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An Analytical Study of Key Determinants Influencing Sustainability in Urban Metro Rail Systems: A Case Study of the Delhi Metro

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***Abstract* – This study examines the key determinants influencing sustainability in urban metro rail systems, with a focused case analysis of the Delhi Metro. Rapid urban growth, rising travel demand, and environmental concerns have made sustainable mass transit essential for Indian cities. The Delhi Metro plays a major role in reducing traffic congestion, lowering air pollution, and supporting efficient urban mobility across the National Capital Region. This research evaluates how service quality, operational performance, connectivity, and environmental factors shape the overall sustainability of the metro system from the commuter's perspective, while also considering demographic diversity across age, gender, and residential locations. The study adopts a mixed-method approach using a structured questionnaire based on a five-point Likert scale, supported by secondary data from official reports. Primary data were collected from 421 metro users across NCR, and statistical analysis was conducted using SPSS through descriptive statistics, correlation, and regression techniques. The findings reveal that sustainability in the Delhi Metro is significantly influenced by multiple factors, with passenger comfort and safety emerging as the strongest determinant, followed by connectivity and traffic congestion reduction. Environmental factors such as lower energy use and reduced air pollution also contribute positively. The regression model confirms overall statistical significance, leading to the rejection of the null hypothesis. The study concludes that user-oriented service quality, network reach, and environmental performance are central to strengthening the long-term sustainability of urban metro rail systems like the Delhi Metro.**
Keywords* – *Urban Metro Rail Systems, Delhi Metro, Sustainable Mass Transit, Traffic Congestion, Air Pollution, Urban Mobility and NCR.

I. INTRODUCTION

Urban metro rail systems play a key role in building sustainable cities. They reduce road congestion, cut fuel use, and lower air pollution. In fast-growing cities like Delhi, the metro has become a major travel option for daily commuters. Sustainability in metro systems depends on travel behavior, service quality, and user demand patterns. Studies on the Delhi Metro show that factors such as age, income, trip purpose, travel distance, and access to stations strongly affect ridership choices. Ranjan, Lal, and Susaeta (2016) found that individual and trip characteristics shape metro usage more than generalized policy measures. Their analysis highlights how reliable service, travel time savings, and comfort influence commuter preference for the metro over private vehicles. These insights show that sustainability is not only a technical issue but also a behavioral one, linked closely to user perception and travel needs.

Demand for public transport is another critical determinant of long-term metro sustainability. Rahman and Balijepalli (2016) examined suburban rail systems in India and identified income level, fare sensitivity, service frequency, and connectivity as key demand drivers. Although their study focused on suburban rail, the findings are highly relevant to metro systems like the Delhi Metro. Strong demand ensures financial stability, efficient capacity use, and reduced dependence on subsidies. In Delhi, rising ridership indicates positive acceptance, but sustained growth depends on affordability, network integration, and last-mile connectivity. Understanding these demand-side factors helps planners improve service design and policy decisions.

Overview of the Delhi Metro Rail System

The Delhi Metro Rail System is one of India's largest and most influential urban transport projects. It was developed to address rising traffic congestion, air pollution, and heavy dependence on private vehicles in the National Capital Region. The system provides high-capacity, reliable, and time-efficient transport across Delhi and surrounding cities. Goel and Sharma highlight that the Delhi Metro has played a major role in reducing private vehicle use by offering a safer, faster, and more predictable travel option. The metro's wide network coverage, punctual operations, and affordable fares have encouraged commuters to shift from cars and two-wheelers to public transport. This shift has contributed to lower fuel consumption, reduced emissions, and improved urban mobility, supporting broader sustainability goals.

Beyond network expansion, the effectiveness of the Delhi Metro depends strongly on station design and service quality. Saygaonkar, Swami, and Parida emphasize the importance of station area planning in improving multimodal integration. Well-designed stations support smooth transfers between metro services, buses, feeder services, walking, and cycling. Features such as clear signage, pedestrian-friendly access, and organized interchange spaces improve overall system efficiency. In addition, commuter satisfaction plays a key role in sustained ridership. Srivastava and Upadhyaya found that factors such as platform cleanliness, safety, information availability, and staff behavior significantly influence user satisfaction levels. High satisfaction strengthens public trust and encourages regular use of the metro system. Together, integrated station design and quality platform services enhance the attractiveness and long-term performance of the Delhi Metro. These aspects make the system not only a transport solution but also a critical component of sustainable urban development in Delhi.

Urbanization and Rising Transport Demand

Rapid urbanization in Delhi has led to sharp growth in population, economic activity, and daily travel needs, placing intense pressure on urban transport systems. Expanding residential zones, job centers, and education hubs have increased average trip lengths and travel frequency. Das and Parikh (2004) earlier warned that unchecked urban growth in metropolitan cities like Delhi would result in higher private vehicle ownership, energy use, and emissions if public transport capacity did not expand in parallel. In response to these challenges, the Delhi Metro emerged as a critical mass rapid transit solution. Rahman (2017) shows that the metro has reshaped travel patterns by absorbing a large share of peak-hour demand and reducing road-based congestion. The system supports compact urban growth by improving accessibility across distant city zones. More recently, Begam et al. (2024) highlight how the Delhi Metro has driven urban transformation by influencing land use, encouraging transit-oriented development, and improving mobility equity. Rising transport demand in Delhi is therefore closely linked to urban expansion, but its impacts are moderated by the presence of a strong metro network. The Delhi Metro helps balance growth with mobility needs by offering a high-capacity, low-emission alternative to private transport. This makes it a key instrument for managing the sustainability challenges created by rapid urbanization.

Sustainability Issues in Urban Public Transport Systems

Urban public transport systems face multiple sustainability challenges due to rapid urban growth and rising mobility needs. These challenges affect environmental quality, social equity, system governance, and long-term service efficiency. Addressing them is essential for ensuring that metro and public transport systems support inclusive, low-carbon, and resilient urban development (Begam et al., 2024).

- **Environmental impacts and emissions:** Urban transport systems contribute to air pollution and energy use when private vehicles dominate travel. Although metro systems reduce emissions per passenger, their benefits depend on ridership levels and energy sources. Doll and Balaban (2013) show that environmental gains increase only when metro systems replace high car usage at scale.
- **Governance and institutional coordination:** Weak coordination between transport agencies, land planners, and local governments reduces system efficiency. Policy gaps delay integration between metro, buses, and non-motorized transport. Rani (2022) argues that poor governance and fragmented decision-making undermine sustainable transport outcomes in large metropolitan regions like Delhi.
- **Urban form and land-use pressure:** Rapid urban expansion increases travel distances and system load. Without transit-oriented development, metro systems struggle to manage demand efficiently. Begam et al. (2024) highlight that unplanned growth around stations reduces sustainability gains by increasing congestion and limiting balanced land-use development near transit corridors.

Metro Rail as a Sustainable Urban Transport Solution

Metro rail systems offer a practical and sustainable solution to growing urban transport demand in large cities. They provide high-capacity mobility while using less energy per passenger and producing lower emissions than road-based transport. By shifting trips from private vehicles to public transport, metro systems help reduce congestion, air pollution, and fuel consumption. Sharma, Newman, and Matan (2015) describe urban rail as a major opportunity for guiding Indian cities toward sustainable development, as it supports compact urban form and efficient land use. Reliable travel times, safety, and comfort further strengthen public acceptance of metro services. The Delhi Metro illustrates these benefits in practice. According to Begam et al. (2024), the system has transformed urban mobility by improving access to jobs, education, and services across the city. It has encouraged development around stations and improved mobility for lower-income groups through affordable fares. Environmental gains arise from reduced road traffic and lower citywide emissions. Social gains include time savings and better travel quality. However, long-term sustainability depends on strong integration with buses, walking, and cycling networks.

Key Determinants of Sustainability in Metro Rail Systems

Sustainability in metro rail systems depends on a balanced interaction between operational efficiency, infrastructure quality, governance, and user satisfaction. High service reliability, optimal train frequency, and effective crowd management directly influence ridership levels and energy efficiency. Infrastructure condition, including track quality, rolling stock maintenance, and station facilities, plays a key role in ensuring safe and uninterrupted operations. Khursheed, Kidwai, and Paul (2025) emphasize that sustainability outcomes improve when infrastructure planning is closely linked with project management practices and performance monitoring. Financial sustainability is another critical determinant, shaped by fare policies, operational costs, and long-term funding mechanisms. Environmental performance depends on energy-efficient systems, regenerative braking, and reduced dependence on road-based transport. Social sustainability is influenced by affordability, accessibility, and passenger comfort, which determine public acceptance of metro services. Governance and coordination among transport agencies further affect integration with other modes and land-use planning. The study on the Delhi Metro Blue Line shows that sustainability is strongest when technical, managerial, and social factors are addressed together. Therefore, metro rail sustainability is not driven by a single factor but by the combined performance of operational, institutional, and user-oriented determinants.

Environmental, Social, and Economic Dimensions of Sustainability

- **Environmental Dimension of Sustainability:** The environmental dimension emphasizes emission reduction, energy efficiency, and lower pollution levels. Metro rail systems replace private vehicle trips, leading to reduced fuel consumption and improved air quality. A social cost–benefit analysis of the Delhi Metro confirms significant environmental gains through lower emissions and accident reduction (MN et al., 2006). Similar outcomes are observed after metro expansion in Mumbai (Abhijna et al., 2025).
- **Social Dimension of Sustainability:** Social sustainability focuses on accessibility, equity, safety, and commuter well-being. Metro systems improve access to employment, education, and services for diverse income groups. The Delhi Metro has delivered major social benefits through time savings, safer travel, and reliable mobility (MN et al., 2006). Improved comfort and positive user perception after new metro lines further strengthen social outcomes (Abhijna et al., 2025).
- **Economic Dimension of Sustainability:** Economic sustainability relates to cost efficiency, productivity gains, and long-term financial benefits. Metro rail systems reduce congestion costs, travel delays, and accident-related losses. The Delhi Metro showed positive net economic returns due to reduced external costs and higher productivity (MN et al., 2006). Metro expansion studies also report household cost savings and stable ridership growth (Abhijna et al., 2025).

II. Systematic Literature Review

Begam et al. (2024) provide a recent and comprehensive perspective on how metro rail systems contribute to sustainable urban transformation, using the Delhi Metro as a core case. Their work frames metro rail as more than a transport project, emphasizing its influence on land use, accessibility, and long-term mobility behavior. Earlier studies on Delhi Metro travel behavior show that individual characteristics such as income, age, and trip purpose strongly shape ridership patterns, reinforcing the need for user-centered planning (Ranjan et al., 2016). Demand-focused research further confirms that service frequency, affordability, and connectivity determine sustained public transport usage (Rahman & Balijepalli, 2016). These findings collectively suggest that sustainability outcomes depend on how effectively metro systems respond to real travel needs. The literature also highlights the role of metro networks in reducing private vehicle dependency, which directly supports environmental and congestion-related goals (Goel & Sharma, 2016). Begam et al. integrate these behavioral and demand-side insights with urban development outcomes, showing that metro-led accessibility can reshape city structure. As a result, sustainability is presented as an outcome of combined mobility, land-use, and behavioral change rather than infrastructure expansion alone.

Chaudhari et al. (2025) focus explicitly on inclusion and equity in Delhi's transport system, adding a strong social sustainability lens to metro rail research. Their analysis shows that accessibility gaps persist despite metro expansion, particularly for women, elderly users, and low-income populations. Earlier studies on urban growth and MRTS development confirm that metro systems can manage rising travel demand but may not equally serve all social groups (Rahman, 2017). Research on commuter satisfaction highlights safety, cleanliness, and information availability as critical for inclusive use (Srivastava & Upadhyaya, 2016). Chaudhari et al. argue that without universal access, affordability, and safe station environments, sustainability remains partial. Evidence from transport scenario studies in Delhi and Mumbai also shows that unequal access encourages continued private vehicle use among excluded groups (Das & Parikh, 2004). By linking social equity with sustainability, recent literature broadens the evaluation framework beyond ridership and emissions.

Khursheed et al. (2025) introduce a performance-based sustainability framework using a PLS-SEM model applied to the Delhi Metro Blue Line. Their study integrates infrastructure quality, operational efficiency, and project management into a unified sustainability assessment. Earlier metro studies often addressed these dimensions separately, such as demand behavior (Ranjan et al., 2016) or environmental benefits (Doll & Balaban, 2013). Khursheed et al. demonstrate that sustainability improves when technical systems and management practices are aligned. Financial stability, service reliability, and maintenance planning emerge as strong predictors of long-term performance. Research on reducing private transport dependency supports this integrated view, showing that consistent service quality drives mode shift (Goel & Sharma, 2016). The literature increasingly supports quantitative, model-based evaluation to capture complex sustainability interactions. This shift reflects a move from descriptive analysis toward decision-support tools for metro planning and optimization.

Abhijna et al. (2025) extend sustainability analysis through before–after studies of metro expansion, providing empirical evidence on behavioral and environmental change. Their work in the Mumbai Metropolitan Region complements Delhi-focused research by confirming reductions in emissions and private vehicle use after new metro lines open. Earlier social cost–benefit analysis of the Delhi Metro also reported positive economic and environmental returns, including time savings and accident reduction (MN et al., 2006). Combined with Delhi-based studies, this literature confirms that metro systems deliver measurable sustainability gains when ridership reaches scale. Urban transformation research further shows that these benefits strengthen when metro expansion aligns with land-use planning (Begam et al., 2024). Overall, recent literature converges on a multi-dimensional view of sustainability, integrating environmental, social, economic, and governance factors.

III. PROBLEM STATEMENT

Rapid urban growth in Delhi has increased pressure on public transport systems. The Delhi Metro plays a vital role in meeting this demand, yet long-term sustainability remains a concern. Issues such as uneven ridership growth, last-mile gaps, service quality variation, energy use, and governance challenges affect system performance. Past studies often examine these factors in isolation. There is a clear need for an integrated analysis that identifies how operational, social, environmental, and economic factors together influence metro sustainability. Without such understanding, planning decisions may fail to deliver lasting benefits.

IV. SIGNIFICANCE OF THE STUDY

This study is important because it provides a structured analysis of key factors that shape metro rail sustainability. By focusing on the Delhi Metro, the study offers practical insights for planners and policy makers. It helps identify which factors most strongly support long-term performance and public acceptance. The findings can guide better planning, service improvement, and policy coordination. The study also adds value to academic research by linking sustainability dimensions in a single framework. Its outcomes may support future metro projects in Indian cities facing similar urban transport challenges.

V. Objective

- To analyze the impact of various factors influencing the sustainability of the Delhi Metro

VI. Hypothesis

- H0: There is no significant impact of various factors on the sustainability practices of the Delhi Metro.
- H1: There is a significant impact of various factors on the sustainability practices of the Delhi Metro.

VII. METHODOLOGY

This methodology explains the planned steps used to study the sustainability of the Delhi Metro Rail system. A clear and systematic process was followed to collect and analyze data in an organized manner. The study used a mixed-method approach, combining quantitative survey data with qualitative secondary information to assess environmental, operational, and financial sustainability. Quantitative data were collected from metro users through a structured questionnaire, while qualitative data were obtained from official reports and policy documents.

Research Method

A structured survey method was used to collect standardized and measurable responses from Delhi Metro users. A questionnaire based on a 5-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5) was designed. The survey measured commuter perceptions related to environmental sustainability, fare affordability, service efficiency, operational reliability, and overall satisfaction. The questionnaire also included demographic details such as gender, age group, income level, occupation, education, and area of residence to support subgroup analysis.

Research Strategy

A cross-sectional research strategy was adopted, where data were collected at a single point in time. This strategy helped in assessing the current sustainability performance of the Delhi Metro system. Correlation and regression analyses were applied to examine relationships between sustainability initiatives and outcomes such as ridership satisfaction, operational efficiency, and financial stability. This approach enabled meaningful comparisons without requiring long-term tracking.

Designing the Questionnaire

The questionnaire was designed in line with the study objectives and key sustainability dimensions. Items were framed to capture perceptions of environmental impact, operational performance, and financial aspects of the Delhi Metro. All questions were kept clear and simple to ensure easy understanding by respondents. The questionnaire was reviewed and refined before final administration to ensure relevance and consistency.

Sampling Design

Convenience sampling, supported by a snowball sampling technique, was used to select Delhi Metro users from various stations across the National Capital Region. Initial respondents were requested to refer other regular metro users, enabling wider participation. A total of 421 responses were collected through Google Forms and in-person interactions.

Data Collection

Primary data were collected using an online Google survey in Delhi, Gurugram, Noida, Faridabad, Ghaziabad, Bahadurgarh, and Ballabhgarh. Respondents were informed about the purpose of the study, and participation was voluntary. Confidentiality and anonymity were ensured. DMRC publications, policy documents, and academic literature to support analysis and interpretation.

Type of Study

Snowball sampling will recruit eligible participants through referrals, collecting cross-sectional data at one time using a five-point Likert scale.

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Data Analysis

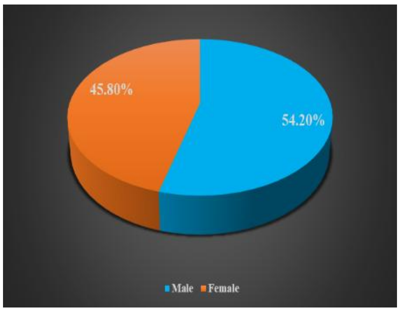
Data analysis was conducted using SPSS software. Descriptive statistics were used to summarize demographic details and general response patterns. Correlation analysis examined relationships between sustainability factors, such as fare affordability and commuter satisfaction. Regression analysis was applied to assess the influence of environmental, operational, and financial sustainability practices on overall system performance. The use of SPSS ensured accurate, systematic, and objective analysis.

VIII.Results

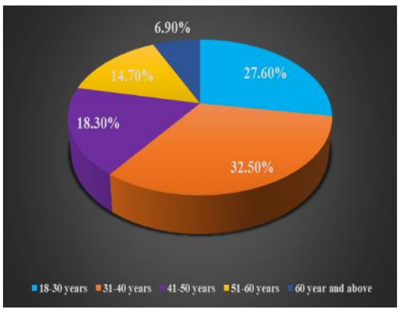
Table 1: Demography

Category	Parameters	Frequency	Percent	Category	Parameters	Frequency	Percent
Gender	Male	228	54.2	Area	Delhi	195	46.3
	Female	193	45.8		Gurugram	83	19.7
	Total	421	100.0		Noida	56	13.3
					Faridabad	25	5.9
Age	18-30 years	116	27.6		Ghaziabad	28	6.7
	31-40 years	137	32.5		Bahadurgarh	18	4.3
	41-50 years	77	18.3		Ballabhgarh	16	3.8
	51-60 years	62	14.7		Total	421	100.0
	60 years & above	29	6.9				
	Total	421	100.0				

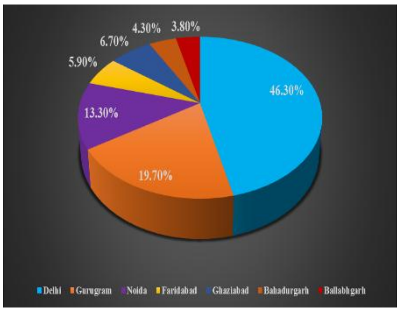
The survey includes 421 respondents and presents both frequency and percent distribution. Gender-wise, 228 respondents (54.2%) are male and 193 (45.8%) are female, showing near balance. Age analysis shows that 31–40 years form the largest group with 137 respondents (32.5%), followed by 18–30 years with 116 (27.6%). The 41–50 years group includes 77 respondents (18.3%), while 51–60 years accounts for 62 (14.7%). Respondents aged 60 years and above are 29 (6.9%). Area-wise, Delhi contributes 195 respondents (46.3%), followed by Gurugram with 83 (19.7%) and Noida with 56 (13.3%). Smaller shares come from Faridabad 25 (5.9%), Ghaziabad 28 (6.7%), Bahadurgarh 18 (4.3%), and Ballabhgarh 16 (3.8%), indicating wide NCR coverage.



Gender



Age



Area

Figure 1: Demography

Table 2: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.529	.280	.263	1.139

a. Predictors: (Constant), Passenger Comfort and Safety, Government Support and Policies, Affordability of Fares, Delhi Metro's Connectivity, Reduced Traffic Congestion, Operational Efficiency, Regular Maintenance, Reducing Air Pollution, Design and Infrastructure, Energy Consumption

Table 3: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	207.211	10	20.721	15.958	.000
	Residual	532.366	410	1.298		
	Total	739.577	420			

a. Dependent Variable: Sustainability of Modern Mass Transit System

b. Predictors: (Constant), Passenger Comfort and Safety, Government Support and Policies, Affordability of Fares, Delhi Metro's Connectivity, Reduced Traffic Congestion, Operational Efficiency, Regular Maintenance, Reducing Air Pollution, Design and Infrastructure, Energy Consumption

The model summary shows a moderate relationship between predictors and sustainability, with R = 0.529. The R^2 value of 0.280 indicates that 28.0% of variation in sustainability is explained by the selected factors, while the adjusted R^2 of 0.263 confirms model stability. The ANOVA results show the regression model is statistically significant, with F = 15.958 and Sig. = 0.000. This confirms that the combined predictors have a meaningful impact on the sustainability of the modern mass transit system.

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Table 4: Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.
	B	Std. Error			
(Constant)	-.140	.280		-.499	.618
Design and Infrastructure	.102	.043	.106	2.406	.017
Delhi Metro's Connectivity	.129	.045	.127	2.893	.004
Reducing Air Pollution	.093	.046	.091	2.030	.043
Energy Consumption	.098	.043	.103	2.270	.024
Regular Maintenance	.022	.046	.021	.474	.636
Operational Efficiency	.089	.042	.095	2.104	.036
Reduced Traffic Congestion	.114	.042	.122	2.699	.007
Passenger Comfort and Safety	.238	.046	.236	5.179	.000
Affordability of Fares	.074	.044	.077	1.707	.088
Government Support and Policies	.024	.048	.023	.501	.617

a. Dependent Variable: Sustainability of Modern Mass Transit System

Table 4 presents the regression analysis explains the influence of all independent variables on the sustainability of the modern mass transit system using beta, t, and significance values. Passenger Comfort and Safety emerges as the most influential factor with a high standardized beta ($\beta = 0.236$), strong t-value ($t = 5.179$), and high statistical significance (Sig. = 0.000), showing a decisive positive effect. Delhi Metro's Connectivity also shows a strong and significant impact ($\beta = 0.127$, $t = 2.893$, Sig. = 0.004), indicating the importance of network reach and integration. Reduced Traffic Congestion significantly contributes to sustainability ($\beta = 0.122$, $t = 2.699$, Sig. = 0.007). Design and Infrastructure has a positive and significant role ($\beta = 0.106$, $t = 2.406$, Sig. = 0.017). Environmental variables such as Energy Consumption ($\beta = 0.103$, $t = 2.270$, Sig. = 0.024) and Reducing Air Pollution ($\beta = 0.091$, $t = 2.030$, Sig. = 0.043) also show meaningful effects. Operational Efficiency is statistically significant ($\beta = 0.095$, $t = 2.104$, Sig. = 0.036). However, Regular Maintenance, Affordability of Fares, and Government Support and Policies show insignificant influence due to higher Sig. values (>0.05).

Table 5: Hypothesis Testing

Variable	t-value	Sig. (p-value)	Pearson r	Spearman ρ	χ^2 Value	Remark (H_1)
Design and Infrastructure	2.406	0.017	0.218	0.224	38.561	Accepted
Delhi Metro's Connectivity	2.893	0.004	0.252	0.249	59.937	Accepted
Reducing Air Pollution	2.03	0.043	0.249	0.25	40.513	Accepted
Energy Consumption	2.27	0.024	0.255	0.252	45.5	Accepted
Regular Maintenance	0.474	0.636	0.202	0.214	55.295	Rejected
Operational Efficiency	2.104	0.036	0.265	0.259	49.603	Accepted
Reduced Traffic Congestion	2.699	0.007	0.275	0.269	57.173	Accepted
Passenger Comfort and Safety	5.179	0	0.378	0.382	102.071	Accepted
Affordability of Fares	1.707	0.088	0.244	0.243	48.392	Rejected
Government Support and Policies	0.501	0.617	0.223	0.228	45.109	Rejected

Table 5 explains hypothesis testing using χ^2 (x2), Pearson r, and Sig. values for all parameters. Passenger Comfort and Safety shows the strongest association with sustainability, supported by high Pearson r (0.378), very strong χ^2 (102.071), and Sig. = 0.000, confirming acceptance. Delhi Metro's Connectivity is also significant, with Pearson r = 0.252, $\chi^2 = 59.937$, and Sig. = 0.004. Reduced Traffic Congestion records a meaningful relationship ($r = 0.275$, $\chi^2 = 57.173$, Sig. = 0.007). Operational Efficiency shows positive association ($r = 0.265$, $\chi^2 = 49.603$, Sig. = 0.036). Design and Infrastructure is significant with Pearson r = 0.218, $\chi^2 = 38.561$, and Sig. = 0.017. Environmental factors, Energy Consumption ($r = 0.255$, $\chi^2 = 45.500$, Sig. = 0.024) and Reducing Air Pollution ($r = 0.249$, $\chi^2 = 40.513$, Sig. = 0.043), also support hypothesis acceptance. In contrast, Regular Maintenance ($r = 0.202$, $\chi^2 = 55.295$, Sig. = 0.636), Affordability of Fares ($r = 0.244$, $\chi^2 = 48.392$, Sig. = 0.088), and Government Support and Policies ($r = 0.223$, $\chi^2 = 45.109$, Sig. = 0.617) show weak significance, leading to hypothesis rejection.

IX. CONCLUSION

This study examined the key determinants influencing sustainability in the Delhi Metro by analyzing primary data collected from 421 respondents across the National Capital Region. The demographic profile reflects balanced participation, with 54.2% male and 45.8% female respondents, indicating inclusive use of the metro system. The majority of commuters belonged to the 31–40 years (32.5%) and 18–30 years (27.6%) age groups, showing that the Delhi Metro primarily serves the working and economically active population. Area-wise representation was broad, with Delhi accounting for 46.3% of respondents, followed by Gurugram (19.7%) and Noida (13.3%), along with participation from other NCR regions. This wide geographic and demographic coverage enhances the reliability of the study and confirms that the Delhi Metro functions as a regional mobility network catering to diverse commuter groups. Overall, the demographic findings support the suitability of the Delhi Metro as a case for evaluating sustainability in urban mass transit systems.

The statistical analysis confirms that sustainability in the Delhi Metro is significantly influenced by several operational, service, and environmental factors. The regression model shows a moderate relationship between the predictors and sustainability outcomes, with R = 0.529 and $R^2 = 0.280$, indicating that 28% of the variation in sustainability is explained by the selected variables. The ANOVA results ($F = 15.958$, $p < 0.001$) validate the overall significance of the model. Passenger Comfort and Safety emerged as the most influential factor, highlighting the importance of user-centric service quality. Connectivity and reduced traffic congestion also showed strong and significant effects, emphasizing the role of network reach and congestion mitigation in promoting sustainable transport. Environmental aspects, including energy consumption and air pollution reduction, further contributed positively to sustainability. In contrast, regular maintenance, fare affordability, and government support did not show significant influence in this study. Overall, the findings lead to the acceptance of the alternative hypothesis and conclude that service quality, connectivity, traffic reduction, and environmental performance are the primary drivers of sustainability in the Delhi Metro system.

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