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Development of a Methodology for Evaluation of Comparative Performance of Alternate Public Transport System in Indian Cities

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Abstract

The development of methodologies for comparative performance evaluation of public transport system is a research field that continues to grow since the need to improve the performance of public transport system is higher as compared to the previous years. The major reasons for evaluating the comparative performance of public transport system are to control operating and travelling cost, impact of systems in a city and justify the alteration in system before its implementation in a city. Therefore, there is need to develop a comprehensive methodology which can evaluate the comparative performance of public transport system separately from user, operator and city perspective as well as combined. Hence, this study presents a comprehensive methodology for evaluating the comparative performance of alternate public transport system in Indian cities. Various performance indices are developed during this study which can be used to evaluate the condition of identified comparative performance indicators. This study also developed overall comparative performance index (OCPI) which can be used to compare the alternate public transport system to an existing system or new public transport system to any similar system or different system. It is expected that this study will be useful to researcher for improvement of public transport system in Indian cities.

Keywords: comparative performance evaluation, performance indicator, public transport system

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INTRODUCTION

It is expected that by 2050, about 60–70% of the population will be living in urban areas in India. With increasing urbanization and the load on rural land, the government has now realized the need for smart cities in urban areas. A ‘smart city’ is an urban region that makes optimal use of the interconnected information available today to better understand and control its operations and optimize the use of limited resource. Public transport system in Indian smart cities must be more creative and attractive due to higher dependency of impoverished urban population, maximum share of captive users, and environmental, economic, and social equity. However, at present due to poor infrastructure and inefficient public transport system there are various problems involved in Indian cities such as severe congestion, deteriorating air quality, increasing incidence of road accidents, land sprawl, and rapidly increasing energy cost& minimum revenue generation. This has resulted in high cost facilities not giving the outcomes that were sought. Further, recently various public transport systems like BRT, LRT, metro rails and various other types of systems are operating, some

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under construction, and also being planned in various Indian cities.[1] It is also observed that the enormous amount of money is required for implementation of these public transport systems in Indian cities. Hence, the major reasons for evaluating the comparative performance of public transport system, in Indian cities are to control operating and travelling cost, impact of systems in a city and justify the alteration in system before its implementation. Therefore, there is acritical need to develop a simple methodology which can scrutinize how well the existing public transport system are operating and justify the alteration in public transport system in Indian cities.

The development of methodologies for comparative performance evaluation of public transport system is a research field that continues to grow since the need to improve the performance of public transport system is higher as compared to the previous years. A critical review of literature shows that most of the researchers[2,3,4,5,6,7,8] evaluated the performance of public transport system from various different perspectives but according to[9,10,11] fewer methodologies are available on evaluation of comparative performance of alternate public transport system. Further there are very few evaluate the performance of public transport system under separate categories i.e. user perspective, operator perspective and city perspective as well as combined performance. However, these research methodologies may not be satisfactory for evaluating the performance of public transport system due to absent of data base or when data is not available in comprehensive way. Hence, this study presents a systematic and simple methodology which can evaluate the comparative performance of alternate public transport system in Indian cities from user, operator and city perspective separately as well as combined with minimal data which are available easily and minimum cost. The proposed methodology can also be executed using a case study of comparative performance evaluation of BRTS system of Bhopal city.

This paper consists of four section among this is the one which presents need of the study and literature review carried out so far and its important deficiencies. The second section presents the proposed methodology. The analysis and result using the proposed methodology is presented in section three. The last section presents the important conclusions drawn based on this study.

PROPOSED METHODOLOGY

This study presents a systematic and simple methodology for comparative performance evaluation of alternate public transport system in Indian context. The proposed methodology can be used to evaluate the comparative performance of an existing public transport system as well as a new public transport system (i.e. system 1) to any similar system or different public transport system (i.e. system 2). Figure 1 presents a framework of a methodology for evaluation of comparative performance of public transport system. The proposed methodology consists of major four stages.

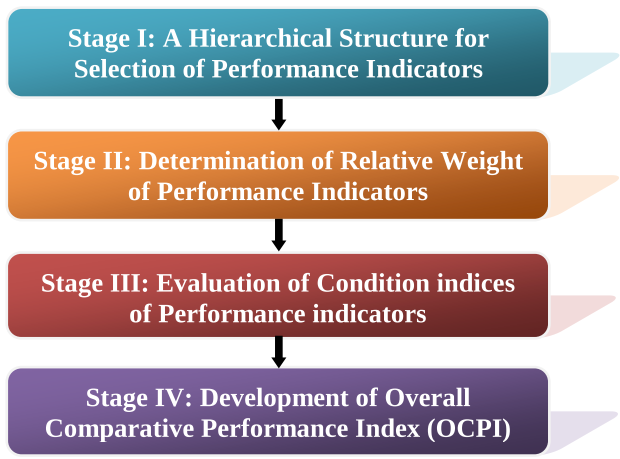

***Fig. 1.** A Framework of Proposed Methodology.*

Stage IA Hierarchical Structure for Selection of Performance Indicators

The main objective of the first stage is to identify the most appropriate comparative performance indicators from user, operator and city perspective which are affecting the performance of public transport system. However, the selection of most appropriate indicators is a complex task because a large number of indicators are available in literature. Therefore this study develops a hierarchical structure for selection of appropriate indicators under separate categories. Figure 2 presents a hierarchical structure for selection of comparative performance indicator. The overall comparative performance of public transport system evaluated under the three major categories i.e. user perspective, operator perspective and city perspective. Each of these categories is further decomposed into total 14 basic comparative performance indicators (i.e. CPI_1-CPI_{14}), eight of them are measured by quantitative indices and the remaining six are measured by qualitative indices. These indicators are selected on the basis of literature review carried out.

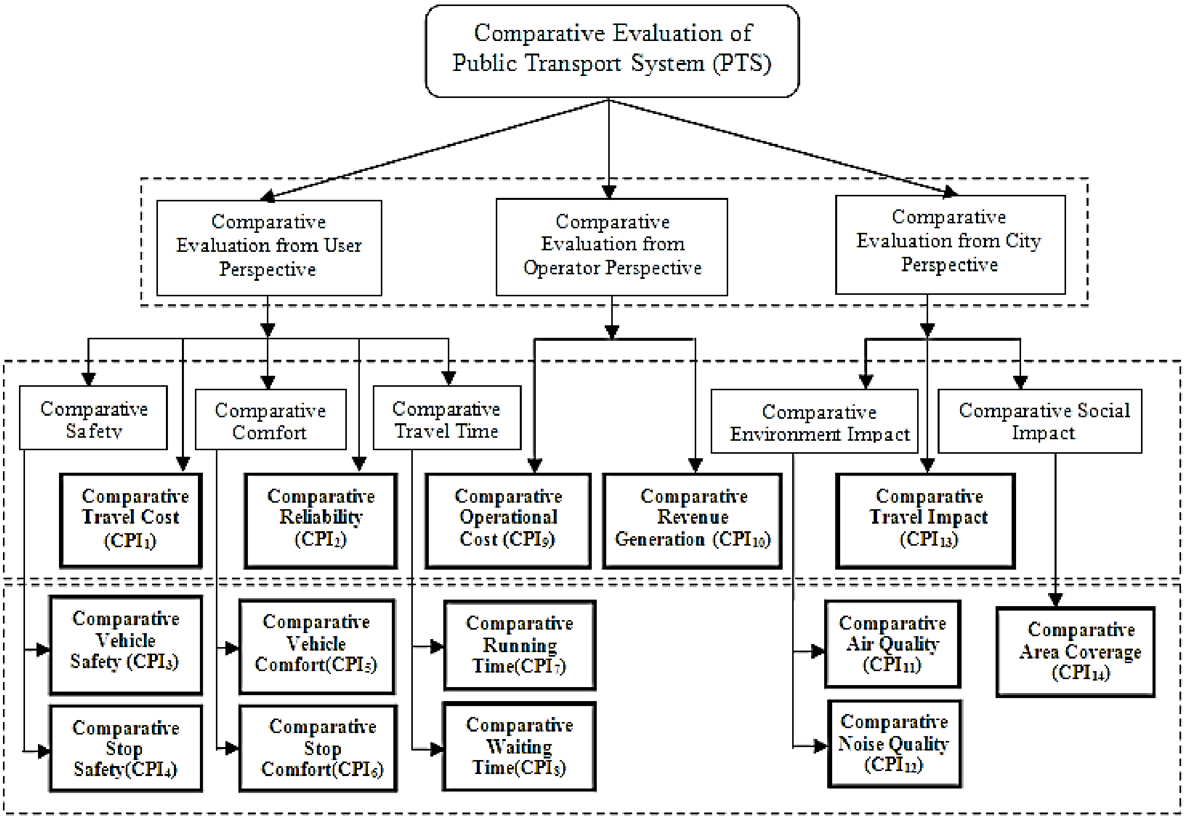

***Fig. 2.** A Hierarchical Structure for Identification of ComparativePerformance Indicators.*

Stage II: Determination of Relative Weight of Performance Indicators

The second stage determines the relative weight of identified comparative performance indicators. The identified indicators may not be equally affecting the overall comparative performance of public transport system. Therefore, a system of weights needs to be introduced to reflect the contribution to comparative performance of public transport. The relative weight of performance indicators are determined using passengers, operators, public transport expert and academician opinion survey and the rating given by them. Table 1 presents relative weight of major performance indicators for evaluation of comparative performance of public transport system. Further it is considered that relative weight of basic factor of user perspective, operator perspective and city perspective are also determined as per passengers, operators, public transport expert and academician opinion survey and the rating given by them. Table 2 presents the relative weight of basic factors of under different performance measures.

Table 1. *Analysis for Determination of Relative Weight of Major Comparative Performance Indicators.*

Weight of major performance indicators	Notation of weight	Number of personputting importance					Average weight	Relative weight
		5	4	3	2	1		
		N_5	N_4	N_3	N_2	N_1		
Comparative user perspective	W_{US}	33	19	11	4	0	4.209	0.457
Comparative operator perspective	W_{OP}	4	13	19	23	8	2.731	0.297
Comparative city perspective	W_{CT}	3	4	19	23	18	2.269	0.246
	Total						**9.209**	**1.000**

5 = Extremely Important, 4 = Very important, 3 =Important, 2 = Important to Some Extent, 1 = Not at all Important.

Table 2. *Analysis for Determination of Relative Weight of Basic Factors of Comparative Performance Indicators.*

S.no.	Weight of basic performance indicators	Notation of weight	Number of personputting importance					Average weight	Local relative weight
			5	4	3	2	1		
			N_5	N_4	N_3	N_2	N_1		
1.	Comparative Travel Cost(CTC)	W_{TC}	24	17	15	7	4	3.746	0.141
2.	Comparative Reliability(CRB)	W_{RB}	13	11	18	17	8	3.060	0.115
3.	Comparative Vehicle Safety (CVS)	W_{VS}	16	17	14	13	7	3.328	0.125
4.	Comparative Stop Safety(CSS)	W_{SS}	9	15	13	23	7	2.940	0.110
5.	Comparative Vehicle Comfort (CVC)	W_{VC}	13	26	14	6	8	3.448	0.130
6.	Comparative Stop Comfort (CSC)	W_{SC}	7	14	18	17	11	2.836	0.107
7.	Comparative Running Time (CRT)	W_{RT}	27	22	12	4	2	4.015	0.151
8.	Comparative Waiting Time (CWT)	W_{WT}	14	15	17	15	6	3.239	0.122
Total								**26.612**	**1.000**
9.	Comparative Operating Cost (COC)	W_{OC}	16	15	13	10	13	3.164	0.434
10.	Comparative Revenue Generation (CRG)	W_{RG}	29	24	9	3	2	4.119	0.566
Total								**7.284**	**1.000**
11.	Comparative Air Quality (CAQ)	W_{AQ}	14	21	17	9	6	3.418	0.254
12.	Comparative Noise Quality (CAQ)	W_{NQ}	6	13	22	18	8	2.866	0.213
13.	Comparative Travel Impact (CTI)	W_{TI}	20	24	16	3	4	3.791	0.282
14.	Comparative Area Coverage (CAC)	W_{AC}	14	21	17	6	9	3.373	0.251
Total								**13.448**	**1.000**

5 = Extremely Important, 4 = Very Important, 3 =Important, 2 = Important to Some Extent, 1 = Not at all Important.

Stage III: Evaluation of Condition Indices of Performance indicator

The third stage developed various important indices for evaluation of condition of identified performance indicators. These indices are developed in such a way that comparative performance of alternate public transport system can be evaluated in Indian cities**.** Table 3 presents a methodology for evaluation of condition of identified performance indicators.

Table 3. *Methodology for Evaluation of Condition Indices of Identified Comparative Performance Indicators.*

ID	Comparative Performance Indicator	Methodology
CPI_1	Comparative Travel Cost Index **(CTCI)**	$\mathbf{CTCI = \frac{ATC_2}{ATC_1}}$ ………. **Equation (1)** ATC_1 = Average travel cost per km for System1 ATC_2 = Average travel cost per km for System 2
CPI_2	Comparative Reliability Index **(CRBI)**	$\mathbf{CRBI = \frac{RBR_1}{RBR_2}}$ ………. **Equation (2)** VSR_1 = Reliability rating given by users for System 1 VSR_2 = Reliability rating given by users for System 2 VSRs $= \frac{5*R5+4*R4+3*R3+2*R2+1*R1}{TNR*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of respondent feel extremely reliable system (5), R4= No. of respondent feel good reliable system (4), R3= No. of respondent feel average reliable system (3), R2 = No. of respondent feelaverage reliable system to some extent (2), R1 = No. of respondent feel not at all reliable system(1)
CPI_3	Comparative Vehicle Safety Index **(CVSI)**	$\mathbf{CVSI = \frac{VSR_1}{VSR_2}}$ ………. **Equation (3)** VSR_1 = Vehicle safety rating given by users for System 1 VSR_2 = Vehicle safety rating given by users for System 2 VSRs $= \frac{5*R5+4*R4+3*R3+2*R2+1*R1}{TNR*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of respondent feel extremely safe during travelling in vehicle (5), R4= No. of respondent feel good safe during travelling in vehicle (4), R3= No. of respondent feel average safe during travelling in vehicle (3), R2 = No. of respondent feel safe to some extent during travelling in vehicle (2), R1 = No. of respondent feel not at all safe during travelling in vehicle (1)
CPI_4	Comparative Stop Safety Index **(CSSI)**	$\mathbf{CSSI = \frac{SSR_1}{SSR_2}}$ ………. **Equation (4)** SSR_1 = Stop safety rating given by users for System 1 SSR_2= Stop safety rating given by users for System 2 SSRs $= \frac{5*R5+4*R4+3*R3+2*R2+1*R1}{TNR*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of respondent feel extremely safe at stop (5), R4= No. of respondent feel good safe at stop (4), R3= No. of respondent feel average safe at stop (3), R2 = No. of respondent feel safe to some extent at stop (2), R1 = No. of respondent feel not at all safe at stop (1)
CPI_5	Comparative Vehicle Comfort Index **(CVCI)**	$\mathbf{CVCI = \frac{VCR_1}{VCR_2}}$ ………. **Equation (5)** VCR_1 = Vehicle comfort rating given by users for System 1 VCR_2 = Vehicle comfort rating given by users for System 2

		$VCR_s = \frac{5*S5+4*S4+3*S3+4*S2+1*S1}{(S1+S2+S3+S4+S5)*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of respondent feel extremely comfort during travelling in vehicle (5), R4= No. of respondent feel good comfort during travelling in vehicle (4), R3= No. of respondent feelaverage comfort during travelling in vehicle (3), R2 = No. of respondent feel comfort to some extent during travelling in vehicle (2), R1 = No. of respondent feel not at all comfort during travelling in vehicle (1)
CPI_6	Comparative Stop Comfort Index **(CSCI)**	$\mathbf{CSCI = \frac{SCR_1}{SCR_2}}$ ……….**Equation (6)** SCR_1 = Stop comfort rating given by users for System 1 SCR_2 = Stop comfort rating given by users for System 2 $SCR_s = \frac{5*S5+4*S4+3*S3+4*S2+1*S1}{(S1+S2+S3+S4+S5)*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of respondent feel extremely comfortat stop (5), R4= No. of respondent feel good comfort at stop (4), R3= No. of respondent feel average comfort at stop (3), R2 = No. of respondent feelcomfort to some extent at stop (2), R1 = No. of respondent feel not at all comfort at stop (1)
CPI_7	Comparative Running Time Index **(CRTI)**	$\mathbf{CRTI = \frac{ART_2}{ART_1}}$ ……….**Equation (7)** ART_1 = Average running timeper km in minutefor System1 ART_2 = Average running time per kmin minute for System 2 ART_S= (60*ATL)/AOS ATL = Average trip length in km AOS = Average operational speed in km/h
CPI_8	Comparative Waiting Time Index **(CWTI)**	$\mathbf{CWTI = \frac{AWT_2}{AWT_1}}$ ……….**Equation (8)** AWT_1 = Average waiting time at stop in minute for System1 AWT_2 = Average waiting time at stop in minute for System 2 AWT_S=60/NVH NBH=No of vehicles reaching at stop per hour
CPI_9	Comparative Operational Cost Index **(COCI)**	$\mathbf{COCI = \frac{AFC_2}{AFC_1}}$ ……….**Equation (9)** AFC_1 = Average fuel cost per seat per km of travel for System1 AFC_2 = Average fuel cost per seat per km of travel for System 2 AFC_s = (FCK*COF)/TNS FCK=Fuel consumption in liter per km COF=Cost of fuel per liter TNS =Total No. of seats per vehicle
CPI_{10}	Comparative RevenueGeneration Index **(CRGI)**	$\mathbf{CRGI = \frac{ARG_1}{ARG_2}}$ ……….**Equation (10)** ARG_1 = Average revenue generation per day per km per vehicle for System1 ARG_2 = Average revenue generation per day per km per vehicle for System 2 ARG_s = TPD*FPK TPD=Total passengers/day/vehicle FPK=Fare per km
CPI_{11}	Comparative Air Quality Index **(CAQI)**	$\mathbf{CAQI = \frac{TAE_2}{TAE_1}}$ ……….**Equation (11)** TAE_1 = Total air emission in gm. per km per vehicle by System1 TAE_2 = Total air emission in gm. per km per vehicle by System 2 TAE_s=(Emission factor per vehicle in gm/km)/seating capacity

CPI_{12}	Comparative Noise Quality Index **(CNQI)**	$\mathbf{CNQI = \frac{NQR_1}{NQR_2}}$ ……….**Equation (12)** NQR_1 = Noise quality rating given by users for System 1 NQR_2 = Noise quality rating given by users for System 2 $NQR_s = \frac{5*S5+4*S4+3*S3+4*S2+1*S1}{(S1+S2+S3+S4+S5)*5}$ TNR=Total no of respondent=R5+R4+R3+R2+R1 R5= No of persons rated very low noise (5), R4= No. of persons rated fair noise (4), R3= No. of persons rated average noise (3), R2 = No. of persons rated high noise (2), R1 = No. of persons rated extremely noise (1)
CPI_{13}	Comparative Travel Impact Index **(CTII)**	$\mathbf{CTII = \frac{ITF_1}{ITF_2}}$ ……….**Equation (13)** ITF_1 = Improvement in traffic flow for System 1 ITF_2 = Improvement in traffic flow for System 2 ITFs=(AOS/DOS) AOSs=Average operational speed (km/hr.) DOSs=Desirable operational speed (km/hr.)
CPI_{14}	Comparative Area Coverage Index **(CACI)**	$\mathbf{CACI = \frac{SCA_1}{SCA_2}}$ ……….**Equation (14)** SCA_1 = Service coverage area for System 1 SCA_2 = Service coverage area for System 2 SCAs=(TCL/TCA) TCL = Total corridor length (km) TCA= Total city area (sq. km.)

Stage IV: Development of Overall Comparative Performance Index (OCPI)

Overall performance index (OCPI) is developed by multiplication of relative weight and condition indices of performance indicators.

OCPI can be used to indicate the overall performance of public transport system in a city. The value of indices greater than one, equal to one and less than one indicates the comparative performance of public transport system1 is better, equal and inferior quality with respect to system2.

The overall Comparative performance index (OPI) is evaluated using equation (15).

$$OCPI = W_{US}*CUPI + W_{OP}*COPI + W_{CT*}CCPI \quad \text{Eq. (15)}$$

Now putting the value of weight in Equation (15) it can be written as Equation (16)

$$OCPI = 0.348*CUPI + 0.241*COPI + 0.412*CCPI \quad \text{Eq. (16)}$$

Comparative User Perspective Index (CUPI)

It is proposed that condition of performance of public transport system from user perspective can be evaluated using an index named as comparative user perspective index (CUPI).

The user perspective indicators such as travel cost, travel time, safety, comfort and reliability affect the user performance of public transport system.

The comparative user performance index (CUPI) is evaluated using Equation (17)

$$CUPI=W_{TC}*CTCI+W_{RB}*CRBI+W_{VS}*CVSI+ +W_{SS}*CSSI+W_{VC}*CVCI+W_{SC}*CSCI+W_{RT}*CRTI + +W_{WT}*CWTI \quad \text{Eq. (17)}$$

Now putting the value of weight in Equation (17) it can be written as Equation (18)

$$CUPI=0.080*CTCI+0.072*CRBI+0.086*CVSI+ +0.063*CSSI+0.074*CVCI+0.061*CSCI+ +0.063*CRTI+0.073*CWTI \quad \text{Eq. (18)}$$

Comparative Operator Perspective Index (COPI)

It is proposed that condition of performance of public transport system from operator perspective can be evaluated using an index named as comparative operator perspective index (COPI). The operator perspective indicators such as operating cost and revenue generation affect the operator performance of public transport system. The comparative operator perspective index (COPI) is evaluated using Equation (18)

$$COPI=W_{OC}*COCI+W_{RG}*CRGI \qquad \text{Eq. (19)}$$

Now putting the value of weight in Equation (19) it can be written as Equation (20)

$$COPI=0.068*COCI+0.080*CRGI \qquad \text{Eq. (20)}$$

Comparative City Perspective Index (CCPI)

It is proposed that condition of performance of public transport system from city perspective can be evaluated using an index named as comparative city perspective index (CCPI). The city perspective indicators such as environment impact, travel impact and social impact affect the city performance of public transport system. The comparative city perspective index (CCPI) is evaluated using Equation (21)

$$CCPI=W_{AQ}*CAQI+W_{NQ}*CNQI+W_{TI}*CTII+ +W_{AC}*CACI \qquad \text{Eq. (21)}$$

Now putting the value of weight in Equation (21) it can be written as Equation (22)

$$CCPI=0.073*CAQI+0.061*CNQI+0.074*CTII+ 0.072*CACI \qquad \text{Eq. (22)}$$

ANALYSIS RESULTS OF COMPARATIVE PERFORMANCE OF BHOPAL BRTS

To illustrate the proposed methodology, performance of BRTS system from DIG Bunglow to New market is compared with performance of mini bus system during peak period.

Analysis results using proposed methodology are presented in this section. The details of input data for analysis using proposed methodology is presented in Table 4. The data has been collected from various authorities and operators of BRTS and mini bus system.

Table 4. *Details of Input Data for Analysis Using Proposed Methodology.*

S. no.	Parameters	BRTS, Bhopal (System 1)	Mini bus (System 2)
1.	Average travel cost per km (Rs /km)	1.71 (Upto 7 km- Fare Rs 12)	2.00 (Upto 5 km- Fare Rs 10)
2.	User reliability rating	3.98	2.78
3.	User vehicle safety rating	3.67	2.23
4.	User stop safety rating	4.45	2.98
5.	User vehicle comfort rating	3.92	2.43
6.	User stop comfort rating	4.12	1.87
7.	Average trip length in km	10	10
8.	Average operational speed in km/h	17.6	15.4
9.	Desirable operational speed in km/h	30	30
10.	No of vehicles reaching at stop per hour	4	6
11.	Fuel consumption in litre per km	0.223	0.289
12.	Cost of fuel per litre(Rs /litre)	49.71	49.71
13.	Total No. of seats per vehicle	45	30
14.	Total passengers/day/vehicle	156	118
15.	Total air emission in gm. per km per vehicle	10.21	13.62
16.	User noise quality rating	3.89	2.90

17.	Total corridor length (km)	24	105
18.	Total city area (sq. km.)	697.2	697.2

(Source: www.mybusbhopal.in, Field Survey).

Analysis results of comparative performance of Bhopal BRTS from user perspective, operator perspective and city perspective are presented in Table 5. The results obtained are logical as BRTS system is considered better than mini bus system.

Also analysis results of overall comparative performance of Bhopal BRTS to (Mini bus) are presented in Table 6.

The overall value of comparative performance index i.e. OCPI is greater than 1 which represents that on the whole BRTS system is performing better than mini bus system in Bhopal city.

Table 5. *Analysis Results of Comparative Performance Indicators.*

S.no.	Comparative performance indicator	Index value
1.	CTCI	1.16
2.	CRBI	1.43
3.	CVSI	1.64
4.	CSSI	1.49
5.	CVCI	1.61
6.	CSCI	2.20
7.	CRTI	1.14
8.	CWTI	0.66
9.	COCI	1.95
10.	CRGI	1.13
11.	CAQI	1.33
12.	CNQI	1.34
13.	CTII	1.14
14.	CACI	0.22

Table 6. *Results of Overall Comparative Performance of BRTS System.*

S. no.	Performance index	Index value
1.	CUPI	1.40
2.	COPI	1.17
3.	CCPI	0.99
	OCPI	**1.23**

Hence, it can be concluded that the proposed methodology is capable of comparing any two public transport system from user, operator and city perspective individually as well as combined comparative performance.

CONCLUSIONS

The main objective of this study is to present a systematic methodology for evaluation of comparative performance of public transport system in Indian cities. Some of the important conclusions drawn from this study are as follows.

1. A critical review of the literature indicated that there is an urgent need to develop a simple methodology which can evaluate the comparative performance of public transport system for Indian cities in a comprehensive manner. Further, it is required to evaluate the comparative performance of public transport system from user perspective, from operator perspective and from city perspectives as to identify the issues related to each separately. This study proposes a simple methodology for evaluation of comparative performance of public transport systems in Indian cities. The proposed methodology consists of four stages.
2. Stage I of this study identifies comparative performance indicators for evaluation of public transport system. Various comparative performance indicators are identified from user, operator and city perspective separately based on hierarchal structure developed in this stage.
3. Stage II of this study determines the relative weight of identified comparative performance indicators. The relative weight of comparative performance indicators are determined using passengers, operators, public transport expert and academician

opinion survey and the rating given by them.

4. A methodology is developed in stage III to evaluate the condition of identified comparative performance indicators. This study identifies eight user performance indices, two operator performance indices and four city performance indices. These indices are developed in such a way which can compare the performance of two different systems separately from user, operator and city perspective.
5. The last stage develops comparative user perspective index (CUPI) which can evaluate the comparative performance of public transport system from user perspective. Similarly, comparative operator perspective index (COPI) and comparative city perspective index (CCPI) are developed during this study which can evaluate the comparative performance of public transport system from operator and city perspective. Further in this stage overall comparative performance index (OCPI) is developed by multiplication of relative weight and condition indices of performance indicators. OCPI can be used to indicate the overall performance of public transport system in a city.
6. The approach proposed in this study is also illustrated using a comparative performance evaluation of BRTS system with mini bus service in Bhopal city. Analysis results indicated that the proposed methodology is capable to compare the performance of any two public transport system from user, operator and from city perspective as well as combined.

Therefore, the proposed methodology can be used to evaluate the comparative performance of an existing public transport system as well as a new public transport system to any similar system or different public transport system from user perspective, from operator perspective and from city perspective so as to identify the issues related to each separately. It is expected that this study will be useful to decision makers to take significant decisions before implementation of new public transit system, alteration of existing system, and reduction & expansion of existing transport systems in Indian cities.

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