Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)
July 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 200
DOI: 10.11159/iccste25.200

Factors Influencing Private Vehicle Users' Transition to Sustainable Transport Modes for Enhanced Environmental Sustainability in Indian Context

Rupam Sam[1], Dr. Sudip Kumar Roy[2]
[1]PhD Scholar, Department of Civil Engineering, IIEST, Shibpur, West-Bengal, India
2020cep007.rupam@students.iiests.ac.in
[2]Professor, Department of Civil Engineering, IIEST, Shibpur, West-Bengal, India
sudip@civil.iiests.ac.in

Abstract: *Air pollution due to vehicular emissions poses a significant environmental and public health concern, contributing to climate change and premature mortality. This study aims to evaluate the perceptions of private vehicle users regarding their contribution to air pollution and their willingness to adopt sustainable modes of transport. In regards to high congestion, poor condition transport modes, poor pavement condition, heterogeneity modes of transport etc., Kolkata, the third largest city in India, is suffering from critical air pollution due to traffic. A structured questionnaire was used to collect from the private vehicle users on perceptions of air pollution along with their commuting behaviors towards public transport. Principal Component Analysis (PCA) was used in order to identify the key underlying factors influencing their perceptions. The results revealed four major components: Health awareness of Pollution Effects, Motivation for Sustainable Transport, Policy and Responsibility Awareness, Perception of Emissions and Information. This study provides valuable insights towards vehicular emissions through promoting sustainable transport, and mitigating the adverse effects of air pollution on public health.*

Keywords: Sustainable Transportation, Air Pollution, Travel Behavior, Perception of Environmental Impact, Public Health

Introduction

The problems due to traffic pollution are particularly severe in several major cities, especially in those where traffic jams are a frequent occurrence. Air pollution has become a critical environmental concern in urban areas, with vehicular emissions being a significant contributor. The rapid growth in private vehicles usage has exacerbated the problem, leading to increased levels of greenhouse gases, particulate matter, and other harmful pollutants. These emissions not only degrade air quality but also pose severe health risks, such as respiratory diseases, cardiovascular issues, and reduced life expectancy. The World Health Organization (WHO) has stated that exposure to air pollution is linked to numerous adverse health effects, including cardiovascular diseases, respiratory infections. Among various types of pollutants, fine particulate matter (PM2.5) is considered the most hazardous, as its microscopic size allows to penetrate the respiratory system easily, leading to premature deaths. [1,2]

The increasing traffic congestion in the metropolitan cities and the inefficient modes of transport are a major cause of air/noise pollution, road traffic accidents and productivity loss due to longer commutes. Previous research has extensively applied the Theory of Planned Behavior (TPB) to study factors affecting purchase intentions [3,4,5,6,7,8]. Key factors studied include government policy and promotion [6,9,10], user attitudes and technological capabilities [3,7], and barriers causing user concerns such as supporting infrastructure, technological readiness, travel behavior, and access to information [4,6]. By reducing the number of vehicles on the roads, traffic related air pollution can be effectively controlled. The governments can make efforts to develop sustainable transport in the cities to reduce air pollution [11].

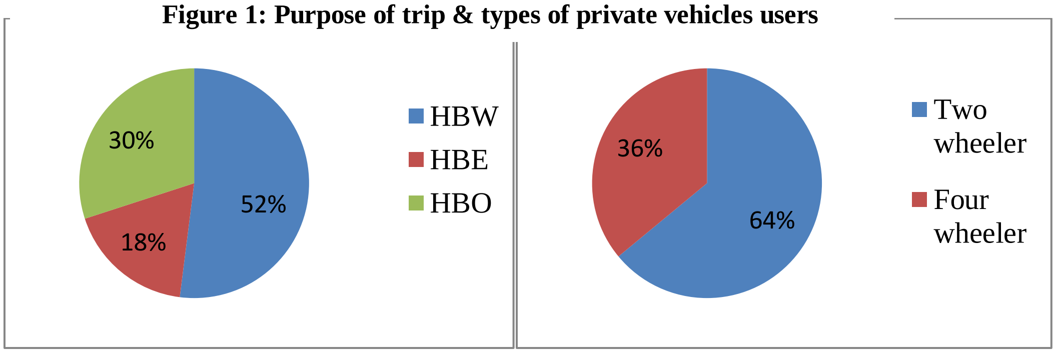
This study focuses solely on the environmental aspects of air pollution caused by private vehicle use, excluding trip-related parameters. The objective of this study is to utilize Principal Component Analysis (PCA) to identify and extract the key components underlying the perceptions of private vehicle users regarding their contribution to air pollution and their willingness to shift to sustainable modes of transport. By reducing the dimensionality of the data, the study aims to uncover the most significant factors influencing commuter decision-making of mode choice.

Methodology: The data collection process for this study was designed to gather comprehensive information on private vehicle users' perceptions of air pollution, health concerns, and their willingness to shift to sustainable modes of transport. Face-to-face interviews were conducted, and the data were recorded electronically to reduce errors and streamline data analysis. The required information for the study gathered through a community-based cross-sectional survey using a structured questionnaire including both open ended and closed ended questions. The survey tool comprises multiple sections, including socio-demographic details, perceptions of pollution and related issues, views on public transport in the city of Kolkata, Capital of the state West-Bengal, India. As Kolkata is affected by several problems such as poor public transport, poor pavement condition, traffic congestion etc., therefore this city is chosen as study area for this study. Assuming that Central Limit Theorem is followed, a total of 330 responses from the private vehicle users were obtained. A stratified random sampling approach was employed to ensure representation across different socio-demographic commuter groups (Table 1) and types of trip along with the types of private vehicles (Fig 1) used by the commuters while parking their vehicles. Commuters' behavior towards pollution and their choice of transport modes assessed in terms of environmental impact using questions based on a Likert scale (Table 2).

Sl No.	Parameters	Description
1	Gender	Male (M), Female (F)
2	Age	<25 years, 25-40 years, 40-55 years, > 55 years
3	Level of education	10th or below, 12th, Bachelors, Masters, Doctorate or higher degree
4	Purpose of travel	Home based work (HBW), Home based education (HBE), Home based others (HBO)
5	Frequency of travel	1 day/week, 2-3 days/week, 4-5 days/week, 6-7 days/week

Table 1: Socioeconomic characteristics of the commuters

Figure 1: Purpose of trip & types of private vehicles users



Sl no	Perception Variables	Likert scale (in a 6-point scale)
1	How often do you experience health issues (e.g., breathing difficulties) that you associate with air pollution?	Never to Always
2	Do you believe vehicular emissions are a major contributor to air pollution in urban areas?	Strongly Disagree to Strongly Agree
3	How concerned are you about the impact of air pollution on public health?	Not Concerned at All to Extremely Concerned
4	How responsible do you feel for reducing air pollution through your transport choices?	Not Responsible at All to Very Responsible
5	Would the opportunity to reduce your personal carbon footprint influence your decision to use sustainable transport?	Not Likely to Very Likely
6	How well-informed are you about the benefits of reducing vehicular emissions?	Not Informed to Very Well Informed
7	Do you think continued reliance on private vehicles will worsen air quality in your area?	Not Likely to Very Likely
8	How effective do you think government policies aimed at reducing air pollution through transport regulations are?	Not Effective to Very Effective
9	If air pollution levels were to worsen, how likely would you be to switch to sustainable transport?	Not Likely to Very Likely
10	How important is reducing air pollution as a motivation for choosing a sustainable mode of transport?	Not Important to Very Important

Table 2: Perception Variables regarding air pollution

Result: This study employed a rigorous methodology encompassing data preparation, Principal Component Analysis (PCA) for dimensionality reduction [12, 13, 14, 15] to analyze factors influencing commuter behaviour. The study followed a systematic methodology, including data cleaning, standardization, and encoding of categorical variables to prepare the dataset for PCA. Key steps in PCA included the computation of a correlation matrix, Kaiser-Meyer-Olkin (KMO) test for sampling adequacy, Bartlett's test of sphericity for correlation significance, and extraction of principal components using eigenvalues and scree plots.

The KMO test was conducted to assess sampling adequacy, with a KMO value greater than 0.5 indicating suitability for PCA. Bartlett's test confirms the presence of significant correlations among variables, with a p-value < 0.05 required for PCA applicability (Table 3). A KMO value of 0.873 indicates that the data is highly suitable for factor analysis.This means there are strong relationships among the variables, and factor analysis is appropriate for reducing the data into meaningful components.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.873
Bartlett's Test of Sphericity	Approx. Chi-Square	119.410
	df	55
	Sig.	.000

Table 3: KMO and Bartlett's Test for sampling adequacy

Table 4 provides information on the proportion of variance for each variable that is explained by the extracted factors in a PCA and it represents the proportion of variance retained after factoring. Higher values (close to 1) suggest that the variable is well represented by the extracted components. These findings highlight the relative contribution of each variable to the underlying factor structure and inform decisions regarding variable retention in the model.

Perception Variables	Initial	Extraction
How often do you experience health issues (e.g., breathing difficulties) that you associate with air pollution?	1.000	.965
Do you believe vehicular emissions are a major contributor to air pollution in urban areas?	1.000	.984
How concerned are you about the impact of air pollution on public health?	1.000	.979
How responsible do you feel for reducing air pollution through your transport choices?	1.000	.779
Would the opportunity to reduce your personal carbon footprint influence your decision to use sustainable transport?	1.000	.965
How well-informed are you about the benefits of reducing vehicular emissions?	1.000	.905
Do you think continued reliance on private vehicles will worsen air quality in your area?	1.000	.876
How effective do you think government policies aimed at reducing air pollution through transport regulations are?	1.000	.979
If air pollution levels were to worsen, how likely would you be to switch to sustainable transport?	1.000	.957
How important is reducing air pollution as a motivation for choosing a sustainable mode of transport?	1.000	.994

Table 4: Communalities

Principal components has been extracted based on eigenvalues greater than 1 (Kaiser criterion) and through visual inspection of the scree plot (Fig 2). Components with eigenvalues >1 were retained. The first Eigen value is equal to 3.252 and explained 29.6% of the variance in the original data. The second factor Eigen value is equal to 2.101 and explains 19.09% of the variance, the third component Eigen value is equal to 1.691 and explains 15.37% of the variance. The forth component Eigen value is equal to 1.347 and explains 12.24% of the variance. Varimax rotation was applied to enhance the interpretability of components, which were labeled based on high-loading variables. After Varimax rotation, the variance is redistributed for better interpretability. The cumulative variance remains 76.28%, but the components now explain the variance more evenly. Thus, Table 5 indicates that four components effectively summarize the dataset.

Total Variance Explained									
Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.252	29.563	29.563	3.252	29.563	29.563	2.547	23.154	23.154
2	2.101	19.098	48.661	2.101	19.098	48.661	2.226	20.233	43.387
3	1.691	15.377	64.038	1.691	15.377	64.038	1.966	17.871	61.258
4	1.347	12.242	76.280	1.347	12.242	76.280	1.652	15.023	76.280

Table 5: Total Variance Explained

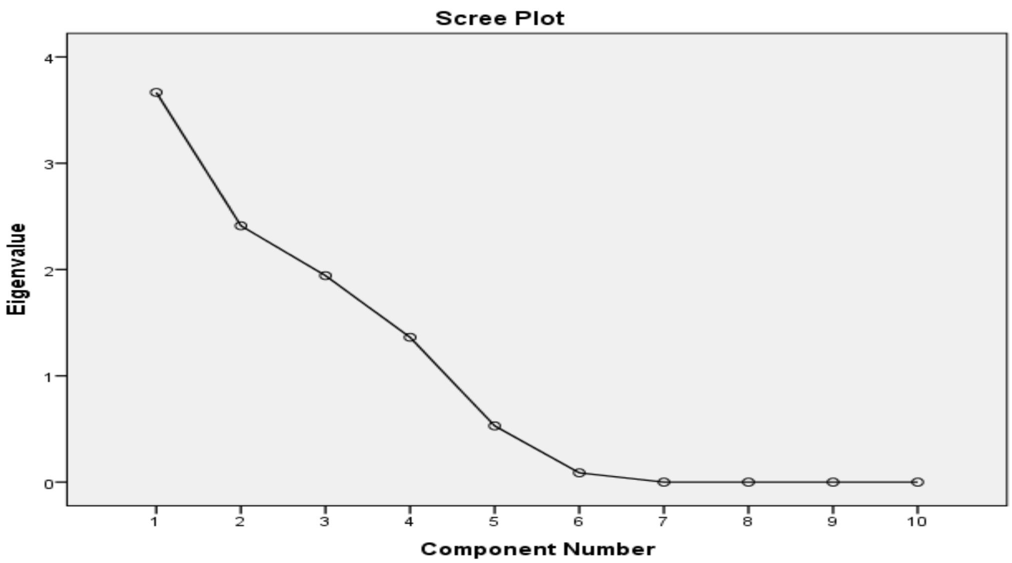


Figure 2: Scree plot

The scree plot is a graphical representation used in PCA to help determine the number of components to retain. The scree plot determines the optimal number of components to retain by plotting the eigenvalues of each component (Fig 2). Here, scree plot retains four components appears to be optimal, as these components capture most of the variance while avoiding unnecessary complexity.

The Rotated Component Matrix is a crucial output in PCA and this simplifies the interpretation of PCA by clearly showing the association between variables and components, helping identify key underlying factors. It enables meaningful labeling of components, providing practical insights for targeted interventions. Higher loadings (typically ≥ 0.5) indicate that the variable significantly contributes to the component. It provides information about how each variable loads onto the extracted components (or factors) after rotation (Table 6).

Perception Variables	Component			
	1	2	3	4
How often do you experience health issues (e.g., breathing difficulties) that you associate with air pollution?	.772	.443	.339	.240
Do you believe vehicular emissions are a major contributor to air pollution in urban areas?	.158	.100	.176	.958
How concerned are you about the impact of air pollution on public health?	.533	.270	.387	.008
How responsible do you feel for reducing air pollution through your transport choices?	.021	.013	.006	.613
Would the opportunity to reduce your personal carbon footprint influence your decision to use sustainable transport?	.218	.720	.220	.254
How well-informed are you about the benefits of reducing vehicular emissions?	.079	.629	.519	.301
Do you think continued reliance on private vehicles will worsen air quality in your area?	.165	.228	.178	.838
How effective do you think government policies aimed at reducing air pollution through transport regulations are?	.347	.259	.619	.015

If air pollution levels were to worsen, how likely would you be to switch to sustainable transport?	.463	.139	.093	.540
How important is reducing air pollution as a motivation for choosing a sustainable mode of transport?	.268	.937	.204	.059

Table 6: Rotated Component Matrix

The rotated component matrix from PCA reveals four distinct perception factors related to air pollution and sustainable transport. The high loadings indicate the underlying dimensions shaping public perceptions, which can inform targeted interventions to promote sustainable transport choices. From the matrix, of each component based on the variable loadings can be interpreted as following:

- Component 1: Health awareness of Pollution Effects (Variable 1 & 3): This component suggests that Component 1 reflects health-related concerns and personal awareness of air pollution.
- Component 2: Motivation for Sustainable Transport (Variable 5 & 10): This component likely captures environmental motivation and responsibility as a driving factor.
- Component 3: Policy and Responsibility Awareness (Variable 6 & 8): Component 3 seems to represent awareness of the impact of personal and policy decisions on air quality.
- Component 4: Perception of Emissions and Information (Variable 2, 4, 7 & 9): This component reflects knowledge and perception of vehicular emissions as a key issue.

These four principal components effectively summarize the key factors and the Rotated Component Matrix highlights the key variables contributing to each component, offering clear insights into the underlying factors.

Conclusions:

Using PCA key factors influencing commuter decision-making were identified, including Health awareness of Pollution Effects, Motivation for Sustainable Transport, Policy and Responsibility Awareness, Perception of Emissions and Information. The findings reveals the importance of improving public transport infrastructure and also raising awareness of the environmental, health impacts of private vehicle use in order to encourage sustainable transportation adoption. This research work contributes to sustainability in transportation by exploring public perceptions related to the air pollution and sustainable transport options. By identifying the principal components, it strengthens the strategies to reduce reliance on private vehicles, promote the adoption of sustainable modes of transport, and ultimately mitigate the environmental impact due to growing travel demand. By addressing these components, urban planners and policymakers can design strategies more effectively in order to reduce vehicular emissions, improvement of the air quality and also promote public health. Future research could build on these findings by considering the longitudinal studies to examine changes in perceptions over time and exploring the additional behavioral and also the external factors influencing sustainable transport adoption in different cities in Indian context. As, the results may vary across various geographic locations, a detailed study on heterogeneity of perception needs to be conducted across geographies, considering the road users' perspective for future analysis.

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