Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 8s (2025)

Applying the TOPSIS Method to Assess Public Transportation Performance: A Case Study of Telangana Public Transport Service

M.Tirumala Devi[1], Sameena Afreen[2], [*]V.Shyam Prasad[3], Abdul Majeed[4], and G.Mahender Reddy[5]

[1]Department of Mathematics, Kakatiya University, Warangal, Telangana, India. oramdevi@yahoo.com

[2]Research Scholar, Department of Mathematics, Kakatiya University, Warangal, Telangana, India, afreensama82@gmail.com ORCID ID: https://orcid.org/0000-0002-4162-0084

[*3]Neil Gogte Institute of Technology, Hyderabad, Telangana, India. Corresponding author: shyamnow4u@gmail.com ORCID ID: https://orcid.org/0000-0002-7966-1682

[4]Muffakham Jah college of Engineering & Technology, Hyderabad, Telangana, India. abdulmajeed.maths@mjcollege.ac.in ORCID ID: https://orcid.org/0000-0002-0286-0042

[5]Anurag University, Hyderabad, Telangana, India. mahender1563@yahoo.co.in ORCID ID: https://orcid.org/0000-0002-1387-0131

Article History:

***Received:** 28-10-2024*

***Revised:**12-11-2024*

***Accepted:**19-12-2024*

Abstract:

The Telangana government implemented a number of advancements in public transportation, including the Hyderabad Metro Rail, among others, to help with traffic issues in the twin cities of Hyderabad and Secunderabad. One of the chief goals of the government and the local operator has been to increase the standard of local urban transportation and thus push the envelope in terms of economy as well as the ease of commuter operation. Effective strategies are required to achieve sustainable growth in light of the complex issues related to traffic congestion and pollution. This study presents a computational framework for evaluating the consumer satisfaction of Telangana's current public transportation system in the above twin cities. The goal of the present study is how each mode of transportation performs in regard to each criterion, which can assist decision-makers and transit authorities in more efficiently allocating resources. For this it was used the additive normalization method and TOPSIS method to determine the optimal mode of transportation for a real-world case-study (Telangana, India). The results showed that metro rail performed better than other means of transportation in the given environment.

Keywords: Public transport; Analytical hierarchy process; Additive normalization method; TOPSIS method.

AMS Subject Classification: 90B06

1. Introduction

Every aspect of human life, including transportation, has been impacted by the spread of COVID-19. One of the industries that has recently experienced growth is public transportation. The most drastic changes during this time were explained by Aparicio et al., 2021; and Tirachini et al., 2020. People opt to use their cars more frequently during the COVID-19 pandemic than before. Due to this situation, demand for public transit decreased significantly, which negatively impacted earnings. This paper provides a computational approach for assessing Telangana's public transportation users' happiness in the post-COVID-19 environment. The present study closely observes the efficacy of the variety of commuting services available in Hyderabad and chooses the best alternative in terms of four criteria viz. Time, Distance, Fare and Eco-friendliness.

Public transportation performance measurement is the first step in solving complex problems since it is crucial for tracking, comparing performance over time, and continuously improving the transportation system. From the perspective of a transit agency, productivity, efficiency, and effectiveness are seen as performance indicators (Eboli et al., 2011); yet, a number of academics contend that the customer's perspective should be taken into account when evaluating the effectiveness of transportation systems.

Larger groups of people can use the local public transport system to travel together on prearranged itineraries. Cars, taxis, trains, and buses are examples of public transit vehicles. With National Highways- NH44,65, 163, 765, and- 765D, Hyderabad is connected to the Indian National Highway Network, while four State Highways- SH1, 4, 6, and 19- start and end in Hyderabad. After Delhi, Bangalore, Chennai, and Mumbai, Hyderabad had the most vehicles, with an approximate population of more than 48 lakh people.

Cab(A_1): Cabs are used for transportation services provided by private companies. As a vital form of transportation, cab services provide an array of benefits from being an all-purpose means of transportation to providing basic mobility in an emergency, from catering to the needs of those who cannot drive them to addressing the mobility issues of tourists and other visitors along with point-to-point hassle-free transport services. Uber, Ola Cabs, and taxicabs are all available for hiring in Hyderabad. Taxis operated by Ola and Uber are rapidly disappearing from Hyderabad's roads. In the past, these two businesses operated approximately 1,20,000 cabs in the twin towns of Secunderabad and Hyderabad. However, they are presently only 40,000 strong.

Hyderabad Metro Rail(HMR)(A_2): The Hyderabad Metro Rail, sometimes referred to as the city's elevated mass rapid transit system, first went into service in 2017. The initial phase of operation ran two lines 30 kilometre from Nagole and Miyapur via the Ameerpet Interchange Station. To supply the existing transit networks, Metro Stations have been built in strategic locations throughout the city. However, it faced criticism for failing to meet its objectives as well as for its sporadic service and expensive costs. Since their inception, the frequency of these services has increased to compensate for their historically low frequency.

HMR Project Summary:

- It spans 72 kilometres across Hyderabad and is the largest public private partnership (PPP) in the metro rail industry in the world.
- The HMR has 3 lines- Blue, Green, and Red- and is well connected to the bus stops and Hyderabad Multi-Model Transportation System(MMTS) stations that are already located along the corridors as well as to the existing Indian railway terminals. The Nagole to Raidurg station, which includes the Secunderabad station on the 27 kilometre, two-phase Hyderabad Metro is made up of the Blue Line and covers 23 kilometre. The distaances from Jubilee Bus Station to Falaknuma, which are 15 kilometre apart are included in the green line. From Miyapur to LB Nagar, the red line spans 27 stations over a distance of 29 kilometers.
- Utilising communication-based train control (CBTC) and regenerative braking technology (RBT), an industry-leading, environmentally friendly, fully automated transportation system is built.

City Bus(A_3)**:** A significant intracity, intercity/regional, and interstate bus service network is managed by the Telangana State Road Transport Corporation (TSRTC), which is funded by the Telangana government, in Hyderabad and Secunderabad. The TSRTC operates intercity and interstate buses from a number of bus stops inside the city's municipal boundaries. From their various depots, which are in charge of staffing and service frequency, city buses are deployed. City and suburban buses are the main modes of transportation in Secunderabad and Hyderabad. The TSRTC provides a range of services with varying levels of comfort, prices, and stops.

- Metro Luxury
- Metro Deluxe
- Metro Express
- City Ordinary

Auto(A_4): Another widely used mode of transportation in Hyderabad and Secunderabad is the rickshaw, also referred to as an "Auto". Because they are slow and their carriages are exposed to air pollution, auto rickshaws are more appropriate for short trips within cities and towns. Autos are convenient and affordable modes of transportation. Almost 1.2 lakh CNG or LPG autos and 40,000 diesel autos are registered within the municipal limits, but just 5,000 are registered beyond the GHMC limits.

2. Literature review

The three primary methods for assessing the efficacy of public transport systems are data envelopment analysis (DEA), analytical hierarchy process (AHP), and stochastic frontier analysis (SFA). Only assessing production efficiency in accordance with economic theory is the sole goal shared by DEA and SFA. Public policy, strategy, planning, performance-related difficulties, and many more fields are among the application areas of AHP. According to these findings, the AHP model serves as a very useful tool for the government as it facilitates the monitoring process and thus paves the way for the improvement of public transport networks. The goal of this project is to develop a criterion matrix that will help decision-makers evaluate and enhance the operation of public transport networks by utilizing the AHP model.

In a paper "Evaluating Performance of Public Transport Networks by Using Public Transport Criteria Matrix Analytic Hierarchy Process Models- Case Study of Stonington, Bays water, and Cockburn Public Transport Network" (Gang Lin et al., 2021), it is observed that there is a direct link between traffic congestion and the threat of life that crept into people's minds during the COVID-19 pandemic. The complicated difficulties related to traffic congestion and pollution and the need for efficient techniques to accomplish sustainable growth are well discussed in the paper titled "An Integrated Approach of Multi-Criteria Decision-Making and Grey Theory for Evaluating Urban Public Transportation Systems" (Ahmad et al., 2021). The results of the present study are also consistent with those of other transport models.

Due to the growing usage of private vehicles and the ensuing environmental impact, metropolitan centres in many countries are dealing with a variety of major issues (Loukopoulos et al., 2005). One important tactic for solving these issues is to use public transport (Wang, 2015). A guide for sustainable urban and territorial development, published in the year 2015 by the United Nations Human Settlements Program, includes recommendations for promoting public transportation. Unfortunately, it can be challenging to gauge how beneficial these measures are. Thus, it is crucial to measure public transportation performance accurately.

Among the measurement methods used to assess public transportation are the Monte Carlo simulation method (Barabino et al., 2020), joint working methods (Silva et al., 2019), and the public transport accessibility indicator (Tiznado-Aitken et al., 2021). A decrease in private automobiles leads to a decrease in traffic and pollution (noise and air) when a city's public transport system is developed to the point that people start depending on it rather than having personal vehicles (Bull, 2004).

Both the local and national economies is benefitted from the improvement and growth of public transportation. Both the drivers of private vehicles and the users of public transportation can save time and money as a result of the developed transit service and increased company productivity. In addition, once advanced and fully- equipped, public transportation infrastructure improves access to business centers and generates jobs, while capital expenditure and operational spending stimulate the economy as a whole.

The impact of physical aspects of services on patron satisfaction in the public transportation industry was assessed by Pantouvakis, 2008. It was discussed how important physical and interactive service components are in relation to total customer satisfaction, both from the perspective of new and returning consumers.

The following four alternatives and four criteria have been taken into account in the current study.

Alternatives	**Criteria**
Cab(A_1)	Time(C_1)
Hyderabad Metro Rail(HMR)(A_2)	Distance(C_2)
City Bus(A_3)	Fare(C_3)
Auto(A_4)	Eco friendly(C_4)

Alternatives	**Physical importance**
Cab(A_1)	About the same thing is meant by the words taxi and cab. The words "taxicab" are the origin of the two terms. Cabs are rented vehicles used to carry people from one location to a predetermined destination for a price, similar to taxis.
Hyderabad Metro Rail(A_2)	A fast transit system that serves the city of Hyderabad, Telangana, India is the Hyderabad Metro.
City Bus(A_3)	Hyderabad local buses are operated by Telangana State Road Transport Company, a public transportation company in Hyderabad.
Auto(A_4)	A three-wheeled motorized public conveyance, such as a motorbike that has been modified, generally with a two-passenger cab installed behind the driver.

Table 1: Physical importance of different modes of transport used in Telangana public transport

Criteria	**Physical importance**
Time(C_1)	Time is something that everyone is familiar with, even though it can be challenging to explain and understand. In spite of the fact that time is defined variously in science, philosophy, religion, and the arts, the system for measuring it remains the same.
Distance(C_2)	Distance is the entirety of an object's movement, regardless of direction. Distance is the amount of space an object has travelled, regardless of its beginning and ending points.
Fare(C_3)	The price a person must pay to utilize a bus, rail, or taxi is known as their fare. The phrase airfare is frequently used in relation to air travel. The system in place to decide how much each individual passenger utilizing a transit vehicle at any particular moment is required to pay is known as the fare structure.
Eco friendly(C_4)	This introduces the idea of "green transportation," which is any form of transportation or vehicle that respects the environment and does not have a negative impact on the nearby environment. Vehicles with a low environmental impact are referred to as green transportation.

Table 2: Physical importance of each benchmarking tool used in Telangana Public Transport

The ratio scale is displayed in Table 3, which is used to compare the significance weights between criteria in accordance with the linguistic meaning of 1 to 9, which represents equal significance to extreme importance.

Crisp No	**1**	**3**	**5**	**7**	**9**	**2,4,6,8**
Definition	Equally important	Moderately important	Strongly important	Demonstrated	Extremely important	Intermediate values

Table 3: Scale of ratios in the analytic hierarchy process

Two indicators are proposed: the consistency ratio (C.R.) and the consistency index (C.I.) to guarantee the consistency of the subjective impressions and the accuracy of the comparison weights. The C.I.'s equation appears as follows:

$$\mathrm{C.I} = \frac{\mathrm{E_{max}} - \mathrm{n}}{\mathrm{n} - 1} \tag{1}$$

where E_{max} is the largest eigen value and *n* is the number of attributes.

Table 4 displays the R.I. (Saaty, 1987) with regard to various size matrices.

Scale of the matrix (n)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
R.I	0.52	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4: For various size matrices, the random index (R.I)

The C.R., however, can be calculated as:

$$\mathrm{C.R} = \frac{\mathrm{C.I}}{\mathrm{R.I}} \tag{2}$$

For a reliable outcome, comparisons are deemed internally consistent when $\mathrm{C.R} \leq 0.1$; if not, it would be assumed that there was a comparison procedure inconsistency. This study builds a comprehensive multi-criteria public transport network performance evaluation model for different application levels using the AHP model.

3. Methodology

The three steps make up the suggested integrated method. First, the criteria and alternatives will be chosen and decided upon through a thorough literature analysis. The weights of each criterion are calculated here using the additive normalization method, and the ranking of public transportation in Telangana State is determined using the TOPSIS method.

3.1 Additive normalization method

To produce the priority vector w_i using this method, it is sufficient to normalize each column of matrix A, add the elements in each resulting row, and then divide the sum by the quantity of the elements in each row. Relations (3) and (4) describe how this process works.

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij,}}, \qquad i, j = 1, 2, 3, \ldots\ldots..n \tag{3}$$

$$w_i = \left(\frac{1}{n}\right) \sum_{j=1}^{n} a'_{ij,} \qquad i = 1, 2, 3, \ldots\ldots..n \tag{4}$$

3.2 TOPSIS Method (Hwang and Yoon, 1981)

To choose the optimal option based on the ideas of the compromise solution, Hwang et al., (1981) created TOPSIS. The compromise option is to choose the option that is the farthest from both the negative ideal solution and the solution that is the closest to the ideal solution in Euclidean space. TOPSIS is a method for calculating the weights of options in relation to a criterion. AHP requests pairwise criterion comparisons and provides a decision hierarchy. The positive ideal solution shows the best results attainable for every criterion, whereas the negative ideal solution shows the worst outcomes conceivable for every criterion. To determine the final ranking of the various public transportation services in the state of Telangana, the TOPSIS technique was used in this study.

A decision matrix that has been normalized as

$$u_{ij} = \frac{w_{ij}}{\sqrt{\sum_{j=1}^{m} w_{ij}^2}}, i = 1,2,3, \ldots.., n \qquad (5)$$

This matrix is called the weighted normalized decision matrix.

$$v_{ij} = w_{ij} * u_{ij}, j = 1,2,3, \ldots., m; i = 1,2,3, \ldots.., n \qquad (6)$$

The ‘Positive ideal solution (PIS)’, and ‘Negative ideal solution (NIS)’ are explained below:

$V^* = \{v_1^*, v_2^*, \ldots.., v_n^*\}$ Maximum values and $V^- = \{v_1^-, v_2^-, \ldots.., v_n^-\}$ minimum values

Each alternative's separation from the PIS and NIS is:

$$d_{ij}^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2}, \; j = 1,2,3, \ldots., m \qquad (7)$$

$$d_{ij}^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \; i = 1,2,3, \ldots., m \qquad (8)$$

The ‘closeness coefficient’ of each alternative is:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1,2,3, \ldots \ldots, m \qquad (9)$$

CC_i values are compared to determine the ‘ranking of alternatives’.

3.3 Results and Findings

The priority vectors for each criterion were determined using the additive normalization approach, and the ranking of the alternatives was determined using the TOPSIS method. The outcomes for the priority vector for pairwise comparisons of criteria to criteria are provided in Tables 5 through Table 8 and Table 9.

Criterion 1	**Cab**	**HMR**	**City Bus**	**Auto**	**Priority vectors**	**C.R**
Cab	1	1/3	3	3	0.240	
HMR	3	1	5	7	0.577	0.023
City Bus	1/3	1/5	1	2	0.112	
Auto	1/3	1/7	½	1	0.071	

Table 5: Comparisons of all option pairs based on the time criterion

Criterion 2	Cab	HMR	City Bus	Auto	Priority vectors	C.R
Cab	1	½	3	1	0.246	
HMR	2	1	3	4	0.471	0.052
City Bus	1/3	1/3	1	1	0.125	
Auto	1	¼	1	1	0.154	

Table 6: Comparisons of all option pairs according to the distance criterion

Criterion 3	Cab	HMR	City Bus	Auto	Priority vectors	C.R
Cab	1	1/7	1/5	1/3	0.058	
HMR	7	1	1	5	0.430	0.044
City Bus	5	1	1	5	0.399	
Auto	3	1/5	1/5	1	0.110	

Table 7: Comparisons of all options in pairs according to the Fare criterion

Criterion 4	Cab	HMR	City Bus	Auto	Priority vectors	C.R
Cab	1	½	3	5	0.334	
HMR	2	1	3	4	0.444	0.035
City Bus	1/3	1/3	1	2	0.137	
Auto	1/5	¼	½	1	0.081	

Table 8: Pairwise comparisons of all alternatives with respect to the eco-friendly criterion

	Time	Distance	Fare	Eco friendly	Priority vectors	C.R
Time	1	3	1/3	1/5	0.150	
Distance	1/3	1	1/3	1/3	0.093	0.090
Fare	3	3	1	3	0.446	
Eco friendly	5	3	1/3	1	0.305	

Table 9: Pairwise comparisons between criteria and criteria

The rankings of alternatives according to the additive normalization method and TOPSIS method are given in Table 10.

	1.039 Time	0.093 Distance	0.446 Fare	0.305 Eco friendly	Weights	Ranking
Cab	0.240	0.246	0.058	0.334	0.319	3
HMR	0.577	0.471	0.430	0.444	1.000	1
City Bus	0.112	0.125	0.399	0.137	0.555	2
Auto	0.071	0.154	0.110	0.081	0.108	4

Table 10: Ranking of Alternatives

Figure 1 demonstrates the various Rankings of Alternatives by ANM and TOPSIS

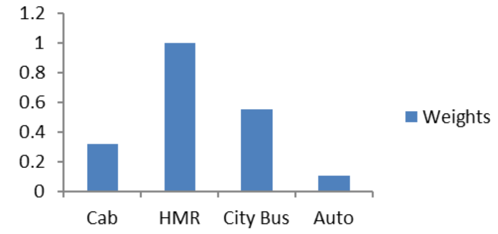

Figure 1: Ranking of Alternatives

4. Conclusion

In order to assess public transportation's effectiveness in terms of cost, time, distance, and environmental impact, AHP techniques were employed in this study. The weights of the criteria were determined using the additive normalization approach, and the ultimate ranking of the alternatives was determined using the TOPSIS method. The outcomes of the new assessment technique, which assigns a city's public transportation performance a grade based on existing standards. Therefore, this is the recommended order for the selections:

Hyderabad Metro Rail> City Bus> Cab >Auto

It is clear from the results above that the Hyderabad Metro Rail (1.000) was the most common rail, followed by the City Bus (0.555) and the Cab (0.319). Auto (0.108) was ranked fourth at the end.

The results of this study can be used to inform future public transportation planners on how to improve public transit. To put it more precisely, the defined model and standards can effectively assist in maximizing the scope of available resources. Governments can also use the results to suggest policies and guidelines that will increase the efficiency of urban public transportation systems. Future studies can adapt this strategy to a number of other locations by including more evaluation criteria and benchmarks.

References

[1] A. Ahmad, M. Sarbast, O. Laila and D. Szabolcs. An Integrated Approach of Multi- Criteria Decision-Making and Grey Theory for Evaluating Urban Public Transportation Systems. Sustainability, 13 (2021), 2740. https://www.mdpi.com/2071-1050/13/5/2740

[2] A. Bull, Traffic congestion : the problem and how to deal with it? ECLAC: Santiago. Chile, (2004). https://searchworks.stanford.edu/view/5646949

[3] A. Pantouvakis and K. Lymperopoulos, Customer satisfaction and loyalty in the eyes of new and repeat customers: Evidence from the transport sector. Manag. Serv. Qual., 18 (2008), 623–643. https://www.researchgate.net/publication/235250076

[4] A. Tirachini and O. Cats, COVID-19 and Public Transportation: Current Assessment, Prospects, and Research Needs. J. Public Transp, 22 (1), (2020). https://digitalcommons.usf.edu/jpt/vol22/iss1/1/

[5] B. Barabino, N. A. Cabras, C. Conversano and A. Olivo, An Integrated Approach to Select Key Quality Indicators in Transit Services. Soc. Indic. Res., 149 (2020), 1045–1080. https://ideas.repec.org/a/spr/soinre/v149y2020i3d10.1007_s11205-020-02284-0.html

[6] C. Silva, L. Bertolini and N. Pinto, Designing Accessibility Instruments: Lessons on Their Usability for Integrated Land Use and Transport Planning Practices. Routledge: New York, (2019). https://doi.org/10.4324/9781315463612

[7] C. L. Hwang and K. Yoon, Methods for Multiple Attribute Decision Making. (1981), 58–191. https://link.springer.com/chapter/10.1007/978-3-642-48318-9_3

[8] Gang Lin, Shaoli Wang, Conghua Lin, Linshan Bu and Honglei Xu, Evaluating Performance of Public Transport Networks by Using Public Transport Criteria Matrix Analytic Hierarchy Process Models—Case Study of

Stonnington, Bayswater, and Cockburn Public Transport Network. Sustainability, 13 (2021), 6949: 1-17. https://www.mdpi.com/2071-1050/13/12/6949

[9] I. Tiznado-Aitken, J. C. Muñoz and R. Hurtubia, Public transport accessibility accounting for level of service and competition for urban opportunities: An equity analysis for education in Santiago de Chile. J. Transp. Geogr., 90 (2021), 102919. https://www.worldtransitresearch.info/research/8365/

[10] J. T. Aparicio, E. Arsenio and R. Henriques, Understanding the Impacts of the COVID-19 Pandemic on Public Transportation Travel Patterns in the City of Lisbon. Sustainability, 13 (15) (2021), 8342. https://www.mdpi.com/2071-1050/13/15/8342

[11] L. Eboli and G. Mazzulla, A methodology for evaluating transit service quality based on subjective and objective measures from the passenger's point of view. Transp. Policy, 18 (2011), 172–181. https://ideas.repec.org/a/eee/trapol/v18y2011i1p172-181.html

[12] P. Loukopoulos, C. Jakobsson Bergstad, T. Gärling, C. M. Schneider and S. Fujii, Public attitudes towards policy measures for reducing private car use: Evidence from a study in Sweden. Environ. Sci.Policy, 8 (2005), 57–66. https://www.researchgate.net/publication/222371172

[13] R. W. Saaty, The analytic hierarchy process—what it is and how it is used. Math. Model. 9 (1987), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

[14] S. Wang, The function of individual factors on travel behaviour: comparative studies on Perth and Shanghai. Proceedings of the State of Australian Cities Conference , Gold Coast, Australia, (2015), 9–11.https://apo.org.au/node/63291