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Sustainable Transportation Attainment Index: multivariate analysis of indicators with an application to selected states and National Capital Territory (NCT) of India

Ubaid Illahi[1] · **Mohammad Shafi Mir**[1]

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Abstract

There is an increasing demand for quantifying, evaluating and reporting sustainability of transportation systems, especially in case of developing countries. However, sustainable transportation being a complicated area of concern is becoming equally challenging. In this concern, the quantification of the sustainable transportation attainment levels covering three pillars of sustainability (i.e., Environmental, Social and Economical) is useful. The main aim of this paper is to develop a model which can quantify and report the attainment levels of sustainable transportation and which is flexible, robust, comprehensive as well as transferable. In this line, a five-stage model is presented which produces a composite index called Sustainable Transportation Attainment Index (I_{STA}). Using I_{STA}, transportation system of various zones can be evaluated, compared and tracked. The shortlisting and finalizing of optimum number of zones and sustainable transportation indicators (STIs), in this study, were done by a proposed tool called Bargain Matrix. STIs were broadly classified into three sustainability pillars which were further divided into ten subdivisions. This study used a total of 116 STIs, which were normalized using rescaling method, weighted and aggregated using principal component analysis/factor analysis. The proposed five-stage model was applied to 26 states and National Capital Territory (NCT) of Delhi, India (i.e., a total of 27 zones). Based on the computed I_{STA}, while Tamil Nadu (0.6002), Telangana (0.5613) and Andhra Pradesh (0.5580) showed "Best Relative Transport Sustainability Attainment," Goa (0.3852) and Chhattisgarh (0.4278) showed "Weakest Relative Transport Sustainability Attainment."

Keywords Sustainable transportation · Indicator sets · Frameworks · Principal component analysis · Factor analysis · Composite index

✉ Ubaid Illahi
ubaidillahi@nitsri.net

Mohammad Shafi Mir
shafi@nitsri.net

[1] Transportation Engineering & Planning Division, Department of Civil Engineering, National Institute of Technology Srinagar, Hazratbal, Srinagar, Jammu and Kashmir 190006, India

1 Introduction

Transportation system, on the one hand, is the engine of overall development, providing access to goods and services, connecting communities, ensuring social well-being and triggering the economic progress. On the other hand, the share of the transportation system in degrading the environment is significant. Moreover, it is a major contributor to community disruption, which is often lopsidedly distributed (Gudmundsson et al. 2016). Thus, it is important to minimize the detrimental effects and simultaneously improve the positive impacts of the transportation system which can be achieved by introducing the term "sustainability" into the picture. In order to achieve sustainability in the transportation system, it should be defined first. There is not a single definition available in the literature which defines sustainable transportation in a complete sense (Jeon and Amekudzi 2005). It is consistent with the fact that every organization has distinct strengths, weaknesses and goals. Although many definitions of sustainable transportation are found in the literature, one of the most accepted definitions among researchers is the one given by Centre for Sustainable Transportation (CST), Canada, which is quoted as:

A sustainable transportation system is defined as one that:

- allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations;
- is affordable, operates fairly and efficiently, offers choice of transport mode and supports a competitive economy, as well as balanced regional development;
- [in coordination with other sectors] limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation and uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on the use of land and the generation of noise.

In order to incline toward these points for achieving sustainable transportation, three pillars of sustainability, i.e., Environmental, Social and Economical, play an important role (Ting and Xiao 2009). For the development of sustainable transportation system, it is important to integrate the qualities associated with interactions and overlapping of these three pillars (Illahi 2018; Tanguay et al. 2010). Choosing the criteria for selection of STIs, Spiekermann and Wegener (2004), in their European Union research project *PROPOLIS (Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability)* inferred that the STI set should contain Environmental, Social and Economic aspects of transportation. The best practices that should be adopted for selection of STIs, as recommended by Litman (2007), are comprehensiveness, comparability, understandability, high quality, accessibility, transparency, cost-effectiveness and performance targets.

There is an increasing demand for quantifying, evaluating and reporting sustainability attainment of transportation systems across the globe (Castillo and Pitfield 2010). This demand is seen more in case of developing and emerging nations particularly in Asia and the Middle East due to the limited number of studies measuring sustainability in transportation systems (De Gruyter et al. 2017; Gwilliam 2003). To know whether we are inclining toward or away from the desired directions, sustainable transportation indicators (STIs) are used (Balachandra and Reddy 2013). STIs aid in establishing benchmarks, identify developments and trends, forecast snags, evaluate options, set performance targets and evaluate a particular dominion or organization (Litman 2007). Sustainability in transportation system, however, cannot be completely captured by individual indicators alone (Zhou et al. 2007). Therefore, in order to cover the broad goal of sustainability in transportation, a composite indicator or index, quantifying multi-dimensional aspects of it, is meritorious. Moreover, using too many STIs is inappropriate and complex for decision-makers because of their hard interpretation, and thus, integrating STIs into a single index is useful (Varzaneh 2014). Three basic steps involved in developing a composite index are: (1) normalization, (2) weighting and (3) aggregation (Reisi et al. 2014). Selection of the respective methods of these steps should be given due importance and thus carefully analyzed.

Gan et al. (2017), in their study, have done a detailed review of different methods of weighting for the development of composite indices. However, broadly the weighting methods are classified into the following three categories: equal weighting, analytical hierarchy process (AHP) and principal component analysis/factor analysis (PCA/FA) (Saisana 2011). In the method of equal weighting, all the STIs are given equal importance (i.e., weight assigned to each STI is equal to unity). In AHP, pairwise sets of STIs are designed which are assigned weights by the experts. Most of the previous studies, as evident from the literature review, have used either equal weighting or AHP. However, these two methods of weighting have some limitations. PCA/FA is gaining importance among the researchers (Mahdinia et al. 2018) as it overcomes the limitations in the other methods of weighting.

As far as equal weighting method is concerned, there is a risk of weighting the same STI twice (Reisi et al. 2014). It is due to the fact the two STIs may be quantifying the same issue of sustainable transportation. Moreover, equal weighting does not take into account the correlation between STIs, and this makes the developed composite index less reliable. When a correlation matrix of STIs is developed, out of those two STIs which possess higher correlation (usually greater than 0.8) only one should be included in the analysis. This is violated in case of equal weighting, thereby making it difficult to fully incorporate all aspects of sustainable transportation in the analysis (Mahdinia et al. 2018). Likewise, there are some drawbacks in using AHP for weighting of STIs. Since experts' opinions are involved in the pairwise comparisons, it may lead to bias weighting. This is because experts might have conflicting opinions on the same issue owing to a different domain of expertise, thereby introducing arbitrary elements and subjectivity as far as weighting procedure is concerned.

The main aim of this paper is to develop a model which can quantify and report the broader term of sustainable transportation attainment levels and which is flexible, robust, comprehensive as well as transferable. Flexible, in the sense, that it should be possible to disintegrate the model into its basic components. Robust means the correlation between the STIs should be respected throughout. To overcome the limitations of previous studies, which have used a few number of STIs, the model should be capable of accepting as many STIs as possible without the issue of interpretability, thus reflecting comprehensiveness. Transferable, in the sense, that it should be possible to apply the model in different regions and at different scales. In this line, a five-stage model is presented which produces a composite index called Sustainable Transportation Attainment Index (I_{STA}). Using I_{STA} different zones can be evaluated, compared and tracked as far as sustainable transportation is concerned. It possesses all the four qualities explained above, i.e., flexibility, robustness, comprehensiveness and transferability.

It is believed that the proposed five-stage model is helpful for transport planners, evaluators, stakeholders, decision-makers and even public. Transport planners and evaluators can disintegrate the model to its basic components and therefore have better control over the sustainability pillars as well as the corresponding subdivisions. Stakeholders and decision-makers could easily understand the relative performance of an area and take decisions as far as budget allocation is concerned. Since the output is a single index with a value ranging from zero to one, even the public can understand and participate in driving transportation toward sustainability.

The remainder of this paper is organized in the following way: Firstly, a brief review of the literature is presented, highlighting previous researches on the development of composite indices. Since the weighting of STIs remains a debatable issue among researchers, the emphasis has been put on various weighting methods used in the previous studies. The next section explains the research methodology which is divided (broadly) into five stages. Each stage has been further divided into steps adopted in this research. Then the study area (which is divided into zones) is explained followed by the data collection related to each zone. This is followed by the justification and selection criteria of STIs. Next, the results from the case study are presented, which is followed by the discussion. Then, the conclusions are presented. Finally, in order to get clarity over the application of the proposed five-stage model, details of computation of I_{STA} of one of the zones (i.e., Andhra Pradesh) are presented in "Appendix."

2 Review of literature

Evaluation and assessment of transportation systems in order to analyze how well policies, projects and programs are performing have seen grown over the years (Illahi and Mir 2019; Mahdinia et al. 2018). Some researchers, on the one hand, have studied a single criterion of transportation system such as "efficiency" in case of (Husain et al. 2002). On the other hand, some others have studied more than one aspect; for example, Mahdinia and Habibian (2017) have studied three aspects of transportation systems—"efficiency," "effectiveness" and "efficacy." This trend over the years is pointing toward the benefits of using multivariate techniques in the analysis and evaluation of transportation systems.

The fact that no single definition defines and addresses all the issues of sustainable transportation is broadly agreed upon (Jeon and Amekudzi 2005). However, it is well defined by the frameworks based on three sustainability pillars (i.e., Environmental, Social and Economical). Castillo and Pitfield (2010), in their work, have proposed a framework what they call *ELASTIC—Evaluative and Logical Approach to Sustainable Transport Indicator Compilation*. In their study, 233 STIs were taken into consideration, which were analyzed, and a suite of fifteen STIs were finalized. Also, some of the following frameworks deserve a mention: TERM (2011) and The Gray Notebook (2011) and other reports published by the European Environmental Agency (EEA). Developing STIs is a challenging task; however, certain guidelines, as evidenced from the literature, aid in developing an appropriate set of STI. In this line, Gudmundsson et al. (2016) have provided a detailed description on the key issues and criteria for the selection and development of STIs. To understand these concepts in a comprehensive manner, four case studies ("European Transport White Paper," "High-Speed Rail in England," "New York's GreenLITES Rating Systems" and "Japan's 'Eco-Model City' Program") were also presented. Cornet and Gudmundsson (2015) reviewed various frameworks and proposed what they call meta-framework which encompasses three vital functions of a framework, i.e., conceptualization, operationalization and utilization.

Shaker and Sirodoev (2016) constructed a multi-metric assessment system, the output of which produced local sustainable development index (LSDI) using household and property composition indicators for evaluating development patterns across the Republic of Moldova. Rassafi and Vaziri (2005) compared 79 countries based on the sustainability index which they developed with the help of 33 STIs. They, in their study, weighted the STIs by means of equal weighting method. In total, 100 cities of the world were compared by Haghshenas and Vaziri (2012) using what they termed as *Overall Sustainable Transport Composite Index*. They weighted nine STIs using equal weighting method. Similarly, Ahangari et al. (2016) developed composite *National Transportation Sustainability Index (NTSI)* using 10 STIs which were weighted using equal weighting method. NTSI was applied to 28 European countries and the transport sustainability was compared for the years 2005 and 2011. Based on 20 STIs, Costa and Neto (2017) developed the *Sustainable Urban Mobility Index (IMUS)* to assess the sustainability of urban transportation using equal weighting method. It was applied to Greater Vitoria, Brazil. Gudmundsson and Regmi (2017) analyzed the sustainability of the transportation system in four cities across Asia–Pacific with the help of *Sustainable Urban Transport Index (SUTI)*. SUTI was developed from 10 STIs using equal weighting method. Alonso et al. (2015) measured the sustainability of urban passenger transport systems in 23 European cities using composite indicator (CI). CI was developed from nine STIs which were weighted using equal weighting method and aggregated to three CIs representing three pillars of sustainability. Using methods of equal weighting and Euclidean distance, 24 STIs were weighted and aggregated by Zito and Salvo (2011) to form the Normalized *Transport Sustainability Index (NTSI)*. NTSI was applied to 36 cities in Europe to evaluate and compare the transport policies adopted from a sustainability point of view. De Gruyter et al. (2017) compared the combined sustainability performance of the urban public transportation system. They, in their study, have selected various cities in the Asia and the Middle East region using 15 STIs which were normalized with the help of distance-to-reference-based approach and weighted by equal weighting method. Jeon et al. (2013) reviewed various methodologies related to transportation planning for sustainability assessment. They, in their study, used 15 STIs from Atlanta metropolitan region which was weighted using equal weighting method and aggregated to form indices, each corresponding to the four parameters: System-effectiveness, Environmental, Social and Economical.

Verma et al. (2015), in their study, selected 16 STIs to measure sustainable transportation in the city of Bangalore in India. They developed a composite index what they termed as *Composite Sustainability Index* (CSI_{LINK}) and used the analytical hierarchy process (AHP) to weight the STIs. AHP was also used by Shiau and Liu (2013), who, in their study, used ten STIs and evaluated the sustainable transportation strategies for Taipei metropolitan area.

Principal component analysis or factor analysis (PCA/FA) was used by Black (2002) to develop an index which was called *Sustainable Transport and Potential Mobility Index*. He applied this index to 28 OECD nations and US states. Shaker (2018) developed a mega-index of sustainable development (MISD) using factor analysis and ranked various American states. Reisi et al. (2014) proposed a methodology to develop a *Composite Sustainable Transport Index* using PCA/FA. The index was developed from nine STIs and was applied to Statistical Local Areas (SLAs) of Melbourne, Australia. Similarly, 89 STIs were weighted and aggregated using PCA/FA by Mahdinia et al. (2018) with an application to 50 states and Federal District of Columbia in the USA.

Mostly, the transportation system evaluation studies have been carried out either at the national level or at city (urban) level (Mahdinia et al. 2018). In these studies, although various STIs and frameworks have been used, the number of STIs included in the analysis is usually very less to address the broader issue of sustainable transportation.

Reviewing the literature clearly signifies that the choice of methodology and methods that are adopted to develop a composite index affects its robustness. This statement is consistent with Danielis et al. (2018), who, in their study, applied different techniques of normalization, weighting and aggregation to estimate a composite index of sustainable urban transportation for 116 Italian provincial towns and concluded that these techniques highly affect the composite index, so developed. In this line, two major limitations were identified in the literature: (1) Most of the studies used either equal weighting method (Ahangari et al. 2016; Alonso et al. 2015; Costa and Neto 2017; De Gruyter et al. 2017; Gudmundsson and Regmi 2017**;** Haghshenas and Vaziri 2012; Jeon et al. 2013; Zito and Salvo 2011) or AHP (Shiau and Liu 2013; Verma et al. 2015) method; (2) few numbers of STIs have been used in the composite index development (Ahangari et al. 2016; Alonso et al. 2015; Black 2002; Haghshenas and Vaziri 2012; Jeon et al. 2013; Reisi et al. 2014; Shiau and Liu 2013). Weighting all the STIs equally lacks an accurate and deep understanding of relationships between STIs, argue Gan et al. (2017). Moreover, it increases the risk of weighting the same STI twice. AHP, on the other hand, uses expert opinion to assign weights to the STIs which restricts the model within a particular geographical zone, thus diminishing its transferability, argue Danielis et al. (2018). Therefore, sustainable transportation attainment is a complex issue and to achieve the goals and objectives that are driven toward it need to be diverse, covering most (if not all) the aspects related to it. To overcome the previously mentioned limitations, this paper aims to propose a five-stage model which uses a diverse group of STIs and utilizes the statistical method called PCA/FA to assign weights to the STIs. This model can provide assessment and evaluation of transportation systems in a comprehensive manner by utilizing rich sources of available data.

3 Research methodology

As already mentioned, the main aim of this paper is to propose a five-stage model for the development of Sustainable Transportation Attainment Index (I_{STA}). I_{STA} is a composite index obtained by dimension reduction method called PCA/FA. Compared to methods like equal weighting and AHP, the method of PCA/FA is meritorious due to fewer cons and more pros (Reisi et al. 2014). The method of PCA/FA reduces a bigger set of original variables (STIs in this study) into a smaller set of artificial variables known as *principal components* or *latent factors*. These principal components are extracted in such a way that most of the variance in the original variables is accounted for. In other words, these principal components are fewer in number and represent as much information as possible of the original variables. It is very important to check the feasibility of applying PCA/FA with utmost care. The following points, in this regard, should be ensured (OECD 2008; Reisi et al. 2014; Saisana 2011):

1. Correlation matrix of STIs is developed and checked for data redundancy.
2. A sampling adequacy test known as Kaiser–Meyer–Olkin (KMO) is applied, and if $0.6 \leq \mathrm{KMO} \leq 1.0$, then it is acceptable.

After the above checks are performed and found satisfactory, latent factors are extracted. Each latent factor depends on a set of coefficients which are also known as *factor loadings*.

These factor loadings measure the correlation between each STI and the latent factor. Two sets of values (which are derived by an iterative method) are required for the extraction of latent factors using PCA/FA (Reisi et al. 2014). These are as follows:

- Eigenvalue: It is the sum of squares of factor loadings reflecting the proportion of variance.
- Eigenvector: It is the row or column of numbers in a correlation matrix.

Eigenvalues greater than 1.0 are usually chosen (Mahdinia et al. 2018), and the reason is that it is not logical to add a latent factor that explains less variance than is contained in the STI itself.

In this study, the method of PCA/FA has been applied to form Tertiary Sustainable Transportation Attainment Index (I_{STA}'') from STIs and then to form Secondary Sustainable Transportation Attainment Index (I_{STA}'') from I_{STA}''. However, the last aggregation is done by equal weighting method. PCA/FA in this study was performed using SPSS-21 software, and mapping of zones (Fig. 4) was done using QGIS software.

In order to evaluate and compare the sustainability of transportation systems, I_{STA} was developed. Broadly, the development of I_{STA} has been divided into five stages which are further subdivided into various steps. These are shown in Figs. 1 and 2, and explained in the succeeding sections.

3.1 Stage 1: Finalizing study zones and STIs

Subject to open choice available, if any organization or researchers need to shortlist the zones and STIs, it is observed that the number of STIs selected are being compromised upon (Ahangari et al. 2016; Alonso et al. 2015; Black 2002; Haghshenas and Vaziri 2012; Jeon et al. 2013; Reisi et al. 2014; Shiau and Liu 2013). Shortlisting more number of zones compared to the number of STIs is often justified by data availability constraints (Black 2002; Jeon et al. 2013; Shiau and Liu 2013; Reisi et al. 2014; Alonso et al. 2015; Ahangari et al. 2016). This results in leaving behind some STIs which would have added more value to the developed Sustainable Transportation Attainment Index. In this study, however, zones and STIs were shortlisted using a matrix what we call as Bargain Matrix. The representative sample of Bargain Matrix is presented in Table 1. Also, the detailed Bargain Matrix used in this study is presented in "Appendix" (7, 8, 9).

Initially, 36 zones which included 29 states and 7 union territories (UTs) of India were checked from the feasibility and availability (of data acquisition) point of view. On exploring various databases of India, state-/UT-wise data of various determinants (for example, the *number of deaths in road accidents* and the *population of a state* are two determinants) was collected. A total of 116 STIs (for example, the *number of fatal deaths in road accidents per capita* is an STI) were developed from these determinants. Finally, based on the expert opinion and with the help of Bargain Matrix, 3 states and 6 UTs were discarded from the analysis. The discarded zones with missing STI values have been presented in "Appendix" (7, 8, 9). Thus, the remaining 26 states and 1UT (also called as the National Capital Territory (NCT) of India) were shortlisted and used in the analysis.

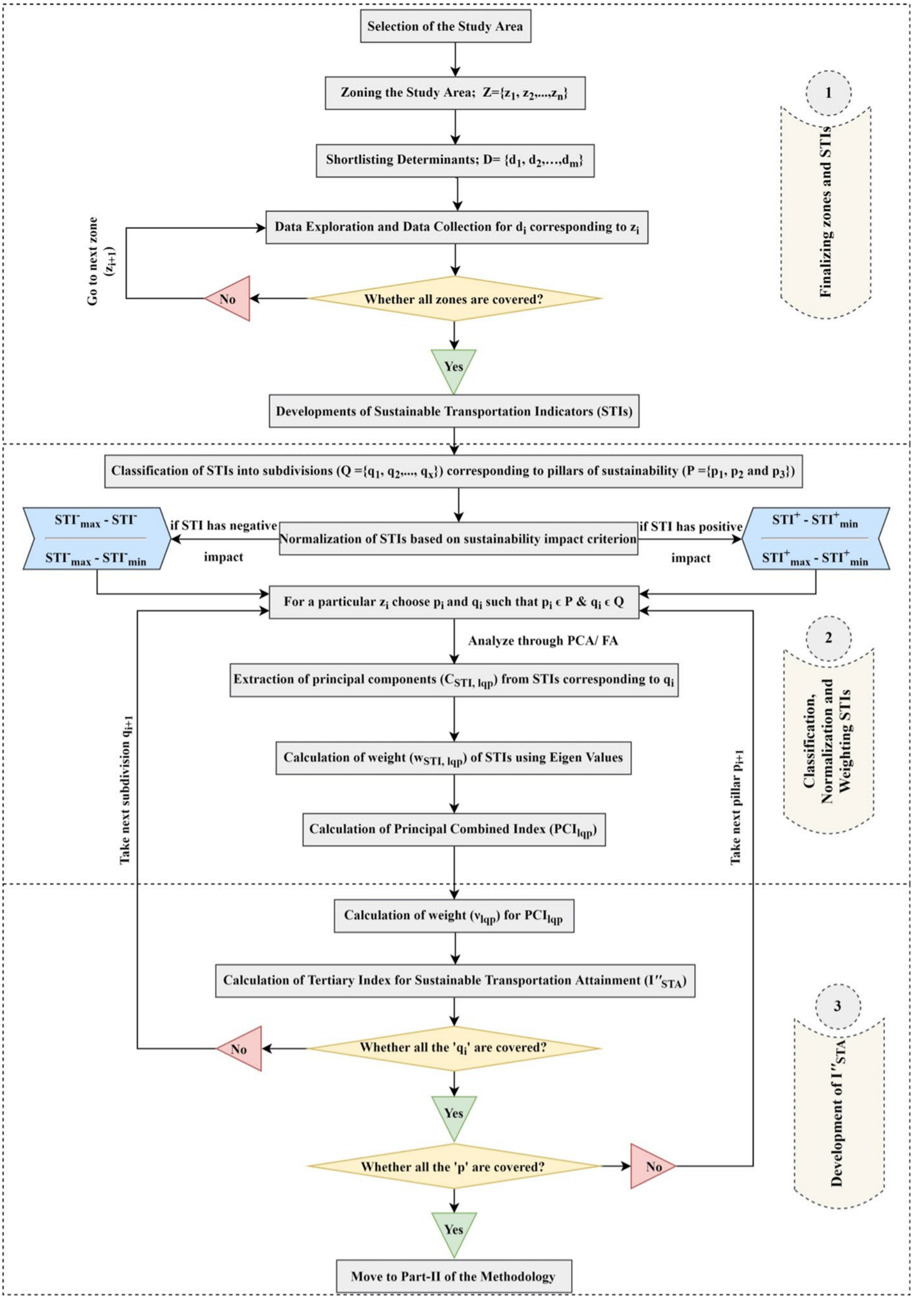

Fig. 1 Methodology for evaluating the attainment of sustainable transportation system (Part-*I*)

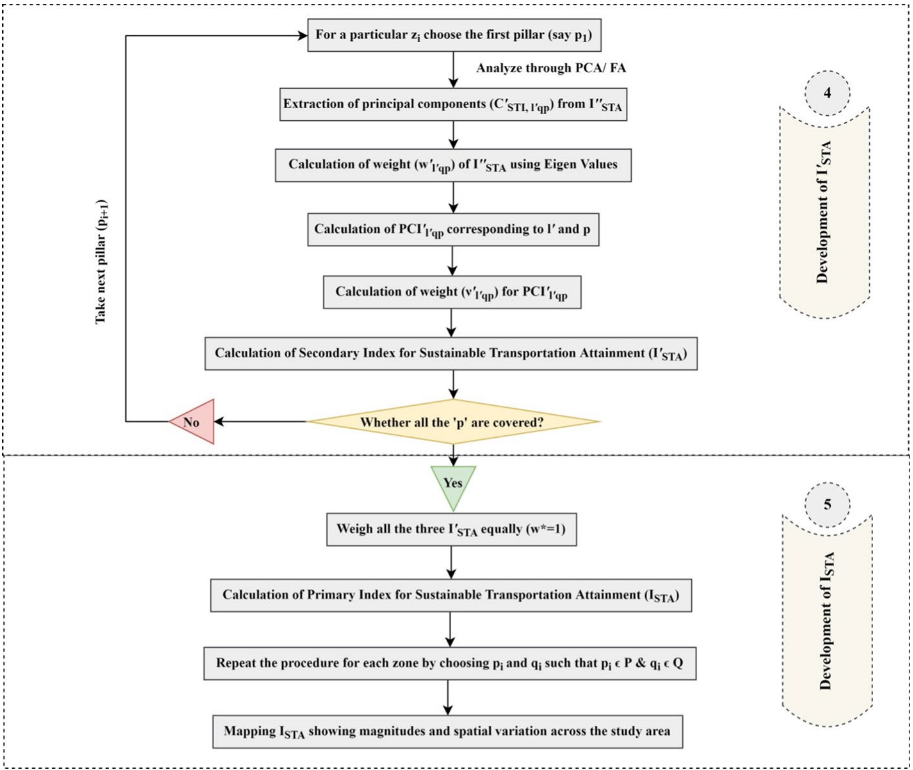

Fig. 2 Methodology for evaluating the attainment of sustainable transportation system (Part-II)

Table 1 Representative Bargain Matrix used for shortlisting the zones and STIs

Zone	STI									
	E_{0101}	…	E_{0406}	S_{0501}	…	S_{0705}	C_{0801}	…	C_{1007}	$\sum Z_x$
Zone 1	x		x	x		x	x		x	X
Zone 2	x		x	x		x	x		x	X
Zone 3	x		x	x		x	x		x	X
…										
Zone 36	x		x	x		x	x		x	X
$\sum STI_y$	Y_{0101}		Y_{0406}	Y_{0501}		Y_{0705}	Y_{0801}		Y_{1007}	

The value of $x = 1$ (missing value) or $x = 0$ (existing value)

$\sum Z_x$ = Sum of missing values across a particular zone, i.e., along the row of the matrix

$\sum STI_y$ = Sum of missing values across a particular STI, i.e., along the column of the matrix

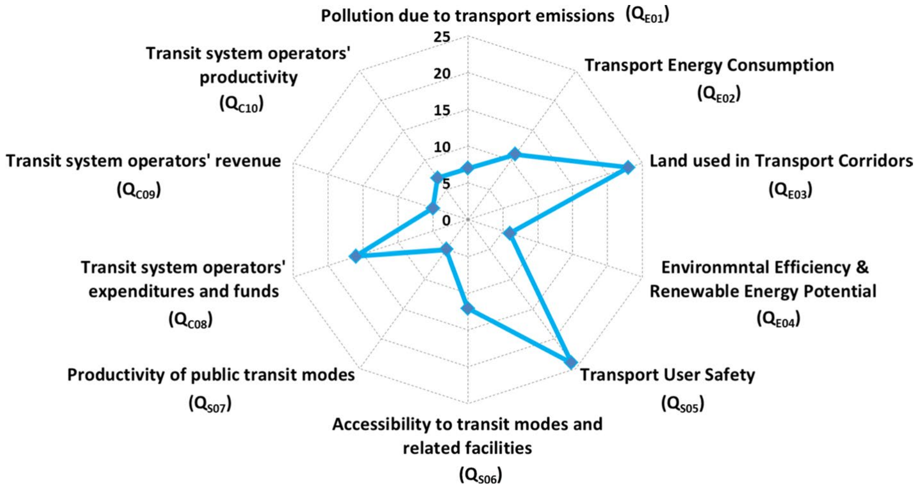

Fig. 3 Number of sustainable transportation indicators (STIs) corresponding to subdivisions used in the study

3.2 Stage 2: Classification, normalization and weighting STIs

3.2.1 Classification of STIs

In this step, a top-down approach was adopted. Firstly, the three sustainability pillars, namely Environmental, Social and Economical, were identified. Next, these three sustainability pillars were further divided into a total of ten subdivisions (i.e., four in Environmental pillar, three in Social pillar and three in Economical pillar). Then, a total of 116 STIs were put in these ten subdivision categories. The distribution of these STIs across the ten selected subdivisions is shown in Fig. 3 by means of a spider/radar plot. Classification of STIs in this manner is useful in tracking each of the subdivision toward its objectives (Mahdinia et al. 2018). The selection of objectives in this study as presented in Table 2, for each subdivision, has been done in accordance with the previous literature such as Litman (2007), Haghshenas and Vaziri (2012) and Mahdinia et al. (2018).

Normalization of STIs

Since the STIs developed have different units of measurement, it is necessary to normalize the STIs first. It is because the STIs are, as such incomparable and may cause discrepancy when the data are analyzed. Normalization is a technique of performing mathematical operation(s) in order to transform the STIs either to a common unit of measurement or to dimensionless (without units) entities. There are various normalization techniques available in the literature, each with pros and cons (Ramani et al. 2010).

In this study, STIs were normalized with the help of rescaling method which transforms the values of STIs between one and zero (Joumard and Gudmundsson 2010). Equation (1) is used to normalize those STIs, the increasing values of which have a positive impact on transport sustainability. Equation (2) is used to normalize those STIs, the increasing values of which have a negative impact on transport sustainability.

Table 2 Selected pillars, corresponding subdivisions and objectives for sustainable transportation

Sustainability pillar	Assigned code	Subdivision	Assigned code	Desired result/objective
Environmental	P_E	Pollution due to transport emissions	Q_{E01}	To decrease air pollutants[a] and greenhouse gas (GHG[b]) emissions due to transportation
		Transport energy consumption	Q_{E02}	To reduce non-renewable energy[c] consumption by transportation
		Land used in transport corridors	Q_{E03}	To decrease the land use[d] by transportation
		Environmental efficiency and renewable energy potential	Q_{E04}	To decrease the burden on environmental by increasing the efficiency of the vehicles
Social	P_S	Transport user safety	Q_{S05}	To improve the safety of transport users[e]
		Accessibility to transit modes and related facilities	Q_{S06}	To make transportation systems more accessible for the transport users
		Productivity of public transit modes	Q_{S07}	To attract more users toward public transit modes[f] of transportation
Economical	P_C	Transit system operators' expenditures and funds	Q_{C08}	To decrease the economic burden of transportation on the governments
		Transit system operators' revenue	Q_{C09}	To increase the derived benefits from the transportation and its users
		Transit system operators' productivity	Q_{C10}	To improve the economic efficiency of the public transit modes[f]

[a]Air pollutants include CO, NO_x, PM_{10}, $PM_{2.5}$ and SO_2

[b]GHG include CO_2, CH_4 and N_20

[c]Non-renewable energy include diesel and petrol

[d]Land use include the land used by roads, railway lines, etc. Land used by parking has not been included due insufficient data availability

[e]Transport users include drivers, passengers, pedestrians, etc.

[f]Public transit modes include buses run by State Road Transport Undertakings (SRTUs)

$$\mathrm{NV}_{\mathrm{STI}}^{+} = \frac{\mathrm{STI}_{x}^{+} - \mathrm{STI}_{\min}^{+}}{\mathrm{STI}_{\max}^{+} - \mathrm{STI}_{\min}^{+}} \tag{1}$$

$$\mathrm{NV}_{\mathrm{STI}}^{-} = \frac{\mathrm{STI}_{\max}^{-} - \mathrm{STI}_{x}^{-}}{\mathrm{STI}_{\max}^{-} - \mathrm{STI}_{\min}^{-}} \tag{2}$$

where $\mathrm{NV}_{\mathrm{STI}}^{+}$ is the normalized value of STI_{x}^{+} with a positive impact on the sustainability. In other words, the increase in the value of STI_{x}^{+} means increasing attainment levels of sustainable transportation. Similarly, $\mathrm{NV}_{\mathrm{STI}}^{-}$ is the normalized value of STI_{x}^{-} with a negative impact on the sustainability, which means the increasing value of STI_{x}^{-} will result in decreasing sustainable transportation attainment levels. $\mathrm{STI}_{\max}^{+}$ and $\mathrm{STI}_{\max}^{-}$ are the maximum values, and $\mathrm{STI}_{\min}^{+}$ and $\mathrm{STI}_{\min}^{-}$ are the minimum values of STI_{x}^{+} and STI_{x}^{-}, respectively.

3.2.2 Weighting of STIs and its aggregation

In this step, STIs were first weighted and then aggregated to form combined indices representing a characteristic of each latent factor (l). So, principal components ($C_{STI,lqp}$), respective latent factors (L) and eigenvalues (EV_{lqp}) of STIs corresponding to each subdivision (q) and sustainability pillar (p) were extracted using PCA/FA. Then, the weight $\left(w_{STI,lqp}\right)$ of STIs corresponding to each latent factor (l) was computed by Eq. (3). Next, the Principal Combined Index (PCI_{lqp}) of each latent factor (l) corresponding to subdivision (q) and sustainability pillar (p) was computed as the sum of product of respective weights computed by Eq. (3) and normalized value ($NV_{STI,lqp}$) as shown in Eq. (4).

$$w_{STI,lqp} = \frac{(C_{STI,lqp})^2}{EV_{lqp}} \quad \text{such that} \quad STI \in STI_q,\ l \in L_q,\ q \in Q_p,\ p \in P \tag{3}$$

$$PCI_{lqp} = \sum_{STI} \{(w_{STI,lqp})(NV_{STI,lqp})\} \quad \text{such that} \quad STI \in STI_q,\ l \in L_q,\ q \in Q_p,\ p \in P \tag{4}$$

3.3 Stage 3: Development of tertiary Sustainable Transportation Attainment Index (I''_{STA})

The Principal Combined Indices (PCI_{lqp}) computed in the previous step were weighted by Eq. (5). Next, these were aggregated using Eq. (6) to get what is called Tertiary Sustainable Transportation Attainment Index (I''_{STA}) which represents the characteristic of each subdivision (q).

$$v_{lqp} = \frac{EV_{lqp}}{\sum_{ld} EV_{lqp}} \quad \text{such that} \quad l \in L_q,\ q \in Q_p,\ p \in P \tag{5}$$

$$I''_{qp} = \sum_{l} \left\{ \left(v_{lqp}\right)\left(PCI_{lqp}\right) \right\} \quad \text{such that} \quad l \in L_q,\ q \in Q_p,\ p \in P \tag{6}$$

where v_{lqp} is the weight applied to the respective Principal Combined Index (PCI_{lqp}); I''_{qp} is the computed Tertiary Sustainable Transportation Attainment Index for each subdivision (q) corresponding sustainability pillar (p).

3.4 Stage 4: Development of secondary Sustainable Transportation Attainment Index (I'_{STA})

In this stage, the indices computed in the previous stage (i.e., I''_{qp}) were first weighted and then aggregated to obtain the indices representing a characteristic of each pillar (p). The analysis was similar to Stage 3 and was done by PCA/FA. However, the outputs of this stage were the three indices representing three pillars of sustainability—Environmental Index (I'_E), Social Index (I'_S) and Economical Index (I'_C) which are represented generally in the form of I'_p and called Secondary Sustainable Transportation Attainment Index (I'_{STA}).

The principal components ($C'_{l'qp}$), respective latent factors (L') and eigenvalues ($EV'_{l'p}$) of previously computed Tertiary Sustainable Transportation Attainment Indices (I''_{qp}) corresponding to each sustainability pillar (p) were extracted using PC FA. Then, the weight $\left(w'_{l'qp}\right)$ of I''_{qp} corresponding to each latent factor (l') was computed by using Eq. (7). Then, the Principal Combined Index ($PCI'_{l'p}$) of each latent factor (l') corresponding to respective sustainability pillar (p) was computed as the sum of the product of respective weights computed by Eq. (7) and I''_{qp} as shown in Eq. (8).

$$w'_{l'qp} = \frac{(C'_{l'qp})^2}{EV'_{l'qp}} \quad \text{such that} \quad l' \in L'_q,\ q \in Q_p,\ p \in P \tag{7}$$

$$PCI'_{l'p} = \sum_q \left\{ \left(w'_{l'qp} \right) \left(I''_{l'qp} \right) \right\} \quad \text{such that} \quad l' \in L'_q,\ q \in Q_p,\ p \in P \tag{8}$$

The Principal Combined Indices ($PCI'_{l'p}$) computed in the previous step were weighted by Eq. (9). Then, these were aggregated using Eq. (10) to get what is called Secondary Sustainable Transportation Attainment Index (I'_{STA}) which represents the characteristic of each pillar (p).

$$v'_{l'p} = \frac{EV'_{l'p}}{\sum_{l'} EV'_{l'p}} \quad \text{such that} \quad l' \in L'_p,\ p \in P \tag{9}$$

$$I'_p = \sum_{l'} \left\{ \left(v'_{l'p} \right) \left(PCI'_{l'p} \right) \right\} \quad \text{such that} \quad l' \in L'_p,\ p \in P \tag{10}$$

where $v'_{l'p}$ is the weight applied to the respective Principal Combined Index ($PCI'_{l'p}$); I'_p is the computed Secondary Sustainable Transportation Attainment Index for each sustainability pillar (p).

3.5 Stage 5: Development of primary Sustainable Transportation Attainment Index (I_{STA})

In order to get the final index, i.e., Primary Sustainable Transportation Attainment Index (I_{STA}), the indices computed in stage 4 (i.e., I'_p) were weighted and then aggregated. Since weight needs to be applied to three sustainability pillars, namely Environmental, Social and Economical, each should be given equal importance for attaining sustainable transportation goals (Zito and Salvo 2011). Therefore, the method of equal weighting was applied in this step. Weight assigned to each I'_p(i.e.,I'_E, I'_S and I'_C) is equal to one. Finally, these three indices were aggregated by using Eq. (11) (Haghshenas and Vaziri 2012; Jeon et al. 2013) to obtain I_{STA}.

$$I_{STA} = \frac{\sum_p \{(w^*)\left(I'_p\right)\}}{P_n} \quad \text{such that} \quad p \in P,\ w^* = 1 \tag{11}$$

where w^* is the weight applied to each Secondary Sustainable Transportation Attainment Index (I'_{STA}) and is equal to one; P_n is the total number of sustainability pillars (i.e., three).

All these steps corresponding to the stages mentioned and described above were repeated for each selected zone. Once I_{STA} for each zone was computed, the zones were ranked and mapped (Fig. 4) using QGIS software. This helps in comparing various zones visually, as far as the sustainable transportation attainment is concerned.

4 Study area

To evaluate the sustainability of a transportation system at state level, 26 states and NCT of Delhi (i.e., a total of 27 zones) of India were used as the study area in this paper. The procedure for shortlisting these 27 zones is explained in Sect. 3.1. Index (Primary) for Sustainable Transportation Attainment (I_{STA}) was computed for all these 27 zones, which were then ranked and mapped. Relatively, the greater the value of I_{STA}, the better is the attainment of a sustainable transportation system and vice versa.

4.1 Data exploration and collection

After exploring various databases, it was found that 2015–2016 was the most recent data available as far as the development of STIs is concerned. Therefore, state-/UT-wise data of 2015–2016 were collected from the following sources: Census of India (CENSUS 2011), Ministry of Statistics and Program Implementation, India (MoSPI 2016), Maps of India portal (India-Maps 2016), Central Pollution Control Board, India (CPCB 2016), Ministry of Civil Aviation, India (MoCA 2016), Ministry of Railways or Indian Railways (Indian-Railways 2016), Datanet India (Datanet-India), Open Government Data Platform, India (OGDP-India), Ministry of Petroleum and Natural Gas, India (MoP&NG), Ministry of Road Transport & Highways, India (MORTH), National Highways Authority of India (NHAI), Ministry of Tourism, India (MoT), and Shakti Sustainable Energy Foundation

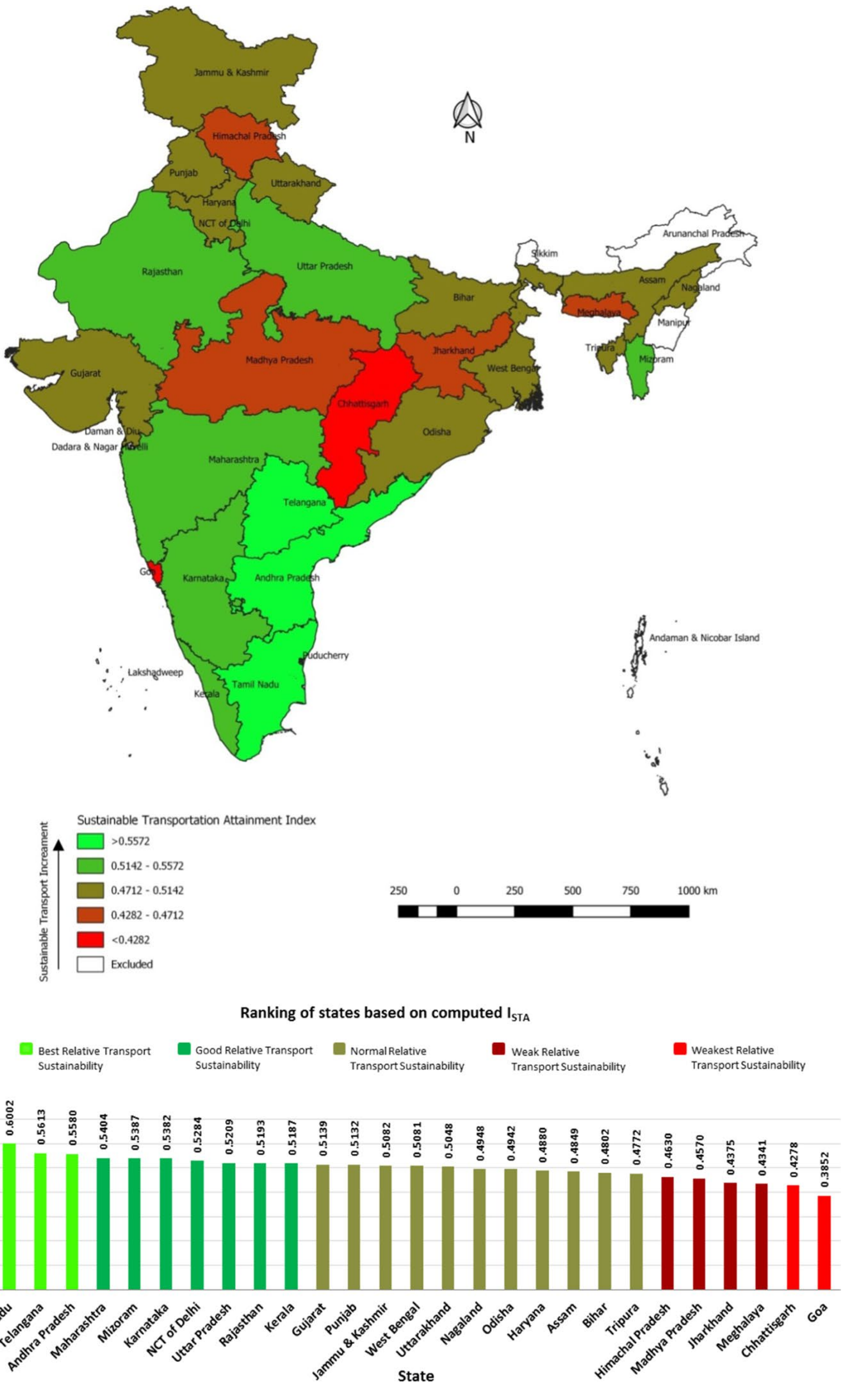

Fig. 4 Mapping and ranking of states and National Capital Territory (NCT) of India by the computed Sustainable Transportation Attainment Index (I_{STA})

Table 3 Developed sustainable transportation indicators (STIs) of Pillar-*I*: Environmental

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{E01}	Annual GHG emissions by transport per capita	E_{0101}	Negative
	Annual GHG emissions by transport per area	E_{0102}	Negative
	Annual GHG emissions by transport per total energy consumption of major petroleum products by transport	E_{0103}	Negative
	Annual GHG emissions by transport per total VKT[a]	E_{0104}	Negative
	Annual average density of PM_{10} in $\mu g/m^3$	E_{0105}	Negative
	Annual average density of SO_2 in $\mu g/m^3$	E_{0106}	Negative
	Annual average density of NO_2 in $\mu g/m^3$	E_{0107}	Negative
Q_{E02}	Annual energy consumption of major petroleum products by transport per capita	E_{0201}	Negative
	Annual energy consumption of major petroleum products by transport per area	E_{0202}	Negative
	Annual energy consumption of major petroleum products by transport per annual VKT	E_{0203}	Negative
	Percent consumption of diesel fuel in transport Sector	E_{0204}	Negative
	Annual energy consumption of major petroleum products by transport per GSDP[b]	E_{0205}	Negative
	Annual energy consumption of major petroleum products by transport per total number of vehicles	E_{0206}	Negative
	Percent length of railway routes electrified per total length of railway routes	E_{0207}	Positive
	Percentage of annual consumption of diesel by public transport modes	E_{0208}	Positive
	Percentage of annual consumption of diesel by private transport modes	E_{0209}	Negative
	Percentage of annual consumption of petrol by public transport modes including shared taxis and three-wheelers	E_{0210}	Positive
	Percentage of annual consumption of petrol by private transport modes including cars and two-wheelers	E_{0211}	Negative

Table 3 (continued)

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{E03}	Total length of roads per capita	E_{0301}	Negative
	Total length of roads per area	E_{0302}	Negative
	Total length of roads per annual VKT	E_{0303}	Negative
	Percentage of total length of NHs per total length of roads	E_{0304}	Negative
	Total length of NHs[c] per capita	E_{0305}	Negative
	Total length of NHs per area	E_{0306}	Negative
	Total length of NHs per annual VKT	E_{0307}	Negative
	Percentage of total length of SHs per total length of roads	E_{0308}	Negative
	Total length of SHs[d] per capita	E_{0309}	Negative
	Total length of SHs per area	E_{0310}	Negative
	Total length of SHs per annual VKT	E_{0311}	Negative
	Percentage of total length of urban roads per total length of roads	E_{0312}	Negative
	Total length of urban roads per capita	E_{0313}	Negative
	Total length of urban roads per area	E_{0314}	Negative
	Total length of urban roads per annual VKT	E_{0315}	Negative
	Percentage of total length of other PWD[e] roads per total length of roads	E_{0316}	Negative
	Total length of other PWD roads per capita	E_{0317}	Negative
	Total length of other PWD roads per area	E_{0318}	Negative
	Total length of other PWD roads per annual VKT	E_{0319}	Negative

Table 3 (continued)

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustainability
	Percentage of total length of rural roads per total length of roads	E_{0320}	Negative
	Total length of rural roads per capita	E_{0321}	Negative
	Total length of rural roads per area	E_{0322}	Negative
	Total length of rural roads per annual VKT	E_{0323}	Negative
Q_{E04}	Percentage of CNG[f] filling stations to petrol filling stations	E_{0401}	Positive
	Annual renewable energy potential per capita	E_{0402}	Positive
	Annual renewable energy potential per total number of vehicles	E_{0403}	Positive
	Annual renewable energy potential per annual VKT	E_{0404}	Positive
	Annual renewable energy potential per annual energy consumption of major petroleum products by transport	E_{0405}	Positive
	SRTUs fuel efficiency (km per liter of HSD[g]/Km per Kg of CNG)	E_{0406}	Positive

[a]VKT = Vehicle kilometers travelled; [b]GSDP = Gross state domestic product; [c]NHs = National Highways; [d]SHs = State Highways; [e]PWD = Public Works Department; [f]CNG = compressed natural gas; [g]HSD = high speed diesel

Table 4 Developed sustainable transportation indicators (STIs) of Pillar-II: Social

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{S05}	Annual reported road traffic crashes per capita	S_{0501}	Negative
	Annual reported road traffic crashes per annual VKT	S_{0502}	Negative
	Annual reported road traffic crashes per total length of roads	S_{0503}	Negative
	Annual reported road traffic crashes per total number of vehicles	S_{0504}	Negative
	Annual reported road traffic crashes per total number of drivers with valid license	S_{0505}	Negative
	Annual reported road traffic fatalities per capita	S_{0506}	Negative
	Annual reported road traffic fatalities per annual VKT	S_{0507}	Negative
	Annual reported road traffic fatalities per total length of roads	S_{0508}	Negative
	Annual reported road traffic fatalities per total number of vehicles	S_{0509}	Negative
	Annual reported road traffic fatalities per total number of drivers with valid license	S_{0510}	Negative
	Annual reported serious injuries in road traffic per capita	S_{0511}	Negative
	Annual reported serious injuries in road traffic per annual VKT	S_{0512}	Negative
	Annual reported serious injuries in road traffic per total length of roads	S_{0513}	Negative
	Annual reported serious injuries in road traffic per total number of vehicles	S_{0514}	Negative
	Annual reported serious injuries in road traffic per total number of drivers with valid license	S_{0515}	Negative
	Annual reported minor injuries in road traffic per capita	S_{0516}	Negative
	Annual reported minor injuries in road traffic per annual VKT	S_{0517}	Negative
	Annual reported minor injuries in road traffic per total length of roads	S_{0518}	Negative
	Annual reported minor injuries in road traffic per total number of vehicles	S_{0519}	Negative
	Annual reported minor injuries in road traffic per total number of drivers with valid license	S_{0520}	Negative
	Annual NMT[a] traffic fatalities per total recorded road traffic fatalities	S_{0521}	Negative
	Annual public transport fatalities per total number of buses	S_{0522}	Negative
	Annual accident cases in railways per total length of railway track	S_{0523}	Negative
	Annual fatalities in railways per total length of railway track	S_{0524}	Negative

Table 4 (continued)

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{S06}	Total number of registered vehicles per capita	S_{0601}	Positive
	Total number of registered vehicles per total number of drivers with valid driving license	S_{0602}	Positive
	Total number of registered vehicles per total number of households	S_{0603}	Positive
	Total number of fuel filling stations per total length of roads	S_{0604}	Positive
	Annual interstate work trips per capita	S_{0605}	Positive
	Annual interstate work trips per area	S_{0606}	Positive
	Domestic/intratourist visits per capita	S_{0607}	Positive
	Domestic/intratourist visits per area	S_{0608}	Positive
	Total length of railway roads per total length of running railway track	S_{0609}	Positive
	Total number of passenger trips by scheduled flight operations per capita	S_{0610}	Positive
	Total number of passenger trips by scheduled flight operations per area	S_{0611}	Positive
	Total number of passenger trips by scheduled flight operations per total number of households	S_{0612}	Positive
Q_{S07}	SRTUs staff/bus ratio	S_{0701}	Positive
	Percentage of SRTUs occupancy ratio	S_{0702}	Positive
	Passengers carried by SRTUs per bus per day	S_{0703}	Positive
	SRTUs passenger kilometers offered	S_{0704}	Positive
	SRTUs passenger kilometers performed	S_{0705}	Positive

[a]NMT = Non-motorized transportation which includes pedestrians and bicyclists traffic

Table 5 Developed sustainable transportation indicators (STIs) of Pillar-III: Economical

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{C08}	Annual SRTUs expenditure per capita	C_{0801}	Negative
	Annual SRTUs expenditure per GSDP	C_{0802}	Negative
	Annual SRTUs expenditure per GSDP per capita	C_{0803}	Negative
	Funds allocated under economic importance and interstate connectivity per capita	C_{0804}	Negative
	Funds allocated under economic importance and interstate connectivity per GSDP	C_{0805}	Negative
	Funds allocated under economic importance and interstate connectivity per GSDP per capita	C_{0806}	Negative
	Funds released under economic importance and interstate connectivity per capita	C_{0807}	Negative
	Funds released under economic importance and interstate connectivity per GSDP	C_{0808}	Negative
	Funds released under economic importance and interstate connectivity per GSDP per capita	C_{0809}	Negative
	Annual accrual allocation of funds under CRF[a] Schemes per capita	C_{0810}	Negative
	Annual accrual allocation of funds under CRF schemes per GSDP	C_{0811}	Negative
	Annual accrual allocation of funds under CRF schemes per GSDP per capita	C_{0812}	Negative
	Annual accrual release of funds under CRF schemes per capita	C_{0813}	Negative
	Annual accrual release of funds under CRF schemes per GSDP	C_{0814}	Negative
	Annual accrual release of funds under CRF schemes per GSDP per capita	C_{0815}	Negative
	Allocation for repair and maintenance of NHs per total length of NHs	C_{0816}	Negative
Q_{C09}	Annual SRTUs revenue per capita	C_{0901}	Positive
	Annual SRTUs revenue per GSDP	C_{0902}	Positive
	Annual SRTUs revenue per GSDP per capita	C_{0903}	Positive
	Revenue from rate of taxes levied on petrol	C_{0904}	Positive
	Revenue from rate of taxes levied on diesel	C_{0905}	Positive

Table 5 (continued)

Subdivision	Sustainable transportation indicator	Assigned code	Impact on sustain-ability
Q_{C10}	Percentage of SRTUs fleet utilization	C_{1001}	Positive
	SRTUs staff productivity measured in km per staff per day	C_{1002}	Positive
	SRTUs vehicle productivity measured in km per bus per day	C_{1003}	Positive
	Annual freight shipment at airports per capita	C_{1004}	Positive
	Annual freight shipment at airports per area	C_{1005}	Positive
	Freight train kilometers performed per capita	C_{1006}	Positive
	Freight train kilometers performed per area	C_{1007}	Positive

[a]CRF = Central Road Fund

(SHAKTI). It is worth noting that the population data were extrapolated because the latest census data in India are available for the year 2011. Also, the population data of old Andhra Pradesh[1] (as per Census-2011) were distributed among new Andhra Pradesh and Telangana, in proportion to the area of the new respective states.

Since the selection of STIs is the foundation of the computed I_{STA}, the guidelines and selection criteria provided in the previous literature (Alonso et al. 2015; Gudmundsson et al. 2016; Haghshenas and Vaziri 2012; Litman 2007; TERM 2011) were considered. A total of 116 STIs were defined to evaluate transport sustainability. It is worth mentioning that this five-stage model for the development of I_{STA} is flexible and can be reinforced with more STIs, subject to more accessibility and availability of data.

As explained in Sect. 3, these 116 STIs were categorized into 10 subdivisions corresponding to three sustainability pillars—Environmental, Social and Economical (Table 2). Each subdivision and STI was assigned a code and its impact on sustainability was checked. This is presented in Tables 3, 4 and 5. Then, these STIs were normalized, weighted and aggregated.

5 Results and discussion

With the help of proposed five-stage model, all the 116 STIs were normalized using Eq. (1) or Eq. (2) depending upon whether the STI has a positive or negative impact on sustainable transportation, respectively. Then the normalized indicators were weighted using PCA/FA and aggregated using Eqs. (3–6). As a result of this, ten Tertiary Sustainable Transportation Attainment Indices (I_{STA}'') were computed, each corresponding to the respective subdivision—I_{E01}'', I_{E02}'', I_{E03}'', I_{E04}'''', I_{S05}'', I_{S06}'', I_{S07}'', I_{C08}'', I_{C09}'' and I_{C10}''. In the next stage, these ten indices were again weighted using PCA/FA and then aggregated using Eq. (7–10) to form three Secondary Sustainable Transportation Attainment Indices (I_{STA}'') corresponding to three sustainability pillars—I_E', I_S' and I_C'. Finally, in the last stage, these three indices were aggregated using Eq. (11), i.e., method of equal weighting to form the Primary Sustainable Transportation Attainment Indices (I_{STA}). Similarly, all these stages and the steps within each stage were repeated for 26 states and NCT of Delhi, India. In this way, I_{STA} was computed for all the 27 study zones which are presented in Table 6. The computed values of I_{STA} are in the range of zero to one. The zones with higher I_{STA} values mean better sustainable transportation attainment than the zones with lower I_{STA} values. Results show that while Tamil Nadu (0.60020), Telangana (0.56130), Andhra Pradesh (0.5580), Maharashtra (0.5404) and Mizoram (0.5387) have the highest computed values of I_{STA}, and Goa (0.3852), Chhattisgarh (0.4278), Meghalaya (0.4341), Jharkhand (0.4375) and Madhya Pradesh (0.4570) have the lowest values of I_{STA}.

For the sake of understanding the proposed five-stage model, detailed computations of one of the states (Andhra Pradesh) are presented in "Appendix" (Tables 10, 11, 12, 13, 14, 15). Table 10 presents the normalized values of STIs for ten subdivisions corresponding to three sustainability pillars—Environmental, Social and Economical. This follows the initial steps of Stage 2 of the proposed five-stage model. Next, the computations of I_{STA}'' are presented in Tables 11, 12 and 13. These follow the remaining steps of Stage 2 and Stage 3 of

[1] Andra Pradesh was divided into two separate states: Andhra Pradesh and Telangana in the year 2014.

Table 6 Tertiary (I_{STA}''), Secondary (I_{STA}'') and Primary (I_{STA}) Sustainable Transportation Attainment Indices across various states and National Capital Territory (NCT) of India

State	Tertiary Index (for each Subdivision)										Secondary Index (for each pillar)			Primary Index
	I_{E01}''	I_{E02}''	I_{E03}''	I_{E04}''	I_{S05}''	I_{S06}''	I_{S07}''	I_{C08}''	I_{C09}''	I_{C10}''	I_E'	I_S'	I_C'	I_{STA}
Andhra Pradesh	0.7165	0.6720	0.8116	0.2242	0.7093	0.1615	0.4924	0.9131	0.2800	0.5274	0.6161	0.4574	0.6006	0.5580
Assam	0.8717	0.6844	0.6272	0.1400	0.6750	0.1146	0.2299	0.9350	0.1686	0.2778	0.6134	0.3332	0.5081	0.4849
Bihar	0.7749	0.6318	0.7993	0.1278	0.7613	0.1460	0.2262	0.9177	0.1000	0.2602	0.5987	0.3685	0.4735	0.4802
Chhattisgarh	0.8017	0.6325	0.8010	0.0072	0.6524	0.1489	0.0000	0.8994	0.1765	0.1040	0.5815	0.2501	0.4520	0.4278
Goa	0.4017	0.3213	0.5946	0.1125	0.4939	0.5154	0.2178	0.7754	0.0697	0.2652	0.3525	0.3965	0.4066	0.3852
Gujarat	0.6539	0.4094	0.7525	0.2472	0.8424	0.1539	0.4336	0.9564	0.1692	0.4238	0.5128	0.4745	0.5544	0.5139
Haryana	0.6531	0.4097	0.7800	0.1378	0.7501	0.2338	0.3401	0.9197	0.1099	0.4820	0.4945	0.4352	0.5343	0.4880
Himachal Pradesh	0.8446	0.4619	0.5215	0.4861	0.6316	0.1865	0.2487	0.7496	0.1860	0.3104	0.5929	0.3491	0.4470	0.4630
Jammu and Kashmir	0.8457	0.5978	0.8749	0.7732	0.7159	0.1080	0.2524	0.7935	0.1489	0.1457	0.7619	0.3524	0.4102	0.5082
Jharkhand	0.6976	0.6257	0.8637	0.0458	0.7129	0.1059	0.0000	0.9424	0.1535	0.2086	0.5684	0.2557	0.4884	0.4375
Karnataka	0.7887	0.6126	0.7280	0.2090	0.7288	0.1636	0.5499	0.9434	0.1225	0.4029	0.6009	0.4859	0.5279	0.5382
Kerala	0.7882	0.6885	0.6650	0.1250	0.6075	0.2146	0.4156	0.9475	0.1964	0.3821	0.5935	0.4131	0.5493	0.5187
Madhya Pradesh	0.8268	0.6380	0.8189	0.0687	0.6216	0.3042	0.0000	0.9074	0.1976	0.1542	0.6071	0.2888	0.4751	0.4570
Maharashtra	0.7027	0.6218	0.6955	0.1232	0.8231	0.1448	0.5946	0.9324	0.2298	0.3309	0.5535	0.5263	0.5413	0.5404
Meghalaya	0.7101	0.5630	0.6953	0.2734	0.8591	0.0494	0.2266	0.6967	0.0993	0.1800	0.5702	0.3692	0.3628	0.4341
Mizoram	0.8709	0.6451	0.6525	0.5944	0.9600	0.1215	0.3974	0.3693	0.7498	0.0855	0.7033	0.4875	0.4254	0.5387
Nagaland	0.8499	0.7053	0.4210	0.3879	0.9949	0.0758	0.2588	0.4865	0.5670	0.1405	0.6270	0.4320	0.4253	0.4948
Odisha	0.8019	0.6059	0.7498	0.1730	0.8141	0.1004	0.1655	0.8966	0.1592	0.4575	0.5993	0.3480	0.5352	0.4942
Punjab	0.6926	0.5257	0.8040	0.1420	0.8284	0.1865	0.3097	0.9355	0.1574	0.4938	0.5464	0.4335	0.5597	0.5132
Rajasthan	0.7136	0.5440	0.7783	0.2659	0.8157	0.1062	0.3353	0.9357	0.1818	0.4779	0.5797	0.4143	0.5640	0.5193
Tamil Nadu	0.7726	0.6689	0.7675	0.1856	0.6648	0.2437	0.8546	0.9489	0.1901	0.5075	0.6154	0.6055	0.5797	0.6002
Telangana	0.8248	0.6609	0.8595	0.1699	0.6992	0.1888	0.5501	0.9240	0.2227	0.4146	0.6427	0.4845	0.5569	0.5613

Table 6 (continued)

State	Tertiary Index (for each Subdivision)										Secondary Index (for each pillar)			Primary Index
	I_{E01}''	I_{E02}''	I_{E03}''	I_{E04}''	I_{S05}''	I_{S06}''	I_{S07}''	I_{C08}''	I_{C09}''	I_{C10}''	I_{E}'	I_{S}'	I_{C}'	I_{STA}
Tripura	0.7610	0.6412	0.5334	0.2051	0.8758	0.0603	0.3257	0.8664	0.1879	0.1451	0.5635	0.4152	0.4529	0.4772
Uttar Pradesh	0.7627	0.6484	0.7931	0.1495	0.7856	0.1362	0.3323	0.9308	0.1043	0.5180	0.6034	0.4131	0.5461	0.5209
Uttarakhand	0.6922	0.6357	0.6310	0.2452	0.8645	0.1673	0.2547	0.9391	0.1520	0.3709	0.5683	0.4181	0.5280	0.5048
West Bengal	0.7573	0.6558	0.7479	0.1038	0.8168	0.1424	0.2706	0.9654	0.1123	0.4171	0.5857	0.4015	0.5371	0.5081
Delhi	0.3509	0.3758	0.8240	0.1849	0.7564	0.5433	0.4612	0.9845	0.1333	0.5809	0.4124	0.5790	0.5938	0.5284

the model. Table 14 presents the computations of I_{STA}'', thus Stage 4 of the model. Finally, the computation of I_{STA} is presented in Table 15 which follows Stage 5 of the model.

Once the I_{STA} values for all the 27 zones were computed, the results were mapped as shown in Fig. 4. These 27 zones were divided into five categories. These categories were made based on the concept of *equal interval* (which is equal to 0.043) of computed I_{STA} using QGIS software. The five categories are "Best Relative Transport Sustainability" with values of I_{STA} greater than 0.5572, "Good Relative Transport Sustainability" with values between 0.5142 and 0.5572, "Normal Relative Transport Sustainability" with values between 0.4712 and 0.5142, "Weak Relative Transport Sustainability" with values between 0.4282 and 0.4712 and "Weakest Relative Transport Sustainability" with values less than 0.4282. This is presented in Fig. 4 as well.

The five-stage model can be disintegrated to its basic components. This flexible attribute of the model can be useful for evaluators and planners, who can recognize, track and improve the strengths and weaknesses of a transportation system, thus driving it toward sustainability. As an example, in the results, the maximum value of I_{STA} was obtained for the state of Tamil Nadu. If the I_{STA} of this state is disintegrated to its basic components, a closer picture of the highest ranked zone can be seen. The reasons for the best sustainable transportation attainment can be explored and analyzed. Focusing on the I_{STA}'' values of the highest ranked state in Table 9, it can be clearly seen that I_{S07}'' has dominated all the other zones. Taking a closer look at I_{S07}'', the data clearly reflected that Tamil Nadu is the only state with the highest number (i.e., seven) of State Road Transport Undertakings (SRTUs) which ultimately improves the STIs related to public transportation, thereby confirming that the more the number of public transport modes, the better is the sustainability of the transportation system.

Contrary to the above example, if the lowest ranked state (i.e., Goa) is disintegrated to its basic components, I_{C09}'' is found to be the weakest. Taking a closer look at this index, the economic efficiency of SRTUs is found weak, relatively. An interpretation that seems to be fitting well in this situation is that the public transit modes are less efficient in Goa which ultimately reduces the sustainable transportation attainment levels. Similarly, other root causes of sustainable transportation attainment can be explored and reported, thus proving a useful tool for transportation evaluators and planners. It is, however, worth mentioning that even the best performing zone can be weak in some aspects, which planners would like to improve. Similarly, there could be some attributes of a zone with low I_{STA} rank which might possess good sustainable transportation attainment levels and where decision-makers or planners would not like to invest. This discussion leads to three important and noteworthy points: (1) composite indices for sustainable transportation are valuable communication tools as they allow for quick and easy comparisons which is consistent with Freudenberg (2003); (2) aggregation of STIs is successful if clear assumptions and methodology are used and if the index can be disintegrated to its basic components which is consistent with Jollands and Lermit (2003); (3) a bigger set of STI is unsuitable and complex for decision making because of their hard interpretation, and integrating different indicators into a single index is useful which is consistent with Varzaneh (2014).

6 Conclusion

The aim of this paper was to develop a model, in order to evaluate the sustainable transportation attainment levels, covering as much ground as possible. In this line, STIs categorized into pillars and subdivisions were used, which were normalized, weighted and aggregated. Normalization was done using rescaling method; weighting and aggregation were done using PCA/FA and equal weighting techniques. The final output of the model is the Sustainable Transportation Attainment Index (I_{STA}). This index takes into account the complexity of the sustainable transportation pillars and subdivisions, yet simplifying the evaluation of sustainability in transportation systems making the interpretability easy and simple. This attribute could be useful for different stakeholders, decision-makers and most importantly public. Moreover, the model can be disintegrated up to the root level (i.e., STI development) and thus proves to be flexible. This attribute can be utilized by the evaluators and planners to recognize, track and improve the strengths and weaknesses of a transportation system, thus driving it toward sustainability.

In this study, 116 STIs were developed from the data (determinants) collected from various authentic sources such as Census of India (CENSUS-2011), Ministry of Statistics and Program Implementation, India (MoSPI), Maps of India portal (India-Maps), and Central Pollution Control Board, India (CPCB). STIs were developed on the basis of guidelines and recommendations from the past literature and also, based on the data accessibility and data availability. To demonstrate the utility of the proposed five-stage model and cover the topic of sustainable transportation in a broader way, a maximum number of STIs possible were developed. As mentioned earlier, this model is flexible. Flexible, in the sense, that STIs can be added or removed depending on the need and objectives toward sustainable transportation.

In this study, the data related to STIs were collected for the year 2015–2016. It is, however, suggested to collect data for more years and apply the proposed five-stage model on those data. That would help in the temporal evaluation of the transportation systems' sustainability. Apart from quantitative data, qualitative data may also be collected and included in the STI set. Lastly, it is suggested that different STIs be put in different pillars of sustainability and/or subdivisions and analyze the effect on the computed I_{STA}.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix

See Tables 7, 8, 9, 10, 11, 12, 13, 14, 15.

Table 7 Missing values Bargain Matrix of Environmental STIs

State/UT	E_{0105}	E_{0106}	E_{0107}	E_{0204}	E_{0205}	E_{0207}	E_{0208}	E_{0209}	E_{0210}	E_{0211}	E_{0402}	E_{0403}	E_{0404}	E_{0405}	$\sum Z_x$
Arunachal Pradesh	1	1	1	0	0	0	0	0	1	1	0	0	0	0	5
Manipur	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3
Sikkim	1	1	1	0	0	0	0	0	0	0	0	0	0	0	3
Andaman & Nicobar (A&N)Islands	0	0	0	1	0	1	1	1	1	1	0	0	0	0	6
Chandigarh	0	0	0	0	0	0	1	1	1	1	0	0	0	0	4
Dadar & Nagar (D&N) Haveli	0	0	0	1	1	1	1	1	1	1	1	1	1	1	11
Daman & Diu	0	0	0	1	1	1	1	1	1	1	0	0	0	0	7
Lakshadweep	1	1	1	1	1	1	1	1	1	1	0	0	0	0	10
Puducherry	0	0	0	0	0	0	1	1	1	1	0	0	0	0	4
$\sum STI_y$	4	4	4	4	3	4	6	6	7	7	1	1	1	1	

1 = missing value; 0 = non-missing value; Z = zone; STI = sustainable transportation indicator; UT = union territory

Table 8 Missing values Bargain Matrix of Social STIs

State/UT	S_{0505}	S_{0510}	S_{0515}	S_{0520}	S_{0522}	S_{0523}	S_{0524}	S_{0602}	S_{0609}	S_{0610}	S_{0611}	$\sum Z_x$
Arunachal Pradesh	1	1	1	1	1	0	0	1	0	0	0	6
Manipur	0	0	0	0	0	0	0	0	0	0	0	0
Sikkim	0	0	0	0	0	0	0	0	1	1	1	3
A&N Islands	0	0	0	0	0	1	1	0	1	0	0	3
Chandigarh	0	0	0	0	0	0	0	0	0	0	0	0
D&N Haveli	1	1	1	1	0	1	1	1	1	1	1	10
Daman & Diu	0	0	0	0	0	1	1	0	1	0	0	3
Lakshadweep	0	0	0	0	0	1	1	0	1	0	0	3
Puducherry	0	0	0	0	0	0	0	0	0	0	0	0
$\sum STI_y$	2	2	2	2	1	4	4	2	5	2	2	

1 = missing value; 0 = non-missing value; Z = zone; STI = sustainable transportation indicator; UT = union territory

Table 9 Missing values Bargain Matrix of Economical STIs

State/UT	C_{0801}	C_{0802}	C_{0803}	C_{0805}	C_{0806}	C_{0808}	C_{0809}	C_{0811}	C_{0812}	C_{0814}	C_{0815}	C_{0901}	C_{0902}	C_{0903}	C_{0904}	C_{0905}	C_{1004}	C_{1005}	C_{1006}	C_{1007}	$\sum Z_x$
Arunachal Pradesh	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0	0	8
Manipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	4
A&N Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Chandigarh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D&N Haveli	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	18
Daman & Diu	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	18
Lakshadweep	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	18
Puducherry	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	5
$\sum STI_y$	5	5	5	3	3	3	3	3	3	3	3	4	4	4	1	1	5	5	5	5	

1 = missing value; 0 = non-missing value; Z = zone; STI = sustainable transportation indicator; UT = union territory

Table 10 Normalized values (NV) of sustainable transportation indicators (STIs) for the state of Andhra Pradesh

Subdivision	STI	Impact	NV	Subdivision	STI	Impact	NV	Subdivision	STI	Impact	NV
Q_{E01}	E_{0101}	–	0.7557	Q_{S05}	S_{0501}	–	0.8086	Q_{C08}	C_{0801}	–	0.9134
	E_{0102}	–	0.9175		S_{0502}	–	0.9221		C_{0802}	–	0.9983
	E_{0103}	–	0.0792		S_{0503}	–	0.5221		C_{0803}	–	0.9983
	E_{0104}	–	0.9123		S_{0504}	–	0.3652		C_{0804}	–	0.9819
	E_{0105}	–	0.8370		S_{0505}	–	0.6181		C_{0805}	–	0.9863
	E_{0106}	–	0.7183		S_{0506}	–	0.2987		C_{0806}	–	0.8220
	E_{0107}	–	0.7944		S_{0507}	–	0.8572		C_{0807}	–	1.0000
Q_{E02}	E_{0201}	–	0.7852		S_{0508}	–	0.5583		C_{0808}	–	1.0000
	E_{0202}	–	0.9240		S_{0509}	–	0.2569		C_{0809}	–	1.0000
	E_{0203}	–	0.9455		S_{0510}	–	0.6456		C_{0810}	–	0.8199
	E_{0204}	–	0.3914		S_{0511}	–	0.8828		C_{0811}	–	0.8621
	E_{0205}	–	0.8822		S_{0512}	–	0.8916		C_{0812}	–	0.9964
	E_{0206}	–	0.6602		S_{0513}	–	0.8080		C_{0813}	–	0.7339
	E_{0207}	+	0.8609		S_{0514}	–	0.7909		C_{0814}	–	0.6425
	E_{0208}	+	0.6757		S_{0515}	–	0.8390		C_{0815}	–	0.9821
	E_{0209}	–	0.6524		S_{0516}	–	0.8902		C_{0816}	–	0.7740
	E_{0210}	+	0.3818		S_{0517}	–	0.9536	Q_{C09}	C_{0901}	+	0.0792
	E_{0211}	–	0.3959		S_{0518}	–	0.7363		C_{0902}	+	0.0665
Q_{E03}	E_{0301}	–	0.8424		S_{0519}	–	0.5928		C_{0903}	+	0.0016
	E_{0302}	–	0.7942		S_{0520}	–	0.6764		C_{0904}	+	0.8395
	E_{0303}	–	0.9529		S_{0521}	–	0.5617		C_{0905}	+	1.0000
	E_{0304}	–	0.8273		S_{0522}	–	0.5821	Q_{C10}	C_{1001}	+	0.9945
	E_{0305}	–	0.9232		S_{0523}	–	0.8820		C_{1002}	+	0.4842
	E_{0306}	–	0.6535		S_{0524}	–	0.8744		C_{1003}	+	0.8473
	E_{0307}	–	0.9633	Q_{S06}	S_{0601}	+	0.1967		C_{1004}	+	0.0536
	E_{0308}	–	0.6478		S_{0602}	+	0.2532		C_{1005}	+	0.0101

Table 10 (continued)

Subdivision	STI	Impact	NV	Subdivision	STI	Impact	NV	Subdivision	STI	Impact	NV
	E_{0309}	–	0.6430		S_{0603}	+	0.1382		C_{1006}	+	0.9838
	E_{0310}	–	0.6920		S_{0604}	+	0.2915		C_{1007}	+	0.4270
	E_{0311}	–	0.9138		S_{0605}	+	0.5670				
	E_{0312}	–	0.9175		S_{0606}	+	0.3719				
	E_{0313}	–	0.8333		S_{0607}	+	0.1476				
	E_{0314}	–	0.9687		S_{0608}	+	0.1908				
	E_{0315}	–	0.8761		S_{0609}	+	0.0311				
	E_{0316}	–	0.7131		S_{0610}	+	0.0182				
	E_{0317}	–	0.8803		S_{0611}	+	0.0041				
	E_{0318}	–	0.8492		S_{0612}	+	0.0144				
	E_{0319}	–	0.9781	Q_{S07}	S_{0701}	+	0.5965				
	E_{0320}	–	0.2451		S_{0702}	+	0.5741				
	E_{0321}	–	0.7874		S_{0703}	+	0.6035				
	E_{0322}	–	0.7862		S_{0704}	+	0.3855				
	E_{0323}	–	0.9481		S_{0705}	+	0.3454				
Q_{E04}	E_{0401}	+	0.0069								
	E_{0402}	+	0.1597								
	E_{0403}	+	0.1010								
	E_{0404}	+	0.0373								
	E_{0405}	+	0.1386								
	E_{0406}	+	0.9867								

Table 11 Computation of Tertiary Sustainable Transportation Attainment Index (I_{STA}'') of Pillar-*I*: Environment for the state of Andhra Pradesh

STI	NV	Extracted principal components (C_{lqp})			Computed weight of STIs (w_{lqp}) using eigenvalues			Principal Combined Index (PCI_{lqp})		
		$l = 1$	$l = 2$	$l = 3$	$l = 1$	$l = 2$	$l = 3$	$l = 1$	$l = 2$	$l = 3$
Subdivision: Q_{E01}										
E_{0101}	0.7557	0.8407	0.4496	0.2112	0.2779	0.0981	0.0412	0.6486	0.8185	0.6817
E_{0102}	0.9175	0.5472	0.7385	−0.1981	0.1178	0.2647	0.0362	Computed weight of PCI_{lqp} (v_{lqp})		
E_{0103}	0.0792	0.7770	0.0450	−0.5088	0.2374	0.0010	0.2392	0.4473	0.3623	0.1903
E_{0104}	0.9123	0.6814	−0.0639	0.6442	0.1825	0.0020	0.3835	Eigenvalues (EV_{lqp})		
E_{0105}	0.8370	−0.4249	0.6157	0.5240	0.0710	0.1840	0.2537	2.5431	2.0601	1.0821
E_{0106}	0.7183	−0.3759	0.5701	−0.0796	0.0555	0.1578	0.0058	$\boldsymbol{I_{E01}''}$		
E_{0107}	0.7944	−0.3836	0.7761	−0.2086	0.0579	0.2924	0.0402	**0.7165**		

STI	NV	C_{lqp}				w_{lqp}				PCI_{lqp}			
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$
Subdivision: Q_{E02}													
E_{0201}	0.7852	0.8280	0.1843	0.3812	0.2375	0.1889	0.0136	0.0792	0.0491	0.6602	0.7520	0.5446	0.7387
E_{0202}	0.9240	0.4463	0.7374	0.1744	0.3564	0.0549	0.2180	0.0166	0.1106	v_{lqp}			
E_{0203}	0.9455	0.6561	−0.4384	0.0629	0.1684	0.1186	0.0770	0.0022	0.0247	0.3985	0.2739	0.2014	0.1261
E_{0204}	0.3914	−0.0756	0.0169	0.9516	−0.0288	0.0016	0.0001	0.4936	0.0007	EV_{lqp}			
E_{0205}	0.8822	0.7015	−0.3006	−0.0951	0.2603	0.1356	0.0362	0.0049	0.0590	3.629	2.495	1.834	1.149
E_{0206}	0.6602	0.4880	−0.5245	−0.3376	0.2048	0.0656	0.1103	0.0621	0.0365	$\boldsymbol{I_{E02}''}$			
E_{0207}	0.8609	−0.0746	−0.6314	0.2094	0.5532	0.0015	0.1598	0.0239	0.2664	**0.6720**			
E_{0208}	0.6757	−0.2986	0.3825	−0.7074	0.4461	0.0246	0.0587	0.2728	0.1732				
E_{0209}	0.6524	−0.3471	0.7413	0.1715	0.4324	0.0332	0.2203	0.0160	0.1627				
E_{0210}	0.3818	0.8421	0.3411	−0.1673	−0.2409	0.1954	0.0466	0.0153	0.0505				
E_{0211}	0.3959	0.8083	0.3849	−0.1566	−0.2765	0.1800	0.0594	0.0134	0.0665				

Table 11 (continued)

STI	NV	C_{lqp}						w_{lqp}					
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
Subdivision: Q_{E03}													
E_{0301}	0.8424	0.8934	0.2984	0.1059	−0.0592	0.1064	0.2330	0.0958	0.0184	0.0037	0.0014	0.0085	0.0485
E_{0302}	0.7942	0.1379	0.8847	0.1927	0.2094	0.2706	−0.1386	0.0023	0.1616	0.0121	0.0174	0.0551	0.0171
E_{0303}	0.9529	0.8950	0.1889	0.2455	−0.1476	−0.2425	0.0650	0.0961	0.0074	0.0196	0.0086	0.0442	0.0038
E_{0304}	0.8273	0.1770	−0.7905	−0.0345	−0.3360	0.3863	−0.0123	0.0038	0.1290	0.0004	0.0447	0.1122	0.0001
E_{0305}	0.9232	0.5566	−0.4915	0.1656	−0.2615	0.4625	0.1420	0.0372	0.0499	0.0089	0.0271	0.1609	0.0180
E_{0306}	0.6535	0.7044	0.0891	−0.0115	0.0145	0.4658	−0.3005	0.0595	0.0016	0.0000	0.0001	0.1631	0.0806
E_{0307}	0.9633	0.8271	−0.3354	0.3473	−0.1755	−0.0906	0.0095	0.0821	0.0232	0.0393	0.0122	0.0062	0.0001
E_{0308}	0.6478	0.0237	−0.4201	−0.4626	0.6555	−0.1887	0.1543	0.0001	0.0364	0.0697	0.1700	0.0268	0.0213
E_{0309}	0.6430	0.6276	−0.1521	−0.2488	0.5987	−0.0705	0.3145	0.0473	0.0048	0.0202	0.1418	0.0037	0.0883
E_{0310}	0.6920	0.2187	0.3444	−0.4309	0.7519	0.0902	0.0220	0.0057	0.0245	0.0605	0.2237	0.0061	0.0004
E_{0311}	0.9138	0.8611	−0.1069	0.1605	0.2021	−0.3051	0.0562	0.0890	0.0024	0.0084	0.0162	0.0700	0.0028
E_{0312}	0.9175	−0.5586	0.1189	0.7399	0.2356	0.0513	0.2255	0.0374	0.0029	0.1784	0.0220	0.0020	0.0454
E_{0313}	0.8333	−0.4918	0.2429	0.6999	0.3038	0.0659	0.0892	0.0290	0.0122	0.1596	0.0365	0.0033	0.0071
E_{0314}	0.9687	−0.4870	0.2763	0.7522	0.1897	0.1176	0.2201	0.0285	0.0158	0.1843	0.0142	0.0104	0.0433
E_{0315}	0.8761	0.1685	0.0292	0.4513	0.0533	−0.4145	−0.6320	0.0034	0.0002	0.0664	0.0011	0.1292	0.3566
E_{0316}	0.7131	0.4151	−0.7506	0.0492	0.3035	0.0947	−0.2576	0.0207	0.1163	0.0008	0.0365	0.0067	0.0592
E_{0317}	0.8803	0.9083	−0.2700	0.2005	0.0911	0.1297	0.0786	0.0990	0.0150	0.0131	0.0033	0.0127	0.0055
E_{0318}	0.8492	0.5405	0.2808	0.0342	0.5319	0.2620	−0.2996	0.0351	0.0163	0.0004	0.1119	0.0516	0.0801
E_{0319}	0.9781	0.8321	−0.1548	0.3529	−0.0046	−0.2983	−0.0758	0.0831	0.0049	0.0406	0.0000	0.0669	0.0051
E_{0320}	0.2451	0.0881	0.6438	−0.5552	−0.4391	−0.1445	0.0088	0.0009	0.0855	0.1005	0.0763	0.0157	0.0001
E_{0321}	0.7874	0.7187	0.5880	−0.0659	−0.1796	0.0267	0.2395	0.0620	0.0713	0.0014	0.0128	0.0005	0.0512
E_{0322}	0.7862	0.2498	0.8853	−0.1545	−0.0320	0.1900	−0.1980	0.0075	0.1618	0.0078	0.0004	0.0271	0.0350
E_{0323}	0.9481	0.7891	0.4326	0.1077	−0.2355	−0.1507	0.1853	0.0747	0.0386	0.0038	0.0219	0.0171	0.0307

Table 11 (continued)

STI	PCI_{lqp}					
	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
Subdivision: Q_{E03}						
E_{0301}	0.8730	0.7568	0.8065	0.7070	0.8297	0.8199
E_{0302}	v_{lqp}					
E_{0303}	0.3927	0.2283	0.1446	0.1191	0.0627	0.0528
E_{0304}	EV_{lqp}					
E_{0305}	8.3340	4.8450	3.0690	2.5270	1.3300	1.1200
E_{0306}	$\boldsymbol{I_{E03}''}$					
E_{0307}	**0.8116**					
E_{0308}						
E_{0309}						
E_{0310}						
E_{0311}						
E_{0312}						
E_{0313}						
E_{0314}						
E_{0315}						
E_{0316}						
E_{0317}						
E_{0318}						
E_{0319}						
E_{0320}						
E_{0321}						
E_{0322}						
E_{0323}						

Table 11 (continued)

STI	NV	C_{lqp}		w_{lqp}		PCI_{lqp}		EV_{lqp}	
		$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$
Subdivision: Q_{E04}									
E_{0401}	0.0069	−0.2125	0.7203	0.0134	0.4482	0.1172	0.5367	3.3806	1.1575
E_{0402}	0.1597	0.9834	0.0411	0.2861	0.0015	v_{lqp}			
E_{0403}	0.1010	0.9628	0.0656	0.2742	0.0037	0.7449	0.2551		
E_{0404}	0.0373	0.7479	0.0483	0.1655	0.0020	$\boldsymbol{I_{E04}''}$			
E_{0405}	0.1386	0.9361	0.0780	0.2592	0.0053	**0.2242**			
E_{0406}	0.9867	0.0755	−0.7901	0.0017	0.5393				

The numbers in bold are the computed indices (final outputs) of the computations corresponding to each sub-division andsustainability pillar. Moreover, these are the values which are taken inputs for the next level of computations until final index is developed

Table 12 Computation of Tertiary Sustainable Transportation Attainment Index (I_{STA}'') of Pillar-II: Social for the state of Andhra Pradesh

STI	NV	Extracted principal components (C_{lqp})						Computed weight of STIs (w_{lqp}) using eigenvalues					
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
Subdivision: Q_{S05}													
S_{0501}	0.8086	0.9164	−0.0364	0.2509	−0.1895	−0.0251	0.0802	0.1184	0.0003	0.0180	0.0132	0.0003	0.0041
S_{0502}	0.9221	0.7751	0.2170	−0.1517	−0.4338	−0.0840	0.3026	0.0847	0.0098	0.0066	0.0690	0.0039	0.0578
S_{0503}	0.5221	0.8081	−0.2838	0.2516	0.3950	−0.0698	−0.0166	0.0920	0.0168	0.0181	0.0572	0.0027	0.0002
S_{0504}	0.3652	0.7459	0.4241	0.0928	0.1745	0.0051	−0.3474	0.0784	0.0374	0.0025	0.0112	0.0000	0.0762
S_{0505}	0.6181	0.3936	0.6821	−0.3543	0.2074	0.3726	−0.1912	0.0218	0.0968	0.0359	0.0158	0.0758	0.0231
S_{0506}	0.2987	0.6400	−0.0713	0.0882	0.2946	−0.3722	0.2536	0.0577	0.0011	0.0022	0.0318	0.0757	0.0406
S_{0507}	0.8572	0.2822	0.5282	−0.3703	−0.2571	−0.2552	0.5210	0.0112	0.0581	0.0392	0.0243	0.0356	0.1715
S_{0508}	0.5583	0.2317	−0.2595	0.0458	0.7722	−0.3824	0.1819	0.0076	0.0140	0.0006	0.2187	0.0799	0.0209
S_{0509}	0.2569	−0.0351	0.6034	−0.3278	0.6248	−0.2107	0.0336	0.0002	0.0758	0.0307	0.1432	0.0242	0.0007
S_{0510}	0.6456	−0.0545	0.6833	−0.4422	0.3520	0.3131	0.0200	0.0004	0.0972	0.0559	0.0454	0.0536	0.0003
S_{0511}	0.8828	0.1705	0.4130	0.8656	−0.0952	0.0212	−0.0340	0.0041	0.0355	0.2142	0.0033	0.0002	0.0007
S_{0512}	0.8916	0.1337	0.7670	0.1950	−0.3616	−0.0307	0.3619	0.0025	0.1224	0.0109	0.0480	0.0005	0.0827
S_{0513}	0.8080	0.1204	0.3224	0.8839	0.1713	−0.0718	0.0034	0.0020	0.0216	0.2234	0.0108	0.0028	0.0000
S_{0514}	0.7909	−0.0591	0.6847	0.6882	−0.0621	0.0970	−0.0474	0.0005	0.0976	0.1354	0.0014	0.0051	0.0014
S_{0515}	0.8390	−0.0720	0.8363	0.0409	0.0642	0.4020	0.0330	0.0007	0.1456	0.0005	0.0015	0.0883	0.0007
S_{0516}	0.8902	0.9137	−0.1764	−0.0233	−0.2206	0.0096	0.0726	0.1177	0.0065	0.0002	0.0179	0.0001	0.0033
S_{0517}	0.9536	0.8327	−0.0008	−0.1462	−0.3891	−0.0434	0.1829	0.0977	0.0000	0.0061	0.0555	0.0010	0.0211
S_{0518}	0.7363	0.8774	−0.3842	−0.0304	0.1713	0.0657	−0.0815	0.1085	0.0307	0.0003	0.0108	0.0024	0.0042
S_{0519}	0.5928	0.8592	−0.0386	−0.1769	0.0715	0.0065	−0.3652	0.1041	0.0003	0.0089	0.0019	0.0000	0.0843
S_{0520}	0.6764	0.7394	0.2292	−0.3641	0.1040	0.1944	−0.3542	0.0771	0.0109	0.0379	0.0040	0.0207	0.0793
S_{0521}	0.5617	0.0193	0.0553	0.6325	0.4329	−0.0674	0.0155	0.0001	0.0006	0.1144	0.0687	0.0025	0.0002
S_{0522}	0.5821	−0.1614	0.3467	−0.3050	0.5335	−0.1722	0.4264	0.0037	0.0250	0.0266	0.1044	0.0162	0.1148
S_{0523}	0.8820	0.1559	−0.4852	0.1512	0.2259	0.6814	0.4102	0.0034	0.0490	0.0065	0.0187	0.2536	0.1063
S_{0524}	0.8744	0.1961	−0.4750	0.1328	0.2528	0.6833	0.4088	0.0054	0.0470	0.0050	0.0234	0.2550	0.1056

Table 12 (continued)

STI	Principal Combined Index (PCI_{lqp})					
	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 5$	$l = 6$
Subdivision: Q_{S05}						
S_{0501}	0.7055	0.7241	0.7456	0.6103	0.7459	0.7288
S_{0502}	Computed weight of PCI_{lqp} (v_{lqp})					
S_{0503}	0.3294	0.2231	0.1624	0.1266	0.0850	0.0735
S_{0504}	Eigenvalues (EV_{lqp})					
S_{0505}	7.0942	4.8047	3.4975	2.7266	1.8309	1.5829
S_{0506}	$\boldsymbol{I_{S05}''}$					
S_{0507}	**0.7093**					
S_{0508}						
S_{0509}						
S_{0510}						
S_{0511}						
S_{0512}						
S_{0513}						
S_{0514}						
S_{0515}						
S_{0516}						
S_{0517}						
S_{0518}						
S_{0519}						
S_{0520}						
S_{0521}						
S_{0522}						
S_{0523}						
S_{0524}						

Table 12 (continued)

STI	NV	C_{lqp}				w_{lqp}				PCI_{lqp}			
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$
Subdivision: Q_{S06}													
S_{0601}	0.1967	0.9147	0.0681	−0.1568	−0.1346	0.1786	0.0023	0.0149	0.0165	0.0912	0.2418	0.2283	0.2135
S_{0602}	0.2532	−0.2637	−0.1804	0.1798	0.8006	0.0148	0.0161	0.0196	0.5832	v_{lqp}			
S_{0603}	0.1382	0.9308	0.0138	−0.1585	−0.1248	0.1849	0.0001	0.0152	0.0142	0.4958	0.2133	0.1745	0.1163
S_{0604}	0.2915	0.0047	0.4994	−0.5156	−0.1106	0.0000	0.1237	0.1612	0.0111	EV_{lqp}			
S_{0605}	0.5670	−0.2160	0.5917	−0.2725	−0.2032	0.0100	0.1736	0.0450	0.0376	4.6856	2.0159	1.6494	1.0989
S_{0606}	0.3719	0.2355	0.4255	−0.4835	0.2892	0.0118	0.0898	0.1417	0.0761	$\boldsymbol{I_{S06}''}$			
S_{0607}	0.1476	0.1422	0.6416	0.7373	−0.0546	0.0043	0.2042	0.3296	0.0027	**0.1615**			
S_{0608}	0.1908	0.4695	0.5948	0.6095	0.0291	0.0470	0.1755	0.2253	0.0008				
S_{0609}	0.0311	−0.0865	−0.5727	0.2792	−0.4944	0.0016	0.1627	0.0473	0.2225				
S_{0610}	0.0182	0.9544	−0.1929	0.0089	0.0752	0.1944	0.0185	0.0000	0.0052				
S_{0611}	0.0041	0.8609	−0.1634	0.0088	0.1628	0.1582	0.0132	0.0000	0.0241				
S_{0612}	0.0144	0.9542	−0.2019	0.0135	0.0820	0.1943	0.0202	0.0001	0.0061				

STI	NV	C_{lqp}		w_{lqp}		PCI_{lqp}		EV_{lqp}	
		$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$
Subdivision: Q_{S07}									
S_{0701}	0.5965	0.6237	0.6853	0.1378	0.3195	0.4646	0.5459	2.8233	1.4699
S_{0702}	0.5741	0.3173	0.8628	0.0357	0.5064	v_{lqp}			
S_{0703}	0.6035	0.8425	−0.0760	0.2514	0.0039	0.6576	0.3424		
S_{0704}	0.3855	0.9010	−0.3548	0.2875	0.0856	$\boldsymbol{I_{S07}''}$			
S_{0705}	0.3454	0.9010	−0.3524	0.2876	0.0845	**0.4924**			

The numbers in bold are the computed indices (final outputs) of the computations corresponding to each sub-division andsustainability pillar. Moreover, these are the values which are taken inputs for the next level of computations until final index is developed

Table 13 Computation of Tertiary Sustainable Transportation Attainment Index (I_{STA}'') of Pillar-III: Economical for the state of Andhra Pradesh

STI	NV	Extracted principal components (C_{lqp})				Computed weight of STIs (w_{lqp}) using eigenvalues				Principal Combined Index (PCI_{lqp})			
		$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$	$l = 1$	$l = 2$	$l = 3$	$l = 4$
Subdivision: Q_{C08}													
C_{0801}	0.9134	0.9271	−0.0768	0.0003	−0.1263	0.1084	0.0018	0.0000	0.0107	0.9595	0.8888	0.8116	0.8305
C_{0802}	0.9983	0.9330	−0.0408	−0.0759	−0.2517	0.1098	0.0005	0.0035	0.0426	Computed weight of PCI_{lqp} (v_{lqp})			
C_{0803}	0.9983	0.9330	−0.0408	−0.0759	−0.2517	0.1098	0.0005	0.0035	0.0426	0.5552	0.2255	0.1153	0.1041
C_{0804}	0.9819	0.9049	−0.0038	0.2647	−0.1765	0.1033	0.0000	0.0425	0.0210	Eigenvalues (EV_{lqp})			
C_{0805}	0.9863	0.9404	0.1615	−0.0586	−0.0737	0.1115	0.0081	0.0021	0.0036	7.931	3.221	1.647	1.487
C_{0806}	0.8220	0.0940	0.2199	−0.6881	0.1991	0.0011	0.0150	0.2874	0.0267	$\boldsymbol{I_{C08}''}$			
C_{0807}	1.0000	0.5443	0.7386	0.1901	0.3418	0.0374	0.1694	0.0219	0.0786	**0.9131**			
C_{0808}	1.0000	0.5462	0.7383	0.0332	0.3702	0.0376	0.1692	0.0007	0.0922				
C_{0809}	1.0000	0.5463	0.7420	0.0643	0.3523	0.0376	0.1709	0.0025	0.0835				
C_{0810}	0.8199	0.7556	−0.4224	−0.0767	0.1806	0.0720	0.0554	0.0036	0.0219				
C_{0811}	0.8621	0.7367	−0.1941	−0.3895	0.2832	0.0684	0.0117	0.0921	0.0539				
C_{0812}	0.9964	0.9491	−0.1616	−0.0786	−0.2128	0.1136	0.0081	0.0037	0.0305				
C_{0813}	0.7339	0.1451	−0.6561	0.4262	0.5471	0.0027	0.1336	0.1103	0.2013				
C_{0814}	0.6425	0.1958	−0.7096	0.0200	0.6339	0.0048	0.1563	0.0002	0.2703				
C_{0815}	0.9821	0.7974	−0.5168	0.1429	−0.1487	0.0802	0.0829	0.0124	0.0149				
C_{0816}	0.7740	0.1269	0.2302	0.8253	−0.0918	0.0020	0.0164	0.4135	0.0057				

STI	NV	C_{lqp} $l = 1$	w_{lqp} $l = 1$	PCI_{lqp} $l = 1$	EV_{lqp} $l = 1$
Subdivision: Q_{C09}					
C_{0901}	0.0792	0.9564	0.2522	0.2800	3.6269
C_{0902}	0.0665	0.9514	0.2495	v_{lqp}	
C_{0903}	0.0016	0.9280	0.2374	1.0000	

Table 13 (continued)

STI	NV	C_{lqp} $l = 1$	w_{lqp} $l = 1$	PCI_{lqp} $l = 1$	EV_{lqp} $l = 1$
C_{0904}	0.8395	−0.6346	0.1110	$\boldsymbol{I_{C09}''}$	
C_{0905}	1.0000	−0.7371	0.1498	**0.2800**	

STI	NV	C_{lqp}			w_{lqp}			PCI_{lqp}		
		$l = 1$	$l = 2$	$l = 3$	$l = 1$	$l = 2$	$l = 3$	$l = 1$	$l = 2$	$l = 3$
Subdivision: Q_{C10}										
C_{1001}	0.9945	0.8099	0.3719	−0.3601	0.2406	0.0646	0.0964	0.7473	0.1821	0.6310
C_{1002}	0.4842	0.8757	0.0282	−0.1709	0.2813	0.0004	0.0217	v_{lqp}		
C_{1003}	0.8473	0.9197	0.1869	−0.1460	0.3103	0.0163	0.0158	0.4388	0.3445	0.2167
C_{1004}	0.0536	−0.1401	0.9503	0.2498	0.0072	0.4219	0.0463	EV_{lqp}		
C_{1005}	0.0101	−0.1615	0.9457	0.2497	0.0096	0.4178	0.0463	2.7263	2.1404	1.3461
C_{1006}	0.9838	0.4641	−0.4078	0.6561	0.0790	0.0777	0.3198	$\boldsymbol{I_{C10}''}$		
C_{1007}	0.4270	0.4433	−0.0510	0.7815	0.0721	0.0012	0.4537	**0.5274**		

The numbers in bold are the computed indices (final outputs) of the computations corresponding to each sub-division andsustainability pillar. Moreover, these are the values which are taken inputs for the next level of computations until final index is developed

Table 14 Computation of Secondary Sustainable Transportation Attainment Index (I_{STA}'') of three Pillars of sustainability for the state of Andhra Pradesh

Subdivision	I_{STA}''	I_{STA}'' value	Extracted principal components ($C_{l'qp}'$)		Computed weight of I_{STA}'' ($w_{l'qp}'$) using eigenvalues		Principal Combined Index ($PCI_{l'qp}'$)		Eigenvalues ($EV_{l'qp}'$)	
			$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$
Q_{E01}	I_{E01}''	0.7165	0.9448	0.1125	0.4844	0.0107	0.6612	0.5457	1.8426	1.1826
Q_{E02}	I_{E02}''	0.6720	0.8505	0.4220	0.3926	0.1506	Computed weight of $PCI'_{l'qp}$ ($v'_{l'qp}$)		$\boldsymbol{I_E'}$	
Q_{E03}	I_{E03}''	0.8116	−0.2672	0.7078	0.0387	0.4237	0.6091	0.3909	**0.6161**	
Q_{E04}	I_{E04}''	0.2242	0.3940	−0.7006	0.0842	0.4151				

Subdivision	I_{STA}''	I_{STA}'' value	$C'_{l'qp}$		$w'_{l'qp}$		$PCI'_{l'qp}$		$EV'_{l'qp}$	
			$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$	$l = 1$	$l = 2$
Q_{S05}	I_{S05}''	0.7093	−0.8721	0.2181	0.4909	0.0459	0.4314	0.4963	1.5494	1.0364
Q_{S06}	I_{S06}''	0.1615	0.8854	0.1376	0.5060	0.0183	$v'_{l'qp}$		$\boldsymbol{I_S'}$	
Q_{S07}	I_{S07}''	0.4924	0.0694	0.9848	0.0031	0.9358	0.5992	0.4008	**0.4574**	

Subdivision	I_{STA}''	I_{STA}'' value	$C'_{l'qp}$	$w'_{l'qp}$	$PCI'_{l'qp}$	$EV'_{l'qp}$
			$l = 1$	$l = 1$	$l = 1$	$l = 1$
Q_{C08}	I_{C08}''	0.9131	0.9474	0.4067	0.6006	2.207
Q_{C09}	I_{C09}''	0.2800	−0.8637	0.3379	$v'_{l'qp}$	$\boldsymbol{I'_C}$
Q_{C10}	I_{C10}''	0.5274	0.7509	0.2554	1.000	**0.6006**

The numbers in bold are the computed indices (final outputs) of the computations corresponding to each sub-division andsustainability pillar. Moreover, these are the values which are taken inputs for the next level of computations until final index is developed

Table 15 Computation of Primary Sustainable Transportation Attainment Index (I_{STA}) for the state of Andhra Pradesh

Pillar	I''_{STA}	I''_{STA} value	I_{STA}
Environmental	I'_E	0.6161	**0.5580**
Social	I'_S	0.4574	
Economical	I'_C	0.6006	

References

Ahangari, H., Garrick, N. W., & Atkinson-Palombo, C. (2016). Relationship between human capital and transportation sustainability for the United States and selected European countries. *Transportation Research Record: Journal of the Transportation Research Board, 2598*(1), 92–101. https://doi.org/10.3141/2598-11.

Alonso, A., Monzón, A., & Cascajo, R. (2015). Comparative analysis of passenger transport sustainability in European cities. *Ecological Indicators, 48*, 578–592. https://doi.org/10.1016/j.ecolind.2014.09.022.

Balachandra, P., & Reddy, B. S. (2013). *Benchmarking Bangalore City for sustainability—An indicator-based approach. Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP)*. Bangalore, India. https://cistup.iisc.ac.in/CiSTUP_Website/pages/research/completed.php.

Black, W. R. (2002). Sustainable TRANSPORT AND POTENTIAL MOBILIty. *European Journal of Transport and Infrastructure Research, 2*(3/4), 179–195.

Castillo, H., & Pitfield, D. E. (2010). ELASTIC—A methodological framework for identifying and selecting sustainable transport indicators. *Transportation Research Part D, 15*(4), 179–188. https://doi.org/10.1016/j.trd.2009.09.002.

CENSUS. (2011). *Census of India: Office of the Registrar General & Census Commissioner*., Ministry of Home Affairs, Government of India. https://censusindia.gov.in/. Accessed 16 August 2018.

Cornet, Y., & Gudmundsson, H. (2015). Building a metaframework for sustainable transport indicators: Review of selected contributions. *Transportation Research Record: Journal of the Transportation Research Board, 2531*, 103–112. https://doi.org/10.3141/2531-12.

Costa, P. B., Neto, G. C. M., & Bertolde, A. *I*. (2017). Urban Mobility Indexes: A Brief Review of the Literature. In *World Conference on Transport Research—WCTR 2016* (Vol. 25, pp. 3645–3655). Shanghai, China: Elsevier B.V. https://doi.org/10.1016/j.trpro.2017.05.330.

CPCB. (2016). *Central Pollution Control Board, Ministry of Environment, Forest and Climate Change*. Government of India. https://cpcb.nic.in/. Accessed 23 July 2018.

Danielis, R., Rotaris, L., & Monte, A. (2018). Composite indicators of sustainable urban mobility: Estimating the rankings' frequency distribution combining multiple methodologies. *International Journal of Sustainable Transportation, 12*(5), 380–395. https://doi.org/10.1080/15568318.2017.1377789.

Datanet-India. (2016). *Datanet India, Governemnet of India*. https://datanetindia.com/aboutus.html. Accessed 16 August 2018.

De Gruyter, C., Currie, G., & Rose, G. (2017). Sustainability measures of urban public transport in cities: A world review and focus on the Asia/Middle East Region. *Sustainability (Switzerland), 9*(1), 1–21. https://doi.org/10.3390/su9010043.

Freudenberg, M. (2003). *Composite indicators of country performance: A critical assessment* (No. 2003/16). OECD Publishing, Paris. https://dx.doi.org/10.1787/405566708255.

Gan, X., Fernandez, I. C., Guo, J., Wilson, M., Zhao, Y., Zhou, B., et al. (2017). When to use what: Methods for weighting and aggregating sustainability indicators. *Ecological Indicators, 81*(June), 491–502. https://doi.org/10.1016/j.ecolind.2017.05.068.

Gudmundsson, H., Hall, R. P., Marsden, G., & Zietsman, J. (2016). *Sustainable transportation: Indicators, frameworks and performance management* (First.). Springer Texts in Business and Economics. https://doi.org/10.1007/978-3-662-46924-8.

Gudmundsson, H., & Regmi, M. B. (2017). *Developing the Sustainable Urban Transport Index. Transport and communications bulletin for Asia and the Pacific* (Vol. 87). Transport and Communications Bulletin for Asia and the Pacific. https://www.unescap.org/sites/default/files/publications/bulletin87_Fulltext.pdf#page=43.

Gwilliam, K. (2003). Urban transport in developing countries. *Transport Reviews, 23*(2), 197–216. https://doi.org/10.1080/0144164032000068939.

Haghshenas, H., & Vaziri, M. (2012). Urban sustainable transportation indicators for global comparison. *Ecological Indicators, 15*(1), 115–121. https://doi.org/10.1016/j.ecolind.2011.09.010.

Husain, N., Abdullah, M., & Kuman, S. (2002). Evaluating public sector efficiency with data envelopment analysis (DEA): A case study in Road Transport Department, Selangor Malaysia. *Total Quality Management, 11*(4–6), 830–836. https://doi.org/10.1080/09544120050008282.

Illahi, U. (2018). Transport planning and traffic safety: Making cities, roads, and vehicles safer. *Transport Reviews, 39*(6), 819–820. https://doi.org/10.1080/01441647.2018.1552632.

Illahi, U., & Mir, M. S. (2019). Sustainable transportation: Indicators, frameworks, and performance management. *Evaluation and Program Planning, 73*, 224–225. https://doi.org/10.1016/j.evalprogplan.2019.01.006.

India-Maps. (2016). *Maps of India, Government of India Portal*. https://www.mapsofindia.com/. Accessed 7 July 2019.

Indian-Railways. (2016). *Ministry of Indian Railways, Government of India*. https://www.indianrailways.gov.in/. Accessed 16 June 2018.

Jeon, C. M., & Amekudzi, A. (2005). Addressing Sustainability in transportation systems: Definitions, indicators, and metrics. *Journal of Infrastructure Systems, 11*(1), 31–50. https://doi.org/10.1061/(asce)1076-0342(2005)11:1(31).

Jeon, C. M., Amekudzi, A. A., & Guensler, R. L. (2013). Sustainability assessment at the transportation planning level: Performance measures and indexes. *Transport Policy, 25*, 10–21. https://doi.org/10.1016/j.tranpol.2012.10.004.

Jollands, N., Lermit, J., & Patterson, M. (2003). *The usefulness of aggregate indicators in policy making and evaluation : A discussion with application to eco-efficiency indicators in New Zealand* (pp. 1–39). ANU Research Publications (April). https://openresearch-repository.anu.edu.au/handle/1885/41033.

Joumard, R., & Gudmundsson, H. (2010). *Indicators of Environmental Sustainability in Transport: An interdisciplinary approach to methods*. INRETS. https://cost356.inrets.fr/pub/reference/reports/Indicators_EST_May_2010.pdf.

Litman, T. (2007). Developing indicators for comprehensive and sustainable transport planning. *Transportation Research Record: Journal of the Transportation Research Board*. https://doi.org/10.3141/2017-02.

Mahdinia, *I*., & Habibian, M. (2017). Evaluating the transportation system performance based on efficiency, effectiveness and efficacy: A case study of the U.S. States. In *Transportation Research Board 96th Annual Meeting*. Washington DC, United States: Transportation Research Board (TRB). https://trid.trb.org/view/1439634.

Mahdinia, I., Habibian, M., Hatamzadeh, Y., & Gudmundsson, H. (2018). An indicator-based algorithm to measure transportation sustainability: A case study of the U.S. states. *Ecological Indicators, 89*, 738–754. https://doi.org/10.1016/j.ecolind.2017.12.019.

MoCA. (2016). *Ministry of Civil Aviation, Governement of India*. https://www.civilaviation.gov.in/. Accessed 25 May 2018.

MoP&NG. (2016). *Ministry of Petroleum and Natural Gas, Government of India*. https://petroleum.nic.in/. Accessed 20 May 2018.

MORTH. (2016). *Ministry of Road Transport & Highways, Government of India*. https://morth.nic.in/. Accessed 2 September 2018.

MoSPI. (2016). *Ministry of Statistics and Program Implementation, Government of India*. https://www.mospi.gov.in/. Accessed 16 May 2018.

MoT. (2016). *Ministry of Tourism, Government of India*. https://tourism.gov.in/. Accessed 5 July 2018.

NHAI. (2016). *National Highways Authority of India, Ministry of Road Transport and Highways, Government of India*. https://www.nhai.org/. Accessed 25 May 2018.

OECD. (2008). *Handbook of Constructing Composite Indicators: Methodology and user guide*. JRC European Commission.

OGDP-India. (2016). *Open Government Data Platform India*. https://data.gov.in/. Accessed 11 June 2018.

Ramani, T. L., Quadrifoglio, L., & Zietsman, J. (2010). Accounting for nonlinearity in the MCDM approach for a transportation planning application. *IEEE Transactions on Engineering Management, 57*(4), 702–710. https://doi.org/10.1109/TEM.2009.2037743.

Rassafi, A. A., & Vaziri, M. (2005). Sustainable transport indicators: Definition and integration. *International Journal of Environmental Science and Technology, 2*(1), 83–96. https://doi.org/10.1007/BF03325861.

Reisi, M., Aye, L., Rajabifard, A., & Ngo, T. (2014). Transport sustainability index: Melbourne case study. *Ecological Indicators, 43*(August), 288–296. https://doi.org/10.1016/j.ecolind.2014.03.004.

Weighting methods, seminar on composite indicators: From theory to practice. Ispra.

Shaker, R. R., & Sirodoev, I. G. (2016). Assessing sustainable development across Moldova using household and property composition indicators. *Habitat International, 55*, 192–204. https://doi.org/10.1016/j.habitatint.2016.03.005.

Shaker, R. R. (2018). A mega-index for the Americas and its underlying sustainable development correlations. *Ecological Indicators, 89*, 466–479. https://doi.org/10.1016/j.ecolind.2018.01.050.

SHAKTI. (2016). *SHAKTI Sustainable Energy Foundation, India*. https://shaktifoundation.in/. Accessed 10 July 2018.

Shiau, T. A., & Liu, J. S. (2013). Developing an indicator system for local governments to evaluate transport sustainability strategies. *Ecological Indicators, 34*, 361–371. https://doi.org/10.1016/j.ecolind.2013.06.001.

Spiekermann, K., & Wegener, M. (2004). Evaluating urban sustainability using land-use transport interaction models. *European Journal of Transport and Infrastructure Research, 4*(3), 251–272.

Tanguay, G. A., Rajaonson, J., Lefebvre, J.-F., & Lanoie, P. (2010). Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecological Indicators, 10*(2), 407–418. https://doi.org/10.1016/j.ecolind.2009.07.013.

TERM. (2011). *TERM 2011: transport indicators tracking progress towards environmental targets in Europe* (No. 7/2011). *EEA Report: Laying the foundations for greener transport*. Copenhagen, Denmark. https://doi.org/10.2800/82592.

Ting, K., & Xiao, W. U. (2009). Transportation and Sustainable Development. In *International conference on transportation engineering* (pp. 2638–2643). Southwest Jiaotong University, Chengdu, China: ASCE.

Varzaneh, M. R. (2014). *Quantifying transport sustainability: Development of an index. University of Melbourne, Australia*. The University of Melbourne, Australia. Retrieved from https://hdl.handle.net/11343/40789.

Verma, A., Rahul, T. M., & Dixit, M. (2015). Sustainability impact assessment of transportation policies—A case study for Bangalore city. *Case Studies on Transport Policy, 3*(3), 321–330. https://doi.org/10.1016/j.cstp.2014.06.001.

WSDOT. (2011). *The Gray Notebook (GNB 43)* (No. 43). *Washington State Department of Transportation* (Vol. November 1). Washington D.C., United States. www.wsdot.wa.gov/accountability.

Zhou, P., Ang, B. W., & Poh, K. L. (2007). A mathematical programming approach to constructing composite indicators. *Ecological Economics, 62*(2), 291–297. https://doi.org/10.1016/j.ecolecon.2006.12.020.

Zito, P., & Salvo, G. (2011). Toward an urban transport sustainability index: An European comparison. *European Transport Research Review, 3*(4), 179–195. https://doi.org/10.1007/s12544-011-0059-0.