International Journal of Heavy Vehicle Systems

ISSN online: 1741-5152 - ISSN print: 1744-232X
https://www.inderscience.com/ijhvs

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DOI: 10.1504/IJHVS.2023.10059684

Article History:

Received:	20 January 2023
Last revised:	05 April 2023
Accepted:	01 May 2023
Published online:	24 January 2024

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Abstract: This study focuses on the optimisation of operator and user-based operational parameters that affect the urban bus transportation system. To optimise the screened parameters identified in user and operator opinion surveys, a fuzzy analytical hierarchy process (FAHP) and goal programming (GP) technique was used. Ten pivotal explanatory parameters were identified viz service hours, journey time delays, ridership quality, operator earnings, road accident rates, fuel consumption, bus fleet intensity, bus stop density, women and child safety, reliability. Further, pairwise comparisons for the identified explanatory parameters were conducted using FAHP, according to selected experts with experience in bus transportation research. Depending upon the magnitude of the parametric weights, the goal programming-based weighted sum of deviations was reduced to obtain the optimal values. Results from the study indicate that delays in bus journey time, operator earnings, bus fleet intensity, and women and child safety are the most essential components.

Keywords: transportation; public transport; goal programming; passenger perceptions; fleet intensity; FAHP; fuzzy analytical hierarchy process; bus transport; safety; journey time; transport quality; explanatory parameters.

Reference to this paper should be made as follows: Solanki, V.S., Agarwal, P.K., Kiran, S. and Agarwal, D.K. (2024) ‘Bus transport system quality benchmarking and optimisation using FAHP & GP technique’, *Int. J. Heavy Vehicle Systems*, Vol. 31, No. 1, pp.147–168.

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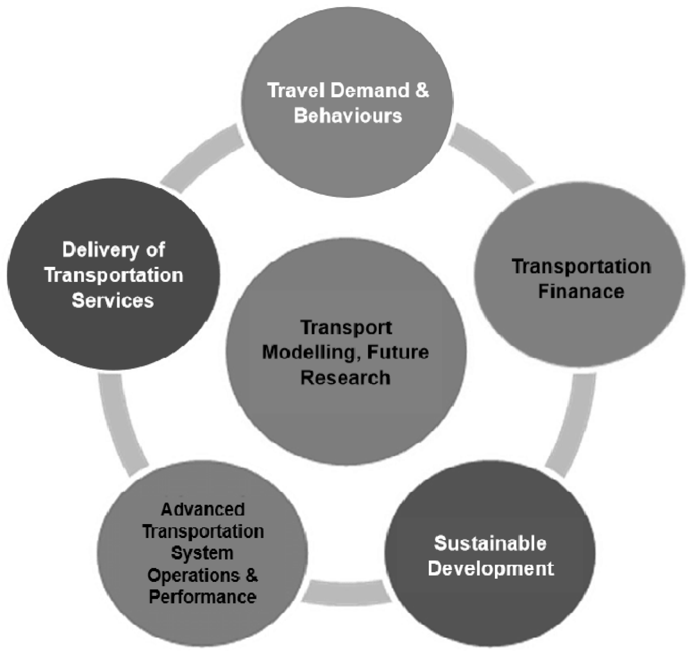
1 Introduction

1.1 Background

Transportation system sustainability is receiving more attention because of its favourable effects on the long-term viability of the environment, society, and economy. Growth and urbanisation are taking place more speedily in developing nations like India. In addition, urban population of India will likely increase to 600 million by 2030 (Zope et al., 2019).

In most Indian cities, the percentage of private vehicles has increased exponentially during the previous two decades. In a 2006 report, 72% of the overall private vehicles consisted of two-wheelers (McLeod et al., 2017). Except for Mumbai, Delhi, Chennai, and Kolkata, all metro cities in India rely on road-based transportation networks represented by mixed operation mode of public transport system and private modes of transport, such as cars, 2-wheelers, and cycles. The issues have gotten worse as the city bus services in various cities have deteriorated over the years, increasing reliance on individualised alternatives (McLeod et al., 2017; Singh, 2016; Pulugurta et al., 2015). Today, India's urban areas cover more than 30% of the population. The most common means of local transportation are local public transport and trains. Private public transport includes bicycles, taxis, auto-rickshaws and rental tricycles. However, buses and BRT systems are common forms of local and interstate public transport (Jasti and Ram, 2018; Amini et al., 2019). The collaborative road transport sector is managed by various government agencies such as state governments or local companies. Figure 1 shows a generic model for sustainable transport.

Figure 1 Sustainable transportation model



1.2 Demand and traffic modelling

The primary difficulty for planning and policy-making is not real-time monitoring of traffic patterns, but precise forecasting of future transportation demand. In recent decades, the concept of travel demand modelling has improved regarding methodologies, toolboxes and practice-ready simulation applications for rapid deployment in any geographic region (Silva Cruz and Katz-Gerro, 2016).

Modelling travel demand enables forecasting the direct impact of transportation initiatives on urban traffic flows (Chowdhury et al., 2018; Ghorbanzadeh et al., 2019). Demand modelling is critical for transportation policy-making, since decisions are nearly arbitrary or absent, solid forecasts of well-functioning traffic model or a future traffic flow standardised for the region of interest for the local data (Kumar et al., 2015; Mahmoudi et al., 2020).

1.3 Research objectives

Identification of explanatory parameters affecting intra-city bus transport system (case studies of areas of Bhopal and Indore).

Weight evaluation of pivotal explanatory parameters using Fuzzy Analytical Hierarchical process.

Benchmarking of intra-city bus transport system considering users' and operators' perception using mixed analytical hierarchical and GP technique.

1.4 Scope of the study

The proposed feasible transportation rating will assist in envisioning and decision-making to enhance the performance metrices for urban transportation systems. In this paper a technique for developing a compound reliable index is devised to quantify performance that could then be compared to certain best practices to provide objectives for improvement. Additionally, it will aid in assessing the transportation system's performance depending on the indicators chosen. Benchmarks for performance enhancement and derived parameters of indices will also help identify the gap between the actual and anticipated levels of performance.

2 Literature review

Evaluating the performance of public road transport systems is critical to managing better, improved and safer traffic. Numerous studies have been conducted to analyse the performance of public transport. For example, Jasti and Ram (2018) examined the effectiveness of the city's public transportation mechanism. Furthermore, fuzzy logic and DEA are used to study the effectiveness of 52 small cities and 43 large cities. The authors evaluated efficiency using four different DEA-based models. An indicator-based model was built, with thirty assessors nestled under eight Performance Metrics, following a weighted scoring mechanism.

Rajak et al. (2016) proposed a new human perception model using Fuzzy Logic's triangular membership function parameters. Characteristics, trip duration, waiting period, transport costs, travelling speed, and displeasure rating were used to generate fuzzy sets. A rule basis was created and validated to determine the human perspective of using public transit.

Krmac and Djordjević (2017) analysed the performance metrics of intelligent rail transit systems based on expert opinion using the group analysis hierarchical process (GAHP) technique. To achieve this, they used a set of 24 indicators, grouped by themes within the economic, social and environmental dimensions of sustainable development. Administrators can take appropriate steps to limit the likelihood and magnitude of risk in this transportation network by identifying issues and analysing and prioritising risk factors (Baradaran, 2017). The results of the GAHP method show the value or relative importance of indicative parameters for intelligent rail transport systems.

Kramar et al. (2019) propose a novel holistic approach to urban transportation system design that includes active decision-making mechanisms involving different stakeholders, including SWOT analysis and FAHP techniques. The results show that the established integrated structures are able to focus on the discovered areas and thus enable the formulation of scenarios. They found that the model better understood how to seek concessions when faced with multi-criteria decision-making and synchronisation of somewhat conflicting goals.

In Cyril et al. (2019), an interconnected AHP-plus-GP approach is used that takes into account both operator and user input. AHP is used to analyse selection factors and determine appropriate weights to use as penalties in GP. The best solutions show that improvements in connectivity, performance, comfort, frequency and reliability will attract users to public transport. This will also influence operators to maximise fleet utilisation and reduce program cancellations (Jasti and Ram, 2019).

To minimise major economic and safety concerns, Murat et al. (2016) used multi-criteria decision-making strategies applying AHP. The study used four hybrid varieties. The decision-making phase takes into account safety features, delays, emission factors, fuel efficiency, and crossing and design costs. The SIDRA intersection procedure is used to evaluate these types of intersections using the parameters given above in the AHP model. The weight levels of elements used in the AHP model have been adjusted to account for economy and capacity.

Achieving sustainable growth on complex issues such as congestion and pollution requires effective approaches. Alkharabsheh et al. (2021) advocated the use of greyscale values in the AHP method to address the ambiguity limitations of standard AHP. They applied the proposed method to a real-world example, calculating and evaluating the delivery quality criteria of the public transport system. Their findings demonstrates the effectiveness and applicability of the established strategies in improving the quality of public transport.

Kiani Mavi et al. (2018) developed the Grey Stepwise Weighted Evaluation Ratio Analysis (SWARA-G) to balance evaluation criteria such as sustainability and risk considerations in bus rapid transit (BRT). According to their research, adding buses to the BRT line is the best option to improve the performance. It differentiates among high- and low-quality transportation corridors (Güner, 2018) and allows for the monitoring and improvement of bus transit quality of service.

2.1 Research gap

The analysis of the literature revealed a significant research gap: very few studies have attempted to increase the performance of the public transportation system via resource optimisation. Also, most studies mentioned above did not consider detailed user and operator perceptions for assessing performance of city-based public transportation. This far, no standardised mathematical technique to dealing with the uncertainties that exist in such assessments has been discovered in the Indian benchmarking framework for urban bus transportation. Various researchers suggested a method to normalise various assumptions in benchmarking using Fuzzy Logic membership function parameters. Relating to urban transportation, especially in Indian context, user’s perception has not yet been considered to a desirable level till today. Most studies described in this section do not aim at optimising the performance parameters depending on users’ and operators’ perspective. In this study we have tried to address some of the identified gaps applying integrated FAHP-GP optimisation module.

3 Methodology

FAHP is a multi-objective decision-making techniques which categorises and filters multiple parameters based on decision criteria. The primary focus of methods are identification and selection of various explanatory factors belonging to users and operators' perceptions for bus transport system in general. Fuzzy analytic hierarchical process is utilised to evaluate the decision input and is calculated the weights (Salehian et al., 2018). Figure 2 represents the proposed model for optimisation-based benchmarking of bus transportation system based on FAHP-GP technique. Figure 3 reviews selected explanatory parameters for passenger satisfaction with indicated priority values.

Figure 2 Optimisation-based benchmarking of bus transport system based on FAHP-GP technique

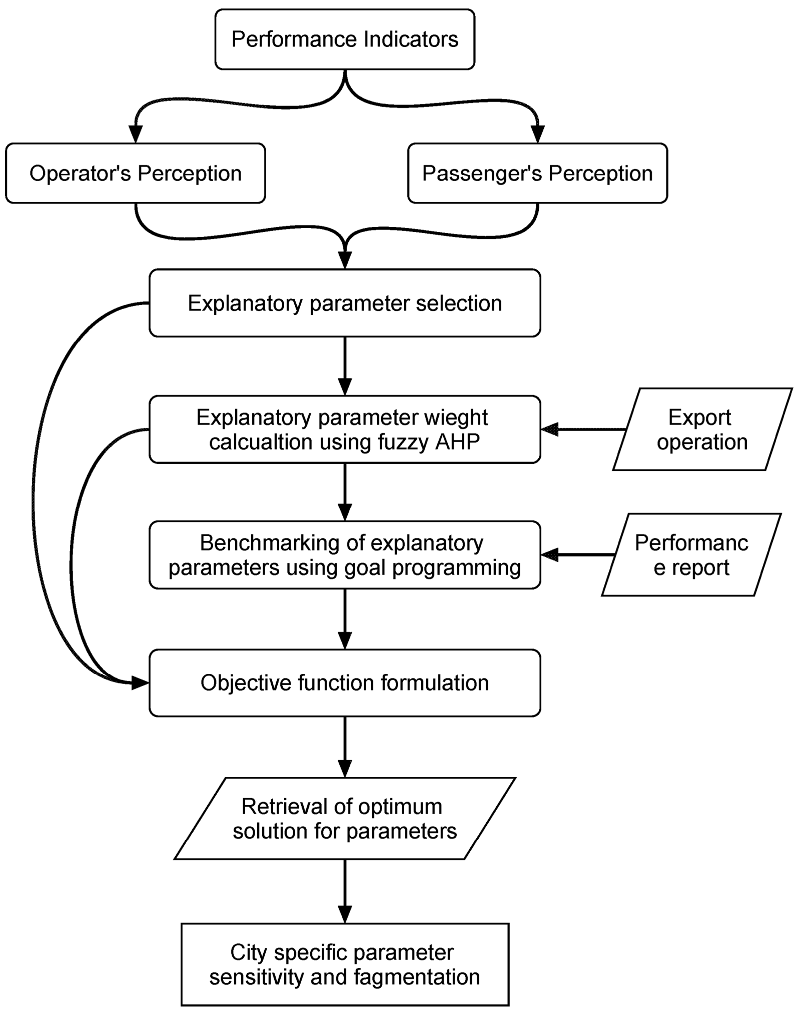
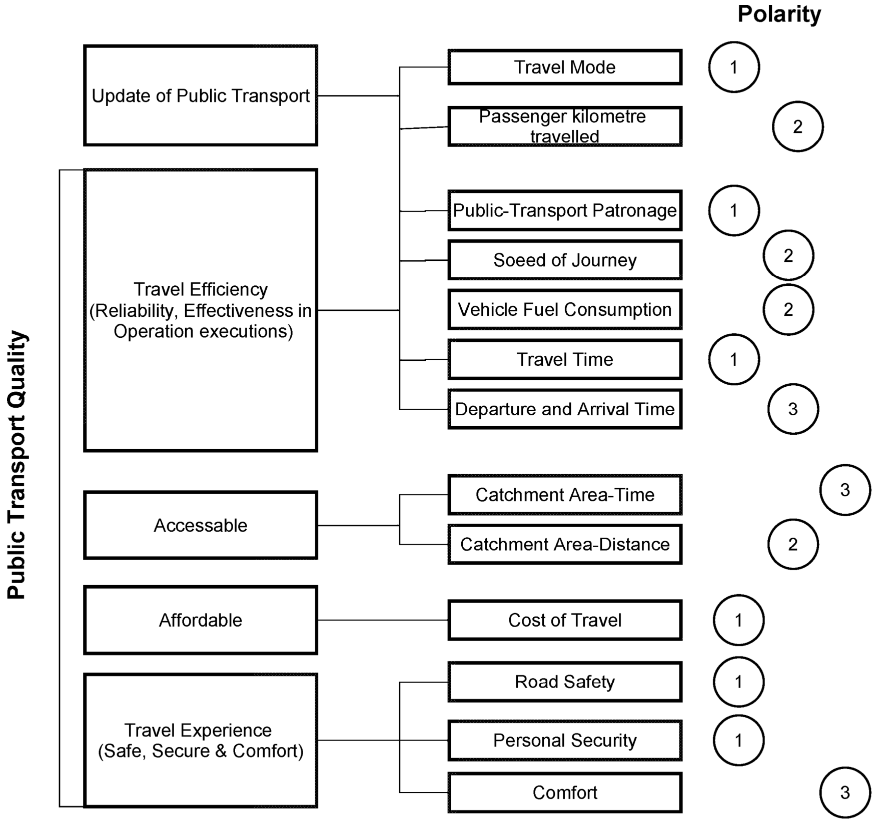


Figure 3 Explanatory parameters and prioritisation of services



3.1 *Fuzzy analytical hierarchy process*

Fuzzy analytical hierarchy process (FAHP) splits a decision objective or target into easy and understandable units, relative to characteristics and then hierarchies the parameters to translate amount of information. The peak level of the hierarchy is termed as goal of the objective or target. The intermittent levels of the structure are the pivotal decision inputs. Based on the passenger and operator opinion survey, about 12 attributes or decision variables have been filtered which are reliability (R), comfort (C), fare availability (BF3), safety and security (SS), bus transport service hours (SA2), bus journey time delay (R3), quality of ridership (C1) and average earning per passenger (BF2). Comfort (C), reliability (R) and safety and security (SS) are typical passenger satisfaction variables while the others are operator-oriented. Based on the hierarchy been established, pairwise contrast matrix in every level has been implemented to determine weights further utilised in the objective function. The different contrast matrices are:

1 *Rank 1*: Goal of the research: Optimisation of indicators/decision variables affecting Bhopal (BCLL) and Indore (AICTS) performance.

2 *Rank 2*: Create interrelations between stakeholders of the Bhopal and Indore bus public transport industry involving the passengers and operators, a 2×2 matrix.

3 *Rank 3*: Finding interrelations between significant decision variables/performance indicators separately for Bhopal and Indore i.e., 7×7 matrix for operator and 4×4 matrix for passengers.

According to Cyril et al. (2019) assigning of parameters' weights and importance of priority is determined based on pairwise comparison. This pairwise distinction of explanatory parameters of the FAHP rating scale collected from experts and users. The precedence of all the explanatory units of the complementary judgement matrix, suppose, *J*, can be calculated after estimating the foremost eigenvector, say, *e*. equation (1) shows the procedure for determining the principal units:

$$J.e = \delta_{max}.e \quad (1)$$

In equation (1), *J* is the complementary judgement matrix, *e* is the foremost eigenvector and δ_{max} determines the maximum eigen value of the judgement matrix *J*. The standardised value of the eigenvector, *e*, retrieves the priorities of all the explanatory units regarding other elements. During the final stage of FAHP, the logical reliability is judged as because the pairwise distinctions are based upon personal judgement. To Discover the reliability of the judgements, a reliability index parameter as per equation (2), is to obtained.

$$RI = (\delta_{max} - N) / (N - 1) \quad (2)$$

In equation (2), RI represents the reliability index and *N* indicates the judgement matrix order. Simultaneously, the reliability ratio is obtained as the ratio of reliability index and indiscriminate index in Table 1. Further, Table 2 enlists the year-wise leading parameters affecting Bhopal and Indore Bus Transport System combined with operational and passenger competence.

Table 1 Descriptive of surveyed data for performance evaluation of bus transit systems in Bhopal and Indore

Socioeconomic characteristics		*Percentage of the total surveyed data*
Gender	Male	62.18
	Female	37.82
Monthly income (in rupees)	Less than 5000	17.2
	5000–10,000	19.8
	10,000–15,000	20.35
	15,000–20,000	18.45
	More than 20,000	24.2
Vehicle ownership	Two wheelers (bike, scooters)	39.98
	Four wheelers	29.76
	None	30.66
Mode chosen	Private vehicle	12.62
	Auto rickshaw	58.54
	City bus	28.84

Table 1 Descriptive of surveyed data for performance evaluation of bus transit systems in Bhopal and Indore (continued)

Socioeconomic characteristics		*Percentage of the total surveyed data*
Statistics of surveyed data		
Age (in years)	15–20	3.23
	21–30	63.35
	31–50	27.12
	Over 50	6.3

Table 2 Parameters considered for bus transport system benchmarking (as identified from user perception and operator perception surveys) for the cities of Indore and Bhopal

S. No.	*Explanatory parameters for bus transport system benchmarking*	*Type of measure (S/O)*	*Abbreviations*
Service availability (SA) –d1			
1	Service hour	O	SA1
2	Headway of service	O	SA2
3	No. of bus stops per km of travel	O	SA3
4	No of transfer	O	SA4
Reliability (R) – d2			
5	Intensity of Buses	O	Bus/1000 population
6	Waiting time at bus stop at terminal stop	O	R1
7	Waiting time at bus stop at intermediate stop	O	R2
8	Delay in total journey time	O	R3
Bus design (BD) – d3			
9	Seating arrangement inside buses	S	BD1
10	Availability of luggage space	S	BD2
11	Availability of vertical rails for passenger protection	S	BD3
12	Availability of adequate lighting system within the bus	S	BD4
Comfort (C) – d4			
13	Quality of ridership	O	C1
14	Accessibility (No of bus stop per 2 km under major corridor)	O	C2
15	Seat availability and quality	S	C3
Customer Service (CS) – d5			
16	Driver training (number of drivers per major route)	S	CS1
17	Ease of submitting complain/request	S	CS2
18	Help provided by conductors in case of emergency	S	CS3
19	Conductor behaviour/professional attitude	S	CS4
20	No. of Buses equipped with GPS with real time information about schedule per route	S	CS5

Table 2 Parameters considered for bus transport system benchmarking (as identified from user perception and operator perception surveys) for the cities of Indore and Bhopal (continued)

S. No.	*Explanatory parameters for bus transport system benchmarking*	*Type of measure (S/O)*	*Abbreviations*
Bus fare (BF) – d6			
21	Fee structure for integrated paratransit and public transport	S	BF1
22	Average earning per passenger (rupees)	O	BF2
23	Fare affordability	S	BF3
24	Ticket concession price per passenger	O	BF4
Safety and Security (SS) – d7			
25	Safety from road accidents while travelling (expressed in terms of no. of accidents/major route)	S	SS1
26	Safety from theft/robbery inside the bus	S	SS2
27	Display of women and child helpline /emergency contact numbers inside busses (Number of busses/route)	S	SS3
28	Safety at bus stops regarding women/child/physically disabled	S	SS4
29	Availability of first aid fits within the bus	S	SS5
30	Provision of CCTV surveillance within the bus	S	SS6
31	Provision of CCTV surveillance at stops	S	SS7
Environmental Sustainability (ES) – d8			
32	If suffocation is caused inside the bus	S	ES1
33	Fuel consumption per km of travel	S	ES2

*S = subjective measure/attribute; O = objective measure.

The decision matrix pairwise distinctions (distinction matrix) often is reliable only if the reliability ratio is less than 1. Now, if operational and user (that is, passenger) weights are amalgamated, it is possible to obtain the ultimate explanatory parameter weights. The weights obtained from the amalgamation act as penalties for the identified explanatory parameters based on the GP technique used in this research.

3.2 Goal programming method

The goal programming technique helps to fix the number of specific goals to each objective. To achieve the numeric goals, GP, assigns weights based on relative importance. Further, as explained by Cyril et al. (2019), GP is an optimisation process utilised primarily in multi-objective decision-making activities in real life. When multiple targets or objectives are clashing with each other, GP helps in finding optimum solutions. The optimal solution is obtained by minimising the weighted sum of all deviations from the numeric goals. A standardised weighted GP with G number of goals, D number of decisions and S system of constraints is shown in equation (3).

Minimising:

$$O_f = \sum_{j=1}^{D} u_j \left(PD_j - ND_j \right) \tag{3}$$

Subject to constraints:

$$\sum_{k=1}^{D} A_{jk} y_k - S_j + D_j = B_j, \ \forall j = 1, \ldots, G, \tag{4}$$

$$S_j, D_j, y_k \geq 0, \ \forall j = 1, \ldots, G; \ k = 1, \ldots, D \tag{5}$$

In equations (3)–(5), O_f represents the objective function, also the sum of the weighted deviations, u_j represents weight assigned to the constraint of the jth goal; A_{jk} is the coefficient of the variable k in the jth goal; y_k is the kth decision variable; B_j represents the right hand value associated with the jth goal and S_j, D_j are the positive and negative deviations representing over-achievement and under-achievement respectively.

3.3 Description of the study area and data collection details

Bhopal is the administrative capital of Madhya Pradesh in central region of India. The population of the city is around 1.8 lakhs as of 2011 census. In Bhopal there had been an exponential increase of 0.6 million in registered private vehicles between the years 2018 to 2019 about 5.2% increase since MoUD, 2008 reports. Typical vehicle classifications for the city of Indore are 50% of four-wheelers, 20% of two-wheeler vehicles, 5% of light commercial vehicles, and 15% of heavy vehicles.

It has been reported that by 2031, all non-motorised users will switch to using the city's public transportation and transit systems (Joewono et al., 2016). Therefore, the authors proactively conducted research on public transportation. Through passenger and operational system assessment and creation of an integrated approach through integrated FAHP and destination planning In second-tier cities such as Bhopal and Indore, the only public transport mechanism is the urban BRT system in Bhopal, the state's only road transport services are buses operated by Bhopal City Link Limited (BCLL) and Ahiya Path (AP) Bhopal's buses provide poor service to users, with daily commuters mostly using private two- and four-wheel vehicles. Hence, it is necessary to improve the public bus transport services using user's opinions in such situation.

3.3.1 Demographics of the selected area

The organisation of buses running to and from Ahilya-Path City in Indore is more well-managed than those run by the BCLL. While the infrastructure does need work and some upgrades for Indore buses, it is still much better than its competitors in Bhopal who face similar issues but do not seem to be taking any steps towards improvement – though this is largely due to poor planning and lack of last-mile connectivity programs like paratransit. Table 3 summarises certain socioeconomic aspects of respondents from preference surveys conducted in both Indore and Bhopal. The table displays what percentage each group falls into along with their monthly income bracket ranges. Of the 750 people surveyed, 311 (62.18%) were male while 189 (37.82%) were female; 17% made less than 5000 rupees monthly before taxes or fees whereas 24% made over 20,000 rupees or higher. About 30% of respondents take public transport because they are economically disadvantaged. A larger percentage (approximately 69%) report using private cars for their daily commute instead. These 346 respondents have experienced Bhopal and Indore's public buses, which were unsatisfactory, so they switched to using privately owned vehicles instead. Table 4 shows that most citizens who regularly commute use rickshaws in many Tier II Indian cities; since these offer an affordable alternative form of transportation. When answering the questionnaire, participants rated five different aspects – such as comfort or cost – on how satisfied they felt with each attribute.

Table 3 Indiscriminate index (II) values for the study

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	0	0	0.43	0.87	1.07	1.18	1.26	1.35	1.43	1.5

Table 4 Foremost parameters affecting bhopal and indore bus transport system combined operational and passenger competence

S. No.	*Item*	*2018–2019*	*2019–2020*	*Increase/decrease from previous year*
1	Bus Transport Service Hours (SA2)- daily	17	12	(-)5
2	Number of bus stops per km of travel (SA3)	3	2	(-)1
3	Delay in bus journey time (R3) in minutes	15	10	(-)5
4	Seating arrangement inside busses (BD1) in passenger per seat	3	1	(-)2
5	Quality of ridership during bus travel (C1) in terms of scale (1–5)*	2	4	(+)2
6	Accessibility in terms of number of bus stops per 2 km of travel on major corridor (C2)	84	71	(-)13
7	No. of Buses equipped with GPS with real time information about schedule per route (CS5)	1	2	(+)1
8	Average earning per passenger (paisa) (BF2)	2345	2889	(+)544
9	Ticket concession price per passenger in paisa (BF3)	878	572	(-)306
10	Safety from road accidents while travelling (expressed in terms of no. of deaths/ major route/ year) (SS1)	327	214	(-)113
11	Display of women and child helpline/ emergency contact numbers inside busses (number of busses/route) (SS3)	3	5	(+)2
12	Fuel consumption per km of travel (in terms of litres per km) (ES2)	3.78	4.14	(+)0.36

3.3.2 Collection of data

The performance optimisation has been done based on the integrated FAHP-GP method. The data was obtained from the annual audit reports from 2016–2017 and 2018–2019 of the BCLL (Pal et al., 2016) and Atal Indore City Transport Services [AICTS] – (Mishra and Sarkar, 2018). According to a recent survey, roughly 28% of daily commuters prefer to take bus for work-based trips on weekdays and recreational trips on weekends compared to paratransit and self-owned private vehicles. AICTS operates with 95 routes while BCLL operates with 4 trunk (TR) and 8 standard (SR) bus routes in the city. BCLL has an average daily ridership of 1.27 lakhs (till February, 2020) with a total system length of 18.6 kilometres. Ahilya Path (Indore BRTS) under preliminary operations of AICTS has an estimated ridership up to 1.67 lakhs for the same period. The gross revenue earned via fare box collections by BCLL for the year 2019–2020 was 5316.45 million INR while the gross revenue expenditure was about 28435.79 m INR. The operating losses of both BCLL and AICTSBusses may be because of leakage in operational efficiency, high staff-to-bus ratio, highly uneconomical route operations, overhyped discounted fare rates and absence bus priority lanes on major routes. The number of possible breakdowns per thousand kilometres for the year 2016–2017 was 160 more than the national average of 100 (Cyril et al., 2019) While the same for Indore city bus services may be attributed to lesser than 65.87 million INR. Such an anomaly in operating losses between both the tier-II cities indicates Indore's exceptional capability of promoting public transit ridership. Under such constraints, both BCLL and AICTS cannot smoothly operate until ground-breaking reforms are applied immediately to control rising operator costs with effective fund utilisation and distribution and innovative public transport passenger attraction schemes.

4 Results

The parameters with optimised values as per the FAHP approach are bus journey time delay, operator earnings, intensity of buses and women and children safety. Tables 5–10 represent various analytic findings of the study. Table 5 highlights pairwise distinction matrix for both operator and passenger. Table 6 represents pairwise distinction matrix of operator-oriented explanatory parameters. Table 7 shows pairwise distinction matrix of passenger-oriented explanatory parameters. Table 8 represents the parameter weights obtained from the FAHP technique. Table 9 shows the optimum values for the Explanatory parameters.

Table 5 Pairwise distinction matrix for both operator and passenger

Factor	*Operator*	*Passenger*	*Priority vector*
Operator	2	1	0.333
Passenger	1	1/2	0.667
Sum	3	1.5	1.000

Table 6 Pairwise distinction matrix of operator-oriented explanatory parameters

Explanatory parameters	*SA2*	*R3*	*C1*	*BF2*	*SS1*	*ES2*	*Priority vector*
SA2	1/4	1/3	1	3	2	3	0.143
R3	1/3	1/4	1/2	1/2	1	2	0.056
C1	1/3	1/4	1/3	1/3	1/2	1	0.071
BF2	1/2	1	3	4	4	4	0.287
SS1	1	2	4	2	3	3	0.338
ES2	1/2	1/4	1/3	1	2	3	0.105

*Reliability ratio (RR): 0.09.

Table 7 Pairwise distinction matrix of passenger-oriented explanatory parameters

Explanatory parameters	*Reliability*	*Comfort*	*Fare affordability*	*Safety and security*	*Priority vector*
Reliability	1	1/10	2	1	0.108
Comfort	1/2	1/10	1	1/4	0.045
Fare affordability	1	1/10	4	1	0.112
Safety and security	10	1	10	10	0.71

*Reliability ratio (RR): 0.08.

Table 8 Parameter weights obtained from the fuzzy AHP technique

Explanatory Parameter	*Symbols*	*Average priority vector*	*Weight (in percent)*
Passenger: 34.108%			
Reliability	R	0.321	5.222
Comfort	C	0.104	3.885
Fare affordability	BF3	0.538	20.667
Safety and Security	SS	0.120	4.334
Operator: 65.892%			
Bus transport service hours	SA2	0.233	14.094
Bus journey time delay (in minutes)	R3	0.147	7.088
Quality of ridership	C1	0.035	6.556
Average earning per passenger (paisa)	BF2	0.456	25.133
Safety from road accidents while travelling (expressed in terms of no. of deaths/major route/year)	SS1	0.076	4.866
Fuel consumption per km of travel (in terms of litres per km)	ES2	0.302	8.155

Table 9 Optimum values for the explanatory parameters

Explanatory parameter	*Unit/element*	*Actual output*	*Target value*
E_1	Bus transport service hours (in hours)	17.5	13–19
E_2	Bus journey time delay (in minutes)	17	15–18
E_3	Quality of ridership (on a scale of 1 to 5)	2	1–5
E_4	Operator earnings (average earning per passenger in paisa)	2608	2430–2704
E_5	Bus transport road accident death rate (deaths/year/major route)	271	256–284
E_6	Fuel consumption (litres per kilometre)	3.96	2.78–4.04
E_7	Bus fleet intensity (busses per route)	7	5–8
E_8	Bus stop density (No. of bus stops/km of travel)	5	4–6
E_9	Accessibility (No. of bus stop per 2 km under major corridor)	11	9–12
E_{10}	Women and children safety (Number of busses displaying women and child helpline numbers/route)	3	1–4

Table 10 Optimised and actual values for explanatory parameters

Variable	*Parameter*	*Actual output*	*Optimal output*	*Percentage increase/decrease*
E_1	Bus transport service hours (in hours)	17.5	16.25	-1.25
E_2	Delay in bus journey time (in minutes)	17	17.01	0.01
E_3	Quality of ridership (on a scale of 1 to 5)	2	3.09	1.09
E_4	Operator earnings (average earning per passenger in paisa)	2608	2607	-1
E_5	Bus transport road accident death rate (in deaths/year/major route)	271	265	-6
E_6	Fuel consumption per km (litres per kilometre)	3.96	3.99	0.03
E_7	Bus fleet intensity (busses per route)	7	6	-1
E_8	Bus stop density (No. of bus stops/km of travel)	5	7	2
E_9	Accessibility (No of bus stop per 2 km under major corridor)	11	9	-2
E_{10}	Women and children safety (Number of busses displaying women and child helpline/route)	3	2	-1

In Table 10 optimised and actual values for explanatory parameters have been correlated. For intercity bus transport services, optimised parameters belonging corresponding to operator efficiency are operator earnings in paisa per passenger (with 95.54% parameter sensitivity). While the ones relevant towards users' efficiency are bus fleet intensity in bus per route (with 95.43% sensitivity), bus stop density in stops per km of travel (with 90.12% parameter sensitivity) and women and child safety (with 94.45% parameter sensitivity).

Thus, the relationship between all the parameters, travel cost and overall satisfaction can be expressed through:

$$\begin{aligned}Overall\,satisfaction &= 0.087 \times maintenance + 0.108 \times availability + 0.112 \times travel\,cost \\ &+ 0.045 \times comfort + 0.148 \times reliability + 0.71 \times safety\end{aligned}$$

4.1 Objective functions and their outputs

The objective function of the optimisation problem is shown in equation (6) which has been created based on positive and negative deviations of the eight optimised attributes for which the minimum and maximum values were obtained using fuzzy-analytical hierarchical process (FAHP) technique. Various variables like bus transport service hours (in hours), delay in bus journey time (in minutes), quality of ridership, operator earnings (average earning per passenger in paisa), bus transport road accident death rate, fuel consumption per year, bus fleet intensity (buses per route), bus stop density (number of bus stops/ km), accessibility (no. of bus stops per 2 km under major corridor), women and children safety (number of busses displaying women/ child helpline per route). The eight variables considered for optimisation are bus transport service hours (in minutes) – E_1, bus journey time delay (in minutes)-E_2, quality of ridership (on a scale of 1 to 5)-E_3, operator earnings per passenger-E_4, bus transport related accidents – E_5, fuel consumption per kilometre- E_6, bus fleet intensity (busses per route)-E_7, bus stop density (no. of bus stops per kilometre)-E_8, accessibility-E_9, women and children safety-E_{10}.

So, if we reduce:

$$\begin{aligned}&19.78.ND_1 + 21.34.PD_1 + 18.72.ND_2 + 17.89.PD_2 + 12.56.ND_3 + 17.68.ND_4 \\ &+16.03.PD_3 + 19.07.ND_5 + 17.55.PD_4 + 12.03.PD_5 + 13.97.ND_6 + 12.11.PD_6 \\ &+9.34.ND_7 + 6.75.ND_8 + 8.37.PD_7 + 3.76.PD_8\end{aligned} \tag{6}$$

The constraints as formulated are:

First precedence: Maximisation of the safety and security of passengers

$$E_5 + E_{10} - ND_1 = 34.52 \tag{7}$$

$$E_5 + E_{10} + PD_1 = 22.31 \tag{8}$$

Second precedence: Maximise the Reliability for Passengers

$$E_2 + E_7 - ND_2 = 24.78 \tag{9}$$

$$E_2 + E_7 + PD_2 = 27.89 \tag{10}$$

Third precedence: Maximise comfort of passengers

$$E_3 + E_9 - ND_3 = 6.24 \tag{11}$$

$$E_3 + E_9 + PD_3 = 7.32 \tag{12}$$

Fourth precedence: Optimise the operator financial attributes tolerably

$$E_4 - ND_4 = 2705 \tag{13}$$

$$E_4 + PD_4 = 2811 \tag{14}$$

Fifth precedence: Maximise the number of stops per kilometre on major route

$$E_8 - ND_5 = 4 \tag{15}$$

$$E_8 + PD_5 = 7 \tag{16}$$

Sixth precedence: Improvement of service availability by increasing service hours

$$E_1 - ND_6 = 9.34 \tag{17}$$

$$E_1 + PD_6 = 18.97 \tag{18}$$

Seventh precedence: Reduction in fuel consumption per km of travel

$$E_6 - ND_7 = 2.39 \tag{19}$$

$$E_6 + PD_7 = 6.78 \tag{20}$$

Eight precedence: Increasing accessibility of passengers

$$E_9 - ND_8 = 13.45 \tag{21}$$

$$E_9 + PD_8 = 4.33 \tag{22}$$

In this paper, eight precedence or constraints were considered in the scopes of 'maximisation of the safety and security of passengers', 'maximise the reliability for passengers', 'maximise comfort of passengers', 'optimise the operator financial attributes tolerable', 'maximise the number of stops per kilometre on major route', 'improvement of service availability by increasing service hours', 'reduction in fuel consumption per km of travel' and 'increasing accessibility of passengers'. The most significant parameter to evaluate the overall satisfaction is safety followed by reliability, availability, maintenance, comfort and travel cost. The optimised decision parameters are derived using the linear weighted integrated FAHP-GP problem using Linear, Interactive and Discrete Optimizer (LINDO) 16.4. The optimised explanatory parameters are tabulated in Table 11. Table 12 enlists the benchmarked (that is, optimised values) of all the ten identified parameters important in deciding performance levels of urban bus transport systems operating in Central India.

Table 11 Sensitivity analysis for the optimisation problem formulated

Explanatory parameter	*Actual output*	*Optimal output*	$E_4 \geq 1887$, $E_7 = 6$	$E_1 = 420$, $E_7 = 6$, $E_9 = 23$	$E_5 = 176$	$E_4 \geq 1887$, $E_5 \geq 3.24$	$E_6 = 3.49$	$E_3 = 2.45$, $E_2 = 18.07$	$E_6 \geq 2.76$, $E_8 = 6$	$E_5 = 254$, $E_{10} = 3$	$E_2 = 16.77$
Objective function value	123.45	145.4	156.7	137.8	145.5	134.45	144.9	137.4	148.9	157.7	166.44
E_1	17.5	17.5	17.19 (98.22%)	17.5 (100%)	15.75 (90%)	13.93 (79.6%)	14.98 (85.61%)	17.5 (100%)	15.76 (90.05%)	6.97 (39.82%)	17.54 (99.77%)
E_2	17	17	16.65 (97.94%)	16.82 (98.94%)	16.04 (94.35%)	17 (100%)	17 (100%)	18.87 (90.09%)	17 (100%)	17 (100%)	15.29 (89.94%)
E_3	2	2	2 (100%)	3 (66.67%)	4 (50%)	2 (100%)	4 (50%)	2 (100%)	1 (50%)	3 (66.66%)	2 (100%)
E_4	2608	2608	2234.28 (85.67%)	2340.94 (89.75%)	2497.42 (95.75%)	2608 (100%)	2608 (100%)	2608 (100%)	2304.87 (88.37%)	2608 (100%)	2608 (100%)
E_5	271	271	271 (100 %)	254 (93.73%)	256 (94.46%)	271 (100%)	271 (100%)	268 (98.98%)	271 (100%)	93(34.31%)	271 (100%)
E_6	3.96	3.96	3.17 (80.05%)	3.96 (100%)	3.96 (100%)	2.31 (58.33%)	3.96 (100%)	3.96 (100%)	3.17 (80.05%)	3.96 (100%)	1.808 (45.65%)
E_7	7	7	6 (85.71%)	7 (100%)	7 (100%)	8 (87.5%)	6 (85.71%)	7 (100%)	7 (100%)	7 (100%)	7 (100%)
E_8	5	5	5 (100%)	5 (100%)	5 (100%)	5 (100%)	5 (100%)	1 (20.22%)	5 (100%)	5 (100%)	6 (83.33%)
E_9	11	11	10 (90.9%)	11 (100%)	11 (100%)	9 (81.81%)	11 (100%)	11 (100%)	10 (90.91%)	9 (81.81%)	10 (90.91%)
E_{10}	3	3	3 (100%)	3 (100%)	4 (75%)	3 (100%)	3 (100%)	3 (100%)	4 (75%)	3 (100%)	3 (100%)

Table 12 Explanatory parameter fragmentation for the cities of Indore and Bhopal based on FAHP-GP optimisation benchmarking

City	*Explanatory parameter*	*Mean (μ) output*	*Standard deviation (σ) of output*	$\geq \mu + \sigma$	$\geq \mu$ and $< \mu + \sigma$	$\geq \mu - \sigma$ and $< \mu$	$< \mu - \sigma$	*Maximum output*	*Minimum output*
Indore	E_1IN	15.61	3.11	E3IN, E9IN, E7IN	E2IN, E10IN	E1IN, E6IN	E4IN, E5IN, E8IN	13.12	18.87
	E_2IN	16.88	0.86					15	17.6
	E_3IN	2	0.79					2	5
	E_4IN	2512.14	146.29					2441.50	2665.50
	E_5IN	241.59	59.54					264	284
	E_6IN	3.66	0.88					2.89	3.87
	E_7IN	6	0.60					5	7
	E_8IN	5	1.50					4	6
	E_9IN	10	0.80					9	11
	E_{10}IN	2	0.78					1	4
Bhopal	E_1BP	16.09	3.23	E3BP, E8BP	E1BP, E5BP, E10BP	E7BP	E4BP, E2BP, E6BP, E9BP	14.56	19.27
	E_2BP	17.16	0.76					15	18
	E_3BP	4.01	1.06					1	5
	E_4BP	2134.56	134.22					2556.50	2704
	E_5BP	259.8	57.14					264	284
	E_6BP	3.33	0.72					3.02	4.01
	E_7BP	5	0.57					5	8
	E_8BP	5	0.81					4	6
	E_9BP	11	0.65					10	12
	E_{10}BP	4	0.67					1	5

5 Conclusion

The FAHP model suggests that increasing bus fleet strength and reducing fuel consumption will help generate above-average operator revenue for intercity bus operations. To increase the density of the bus fleet in cities such as Indore (population 3.12 million), an additional 13 or so buses will be required per route. And for a city like Bhopal (population 2.45 million), it takes about 8 buses one way. It is also possible to increase the strength or frequency of the fleet to reduce the ratio of people to buses. The staff-to-bus ratio can be limited by limiting single-occupancy policies and dynamic staff shift time management. The FAHP-GP model also suggests that the number of bus stops should be increased to improve passenger accessibility. The study also recommends that, to reduce crime and reporting against women and children, more buses should display emergency helpline phone numbers and integrate with advanced onboard passenger information systems. From an operator's point of view, operator revenue (in paise per passenger) is a parameter that needs to be increased during the operating hours of some major routes. Operators' revenues can be increased by introducing flexible ticketing systems such as GPS-ETM (Global Positioning Integrated Electronic Ticketing Machine) as well as computerised workforce planning at bus stops on all major routes. Benchmarking of sensitivity data is often required to track negative and positive biases in explanatory parameters that affect the efficiency of transit operations. At least 7 buses are required on each route for both the cities of Bhopal and Indore. The average operator earnings should be limited to 2608 paise per passenger. The bus stop density per kilometre of travel should be increased to 3. Women and children helpline numbers should be displayed on each major route.

Acknowledgements

All authors contributed to the study conception and design. For preparation of material and final draft Vijay Singh Solanki performed data collection, created the tables and figures and conducted data analysis. P.K. Agarwal commented on previous versions of the manuscript and provided a factual review and helped edit the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors declare there are no conflict of interest in the publication of this paper.

Authors are responsible for correctness of the statements provided in the manuscript. The authors report there are no competing interests to declare. The authors did not receive support from any organisation for the submitted work.

Data availability

The data that support the findings of this study are available from the corresponding author (i.e., Vijay Singh Solanki), upon reasonable request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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