	8	3	1	6	2	1	1	6	0	8 [b]
TSP	1247	720	315	2415	412	191	189	2415	72	1419 [b]

[a]=statistically significant $p<0.01$, [b]=statistically significant $p<0.05$, [c]=highly statistically significant $p<0.001$

The Bhachau model demonstrates how strategic feeder links can shift users from costly private transport to efficient public options, promoting both economic and environmental benefits. The implementation of a feeder bus system in Bhachau has resulted in a marked reduction in vehicular emissions. Table 10 shows that total CO_2 emissions decreased by 611,898 grams per day, from 2,030,718 grams to 1,418,820 grams, primarily due to reduced reliance on private cars and auto-rickshaws. CO emissions declined by 77,912 grams, and NO_x by 32,642 grams, indicating notable improvements in air quality. The shift was driven by replacing fragmented private trips with structured public transport, validating the argument that organized feeder systems improve environmental outcomes in suburban areas (31).

The outcome of present investigation like multimodal synchronization can achieve both congestion mitigation and emissions control supported by previous research study (32). The feeder service achieved this while maintaining the bus emissions constant and adding only 24,916 gram/day CO_2 through feeder operations, a minimal trade-off for significant environmental gains.

In Bhachau, the introduction of a feeder bus led to a statistically significant modal shift away from private transport. Car, auto, and two-wheeler passenger counts declined by 67%, 73.5%, and 40% respectively ($p < 0.01$), while bus ridership surged by over 900% ($p < 0.001$). Vehicle counts mirrored these changes, demonstrating a realignment of travel patterns. While per-passenger costs for private modes remained constant, the cost for bus passengers dropped by over 90%, indicating a significant improvement in operational efficiency and affordability. These results support feeder bus integration as a viable, data-backed solution to reduce cost and emissions.

In Bhachau, the introduction of feeder bus services resulted in significant reductions across nearly all emissions. Carbon dioxide (CO_2) emissions dropped by 27.6%, saving over 612 kg/day, while CH_4 and CO levels reduced by more than 55% and 60%, respectively ($p < 0.001$). Key air pollutants including NO_x, SO_2, VOCs, and TSP also declined by 30–40%, demonstrating statistically significant changes. Even lesser-emitted compounds like NH_3

and N_2O saw measurable drops ($p < 0.05$). These results affirm the positive environmental impact of shifting from private to shared feeder transport in regional towns like Bhachau.

The outcome of the present investigation not only align with recent government initiatives such as the Gati Shakti National Master Plan (33) and the National Urban Transport Policy (NUTP) (34) but will resolve the future consequences of first and last mile connectivity. However, the schemes also emphasize the importance of integrated and sustainable transport systems in India. Gati Shakti seeks to promote seamless multimodal connectivity across rail, road, and bus networks, thereby improving efficiency and reducing overall logistics and travel costs (33). Similarly, NUTP highlights the need for environmentally friendly, safe, and affordable public transport solutions that strengthen last-mile connectivity (34). The significance of digital integration and multimodal coordination in improving Kachchh's fragmented transport systems has been highlighted in a recent study (35). The introduction of feeder bus services, as demonstrated in present investigation, supports these policy objectives by reducing dependence on private vehicles, lowering emissions, and improving accessibility for railway passengers. Further, the outcome of the present investigation will create a similar facilities developed in different regions of India like Delhi multimodal hubs integrating metro, bus, and feeder services, and Gujarat electric bus programs in a smaller scale for a remotely located semiarid and economical growing district of Kachchh towards long-term sustainability.

Conclusion

The introduction of a feeder bus system significantly improved multimodal transport efficiency. In the actual scenario, a total of 2,774 vehicles were required daily to carry 12,391 passengers, resulting in a total operational cost of ₹2,286,288 and an average cost per passenger of ₹299.95 for cars and ₹1,112.16 for buses.

After deploying 92 feeder buses on key routes (reducing 57% of cars, 78% of autos, and 50% of two-wheelers), the vehicle count dropped to 1,326. The cost per passenger significantly reduced to ₹130.34 for mainline buses and ₹9.58 for feeder buses, making public transport far more economical and accessible.

Moreover, bus occupancy rose 4 times, improving transport efficiency. This not only reduces traffic congestion but also lowers emissions and promotes modal shift, aligning with sustainable urban mobility goals.

The implementation of feeder bus services across five railway stations has led to a significant reduction in transport-related emissions. Figure 7 shows that total CO_2 emissions declined from approximately 26 million units to 18.2 million, a reduction of over 7.84 million units. Major pollutants also decreased substantially, with CO reduced by more than 1 million units and NOx by about 425,877 units. These reductions, driven by the modal shift from private vehicles (cars, autos, and two-wheelers) to more efficient feeder buses, were accompanied by notable declines in methane, nitrous oxide, and ammonia emissions, contributing to improved air quality and reduced environmental harm. The intervention demonstrates the potential of integrated public transport systems in minimizing emissions and promoting sustainable mobility. Overall, the feeder bus system significantly improves environmental outcomes while enhancing connectivity to railway stations, particularly in regions like Kachchh where air quality and fuel use are growing concerns.

In the context of Kachchh's environmental sensitivity and geographic remoteness, the findings emphasize that targeted feeder bus services offer a practical and scalable solution for enhancing regional connectivity while supporting the objectives of the Gati Shakti Master Plan and National Urban Transport Policy (NUTP). Strengthening institutional coordination and addressing financial barriers will be essential to realize these benefits at scale.

Overall, the study reinforces that feeder bus integration is not merely a local intervention but a replicable strategy to advance efficiency, accessibility, and sustainability in India's transport sector.

Policy Recommendations

Based on the findings of this study, the following policy measures are suggested to strengthen multimodal integration in regions like Kachchh:

Prioritize feeder bus networks around major railway stations to reduce private vehicle dependence and improve last-mile connectivity.

Integrate planning under the Gati Shakti framework to ensure seamless multimodal linkages between rail, GSRTC, and municipal-level transport services. Promote eco-friendly fleets by gradually introducing electric or CNG feeder buses, aligning with India's sustainable mobility goals. Enable institutional coordination between Indian Railways, GSRTC, and municipal governments to jointly manage routes, scheduling, and funding. Introduce innovative financing models such as public–private partnerships and cross-subsidization to address financial barriers in low-density regions.
Enhance first- and last-mile access through supporting infrastructure for e-rickshaws, shared mobility, cycling, and pedestrian pathways.
Establish monitoring frameworks for continuous evaluation of modal shifts, emissions, and user satisfaction to refine feeder bus operations.

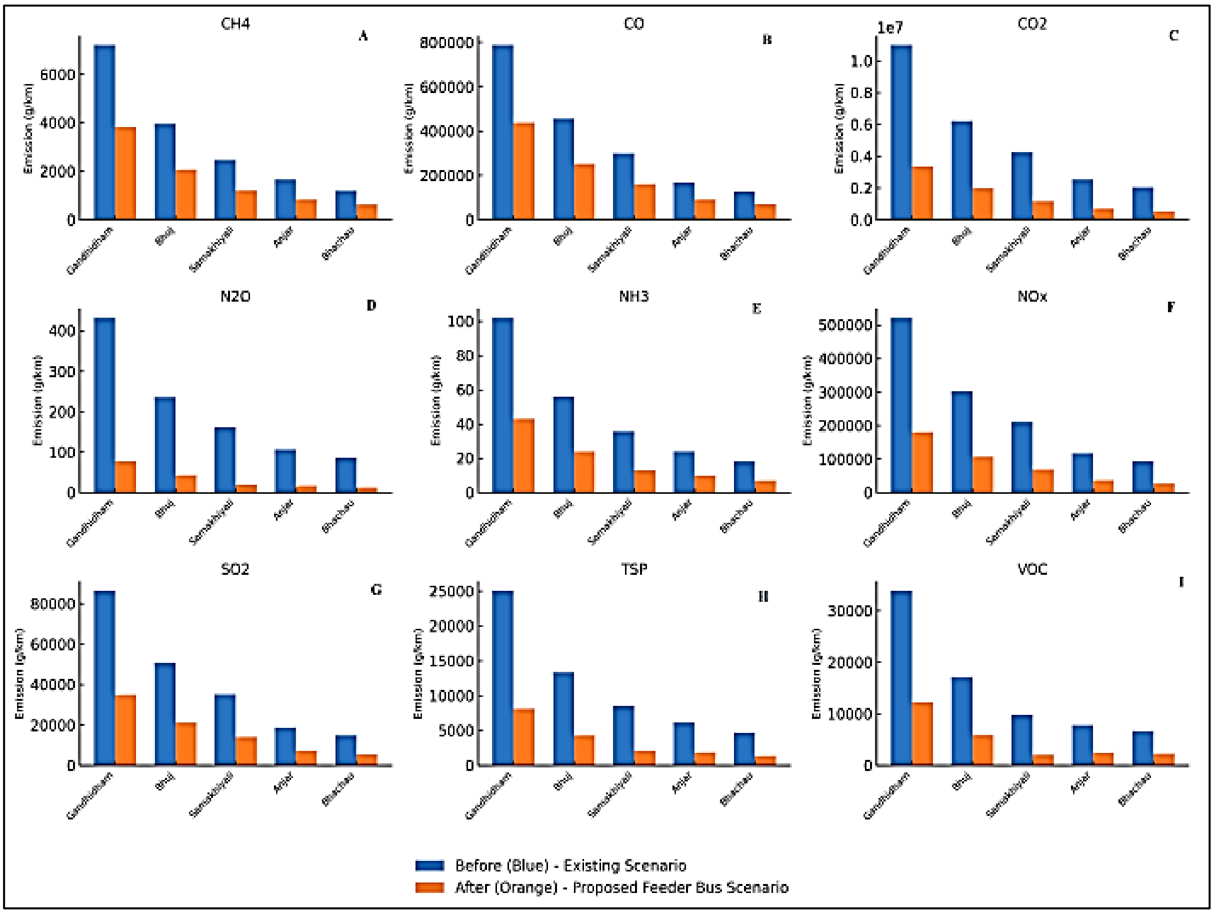

Figure 7: A. Emission of CH_4 before and after, B. Emission of N_2O before and after, C. Emission of CO before and after, D. Emission of CO_2 before and after, E. Emission of NH_3 before and after, F. Emission of NO_2 before and after, G. Emission of SO_2 before and after, H. Emission of TSP before and after, I. Emission of VOC before and after (at Gandhidham, Bhuj, Samakhiyali, Anjar and Bhachau)

Abbreviations

CH_4: Methane, CO_2: Carbon Dioxide, CO: Carbon Monoxide, N_2O NO_x: Nitrogen Oxides, SO_2: sulphur Dioxide, TSP: Total Suspended particles, VOC: Volatile Organic Compound.

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Author Contributions

Devang Majithiya: Study conception and design, data collection, analysis, interpretation of results, writing and reviewing article, Harishkumar Varia: reviewing article, Correspondence.

Conflict of Interest

The authors declare that there are no conflicts of interest related to this research.

Ethics Approval

Not applicable.

Declaration of Artificial Intelligence (AI) Assistance

During the preparation of this work, the authors have used OpenAI's ChatGPT to assist in drafting, editing, and refining the manuscript. After using this tool, the authors reviewed and edited the content as necessary and take full responsibility for the final version of the manuscript.

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