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A Comprehensive Methodology for Comparative Performance Evaluation of Public Transport Systems in Urban Areas

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Abstract

The implementation of a new public transport system requires a huge amount of funds mainly in infrastructure, construction and maintenance. Hence, prior to making investment in transport technologies, poor economic condition and limitation of the infrastructure facilities, there is a continued need to improve the performance of public transport system in urban areas in developing countries. However, the performance improvement of public transport system is a complicated process because it can be viewed through three different perspectives i.e. user, operator and city perspectives. Hence, for efficient operation and sustainability, the requirements of these three perspectives should be met with. The performance evaluation process is useful for monitoring, controlling and improving the facilities of public transport systems in relation to different aspects from different perspectives. However, most of the studies are not structured considering all three perspectives in a simple manner so that cannot find significant comparative information for performance evaluation of public transport systems in urban areas. Therefore, this study presents a comprehensive methodology for comparative performance evaluation of public transport system from user, city and operator perspective as well as combined in urban areas. The methodology proposed in this study is also illustrated using BCLL bus system and Mini bus system in Bhopal city. It is expected that this study will be useful to take significant decisions before implementation of new system or alteration in existing system and performance improvement of existing urban transport system in developing countries.

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Keywords: Public transport system, Comparative performance evaluation; User perspective, City perspective, Operator perspective, Performance indicators,

1. Introduction

In most of the Indian cities, the demand of public transport is very high due to increased urbanization, population growth, rising traffic demand, dispersal of amenities and urban activities [Kanuganti et al. (2013), Singh (2012), Agarwal et al., (2015), Advani and Tiwari (2006)]. Hence, recently various types of alternate public transport systems like Bus rapid transit system (BRTS), Mass rapid transit system (MRTS), Light rail transit (LRT), Mono rail, Mini bus, and other different types of city bus systems are operating and also being planned in various Indian cities. However, the existing infrastructure in Indian cities is not appropriate to support these public transport

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systems, which results in an increase in travel cost and travel time, degradation of comfort and safety, higher traffic congestion, intensifying traffic accidents, thereby creating a huge economic loss, and environmental degradation. Due to the inefficient operation of public transport system, public prefers to use privately-owned vehicles which are more comfortable, safe, flexible and reliable but costly [Aidoo et al., (2010), Badami and Haider (2007)]. Further, the implementation of a new public transport system requires a huge amount of funds mainly in infrastructure, construction and maintenance. Hence, prior to making investment in transport, poor economic condition, limitation of infrastructure facilities and better utilization of existing infrastructure, there is a continued need to evaluate and compare the performance of public transport systems in urban areas. Gurjar et al., (2017) studied that the performance evaluation of public transport system is a complicated and continuing process. This complexity is raised due to the multiple performance indicators and different perspectives. Broadly, the performance of a public transport system can be viewed through three different perspectives i.e. user, operator and city perspectives. The requirement of these three perspectives may be different or may affect each other. For instance user perspective is to have least travel cost, while operator perspective is to minimize expenses and maximize profit while city perspective may be entirely different. User perspective of a public transport service is influenced by users' personal needs, their assessment of what is possible to be delivered and various situational factors [Bhat et al., (2005)]. It is primarily concerned with the quality of system, availability, affordability and accessibility to the service as well as comfort-discomfort and safety at the same time. Dodson et al., (2011), and Kittelson et al., (2003) discussed that public transport service benefits the whole community or a city when it can contribute to social cohesion, reduction of air pollution, provide mobility to people without access to private automobile, parking congestion mitigation, reduction of traffic congestion, and job accessibility and sustainable environmental outcomes. Sheth et al., (2007) discussed that the main objective of operator's perspective is for the system to make profitable as much as possible. Iseki et al., (2007) discussed that the basic requirement of public transport system from operator perspectives are adequate capacity, minimum operating cost, minimum investment cost, flexibility of operation and maximum passenger travelled in vehicles. Therefore, a single measure or a single perspective is inappropriate for all situations. A review of literature reveals that most of the studies [Alonso et al., (2015), Chowdhury et al., (2015), Cascajo, (2014), Niyonsenga, (2012), Abreha, (2007), Litman (2007), Kittelson and Associates, (2003)] conducted in context to the developed countries might be irrelevant for the developing countries due to difference in socio economic structure. Thus, many studies of developed countries are inappropriate for identifying problems and significant improvements in performance of existing public transport systems in Indian context. Further, It is observed that most of the studies [Some example are Roux et al., (2012), Baskaran and Krishnaiah (2011), Hasnine (2011), Abreha, (2007)] provided performance indicators without clearly specifying from whose perspective these indicators should be used in an evaluation process. Very few attempts are made to evaluate the performance of existing public transport systems from all three perspectives together. Further, the classification of performance indicators from these three perspectives is a complicated task, because many indicators are available in literature and there is no comprehensive classification. Thus, the outcome of most of the studies does not indicate effective changes to be made for improvement of various aspects related to these three perspectives. Most of the studies [some examples are Aidoo et al (2013), Putra (2013), Singh et al (2014),] developed qualitative indices and limited studies are proposed quantitative indices which are often relatively straight forward, but in practice may be much more complicated due to absence of data base or the process of data collection is more time consuming, difficult and expensive. Mistretta M. et al (2009) discussed that in most indices will not have any comparisons of services directly to identify necessary changes needed to provide more effective service. Many studies are [MoUD (2009), Agarwal et al (2015), DULT (2013)] simply aggregate the performance indices to estimate the overall performance of alternate public transport system. But aggregation of these indices on a generalized basis and quantifying them on a common scale is not appropriate, due to which a greater or lesser impact of these indicators in performance of public transport system from different perspectives is observed. In summary, the performance of public transport system may be good corresponding to any one perspective out of three and other may be poor. In this type of situation decision makers not assured the system work efficiently are not. Further, the all three perspective not affect equally the performance of public transport system. Hence, for efficient operation and sustainability, the requirements of these three perspectives should be met with. Hence there is a need to develop a comprehensive methodology for evaluating the comparative performance of the public transport systems in Indian context not only from user, operator and city perspective but that takes care of all three perspectives together. Therefore, this study presents a comprehensive methodology for comparative performance evaluation of public transport system from user, city and operator perspective as well as combined in urban areas. The proposed methodology comprises of four stages, in reference to user, city, operator perspective and overall perspective of all three together so as to identify the issues related to each separately as well as combined. The methodology proposed in this study is also illustrated using BCLL bus system and Mini bus system in Bhopal city. It is expected that this study will be useful to take significant decisions before implementation of new system or alteration in existing system and performance improvement of existing urban transport system in developing countries.

2. Research Methodology

In the present study, four stage methodologies for comparative performance evaluation of public transport system are developed. They are developed in reference to user, city, and operator perspective separately and are referred as stage I, II and III. The methodology that considers all three together is referred as stage IV. The framework for proposed research methodology is presented in the Figure 1.

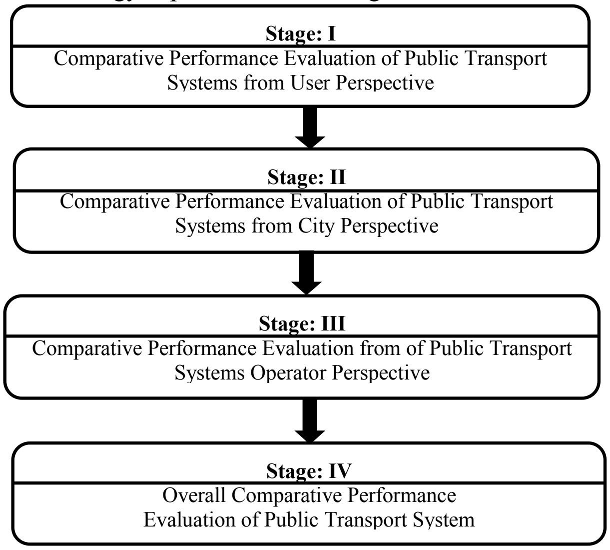

Figure 1: Framework of a Proposed Research methodology

The methodologies of the stage I, II and III, each have four sub stages. The most appropriate comparative key performance indicators from user, city and operator perspective are identified in sub stage IA, IIA and IIIA respectively. The criteria used for identification of performance indicator in this study are logically acceptable from Indian context, consistent with goals and objectives, easy to understand, measurable, minimum cost and time for data collection or availability of data. The sub stage IB, IIB and IIIB is to develop a methodology for evaluation of condition of identified comparative performance indicators related to user, city and operator perspective respectively. The comparative performance indices are developed in such a manner so that it is compared and quantified the performance of public transport system 'I' with respect to public transport system 'II' with minimal data. The significant differences exist among different categories of performance indicators that have a greater or lesser impact on overall performance of public transport system in urban areas. Therefore, the relative weight of identified comparative performance indicators is determined in third sub stage of each stage using Fuzzy analytical hierarchical process (FAHP) technique by opinion survey of transport experts from relevant fields and academic. Finally in sub stage ID, IID, and IIID determined comparative performance from user, city and operator perspective respectively. The stage IV methodology has three sub stages. In sub stage IVA interrelationship between user, city and operator indicators is developed. In sub stage IVB, relative weights are determined for the major performance indicators. The overall comparative performance is then determined in sub stage IVC.

3. Stage-I: Comparative Performance Evaluation of Public Transport System from User Perspective

Logically on the basis of literature review preliminary total nine comparative user performance indicators are identified in sub stage-IA. These are comparative in-vehicle time, comparative out-of-vehicle time, comparative reliability, comparative in-vehicle cost, comparative out-of-vehicle cost, comparative service information, comparative user comfort, comparative user safety, and comparative vehicle staff behaviour. A questionnaire based survey was conducted on these indicators to identification of importance level on a Likert scale from 1 to 7. A factor analysis was conducted on responses of 286 respondents on identified performance indicators using SPSS 20.0 software tool. Out of nine performance indicators, two indicators i.e. comparative service information and comparative vehicle staff behaviour are eliminated on the basis of mean importance value, determinant value of correlation matrix, Kaiser-Meyer-Olkin Measure (KMO) value and Bartlett's test of sphericity of sampling adequacy. The Cronbach's alpha was also calculated to measure the internal consistency of remaining seven indicators. On the basis of the results of factor analysis a structural model (hierarchical structure) is developed and presented in Figure 2.

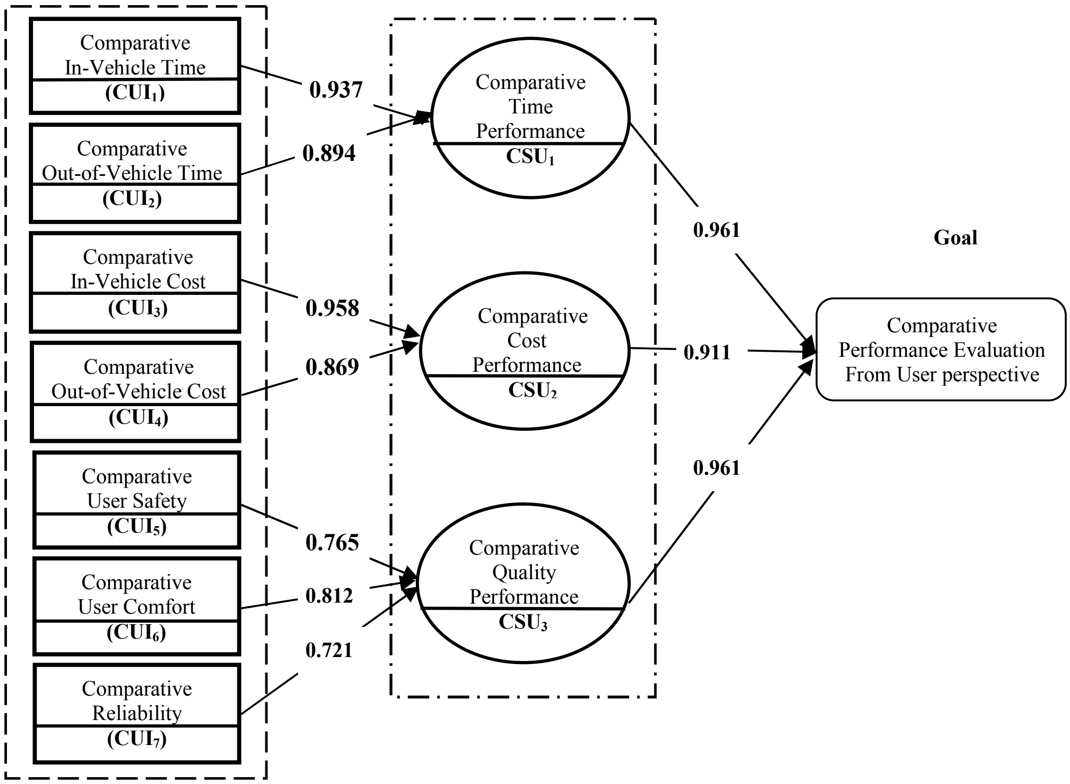

Figure 2: Development of a Hierarchical Structure for Identification of Comparative User Performance Indicators

The sub stage -IB served to develop a methodology which can evaluate the condition of identified comparative key user performance indicators which presents in Table 1. The value of indices of may vary from 0 to 1.The value of indices are divided into seven satisfaction level. The satisfaction level is categorized as poorly satisfied (< 0.30), preferably satisfied (0.30-0.45), average satisfied (0.45-0.55), fairly satisfied (0.55-0.70), good satisfied (0.70-0.85) and extremely satisfied (0.85-1.00). In sub stage-IC the relative weight of comparative user performance indicators are obtained by FAHP technique and presented in Table 2. The overall performance of public transport system 'I' with respect to public transport system 'II' from user perspective can be evaluated in sub stage-ID using an index named as user comparative performance index ($UCPI_{I/II}$). The value of $UCPI_{I/II}$ may be greater than, equal to, or less than one. The value of indices greater than, equal to or less than one indicates the performance of public transport system 'I' is superior, equal and inferior quality with respect to public transport system 'II'. A methodology for development of $UCPI_{I/II}$ is presented in Table 3.

Table 1: A methodology for evaluation of comparative user performance indicators

Performance indicators	A methodology for Evaluation of comparative user performance indicators
Comparative In-Vehicle Time Index (**$CITI_{I/II}$**)	$\mathbf{CITI_{I/II} = \frac{IVTI_{I}}{IVTI_{II}}}$ and $\mathbf{IVTI_{s} = \frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{DTI_{s,i}}{ATI_{s,i}}\right\}}$ $IVTI_s$ =In-vehicle time Index of public transport system ‘s’., $DTI_{s,i}$= Desirable time spent by passengers in a vehicle of public transport system ‘s’ from origin to destination on a route ‘i’, in minute., $ATI_{s,i}$= Average time spent by passengers in a vehicle of alternate public transport system‘s’ from origin to destination on a route ‘i’ in minute.
Comparative Out-of- Vehicle time Index (**$COTI_{I/II}$**)	$\mathbf{COTI_{I/II} = \frac{OVTI_{I}}{OVTI_{II}}}$ and $\mathbf{OVTI_{s} = 1 - \left[\frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{ATO_{s,i}}{TDT_{s,i}}\right\}\right]}$ $OVTI_s$ =Out-of-vehicle time Index of public transport system ‘s’., $ATO_{s,i}$ = Average time spent by passenger from out of vehicle of alternate public transport system‘s’ from origin to destination on a route ‘i’ in minute, $TDT_{s,i}$=Total desirable time spent by passengers from origin to destination for public transport system ‘s’ on a route ‘i’ in minute
Comparative In-Vehicle Cost Index (**$CICI_{I/II}$**)	$\mathbf{CICI_{I/II} = \frac{IVCI_{I}}{IVCI_{II}}}$ and $\mathbf{IVCI_{s} = 1 - \left[\frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{AFI_{s,i}}{AFI_{c,i}}\right\}\right]}$ $IVCI_s$ =In-vehicle cost Index of public transport system ‘s’., $AFI_{s,i}$ = Average fare spent by a passenger in a vehicle of public transport system ‘s’ to travel 1 km distance from origin to destination on a route ‘i’ in rupees per km., $AFI_{c,i}$ = Average fare spent by a passenger in a car to travel 1 km distance from origin to destination on a route ‘i’ in Rs/km.
Comparative Out-of- Vehicle Cost Index (**$COCI_{I/II}$**)	$\mathbf{COCI_{I/II} = \frac{OVCI_{I}}{OVCI_{II}}}$ and $\mathbf{OVCI_{s} = 1 - \left[\frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{AFO_{s,i}}{TTF_{s,i}}\right\}\right]}$ $OVCI_s$ =Out-of-vehicle cost Index of public transport system ‘s’., $AFO_{s,i}$ = Average fare spent by a passenger from out of a vehicle from origin to destination for public transport system ‘s’ on a route ‘i’ in rupees per km. $TTF_{s,i}$= Total fare spent by passengers from origin to destination for public transport system ‘s’ on a route ‘i’ in rupees per km.
Comparative User Safety Index (**$CUSI_{I/II}$**)	$\mathbf{CUSI_{I/II} = \frac{USCI_{I}}{USCI_{II}}, USCI_{s} = \frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{5 \times NSR_{5s,i} + 4 \times NSR_{4s,i} + 3 \times NSR_{3s,i} + 2 \times NSR_{2s,i} + 1 \times NSR_{1s,i}}{5 \times TNS_{s,i}}\right\}}$ $USCI_s$ = User safety condition index of public transport system ‘s’., $NSR_{5s,i}$= number of respondent given safety rating 5 for public transport system ‘s’ on a route ‘i’., $NSR_{4s,i}$= number of respondent given safety rating 4 for public transport system ‘s’ on a route ‘i’., $NSR_{3s,i}$= number of respondent given safety rating 3 for public transport system ‘s’ on a route ‘i’., $NSR_{2s,i}$ = number of respondent given safety rating 2 for public transport system ‘s’ on a route ‘i’., $NSR_{1s,i}$ = number of respondent given safety rating 1 for public transport system ‘s’ on a route ‘i’., $TNS_{s,i}$ =Total number of respondent given safety rating for public transport system ‘s’ on a route ‘i’.
Comparative User comfort index (**$CUCI_{I/II}$**)	$\mathbf{CUCI_{I/II} = \frac{UCCI_{I}}{UCCI_{II}}, UCCI_{s} = \frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{5 \times NCR_{5s,i} + 4 \times NCR_{4s,i} + 3 \times NCR_{3s,i} + 2 \times NCR_{2s,i} + 1 \times NCR_{1s,i}}{5 \times TNC_{s,i}}\right\}}$ $UCCI_s$ = User comfort condition index of public transport system ‘s’., $NCR_{5s,i}$= number of respondent given comfort rating 5 for public transport system ‘s’ on a route ‘i’, $NCR_{4s,i}$= number of respondent given comfort rating 4 for public transport system ‘s’ on a route ‘i’, $NCR_{3s,i}$= number of respondent given comfort rating 3 for public transport system ‘s’ on a route ‘i’, $NCR_{2s,i}$ = number of respondent given comfort rating 2 for public transport system ‘s’ on a route ‘i’, $NCR_{1s,i}$ = number of respondent given comfort rating 1 for public transport system ‘s’ on a route ‘i’, $TNC_{s,i}$ =Total number of respondent given comfort rating for public transport system ‘s’ on a route ‘i’
Comparative Reliability Index (**$CRBI_{I/II}$**)	$\mathbf{CRBI_{I/II} = \frac{RBTI_{I}}{RBTI_{II}}}$ and $\mathbf{RBTI_{s} = \frac{1}{NOR_{s}} \times \left\{\sum_{i=1}^{i=n} \frac{NOT_{s,i}}{TNT_{s,i}}\right\}}$ $RBTI_s$ =Reliability index of public transport system‘s’., $NOT_{s,i}$=Number of trips on time for public transport system ‘s at stop of a route ‘i’ in Nos. $TNT_{s,i}$=Total number of trips for public transport system ‘s’ on a route ‘i’ in Nos.

**Public transport system ‘s’ represents public transport system ‘I’ and public transport system ‘II’*

Table 2: Detailed Summary of Relative Weight of Comparative User Performance Indicators

S. No.	Comparative Key User Performance Indicators	Notation	Relative Weight	Comparative Sub User Performance Indicators	Notation	Relative Weight
1	Comparative in-vehicle time	W_{IVT}	0.238	Comparative Time Performance	W_{TMP}	0.334
2	Comparative out-of-vehicle time	W_{OVT}	0.096			
3	Comparative in-vehicle cost	W_{IVC}	0.259	Comparative Cost Performance	W_{CSP}	0.402
4	Comparative out-of-vehicle cost	W_{OVC}	0.143			
5	Comparative user safety	W_{USF}	0.086	Comparative Quality Performance	W_{QTP}	0.264
6	Comparative user comfort	W_{UCF}	0.110			
7	Comparative reliability	W_{RBT}	0.068			
		Sum	**1.000**		**Sum**	**1.000**

Table 3: A methodology for development of user comparative performance index ($UCPI_{I/II}$)

S. No	Performance index	
1	Comparative time performance index **($CTPI_{I/II}$)**	$\mathbf{CTPI_{I/II}} = \frac{\mathbf{W_{IVT} \times CITI_{I/II} + W_{OVT} \times COTI_{I/II}}}{\mathbf{W_{IVT} + W_{OVT}}}$ ………………………………………. **Eq. (1)** $CITI_{I/II}$=Comparative in-vehicle time index of public transport system 'I' w.r.t. public transport system 'II' $COTI_{I/II}$=Comparative out-of-vehicle time index of public transport system 'I' w.r.t. public transport system 'II'
2	Comparative cost performance index **($CCTI_{I/II}$)**	$\mathbf{CCTI_{I/II}} = \frac{\mathbf{W_{IVC} \times CICI_{I/II} + W_{OVC} \times COCI_{I/II}}}{\mathbf{W_{IVC} + W_{OVC}}}$ …………………………………………. **Eq. (2)** $CICI_{I/II}$=Comparativein-vehicle cost index of public transport system 'I' w.r.t. public transport system 'II' $COCI_{I/II}$=Comparativeout-of-vehicle cost index of public transport system 'I' w.r.t. public transport system 'II'
3	Comparative quality performance index **($CQPI_{I/II}$)**	$\mathbf{CQPI_{I/II}} = \frac{\mathbf{W_{UST} \times CUSI_{I/II} + W_{UCT} \times CUCI_{I/II} + W_{RBT} \times CRBI_{I/II}}}{\mathbf{W_{USF} + W_{UCF} + W_{RBT}}}$ ………………. **Eq. (3)** $CUSI_{I/II}$=Comparative user safety condition index of public transport system 'I' w.r.t. public transport system 'II' $CUCI_{I/II}$=Comparative user comfort condition index of public transport system 'I' w.r.t. public transport system 'II' $CRBI_{I/II}$= Comparative reliability indexof public transport system 'I' w.r.t. public transport system 'II'.,
4	User comparative performance index **($UCPI_{I/II}$)**	$\mathbf{UCPI_{I/II} = W_{TMP} \times CTPI_{I/II} + W_{CSP} \times CCTI_{I/II} + W_{QTP} \times CQPI_{I/II}}$ ………………. **Eq. (4** $CTPI_{I/II}$=Comparative time performance index of public transport system 'I' w.r.t. public transport system 'II' $CCTI_{I/II}$=Comparative cost performance index of public transport system 'I' w.r.t. public transport system 'II' $CQPI_{I/II}$=Comparative quality performance index of public transport system 'I' w.r.t. public transport system 'II'

4. Stage-II: Comparative Performance Evaluation of Public Transport System from City Perspective

Preliminary total nine comparative key city performance indicators are identified in sub stage-IIA, logically on the basis of literature review. These are comparative city mobility, comparative city coverage, comparative transport capacity, comparative service equity, comparative air quality, comparative noise quality, comparative economic activity and comparative city employment. Out of nine performance indicators, one indicators i.e. comparative service equity are eliminated similarly, as discussed in section 3. A hierarchical structure is developed on the basis of the results of factor analysis and presented in Figure 3. The sub stage-IIB served to develop a methodology which can evaluate the condition of identified comparative key city performance indicators which presents in Table 4.

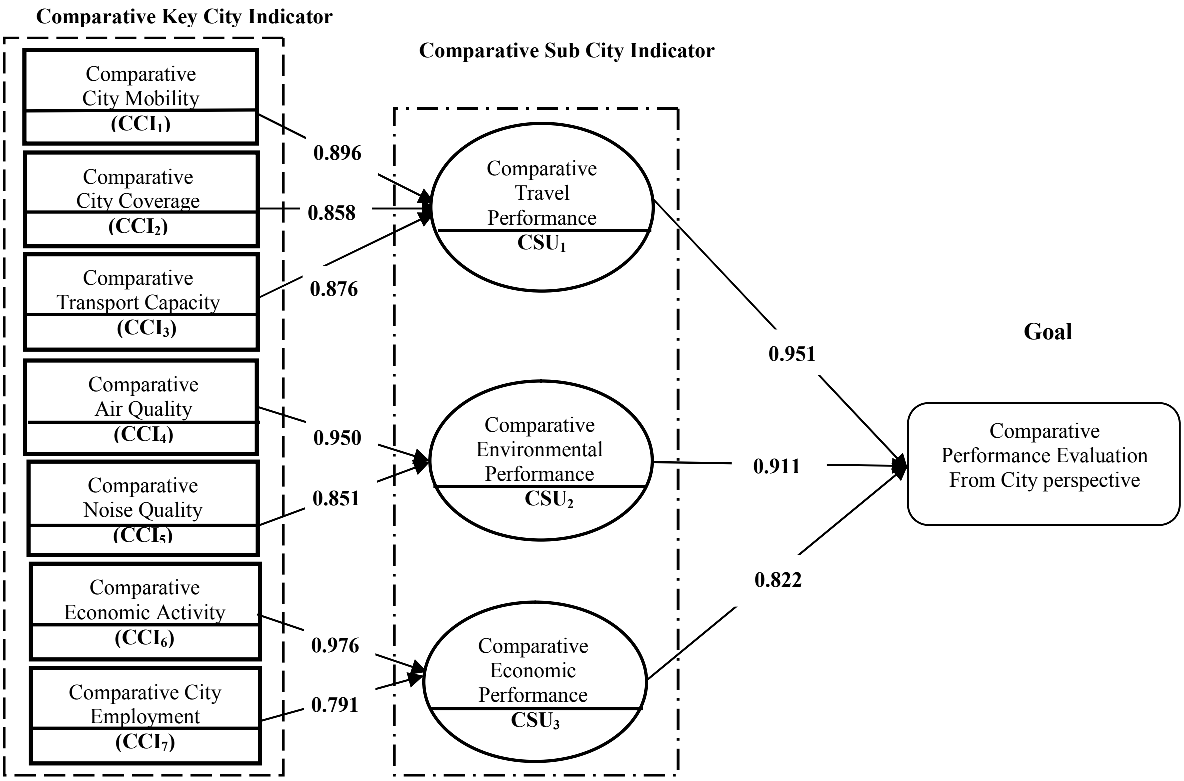

Figure 3: A Hierarchical Structure for Identification of Comparative City Performance Indicators

Table 4: A methodology for evaluation of comparative city performance indicators

Performance indicators	A methodology for evaluation of comparative city performance indicators
Comparative city mobility ($CCMI_{I/II}$)	$$CCMI_{I/II} = \frac{CMBI_I}{CMBI_{II}}, \quad \text{and} \quad CMBI_s = \frac{1}{NOR_s} \times \left\{\sum_{i=1}^{i=n} \frac{AOS_{s,i}}{DOS_{s,i}}\right\}$$ $CMBI_s$=city mobility index for public transport system'ʻs'., $AOS_{s,i}$= Average operational speed of a vehicle of public transport system'ʻs' on a route 'i' in kmph. $DOS_{s,i}$= Desirable operational speed of a vehicle of public transport system'ʻs' on a route 'i' in kmph.
Comparative transport system capacity index ($CTCI_{I/II}$)	$$CTCI_{I/II} = \frac{TSCI_I}{TSCI_{II}} \text{ and } TSCI_s = \frac{1}{NOR_s} \times \left\{\sum_{i=1}^{i=n} \frac{TNP_{s,i}}{MCP_{s,i}}\right\} \text{where, } MCP_{s,i} = 2 \times ANT_{s,i} \times TNV_{s,i} \times TSC_{s,i}$$ $TSCI_s$ =Transport system capacity index for public transport system'ʻs'., $TNP_{s,i}$=Total number of passengers travelled per day in vehicles of public transport system 's' on a route 'i' in Nos., $MCP_{s,i}$= Maximum capacity of passengers travelled per day in vehicles of public transport system 's' on a route 'i' in Nos. $ANT_{s,i}$ =Average number of trips per day per vehicle of public transport system 's' on a route 'i' in Nos. $TNV_{s,i}$ = Total number of vehicles of public transport system 's' ply on a route 'i' in Nos., $TSC_{s,i}$= Total seating capacity of a vehicle of public transport system 's' on a route 'i' in Nos.
Comparative city coverage index ($CCCI_{I/II}$)	$$CCCI_{I/II} = \frac{CCGI_I}{CCGI_{II}}, \quad \text{and} \quad CCGI_s = \frac{TLR_s}{LRN_c}$$ $CCGI_s$ =City coverage index for public transport system 's', TRL_S = Total length of routes on which ply vehicles of public transport system 's' in a city in km. LRN_c= Length of road network in a city in km
Comparative air quality index ($CAQI_{I/II}$)	$$CAQI_{I/II} = \frac{AQCI_I}{AQCI_{II}} \quad \text{and } AQCI_s = 1 - \left[\frac{1}{NOR_s} \times \left\{\sum_{i=1}^{i=n} \frac{TAN_{s,i}}{MAN_s}\right\}\right] \text{ Where, } TAN_{s,i} = \frac{TVK_{s,i} \times \sum \{AER_{p,s} \times SCF_{p,s,i}\}}{TNV_{s,i} \times TSC_{s,i}}$$ $$\text{Where, } TVK_{s,i} = 2 \times \{TNV_{s,i} \times (LOR_{s,i} \times ANT_{s,i} + ADO_{s,i})\} \text{ and } SCF_{p,s,i} = e^{\left[A_{p,s} \times \{AJS_{s,i} - 27.6\} + B_{p,s} \times \{AJS_{s,i} - 27.6\}^2\right]}$$ $AQCI_s$ =Air quality condition index for Public transport system 's'., $TAN_{s,i}$= Total air emission from a vehicle of public transport system 's' on a route 'i' in a city in kg per day per seat per vehicle. MAN_s = Maximum air emission from a vehicles of public transport system 's' on any route in a city in kg per day per seat per vehicle. p= Types of pollutant (Such as CO, CO_2, HC, and NO_x), $TVK_{s,i}$= Total vehicle kilometre travelled by a vehicle of public transport system 's' on a route 'i' in km. $AER_{p,s}$=Air emission rate of pollutant 'p' from a vehicle of public transport system 's' in gm/km . $SCF_{p,s,i}$= Speed correction factor of pollutant 'p' for a vehicle of public transport system 's' on a route 'i'. $LOR_{s,i}$= Length of route for Public transport system 's' in km.. $ADO_{s,i}$ = Average distance travelled by a vehicle from origin to vehicle stop of Public transport system 's' on route 'i'. AJS = Average Journey speed of Public transport system 's' on route 'i' in miles per hour (ranging from 2.5 to 65 mile/hour), $A_{p,s}$, $B_{p,s}$ = Cycle correction factor for pollutant 'p' of Public transport system 's'
Comparative noise quality index ($CNQI_{I/II}$)	$$CNQI_{I/II} = \frac{NQCI_I}{NQCI_{II}}, NQCI_s = \frac{1}{NOR_s} \times \sum_{i=1}^{i=n} \frac{5 \times NNR_{5s,i} + 4 \times NNR_{4s,i} + 3 \times NNR_{3s,i} + 2 \times NNR_{2s,i} + 1 \times NNR_{1s,i}}{5 \times TNN_{s,i}}$$ $NQCI_s$ =Noise quality condition index for public transport system 's', $NNR_{5s,i}$= number of respondent given 5 rating to noise quality of public transport system 's' on a route 'i'., $NNR_{4s,i}$= number of respondent given 4 rating to noise quality of Public transport system 's' on a route 'i'., $NNR_{3s,i}$= number of respondent given 3 rating to noise quality of public transport system 's' on a route 'i'., $NNR_{2s,i}$ = number of respondent given 2 rating to noise quality of public transport system 's' on a route 'i'.,$NNR_{1s,i}$ = number of respondent given 1 rating to noise quality of Public transport system 's' on a route 'i'., $TNN_{s,i}$ =Total number of respondent given noise rating for Public transport system 's' on a route 'i'
Comparative economic activity index ($CEAI_{I/II}$)	$$CEAI_{I/II} = \frac{EATI_I}{EATI_{II}} \quad \text{and} \quad EATI_s = \left[\sum_{i=1}^{i=n} \frac{AVL_{s,i}}{MVL}\right]$$ $CEAI_s$ =Economic activity index for public transport system'ʻs'. $AVL_{s,i}$ = Average value of land area near the route 'i' on which ply vehicles of Public transport system 's' in Rs/ft^2. MVL= Maximum value of land area near any route of a city in Rs/ft^2
Comparative employment generation index ($CEGI_{I/II}$)	$$CEGI_{I/II} = \frac{EMGI_I}{EMGI_{II}} \quad \text{and} \quad EMGI_S = \frac{NJG_s}{TJG_t}$$ $EMGI_s$ =Employment generation index for public transport system'ʻs'., NJC_s = Number of jobs generated by public transport system'ʻs' in a city in Nos. TJC_t= Total No. of Job generated by all public transport system in a city in Nos.

**Public transport system'ʻs' represents public transport system 'I' and public transport system 'II'*

The detail summary of relative weight of comparative city performance indicators obtained in sub stage-IIC from FAHP technique is presented in Table 7. The overall performance of public transport system 'I' with respect to public transport system 'II' from city perspective can be evaluated in sub stage-IID using an index named as city comparative performance index ($CCPI_{I/II}$). The value of $CCPI_{I/II}$ may be greater than, equal to, or less than one similarly as discussed earlier. A methodology for development of $CCPI_{I/II}$ is presented in Table 25.

Table 5: Detailed summary of relative weight of comparative key city performance indicators

S. No.	Comparative Key City Performance Indicators	Notation	Relative Weight	Comparative Sub-City Performance Indicators	Notation	Relative Weight
1	Comparative City Mobility	W_{MBT}	0.152	Comparative Travel Performance	W_{TLP}	0.462
2	Comparative Transport Capacity	W_{TSC}	0.161			
3	Comparative City Coverage	W_{RCG}	0.149			
4	Comparative Air Quality	W_{AQT}	0.166	Comparative Environmental Performance	W_{ELP}	0.287
5	Comparative Noise Quality	W_{NQT}	0.121			
6	Comparative Economic Activity	W_{EAT}	0.110	Comparative Economic Performance	W_{ECP}	0.251
7	Comparative City Employment	W_{CEM}	0.141			
		Sum	**1.000**		**Sum**	**1.000**

Table 6: A methodology for development of city comparative performance index ($CCPI_{I/II}$)

S. No	Performance index	
1	Comparative travel performance index	$$\mathbf{CTLI_{I/II}} = \frac{\mathbf{W_{CMB} \times CCMI_{I/II} + W_{TSC} \times CTCI_{I/II} + W_{CCG} \times CCCI_{I/II}}}{\mathbf{W_{CMB} + W_{TSC} + W_{CCG}}} \ldots\ldots\ldots\ldots\ldots \mathbf{Eq.(5)}$$ $CCMI_{I/II}$=Comparative city mobility index of public transport system 'I' w.r.t. public transport system 'II', $CTCI_{I/II}$= Comparative transport capacity index of public transport system 'I' w.r.t. public transport system 'II', $CCCI_{I/II}$=Comparative city coverage index of public transport system 'I' w.r.t public transport system 'II',
2	Comparative environmental performance index	$$\mathbf{CELI_{I/II}} = \frac{\mathbf{W_{AQT} \times CAQI_{I/II} + W_{NQT} \times CNQI_{I/II}}}{\mathbf{W_{AQT} + W_{NQT}}} \ldots\ldots\ldots\ldots\ldots \mathbf{Eq.(6)}$$ $CAQI_{I/II}$=Comparative air quality index of public transport system 'I' w.r.t. public transport system 'II'., $CNQI_{I/II}$= Comparative noise quality index of public transport system 'I' w.r.t. public transport system 'II'.,
3	Comparative economical performance index	$$\mathbf{CECI_{I/II}} = \frac{\mathbf{W_{EAT} \times CEAI_{I/II} + W_{CEM} \times CCEI_{I/II}}}{\mathbf{W_{CEM} + W_{EAT}}} \ldots\ldots\ldots\ldots\ldots \mathbf{Eq.(7)}$$ $CEAI_{I/II}$= Comparativeeconomic activity Index of public transport system 'I' w.r.t. public transport system 'II'., $CCEI_{I/II}$= Comparative city employment Index of public transport system 'I' w.r.t. public transport system 'II'.,
4	City Comparative Performance Index	$$\mathbf{CCPI_{I/II} = W_{TLP} \times CTLI_{I/II} + W_{ELP} \times CELI_{I/II} + W_{ECP} \times CECI_{I/II}} \ldots\ldots\ldots\ldots \mathbf{Eq.(8)}$$ $CTLI_{I/II}$=Comparative travel performance index of public transport system 'I' w.r.t. public transport system 'II'., $CELI_{I/II}$=Comparative environmental performance index of public transport system 'I' w.r.t. public transport system 'II'., $CECI_{I/II}$=Comparative economy performance index of public transport system 'I' w.r.t. public transport system 'II'.,

5. Stage-III: Comparative Performance Evaluation of Public Transport System from Operator Perspective

A hierarchical structure is developed for identification of comparative operator performance indicators on the basis of the results of factor analysis in stage-IIIA similarly, as discussed in section 3 and presented in Figure 3. A methodology for evaluation of condition of identified comparative key city performance indicators are served in sub stage-IIB and presented in Table 4. In sub stage-IIIC the relative weight of comparative operator performance indicators are obtained by FAHP technique and presented in Table 9.

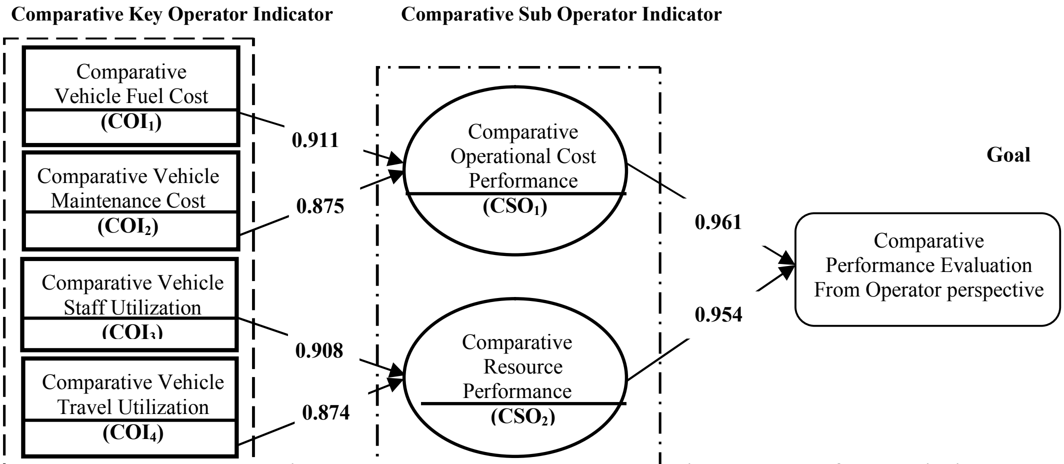

Figure 4: Development of a hierarchical structure for identification of comparative operator performance indicators

Table 7: A methodology for evaluation of comparative operator performance indicators

S. No	Performance indicators	A methodology for evaluation of comparative operator performance indicators
	Comparative vehicle fuel cost index ($\mathbf{CVFI_{I/II}}$)	$\mathbf{CVFI_{I/II}} = \frac{\mathbf{VFCI_I}}{\mathbf{VFCI_{II}}}$ and $\mathbf{VFCI_s} = \mathbf{1} - \left[\frac{\mathbf{1}}{\mathbf{NOR_s}} \times \sum_{i=1}^{i=n} \left\{\frac{\mathbf{TFC_{s,i}}}{\mathbf{TRG_{s,i}}}\right\}\right]$ $VFCI_s$ =Vehicle fuel cost index for alternate public transport system 's'., $TFC_{s,i}$= Total fuel cost of public transport system's' on a route 'i' in rupees per day. $TRG_{s,i}$= Total revenue generation from alternate public transport system's' on a route 'i' in rupees per day.
	Comparative vehicle maintenance cost index ($\mathbf{CVMI_{I/II}}$)	$\mathbf{CVMI_{I/II}} = \frac{\mathbf{VMCI_I}}{\mathbf{VMCI_{II}}}$ and $\mathbf{VMCI_s} = \mathbf{1} - \left[\frac{\mathbf{1}}{\mathbf{NOR_s}} \times \sum_{i=1}^{i=n} \left\{\frac{\mathbf{TMC_{s,i}}}{\mathbf{TRG_{s,i}}}\right\}\right]$ $VMCI_s$ =Vehicle Maintenance cost index for alternate public transport system 's'., $TMC_{s,i}$= Total maintenance cost of a vehicle of public transport system 's' in rupees per day. $TRG_{s,i}$= Total revenue generation from public transport system's' on a route 'i' in rupees per day.
	Comparative vehicle Staff Utilization index ($\mathbf{CVSI_{I/II}}$)	$\mathbf{CVSI_{I/II}} = \frac{\mathbf{VSUI_I}}{\mathbf{VSUI_{II}}}$ and $\mathbf{VSUI_S} = \mathbf{1} - \left[\frac{\mathbf{1}}{\mathbf{NOR_s}} \times \sum_{i=1}^{i=n} \frac{\mathbf{TSC_{s,i}}}{\mathbf{TRG_{s,i}}}\right]$ $VSUI_s$ =Vehicle staff utilization index for Public Transport System 's'., $TSC_{s,i}$= Total staff cost in a vehicle of public transport system's' in a day in rupees.,
	Comparative vehicle travel utilization index ($\mathbf{CVTI_{I/II}}$)	$\mathbf{CVTI_{I/II}} = \frac{\mathbf{VTUI_I}}{\mathbf{VTUI_{II}}}$ and $\mathbf{VTUI_S} = \mathbf{1} - \left[\frac{\mathbf{1}}{\mathbf{NOR_s}} \times \sum_{i=1}^{i=n} \frac{\mathbf{TRK_{s,i}}}{\mathbf{TVK_{s,i}}}\right]$ $VTUI_s$ =Vehicle travel utilization index for public transport system's'., $TRK_{s,i}$ =Total revenue kilometer by vehicles of public transport system 's' on a route 'i' in km per day.,

**Public transport system 's' represents public transport system 'I' and public transport system 'II'*

Table 8: Detailed summary of relative weight of comparative operator performance indicators

S. No.	Comparative Key Operator Performance Indicators	Notations	Relative Weight	Sub-operator Performance Indicators	Notations	Relative Weight
1	Comparative Vehicle Fuel Cost	W_{VFC}	0.306	Operational Cost Performance	W_{OPC}	0.531
2	Comparative Vehicle Maintenance cost	W_{VMC}	0.225			
3	Comparative Vehicle Staff Utilization	W_{VSU}	0.185	Resource Performance	W_{RSP}	0.469
4	Comparative Vehicle Travel Utilization	W_{VTU}	0.284			
		Sum	**1.000**		**Sum**	**1.000**

A methodology is developed in sub stage-IIID for overall performance of public transport system 'I' with respect to public transport system 'II' from operator perspective. A methodology is presented in Table 10.

Table 9: A methodology for development of operator comparative performance index ($\mathbf{OCPI_{I/II}}$)

S. No	Performance index	
1	Comparative operational cost performance index ($\mathbf{COCI_{I/II}}$)	$\mathbf{COCI_{I/II}} = \frac{\mathbf{W_{VFC} \times CVFI_{I/II} + W_{VMC} \times CVMI_{I/II}}}{\mathbf{W_{VFC} + W_{VMC}}}$ ……………………………………… **Eq. (9)** $VFCI_s$= Comparative vehicle fuel cost index of public transport system 'I' with respect to public transport system 'II'., $VMCI_s$= Comparative vehicle maintenance cost index of public transport system 'I' with respect to public transport system 'II'.,
2	Comparative resource performance index ($\mathbf{CRPI_{I/II}}$)	$\mathbf{CRPI_{I/II}} = \frac{\mathbf{W_{VSU} \times CVSI_{I/II} + W_{VMC} \times CVTI_{I/II}}}{\mathbf{W_{VSU} + W_{VTU}}}$ ……………………………………… **Eq. (10)** $CVSI_{I/II}$=Comparativevehicle staff utilization index of public transport system 'I' with respect to public transport system 'II'., $CVTI_{I/II}$= Comparativevehicle travel utilization index of public transport system 'I' with respect to public transport system 'II'.,
3	Operator comparative performance index ($\mathbf{OCPI_{I/II}}$)	$\mathbf{OCPI_{I/II} = W_{OPC} \times COCI_{I/II} + W_{RSP} \times CRPI_s}$ …………………………………………… **Eq. (11)** $COCI_{I/II}$=Comparative operational cost performance index of public transport system 'I' with respect to alternate public transport system 'II'., $CRPI_{I/II}$= Comparative resource performance index of public transport system 'I' with respect to alternate public transport system 'II'.,

Stage-IV: Overall Comparative Performance Evaluation of Public Transport System

A hierarchical structural model is developed in sub stage-IVA for inter-relationship between comparative major performance indicators, comparative user performance indicators, comparative city performance indicators and comparative operator performance indicators. A hierarchical structural model is presented in Figure 4.

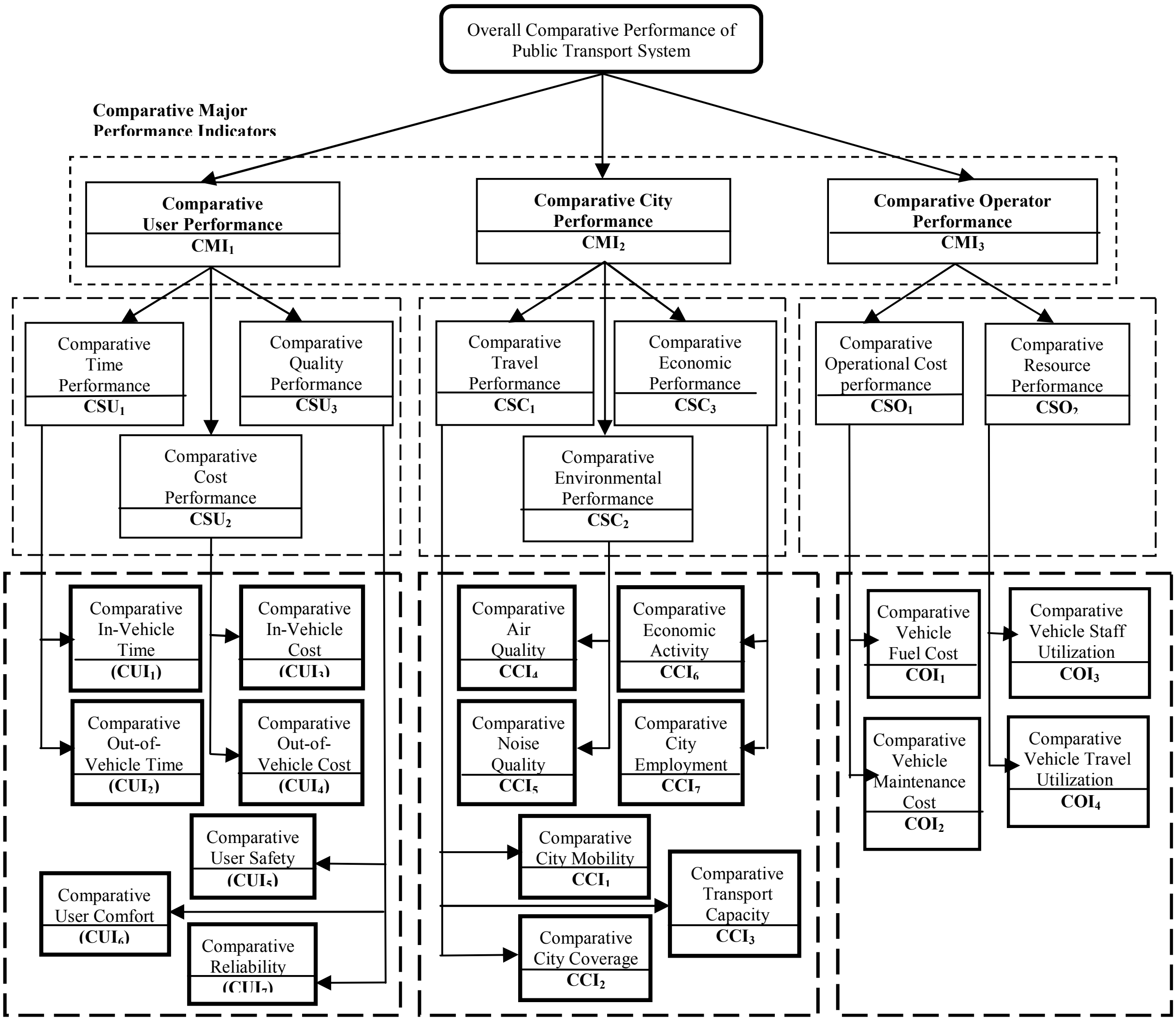

Figure 5: Development of a Hierarchical Structure for Identification of Comparative Major Performance indicators

The relative weight of comparative user performance, comparative city performance and comparative operator performance are assigned 0.346, 0.442 and 0.212 respectively in sub stage-IVB by FAHP technique. It is recommended that the overall comparative performance index ($OLCPI_{I/II}$) is developed by multiplication of condition of comparative user performance, comparative city performance and comparative operator performance and their relative weight respectively. The value of overall comparative performance index (OLCPII/II) may be greater than one, equal to one and less than one similarly as discussed earlier. The overall comparative performance index (OLCPII/II) is evaluated using equation (12).

$$\mathbf{OLCPI_{I/II} = 0.346 \times UCPI_{I/II} + 0.452 \times CCPI_{I/II} + 0.212 \times OCPI_{I/II}} \text{...............} \mathbf{Eq\ (12)}$$

6. Analysis and results of comparative performance evaluation of Bhopal transport system

This section illustrates the proposed methodology using application on evaluation of comparative performance of Bhopal transport systems. To accomplish these application two public transport systems are considered i.e. public transport system 'I' (BCLL bus system) and public transport system 'II' (Mini bus system). The five important routes are considered for each system. The basic input data of selected routes for both systems are presented in Table 10 to Table 20. These data are collected from literature review, various authorities and operators of BCLL and

Mini bus system as well as field survey and questionnaire survey in Bhopal city.

Table 10: Basic details of existing routes of public transport system's' considered in study area

S. No	Public transport system 's'	Details of Route 'i'	Length of route 'i'	Number of Bus stop on a route 'i'	Average number of trips in a day per vehicle	Total number of vehicles ply on a route 'i' in a day	Average distance travelled from depot to origin of route to by a vehicle ***	Passenger Carrying capacity of a vehicle ***
		Unit	km	Nos.	Nos.	Nos.	km	Nos.
		Notation	$LOR_{I,i}$	$NBS_{I,i}$	$ANT_{I,i}$	$TNV_{I,i}$	$ADO_{I,i}$	$PCV_{I,i}$
1	*Public Transport System 'I' **(BCLL bus system)**	**SR_1** (Sehore Naka to Bairagarh Chichili)	19.30	29	4	17	10	80
		SR_2 (Nehru Nagar to Katara Hills)	20.50	44	4	19	10	80
		SR_4 (People's College to Bairagarh Chichili)	22.80	36	4	26	10	80
		SR_5 (Chirayu Hospital to Awadhpuri)	27.90	45	4	24	10	80
		SR_8 (Coach Factory to Bairagarh Chichili)	23.40	49	4	28	10	80
2	**Public Transport System 'II' **(Mini bus system)**	**RA_1** (Nayapura Kolar to Nadra Bus Station)	21.5	30	5.5	21	10	44
		RT_1 (Indus Garden to Lambakheda)	17.4	18	6.0	35	10	44
		RT_2 (Indus Garden to Gandhi Nagar)	27.4	23	5.0	46	10	44
		RT_7 (Bairagarh to Bagmugalia)	28.2	28	4.0	18	10	44
		RT_{11} (Bairagarh To Aura Mall Trilanga)	25.3	29	4.5	32	10	44

[Source: www.mybrts.com,** www.myblogspot.com,* **Field Survey]*

Table 11: Details of input data for public transport system 'I' for application of Stage-I

S. No.	Parameters	Unit	Notation	Input Value for Route 'i'					Input Data Source
				SR_1	**SR_2**	**SR_4**	**SR_5**	**SR_8**	
1	Desirable journey speed of a vehicle from origin to destination	kmph	DJS_I	30	30	30	30	30	Wilbur Smith Associates, (2008)
2	Average time spent by a passenger in a vehicle from origin to destination	Minute	$ATI_{I,i}$	85.0	89.0	94.0	116.0	101.0	Field survey
3	Number of vehicles passes through the stop within an hour	Nos.	$NVH_{I,i}$	4	4	6	5	6	Field survey at Major stop
4	Average transfer time of a vehicle from origin to destination	Minute	$TFT_{I,i}$	14.5	13.6	15.3	14.9	12.8	Questionnaire Survey in Field
5	Average fare in-vehicle spent by a passenger to travelling 1 km distance in a trip	Rs/km	$AFI_{I,i}$	Details of fare chart on km basis is given in Table 14					www.mybrts.com
6	Rate of fuel which is used in car in rupees per liter (Petrol)	Rs/lit	ROF_c	75.87	75.87	75.87	75.87	75.87	Bhopal Petrol pump Survey
7	Average fuel efficiency of car in km per liter	km/lit	AFE_c	17	17	17	17	17	Car Operators
8	Parking fare from origin to destination	Rs	$APF_{I,i}$	0	0	0	0	0	Questionnaire Survey in Field
9	Average transfer fare of a vehicle from origin to destination	Rs	$ATF_{I,i}$	10	10	7	7	7	Questionnaire Survey in Field
10	Safety rating given by users	Rating	$NSR_{Rs,i}$	The details of safety rating given by users is presented in Table 15					Questionnaire Survey in Field
11	Comfort rating given by users	Rating	$NCR_{Rs,i}$	The details of comfort rating given by users is presented in Table 16					Questionnaire Survey in Field
12	Number of trips on time at stop by vehicles in a day	Nos.	$NOT_{I,i}$	48	59	78	72	87	Field survey at Major stop
13	Total number of trips by vehicles in a day	Nos.	$TNT_{s,i}$	68	76	112	96	104	BCLL bus Operator Survey

Table 12: Details of input data for public transport system 'II' for application of Stage-I

S. No.	Parameters	Unit	Notation	Input Value for Route 'i'					Input Data Source
				RA_1	RT_1	RT_2	RT_7	RT_{11}	
1	Desirable journey speed of a vehicle from origin to destination	kmph	DJS_{II}	30	30	30	30	30	Wilbur Smith Associates, (2008)
2	Average time spent by a passenger in a vehicle from origin to destination	Minute	$ATI_{II,i}$	111	89	131	124	119	Questionnaire Survey in Field
3	Number of vehicles passes through the stop within an hour	Nos.	$NVH_{II,i}$	5	7	6	4	6	Field survey at Major stop
4	Average transfer time of a vehicle from origin to destination	Minute	$TFT_{II,i}$	12.5	13.0	14.5	16.5	12.5	Questionnaire Survey in Field
5	Average fare in-vehicle spent by a passenger to travelling 1 km distance from origin to destination	Rs/km	$AFI_{II,i}$	Details of fare chart on km basis is given in Table 14					Jain and Nanda (2014)
6	Rate of fuel which is used in car in rupees per liter (Petrol)	Rs/km	ROF_c	75.87	75.87	75.87	75.87	75.87	Bhopal Petrol pump Survey
7	Average fuel efficiency of car in km per liter	km/lit	AFE_c	17	17	17	17	17	Car Operators
8	Average parking fare from origin to destination	Rs	$APF_{II,i}$	0	0	0	0	0	Questionnaire Survey in Field
9	Average transfer fare of a vehicle of from origin to destination	Rs	$ATF_{II,i}$	5	7	7	5	7	Questionnaire Survey in Field
10	Safety rating given by users	Rating	$NSR_{II,i}$	The details of safety rating given by users is presented in Table 15					Questionnaire Survey in Field
11	Comfort rating given by users	Rating	$NCR_{II,i}$	The details of comfort rating given by users is presented in Table 16					Questionnaire Survey in Field
12	Number of trips on time at stop by vehicle in a day	Nos.	$NOT_{II,i}$	62	109	113	44	83	Questionnaire Survey in Field
13	Total number of trips by vehicle in a day	Nos.	$TNT_{II,i}$	116	210	230	72	144	Questionnaire Survey in Field

Table 13: Details of fare on km basis of public transport system' **s'**

S. No.	Particular	Input value for public transport system 's'											
1	Travel distance in km	0-2	2-3	3-7	7-10	10-13	13-16	16-19	19-22	22-25	25-28	28-30	31-34
2	Travel fare for public transport system 'I'	5	9	12	14	17	19	22	24	26	28	30	30
3	Travel fare for public transport system 'II'	5	7	10	12	15	17	19	21	23	25	27	30

*[Source: *www.mybrts.com and Jain and Nanda (2014)]*

Table 14: Safety rating given by users for public transport system 's' on route 'i'

S. No.	Description	Notation	Safety Rating given by Users on a Route 'i'									
			Public transport system 'I'					Public transport system 'II'				
			SR_1	SR_2	SR_4	SR_5	SR_8	RA_1	RT_1	RT_2	RT_7	RT_{11}
1	Number of users given safety rating 5 for public transport system 's,	$NSR_{5S,i}$	9	9	11	10	8	6	9	6	7	7
2	Number of users given safety rating 4 for public transport system 's'	$NSR_{4S,i}$	11	13	12	11	14	7	8	12	11	13
3	Number of users given safety rating 3 for public transport system 's'	$NSR_{3S,i}$	17	14	16	15	13	11	13	11	12	13
4	Number of users given safety rating 2 for public transport system 's'	$NSR_{2S,i}$	9	10	8	9	11	13	11	11	12	10
5	Number of users given safety rating 1 for public transport system 's'	$NSR_{1S,i}$	7	7	6	8	7	16	12	13	11	10
6	Total number of users given safety rating for public transport system 's'	$TNS_{S,i}$	53	53	53	53	53	53	53	53	53	53

[Source: Questionnaire Survey in field]

Table 15: Comfort rating given by users for public transport system 's' on route 'i'

S. No.	Description	Notation	Comfort Rating given by users on a Route 'i'									
			Public transport system 'I'					Public transport system 'II'				
			SR_1	SR_2	SR_4	SR_5	SR_8	RA_1	RT_1	RT_2	RT_7	RT_{11}
1	Number of users given comfort rating 5 for public transport system 's'	NCR_{5S},i	11	9	13	9	12	4	3	3	4	5
2	Number of users given comfort rating 4 for public transport system 's'	NCR_{4S},i	12	12	11	10	15	9	6	12	11	9
3	Number of users given comfort rating 3 for public transport system 's'	NCR_{3S},i	15	13	11	13	12	12	9	13	12	12
4	Number of users given comfort rating 2 for public transport system 's'	NCR_{2S},i	12	15	14	16	11	16	15	14	15	17
5	Number of users given comfort rating 1 for public transport system 's'	NCR_{1S},i	3	4	4	5	3	12	13	14	11	10
	Total number of users given comfort rating for public transport system 's'	TNC_S,i	53	53	53	53	53	53	53	53	53	53

[Source: Questionnaire Survey in field]

Table 16: Details of input data for public transport system 'I' for application of Stage-II

S. No	Parameters	Notation	Unit	Value					Source of Input Data
				SR_1	SR_2	SR_4	SR_5	SR_8	
1	Average Operational speed in a trip	$AOS_{I,i}$	kmph	42.62	37.95	39.93	37.20	31.65	Field Survey (RadarSpeed Gun)
2	Maximum Operational speed in a trip	$MOS_{I,i}$	kmph	60	60	60	60	60	Bhopal RTO Guidelines
3	Total number of passengers to travel per day	$TNP_{I,i}$	Nos.	3820	6500	11890	10792	10908	Field survey
4	passenger carrying capacity of a vehicle	TCV_I	Nos.	80	80	80	80	50	Field survey
5	Total route length of roads on which ply vehicles in a city	TRL_I	km	291.17					Singh, et al. (2012)
6	Total Network Length of roads in a city	TNL	km	1500					Jaiswal (2012)
7	Average operational mile speed in miles per hour	AMS_I,i	Mile/h	26.50	23.59	24.82	23.13	19.68	Survey by Speed Radar method
8	Cycle correction factor for pollutant 'p' (CARB technology)	A, B	Unit less	Details of Cycle correction factor for pollutant 'p' are presented in previous Table 18					ARAI,2007
9	Air emission rate of pollutant 'p', from a vehicle	$AER_{p,I}$	gm/km	Details of air emission rate of pollutant 'p' are presented in Table 20					ARAI,2007
10	Noise quality Rating given by users	$NNR_{Rs,i}$	Rating	Details of respondent of Noise rating is presented in Table 21					Questionnaire Survey
11	Average land value near the transport route on which ply	$APV_{I,i}$	Rs/ft^2	3567	4266	3678	3216	3782	Bhopal Collector Guidelines (2016)
12	Maximum land value of area near any transport route	MLV	Rs/ft^2	8357	8357	8357	8357	8357	
13	No of jobs created by in a city	$NJC_{I,i}$	Nos.	980					Bhopal city link limited
14	Total No. of Job created by transport system in a city	TJC_t	Nos.	4730					Bus Operator Survey

Table 17: Details of Cycle Correction Factor for Pollutant 'p' of Public Transport System 'I'

S. No.	Parameters	Notation	Value
1	Cycle correction factor for pollutant 'CO' of public transport system 'I'	$A_{CO,I}$	-0.0287910
		$B_{CO,I}$	0.0019220
2	Cycle correction factor for pollutant 'CO2' of public transport system 'I'	$A_{CO2,I}$	-0.0259500
		$B_{CO2,I}$	-0.0003090
3	Cycle correction factor for pollutant 'HC' of public transport system 'I'	$A_{HC,I}$	-0.0317600
		B_{HC},I	0.0009080
4	Cycle correction factor for pollutant 'NOX' of public transport system 'I'	$A_{NOX,I}$	0.0089670
		$B_{NOX,I}$	-0.0000270

[Source: ARAI, (2007)]

Table 18: Details of input data for public transport system 'II' for application of Stage-II

S. No.	Parameters	Notation	Unit	Value					Source of Input Data
				$RT_1(A_1)$	RT_1	RT_2	RT_7	RT_{11}	
1	Average Operational speed in a trip	$AOS_{II,i}$	kmph	30.21	31.89	29.75	28.25	34.26	Field survey
2	Maximum Operational speed in a trip in a city	$MOS_{II,i}$	kmph	60.00	60.00	60.00	60.00	60.00	Bhopal RTO Office
3	Total number of passengers to travel per day	$TNP_{II,i}$	Nos.	6783	11795	15686	5922	10528	Field survey
4	Passenger carrying capacity of a vehicle in a day	$PCV_{II,i}$	Nos.	44	44	44	44	44	Field survey
5	Total route length of roads on which ply vehicles	TRL_I	km	276.67					Jaiswal A. (2014)
6	Total Network Length of roads in a city	TNL	km	1500					Bhopal Smart city Authority
7	Average operational mile speed in miles per hour	$AMS_{II,i}$	Mile/h	18.78	19.83	18.50	17.56	21.30	Field survey
8	Cycle correction factor for pollutant 'p' (CARB Technology)	A, B	Unit less	Details of Cycle correction factor for pollutant 'p' are presented in previous Table 18					ARAI,2007
9	Air emission rate of pollutant 'p', from a vehicle	$AER_{p,I}$	gm/km	Details of air emission rate of pollutant 'p' are presented in previous Table 20					ARAI,2007
10	Noise quality Rating given by users	$NNR_{RII,i}$	Rating	Noise rating given by users are presented in Table 21					Questionnaire Survey
11	Average land value near the transport route on which ply	$APV_{II,i}$	Rs/ft^2	3126	3028	3286	2968	3925	Bhopal Collector Guidelines (2016)
12	Maximum land value of area near any transport route	MLV	Rs/ft^2	8357	8357	8357	8357	8357	
13	No of jobs created in a city	$NJC_{I,i}$	Nos.	1350					Bhopal city link limited
14	Total No. of Job created by transport system in a city	TJC_t	Nos.	4730					Survey

Table 19: Details of air emission rate of pollutant 'p' from public transport system's'

S. No.	Parameters	Public transport system 'I'		Public transport system 'II'	
		Notation	Air Emission Rate (gm/km)	Notation	Air Emission Rate (gm/km)
1	Air emission rate of pollutant 'CO', from a vehicle	$AER_{CO,I}$	3.92	$AER_{CO,II}$	3.66
2	Air emission rate of pollutant 'CO_2', from a vehicle	$AER_{CO2,I}$	602.1	$AER_{CO2,II}$	401.25
3	Air emission rate of pollutant 'HC', from a vehicle	$AER_{HC,I}$	0.16	$AER_{HC,II}$	1.35
4	Air emission rate of pollutant 'NO_X', from a vehicle	$AER_{NOx,I}$	6.53	$AER_{NOx,II}$	2.12

[Source: ARAI, (2007)]

Table 20: Noise quality rating given by users for public transport system's' on Route 'i'

S. No.	Description	Notation	Noise Rating given by users on a Route 'i'									
			Public transport system 'I'					Public transport system 'II'				
			SR_1	SR_2	SR_4	SR_5	SR_8	RA_1	RT_1	RT_2	RT_7	RT_{11}
1	Number of users given noise rating 5 for public transport system 's'	$NNR_{5S,i}$	13	12	14	11	12	9	8	8	5	6
2	Number of users given noise rating 4 for public transport system 's'	$NNR_{4S,i}$	9	10	12	13	12	8	7	10	11	9
3	Number of users given noise rating 3 for public transport system 's'	$NNR_{3S,i}$	16	13	11	12	13	13	16	15	12	15
4	Number of users given noise rating 2 for public transport system 's'	$NNR_{2S,i}$	9	10	9	11	9	11	12	11	13	14
5	Number of users given noise rating 1 for public transport system 's'	$NNR_{1S,i}$	6	8	7	6	7	12	10	9	12	9
6	Total number of users given noise rating for public transport system 's'	$TNN_{S,i}$	53	53	53	53	53	53	53	53	53	53

[Source: Questionnaire Survey in field]

Table 21: Details of Input Data for Public transport system 'I' for Application of Stage-III

S. No	Parameters	Notation	Unit	Value					Source of Input Data
				SR_1	SR_2	SR_4	SR_5	SR_8	
1	Average fuel required by a vehicle in a day	$AFR_{I,i}$	Liters	50	53	55	60	55	BCLL bus operator survey
2	Rate of fuel used in a vehicles	ROF_I	Rs/Lit	62.67	62.67	62.67	62.67	62.67	Bhopal Petrol Pump Survey
3	Maintenance cost per km	$MCK_{I,i}$	Rs/km	3.93	3.93	3.93	3.93	3.93	www.team.bhp .com
4	Revenue generation by fare in a day	$RFV_{s,i}$	Rs	32153	51438	113580	94183	96938	BCLL Bus Authority
5	Number of vehicles used in advertising	$NVA_{I,i}$	Nos.	8	10	13	12	13	
6	Revenue generation by advertisement from a vehicle per day per vehicle	$RAV_{I,i}$	Rs	1750	1750	1750	1750	1750	BCLL Bus Authority
7	Number of bus shelters used in advertising	$NBS_{I,i}$	Nos.	38	39	32	34	39	BCLL Bus Authority
8	Revenue generation from advertisement by a bus stop shelter per day per shelter	$RAS_{I,i}$	Rs	950	950	950	950	950	BCLL Bus Authority
9	Number of drivers required for operation of vehicle	$NOD_{I,i}$	Nos.	17	19	28	24	26	BCLL Bus Authority
10	salary per day paid to drivers	$SOD_{I,i}$	Rs	600	600	600	600	600	
11	Number of conductors required for operation of a vehicle	$NOC_{I,i}$	Nos	17	19	28	24	26	BCLL Bus Authority
12	Salary per day paid to conductor	$SOC_{I,i}$	Rs	400	400	400	400	400	
13	Total number of passengers travelled per day	$TNP_{I,i}$	Nos.	3820	6500	11890	10792	10908	BCLL Bus Authority

Table 22: Details of input data for public transport system 'II' for application of Stage-III

S. No.	Parameters	Notation	Unit	Value					Source of Input Data
				RA_1	RT_1	RT_2	RT_7	RT_{11}	
1	Average fuel required by a vehicle in a day	$AFR_{II,i}$	Liters	30	27	35	30	30	Mini Bus Operator
2	Rate of fuel used in a vehicles	ROF_{II}	Rs/Lit	62.67	62.67	62.67	62.67	62.67	Bhopal petrol pump survey
3	Maintenance cost per km	$MCK_{II,i}$	Rs/km	2.96	2.96	2.96	2.96	2.96	www.team.bh p.com
4	Revenue generation per day by fare	$RFV_{II,i}$	Rs	69390	113700	193100	51000	110000	Mini bus operator
5	Number of vehicles used in advertising	$NVA_{II,i}$	Nos.	0	0	0	0	0	Mini Bus Operator
6	Revenue generation by advertisement from a vehicle per day per vehicle	$RAV_{II,i}$	Rs	0.00	0.00	0.00	0.00	0.00	Mini Bus Operator
7	Number of bus shelters used in advertising	$NBS_{II,i}$	Nos.	0	0	0	0	0	Mini Bus Operator
8	Revenue generation from advertisement on a bus stop shelter per day per shelter	$RAS_{II,i}$	Rs	0.00	0.00	0.00	0.00	0.00	Mini Bus Operator
9	Number of drivers required for operation	$NOD_{II,i}$	Nos.	21	35	46	18	32	Field Survey Mini Bus Operator
10	salary per day paid to drivers	$SOD_{II,i}$	Rs	500	500	500	500	500	
11	Number of conductors required for operation of a vehicle	$NOC_{II,i}$	Nos	21	35	46	18	32	Field Survey
12	Salary per day paid to conductor of a vehicle	$SOC_{II,i}$	Rs	300	300	300	300	300	Mini Bus Operator
13	Total number of passengers travelled per day	$TNP_{II,i}$	Nos.	6783	11795	15686	5922	10528	Mini Bus Operator

6.1 Analysis and Results of Comparative Performance Evaluation from User Perspective

The comparative performance of public transport system ‘I’ (i.e. BCLL bus system) with respect to public transport system ‘II’ (i.e. Mini bus system) from user perspective is evaluated using proposed methodology of Stage-I. The input data in Table 10, Table 11, Table 12, Table 13, Table 14 and Table 15 are analyzed to determine the performance of BCLL bus system and Mini bus system. The results obtained from the analysis of input data of BCLL bus system and Mini bus system are presented in Figure 6.

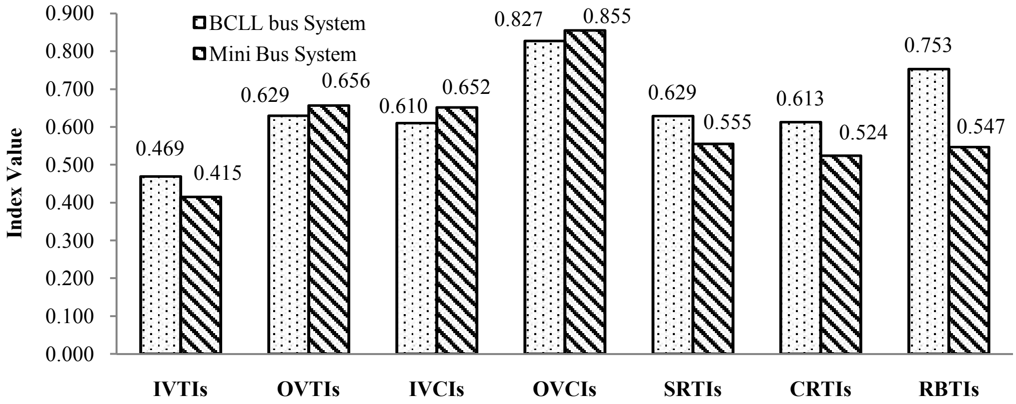

Figure 6: Analysis results of performance of Bhopal bus systems from various aspects of user perspective

It is clearly indicated that analysis results from Figure 6 the users are average satisfied from in-vehicle time aspect, fairly satisfied from out-of-vehicle time, in-vehicle cost, user safety, and user comfort aspects and good satisfied from out-of-vehicle cost, and reliability aspects from performance of BCLL bus system of Bhopal city. Further, the analysis results also indicated that the users are preferably satisfied from in-vehicle time aspect, fairly satisfied from out-of-vehicle time, in-vehicle cost, user safety, and user comfort aspects and good satisfied from out-of-vehicle cost, and reliability aspects from performance of Mini bus system of Bhopal city. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from user aspects are also presented in Figure 7.

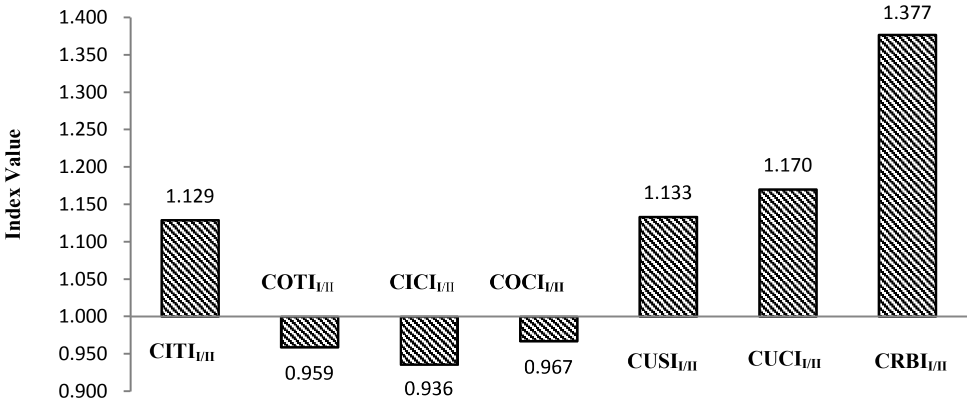

Figure 7: Results of comparative performance of BCLL bus system w.r.t Mini bus system from various user aspects

The analysis results from Figure 7 clearly indicated the performance of BCLL bus system is superior with respect to Mini bus system under in-vehicle time, user safety, user comfort, and reliability aspects from user perspective. It is logically true because BCLL bus system having more operating speed, more comfortable seats, excellent route information facilities, safety devices such as first treatment box, emergency gate, fire extinguisher, proper seating facilities, lighting facilities in bus as well as stop in Bhopal city. While the Mini bus system is flexible and having poor route information facilities, no sheltered bus stops, no safety devices, rough driving, poor quality of seats, low passenger carrying capacity. Further, the performance of BCLL bus system is inferior with respect to Mini bus system under out-of-vehicle time, in-vehicle cost, and out-of-vehicle cost from user perspective. It is also logically true because BCLL bus system having more travelling fare, fixed bus stops, more walking distance and more transfer time. While Mini bus system having low travelling fare, flexible stops for users, less walking distance and low transfer time. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from time, cost and quality aspects as well as combined from user perspective are presented in Figure 8.

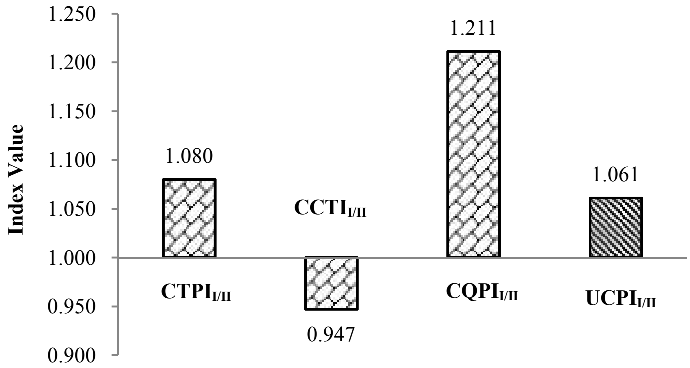

Figure 8: Analysis results of comparative performance of BCLL bus system w.r.t. Mini bus system from time, cost and quality aspects

The analysis results from Figure 8 clearly indicated the performance of BCLL bus system with respect to Mini bus system is superior under time aspect and quality aspect and inferior from cost aspects. However the overall comparative performance of BCLL bus system with respect to Mini bus system is superior.

6.2 Analysis and Results of Comparative Performance Evaluation from City Perspective

This section presented the analysis results of comparative performance of Bhopal bus system from city perspective. The input data of Table 10, Table 16, Table 17, Table 18, Table 19, and Table 20 are analyzed to determine the performance of BCLL bus system and Mini bus system using proposed methodology of Stage-II. The results obtained from the analysis of input data of BCLL bus system and Mini bus system are presented in Figure 9.

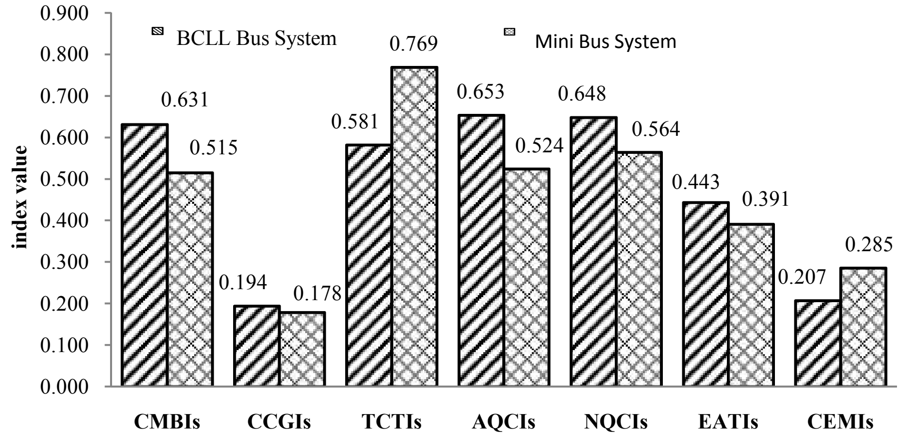

Figure 9: Analysis results of performance of Bhopal bus systems from various aspects of city perspective

It is clearly indicated that analysis results from Figure 9, the performance of BCLL bus system are poorly satisfactory from route coverage and local employment aspects, preferably satisfactory from land value aspect and fairly satisfactory from mobility, passenger carrying capacity, air quality and noise quality aspects from city perspective. Further, the analysis results also indicated that The performance of Mini bus system are poorly satisfactory from route coverage and local employment aspects, preferably satisfactory from mobility, air quality and land value aspect and fairly satisfactory from passenger carrying capacity and noise quality aspects from city perspective. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from various city aspects are presented in Figure 10.

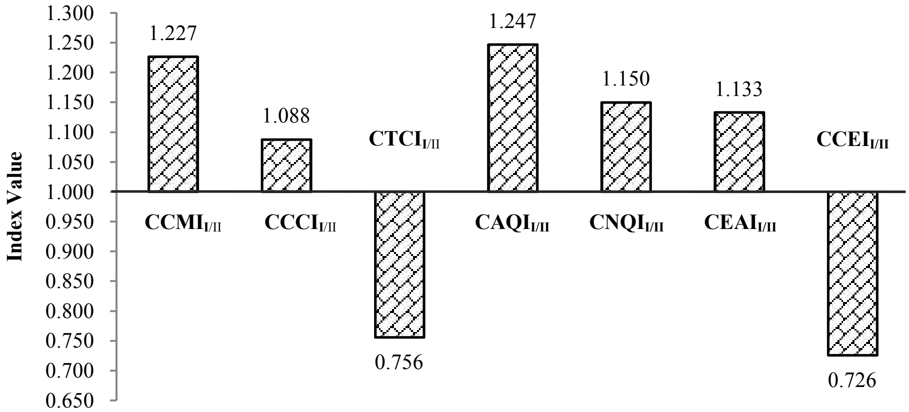

Figure 10: Graphical analysis results of comparative performance of BCLL bus system w.r.t Mini bus system from various city aspects

The analysis results from Figure 10 clearly indicated the performance of BCLL bus system is superior with respect to Mini bus system under city mobility, city coverage, air quality, noise quality, and land value aspects from in context of Bhopal city perspective. It is logically true because BCLL bus system having more operating speed, excellent route information facilities, less no of buses operating, high seating capacity and major route connectivity. While the Mini bus system is flexible and having poor route information facilities, low seating capacity and more no of mini buses operating. Further, the performance of BCLL bus system is inferior with respect to Mini bus system under transport capacity and city employment aspects from Bhopal city perspective. It is also logically true because BCLL bus system having more passengers travelled in a day and more no of buses create more jobs. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from travel, environmental and economic aspects as well as combined from city perspective are presented in Figure 11.

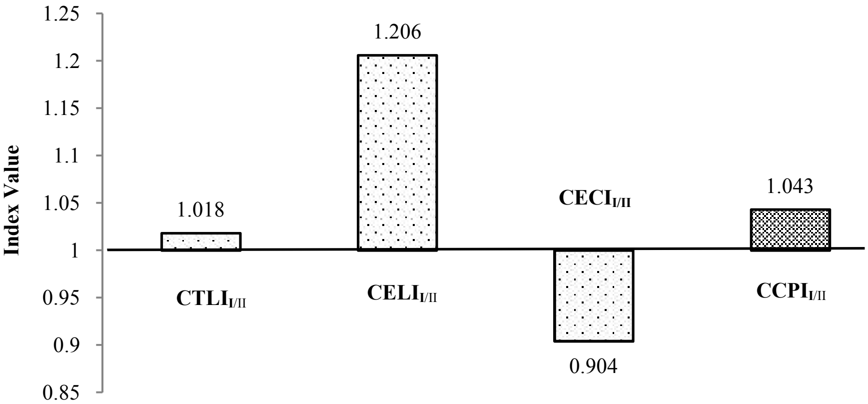

Figure 11: Results of comparative performance of BCLL bus w.r.t Mini bus system from travel, environmental, and economic aspects

The analysis results from Figure 11 clearly indicated the performance of BCLL bus system with respect to Mini bus system is superior under travel aspect and environmental aspect and inferior from economic aspects. However the overall comparative performance of BCLL bus system with respect to Mini bus system is superior.

6.3 Analysis and Results of Comparative Performance Evaluation from Operator Perspective

This analysis result of comparative performance of Bhopal bus transport systems from operator perspective is presented in this section. The input data of Table 10, Table 22 and Table 23 are analyzed to determine the performance of BCLL bus system and Mini bus system from operator perspective. The results obtained from the analysis of input data of BCLL bus system and Mini bus system are presented in Figure 12.

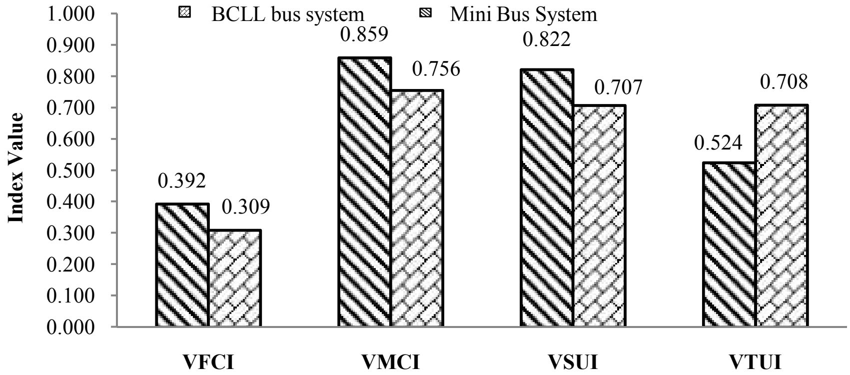

Figure 12: Graphical results of alternate bus systems from various aspects from operator perspective

It is clearly indicated that analysis results from Figure 12, the performance of BCLL bus system are poorly satisfactory from vehicle fuel cost aspect, good satisfactory from maintenance cost and staff utilization aspects and average satisfactory from vehicle travel utilization aspect from city perspective. Further, the analysis results also indicated that The performance of Mini bus system are poorly satisfactory from vehicle fuel cost aspect, good satisfactory from maintenance cost, staff utilization and vehicle travel utilization aspect from city perspective. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from various operator aspects are presented in Figure 13.

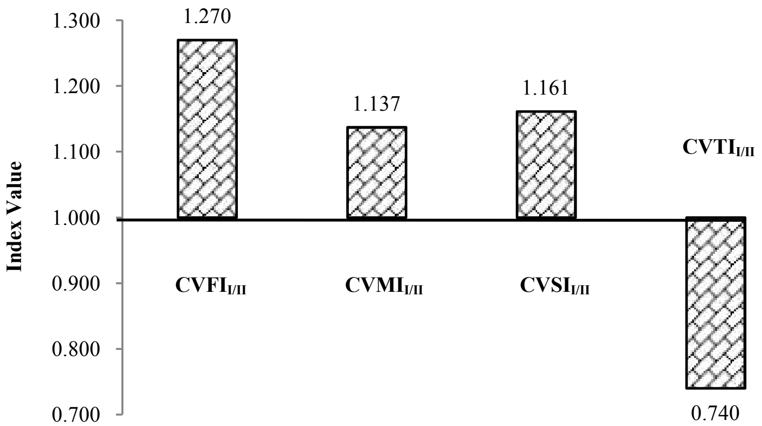

Figure 13: Graphical Results of Comparative Performance of BCLL Bus System w.r.t Mini Bus System from Various Operator Aspects

The analysis results from Figure 13 clearly indicated the comparative performance of BCLL bus system is superior with respect to Mini bus system under vehicle fuel cost, maintenance cost and staff utilization aspects from operator perspective. Further, the analysis and results of comparative performance of BCLL bus system with respect to Mini bus system from vehicle operational cost aspect and resource utilization aspects as well as combined from operator perspective are presented in Figure 14.

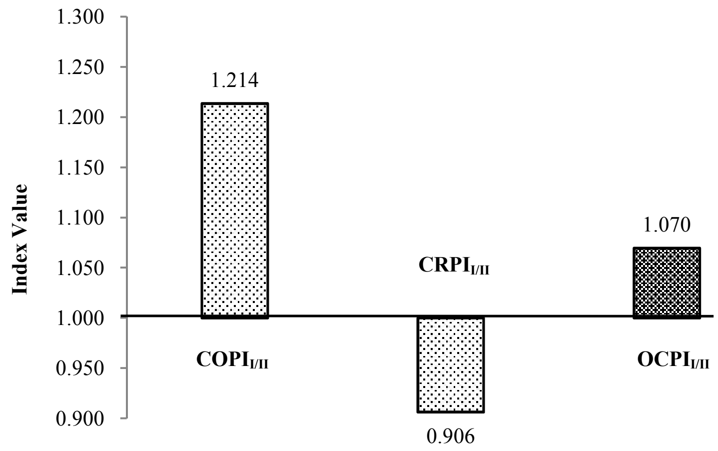

Figure 14: Results of comparative performance of BCLL bus system w.r.t. Mini bus system from operational cost and resource aspects

The analysis results from Figure 14 clearly indicated the performance of BCLL bus system with respect to Mini bus system is superior under time aspect and quality aspect and inferior from cost aspects. However the overall comparative performance of BCLL bus system with respect to Mini bus system is superior.

6.4 Analysis and Results of Overall Comparative Performance Evaluation of Bhopal Bus System

The overall comparative performance of BCLL bus system w.r.t. Mini bus system is evaluated using proposed methodology of Stage-IV and presented in Figure 15. The analysis results from Figure clearly indicated the overall performance of BCLL bus system with respect to Mini bus system is superior under user aspect, city aspects and operator aspects individually as well as combined.

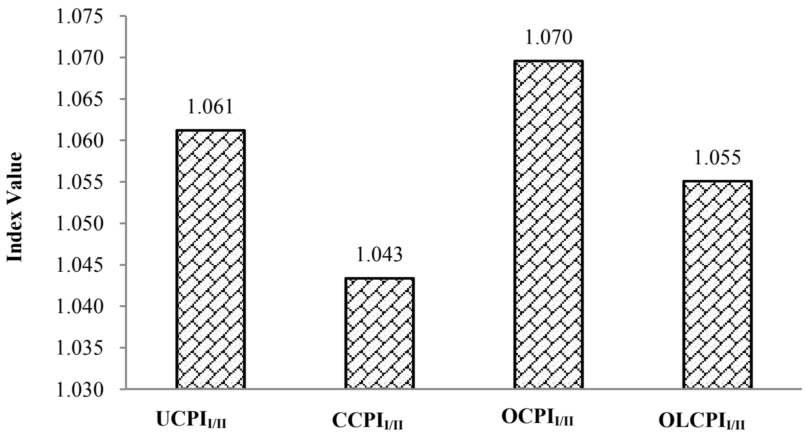

Figure 15: Analysis results of overall comparative performance of BCLL bus system with respect to Mini bus system

7. Conclusions

This study is unique in the sense as it developed a comprehensive methodology for evaluating performance of alternate public transport system in Indian context giving importance to all stakeholders interests which is essential for sustainability and overall development. It has identified performance indicators separately from each perspectives i.e. user, city and operator. The performance indices developed in the present study are simple but effectively represent the realistic condition of the public transport system in Indian context. Different categories of performance indicators have a greater or lesser impact in evaluating the performance of alternate public transport system. Hence, relative contribution of these performance indicators is also considered in analyzing the overall performance of public transport system in Indian context. Therefore the developed methodology has wide applicability not only for India but to other similar developing nations. An application of the methodology developed in this study is illustrated by comparing the relative performance of BCLL bus system with respect to Mini Bus system of Bhopal city. The result of analysis shows that performance index $UCPI_{I/II,}$ $CCPI_{I/II}$ and $OCPI_{I/II}$ values are 1.061, 1.043 and 1.070 respectively. Thus, the BCLL bus system is superior to the Mini bus system from user, city and operator perspectives. Further, the value of $OLCPI_{I/II}$ is 1.055 that indicates that BCLL bus system is superior to the Mini bus system from overall perspectives too. Further, examining the details of comparative user, operator and city indices it is noted that the value of city coverage index and city employment index of BCLL and Mini bus system is less than 0.3; this indicates that both the systems are poor in respect to city coverage and city employment aspects and hence, there is a need to improve these aspects. However, in respect to other aspects related to city, operator or user both the systems obtain the value of different indices more than 0.30 but less than 0.85 and hence, the performance may be said to be satisfactory. For extremely satisfied criteria, there is a need to maintain this level. Thus, the methodology will be useful to identify the shortcomings in transport systems from user, city, and operator's point of view individually as well as combined. Further, the methodology will also be useful to compare any two alternate public transport system such that it helps decision makers to take significant decisions before implementation of alternate public transport system in Indian cities.

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