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Analytical hierarchy process for assessing sustainability

Indicators of public transportation systems, pedestrians and feeder services in developing countries

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Abstract

Purpose – The purpose of this paper is to study the analytical hierarchy process (AHP) based on assessment of sustainability indicators for public transportation system including pedestrians and feeder services in developing country.

Design/methodology/approach – A hybrid approach based on the AHP is considered for assessment of the sustainability of public transportation system including pedestrians and feeder services. Sustainability related indicators for public transportation system (namely for metro, bus and feeder bus) and pedestrians based on past data were reviewed and subsequently, more important indicators catering needs of developing country have been added to achieve significant sustainability score and a total of 17 indicators were selected for assessment of comprehensive sustainability (seven indicators under economic, six under social and four under environmental categories).

Findings – For quantifying the assessment, specific user interview surveys are performed in south Delhi region and accordingly perception of user and transportation-related operational characteristics of the public transport system were also collected. Preliminary result shows air pollution in environmental category, public health in social category and productivity in economic category is most influential parameters in developing country.

Originality/value – AHP method is applied for rating the criteria and setting out the priority of designed sustainable indicators. Subsequently sustainable mitigation measures and scenarios for the study area can be evaluated utilizing developed comprehensive sustainability indicator for public transportation system including pedestrian and feeder services available in developing country.

Keywords Sustainable development, Sustainability indicators, Developing country, Climate change, Analytical hierarchy process (AHP), Sustainable public transportation system

Paper type Research paper

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Introduction

Developing countries like India are facing radical change in urban transport systems due to the rapid growth of traffic and population in developing countries. Major cities such as Delhi are facing tremendous congestion, air pollution and social problems due to rapid increase in vehicle ownership, while the road network density and the road-widths still remain the same. As vehicle ownership is increasing, the level of utilization of public transport systems is reducing, especially in Delhi, due to poor public transportation facility. Overall, such transportation systems remain unsustainable. Much research has been carried out to understand the urban transportation system sustainability indicator to improve the performance of transportation system (Litman, 2010) in the developed world, but for developing countries, traffic has heterogeneous character and commuter income expenditure on transport and affordability to pay on transport is quite different, compared to developed countries.

Therefore, a need for sustainability transportation indicators for developing countries is required to understand the severity of congestion, transportation demand and supply, and the impact of transport projects on the social, economic and environmental spheres of the developing society. In this paper, transportation-related sustainable indicators were selected for public transportation system (metro, bus and feeder) and pedestrian by reviewing past research. Some more sustainability related parameters were added to achieve more significant scores regarding sustainability by assessment of the selected indicators (no. of indicators: economic – seven, social – six, environmental – four). A hybrid approach based on the analytical hierarchy process (AHP) is considered for assessment of the sustainability of public transportation system including pedestrian and feeder services in south Delhi region. AHP is used for rating the criteria and setting out the priority of designed sustainable indicators. Later on, sustainability score is achieved after assessment for the selected routes in Delhi city of India. Preliminary results show air pollution in the environmental category, public health in social category and productivity in economic category are most influential parameters.

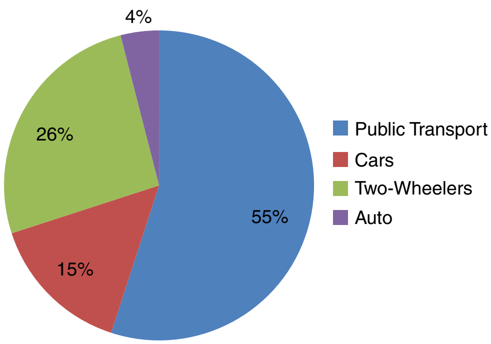
Literature review and existing condition

Hernandez-Moreno and De Hoyos-Martines (2010) defined the concept of sustainability as a need for the current society to be satisfied without compromising the needs of future generations. While, urban sustainability has been defined as a concept that emphasizes the interrelationship between transport networks, urban structure and urban life. To achieve the sustainability in any field a single indicator is not enough and Litman also concluded this in his research. Litman (2010) concluded that a single indicator is not adequate to encompass sustainability but a set of indicators, which should reflect various goals, objectives and impacts should be used. Sinha (2003) identified various causes for which the sustainability is less in developing countries. Increasing urbanization in an unparalleled way, increase of motorization and decreasing use of public transport. Their study concluded that sustainability, transit, land use, and technology are intrinsically related. Sustainability indicators vary from country to country because of different approaches and priorities (Zavadskas *et al.*, 2005). Indicators are the best way to move human activities towards the direction of sustainability. Sustainability indicators tend to be quantitative and explicit but in practice, more qualitative and implicit is used. Kennedy (2005) proposed four pillars for sustainable transportation namely: effective governance of land use and transportation; fair, efficient, stable funding; strategic infrastructure investment;

and attention to neighbourhood design. Black (1997) investigated sustainable transportation in North America. Anderson *et al.* (2005) present means and measures through which freight transport can be made more sustainable.

Urban transport problem scenario in New Delhi

Delhi has an extensive road network. The road network of 14,316 km lane that existed in 1981 was expanded to 28,508 km lane in 2001 and 31,373 km lane in 2009. The total number of vehicles registered too demonstrated a significant increase from 562,000 in 1981 to 3,457,000 in March 2001 and 6,933,000 in March 2011 (source: Delhi Government_1). Figure 1 shows modal shares of daily trips in Delhi. According to the (Government of India MORTH, 2013) the number of registered motor vehicles in Delhi exceeded the combined vehicle population of four cities (Chennai, Kolkata, Lucknow and Mumbai). Number of passengers cars in Delhi has been calculated as 1,881,135 (171 cars per 1,000 people), as opposed to 511,457 (109 cars per 1,000 people) in Chennai, 142,861 (51 cars per 1,000 people) in Lucknow and 509,246 (41 cars per 1,000 people) in Mumbai. Table I shows projected modal splits of traffic. Table II shows recommended sustainability indicator set by PROPOLIS. Table III shows recommended sustainability indicator set by KONSULT). Sustainable transportation and sustainability indicators of public transportation system are ways of quantifying objectives or sub-objectives. For example, casualty numbers would measure the overall safety objective; locations exceeding a pollution threshold a part of the environmental objective. However, output and intermediate outcome



Source: Delhi Government website

Figure 1. Modal shares of daily trips in Delhi 2007

Sl. no.	Mode	Daily trips-2021 (intra city)	Modal share (%)	Daily trips-2007	Modal share (%)
1.	Car	2,983,510	17.1	1,806,380	15.5
2.	Two wheeler	3,490,954	20.0	2,976,832	25.5
3.	Auto	549,351	3.2	518,329	4.4
4.	Public transport	10,409,024	59.7	6,369,088	54.6
	Total	17,432,839	100	11,670,629	100

Source: Delhi Government website

Table I. Projected modal splits

Sustainability dimension	PROPOLIS Indicators	Parameters
Environmental indicators	Global climate change	Greenhouse gases from transport
	Air pollution	Acidifying gases from transport
		Volatile organic compounds from transport
	Consumption of natural resources	Consumption of mineral oil products, transport
		Land coverage
		Need for additional new construction
	Environmental quality	Fragmentation of open space
		Quality of open space
	Health	Exposure to PM from transport in the living environment
		Exposure to NO_2 from transport in the living environment
		Exposure to traffic noise
		Traffic deaths
		Traffic injuries
Social indicators	Equity	Justice of distribution of economic benefits
		Justice of exposure to PM
		Justice of exposure to NO_2
		Justice of exposure to noise
		Segregation
	Opportunities	Housing standard
		Vitality of city centre
		Vitality of surrounding region
		Productivity gain from land use
	Accessibility and traffic	Total time spent in traffic
		Level of service of public transport and slow modes
		Accessibility to city centre
		Accessibility to services
		Accessibility to open space
Economic indicators	Total net benefit from transport	Transport investment costs
		Transport user benefits
		Transport operator benefits
		Government benefits from transport
		Transport external accident costs
		Transport external emissions costs
		Transport external greenhouse gases costs
		Transport external noise costs

Table II. Recommended sustainability indicator set by PROPOLIS

indicators may be helpful in understanding how a change in performance has been obtained. To be effective, outcome indicators must be exhaustive, in that they cover the whole range of objectives, provide sufficient information to decision makers, and be sensitive to changes in the strategies that are tested (source: www.konsult.leeds.ac.uk/dmg/07/).

To understand the sustainability indicator, very little analysis has been carried out by different researchers using multiple criteria decision making (MCDM) approaches Rossi *et al.*, Awasthi and Chauhan and Atadero. MCDM approaches for evaluation MCDM methods are widely diverse. Chen and Hwang classified a group of MCDM methods according to the type of information and the salient features of information

Sustainability dimension	KONSULT Indicators	Parameters
Environmental indicators	Environmental protection	Vibration Level of different air quality (local) pollutants Visual intrusion Townscape quality (subjective) Fear and intimidation Severance (subjective) CO_2 emissions of the area as a whole Fuel consumption for the area as a whole
	Sustainability	
Social indicators	Safety and security	Personal injury, accidents by user type per unit exposure (for links, intersections and networks) Insecurity (subjective)
	Accessibility	Activities (by type) within a given time and money cost for a specified origin and mode Weighted average time and money cost to all activities of a given type from a specified origin by a specified mode Indicators as above, considered separately for different impact groups
	Equity	Delays for vehicles (by type) at intersections Delays for pedestrians at road crossings
Economic indicators	Economic efficiency	Time and money costs of journeys actually undertaken Variability in journey time (by type of journey) Costs of operating different transport services
	Economic regeneration	Environmental and accessibility indicators as above, by area and economic sector Operating costs and revenues for different modes Cost and revenues for parking and other facilities
	Finance	Tax revenue from vehicle use

Table III. Recommended sustainability indicator set by KONSULT

received from the decision maker. MCDM is one of the established branches of decision. Most commonly used MCDM methods:

- The weighted sum model.
- The weighted product model.
- The AHP.

Methodology

In developing countries rapid growth in motor vehicles has been seen in the past few years and is expected in the future, primarily in urban areas impacting the environmental and social impacts significantly and quality of life and urban productivity. These impacts are in terms of congestion, energy consumption, air pollution and traffic crashes. Basic purposes of urban transportation are to support the mobility requirements of growing cities and require new approaches. However, urban transport is a political rather than a technical issue. The technical aspects are relatively simple. Therefore indicators relating to user choices and decisions, relating to the type of city they want and the way we want to live, benefit from a transport system giving priority to the needs of the poor majority rather than the automobile owning minority. The most efficient, economical way to move a city's population, as cleanly and as comfortably as possible and other possible ways to minimize traffic jams due to automobile for sustainable measures are warranted. The use of indicators in the field of urban transport can help identify critical areas that need to be improved to popularize the use of public transport. Figure 2 shows the details on the methodology adopted in the present study.

Assessment approach

Approach taken up for the assessment of indicators of sustainability for public transportation involves technique namely AHP. AHP is used to allocate weights or rate to the selected criteria for assessment of public transportation. Saaty (1990) proposed AHP and it is a MCDM technique. AHP consist of various steps which are as follows:

- Defining the problem and determining its goal.
- Structuring the hierarchy from the top (the objectives) through the intermediate levels (criteria) to the lowest level (alternatives).
- Constructing a set of pair-wise comparison matrices (size $n \times n$) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table IV.

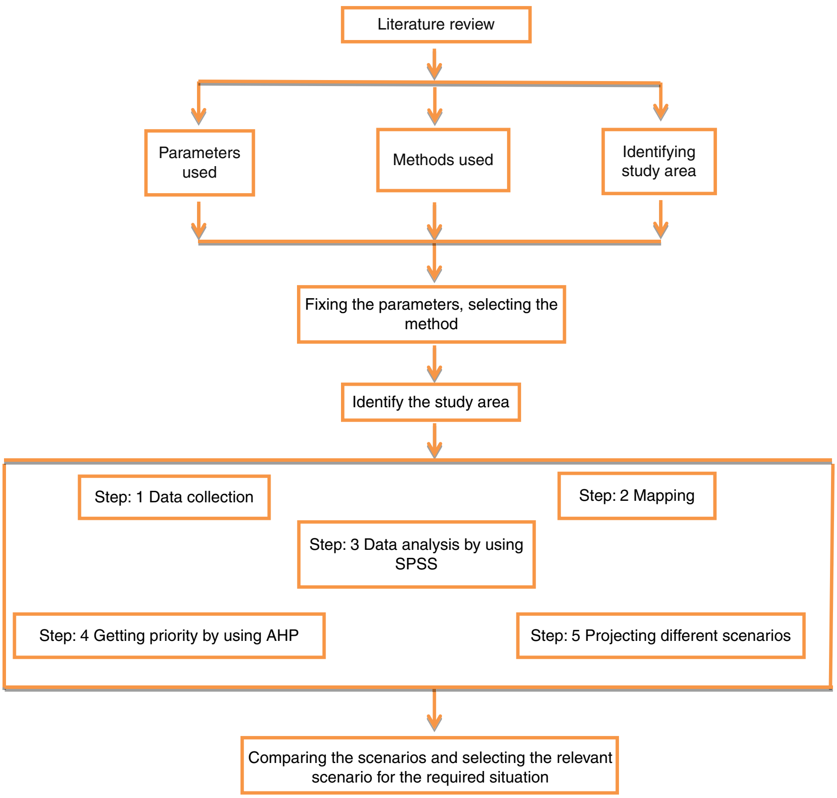


Figure 2.
Flow chart of the methodology

- The pair-wise comparisons are done in terms of preference of one element over the other. There are $n(n-1)/2$ judgments required per matrix to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison. Having made all the pair-wise comparisons, the consistency is determined by using the eigen value λ_{max} to calculate the consistency index CI where $CI=(\lambda_{max}-n)/(n-1)$ where n is the matrix size. Judgment consistency can be checked by seeing the value of consistency ratio CR for the appropriate matrix value in Table V.
- If $CR \leqslant 0.1$, the judgment matrix is acceptable otherwise it is considered inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved. Hierarchical synthesis is now used to weight the normalized eigen vectors by the weights of the criteria and the sum is taken overall weighted eigen vector entries corresponding to those in the next lower level of the hierarchy.

The strength of AHP is that it allows the verification of transitivity property in criteria weights, that is if criteria has higher weight than criteria by which has higher weight

Numerical rating verbal judgment of preferences
1 Equally preferred
3 Moderately preferred
5 Strongly preferred
7 Very strongly preferred
9 Extremely preferred
2, 4, 6, 8 Intermediate values between the two adjacent judgments
Reciprocals when activity i compared to j is assigned one of the above numbers, then activity j compared to i is assigned its reciprocal

Table IV. Pair-wise comparison scale for AHP preferences

Global objective	Sub-objectives	Criteria
	Environmental effects	Noise pollution
		Energy consumption
		Land consumption
		Air pollution
	Social effects	Public health
		User rating
		Affordability
		Accessibility
Sustainability		Safety and security
		Additional facilities provided
	Economic effects	Household expenditure allocated to transport
		Transport emission cost
		Productivity
		Transfer time
		Transport costs and prices
		Additional employment
		Economic efficiency

Table V. Set of Indicator prepared for this study than criteria c, then criteria a will always have higher weight than criteria c. This is the reason why it is chosen over other simple weight allocation techniques.

Find the eigen vector of the matrix:

Matrix N for n (=3) criteria; (for $n=n^2-(n/2)$)

$$N = \begin{bmatrix} 1 & a_{12} & a_{13} \\ {a_{12}}^{-1} & 1 & a_{23} \\ {a_{13}}^{-1} & {a_{23}}^{-1} & 1 \end{bmatrix}$$

$$\text{Sum of columns} = \text{Sc}_1 \quad \text{Sc}_2 \quad \text{Sc}_3$$

Normalize and calculate first normalized principle eigen vector x_1:

$$N = \begin{bmatrix} 1/\text{Sc}_1 & a_{12}/\text{Sc}_2 & a_{13}/\text{Sc}_3 \\ {a_{12}}^{-1}/\text{Sc}_1 & 1/\text{Sc}_2 & a_{23}/\text{Sc}_3 \\ {a_{13}}^{-1}/\text{Sc}_1 & {a_{23}}^{-1}/\text{Sc}_2 & 1/\text{Sc}_3 \end{bmatrix}$$

Eigen vector X_1

$$X_1 = \begin{bmatrix} \sum \text{row}_1/n \\ \sum \text{row}_2/n \\ \sum \text{row}_3/n \end{bmatrix}$$

Square normalized matrix $[N]$ and calculate next iteration of eigen vector until difference.

$X_{k+1}-x_k$ is neglectable X_2 $[N]^2$.

Find the eigen vector of the matrix.

Calculate largest eigen value λ:

$$\lambda = \text{Sc}_1.x_1 + \text{Sc}_2.x_2 + \text{Sc}_3.x_3$$

Calculate consistency index:

$$\text{CI} = \lambda - n/n - 1$$

Verify consistency ratio < 10 percent: CR = CI/RI (Tables IV and VI).

Estimation of transportation sustainability

The global utilities are used to determine the city sustainability at any given time t using a transport sustainability index (TSI). Let us denote the global utilities for the criteria $C_1, C_2, \ldots, C_N$ at time t_n by $u_1(t_n), u_2(t_n), u_3(t_n), \ldots, u_N(t_n)$.

Then, the TSI at time t_n is given by:

$$\text{TSI}(t_n) = u_1(t_n) \times w_1 + u_2(t_n) \times w_2 + u_3(t_n) \times w_3 + \ldots + u_n(t_n) \times w_N$$

where $w_1, w_2, \ldots, w_N$ represent the weights of criteria $C_1, C_2, \ldots, C_N$ obtained from AHP.

Table VI.
Average random consistency (RI)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	00	0.5	0.8	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Result and discussion

AHP has been designed in this case as two level of hierarchy as shown in Table VII. The result obtained shows different weights as compared to three main parameters defining sustainability is shown in Table VIII.

In these preliminary results, an online AHP software is used which is based on dummy data which shows the approach of the present study in the selected area in the field of sustainability. The weightage used for the parameter is according to global priority which is attained by the online AHP software Goepel, 2015 by itself. In actuality, the priority (weightage) of the individual parameter with each other is being calculated by a survey which is done through expert opinion through which, importance will be given to a parameter over another on the scale of 1-9. The weightage in terms of priority of the individual parameter over another can be found out and then, by multiplying the homogenized utility value with the weightage of the parameter and sum of all of them, give the value of sustainability index. The result shown in this paper is basic only on the basis of public transportation system data assumed for the outer ring road (south Delhi region). The further investigation is being carried out which will comprise of all the data together for the parameter set prepared for this study for the assessment of sustainability indicators for the public transportation system including pedestrian and feeder services (Figure 3).

Decision hierarchy

Level 0	Level 1	Level 2	Global Priorities
Transportation sustainability	Environment 0.3333	Noise pollution 0.1343	4.5
		Air pollution 0.5907	19.7
		Energy consumption 0.213	7.1
		Land consumption 0.062	2.1
	Social 0.3333	Public health 0.428	14.3
		User rating 0.1256	4.2
		Affordability 0.0935	3.1
		Accessibility 0.1082	3.6
		Safety and security 0.2166	7.2
		Additional facilities provided 0.0282	0.9
	Economic 0.3333	Household 0.2625	8.8
		Transport emission cost 0.057	1.9
		Productivity 0.282	9.4
		Travel time ratio 0.1741	5.8
		Transport costs and prices 0.0692	2.3
		Additional employment 0.0751	2.5
		Economic efficiency 0.0802	2.7
			1.0

Note: Green color indicates highest sustainability index obtain from expert

Table VII. AHP designed for transport sustainability indicators

Table VIII.
Results from AHP process

	Global priorities value	Homogenized utility value	
Environmental effects			
Noise pollution	4.5	0.5956	2.6802
Energy consumption	7.1	0.6206	4.4063
Land consumption	2.1	0.5286	1.1101
Air pollution	19.7	0.6047	11.913
	33.4		20.1096
Social effects			
Public health	14.3	0.6087	8.7044
User rating	4.2	0.6068	2.5485
Affordability	3.1	0.6559	2.332
Accessibility	3.5	0.3253	1.1385
Safety and security	7.2	0.4297	3.0938
Additional facilities provided	0.9	0.2039	0.1835
	33.2		18.0007
Economic effects			
Household expenditure allocated to transport	8.8	0.5532	4.8681
Transport emission cost	1.9	0.4407	0.8373
Productivity	9.4	0.3704	3.4817
Transfer time	5.8	0.6834	3.9637
Transport costs and prices	2.3	0.5512	1.2677
Additional employment	2.5	0	0
Economic efficiency	2.7	0.6038	1.6302
	33.4		16.0487
Total	100		54.159

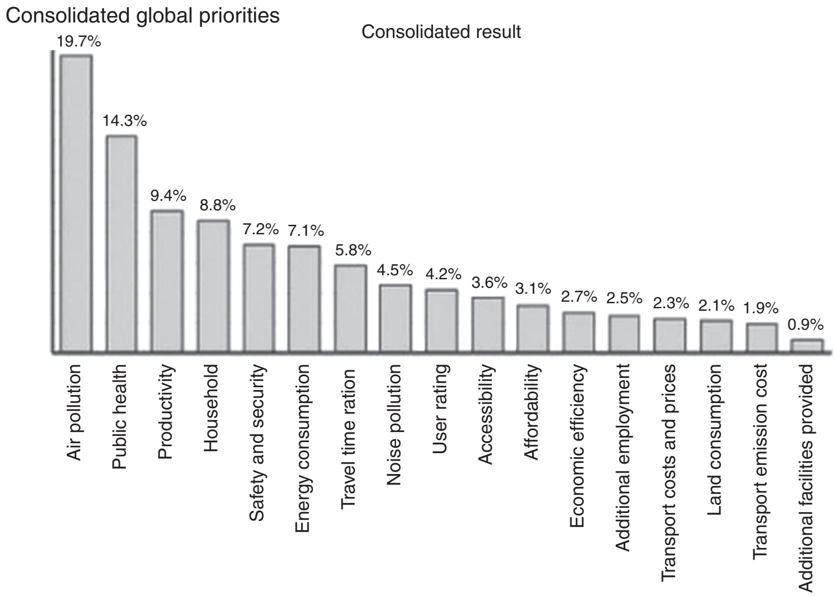


Figure 3.
Global priority in consolidation

Conclusion

This paper provide a methodology for determination of sustainability of public transportation system including pedestrian and feeder services in the south Delhi region which represent regions from a developing country. Transportation priority indicators are the indicators which affect the sustainability by getting weightage. We can concentrate on the indicator after getting priority which affects sustainability to achieve maximum sustainability in the field of transportation. In this paper an integrated decision-making approach based on AHP for assessment of transport measures on city sustainability is presented which comprises of selecting evaluation criteria, data collection and evaluation of city sustainability using a TSI and impact assessment of the existing public transportation. The current work comprises of the selected indicators of sustainability which are less in number due to time limit. Preliminary result shows air pollution in environmental category, public health in social category and productivity in economic category are most influential parameters. Future work will involve detailed assessment of public transportation sustainability by making an indicator set of more parameters in number and with that, more accurate sustainability will be achieved.

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