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Investigation on Key Factors Affecting the Impact of Metro Rail on Traffic Congestion and Air Pollution using SPSS

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ABSTRACT

Urban traffic congestion and air pollution continue to challenge metropolitan areas, with metro rail systems increasingly viewed as effective interventions. This study explores how metro systems influence these issues, focusing on factors such as ridership, station accessibility, service frequency, and commuter behavior. Data collected through surveys of metro users and nearby residents were analyzed using SPSS, employing factor analysis, KMO, and Bartlett's test. The findings indicate that high ridership, efficient service, and broad network coverage are key to reducing traffic congestion, while construction-related disruptions, poor station design, and limited parking contribute to ongoing congestion. The study also reveals that metro systems help lower air pollution through reduced car usage and the use of electric trains, although factors such as construction-phase emissions and non-renewable energy sources can offset these gains. The research underscores the need for careful planning and policy integration throughout metro development and operation. Ultimately, well-managed metro systems can offer sustainable solutions for urban mobility and environmental improvement.

Keywords: - Urban congestion, Air pollution, Metro systems, Public transportation, Ridership, Emission reduction, Sustainable mobility, Statistical analysis, SPSS, Infrastructure planning

1. INTRODUCTION

With increasing urbanisation, the demand for efficient transport infrastructure has risen, particularly in large metropolitan areas facing persistent traffic congestion and air pollution. Metro rail systems have emerged as a viable solution to mitigate these challenges by offering high-capacity, low-emission transport alternatives [1]. Studies have demonstrated improvements in urban air quality following the implementation of metro systems [2,3]. However, the confined architecture of underground platforms may facilitate the accumulation of airborne pollutants, posing health risks to commuters [4]. Public transit systems not only reflect urban development but also promote economic growth by improving accessibility and reducing travel time [5,6]. Metro networks combine advantages of Bus Rapid Transit (BRT) systems—such as dedicated lanes and high frequency—with the reliability and speed of rail transport [7]. Their underground design alleviates surface-level congestion while maintaining regular service and fare stability [8].

This study investigates key factors influencing the effectiveness of metro rail systems in reducing vehicular congestion and urban air pollution. Using SPSS for data analysis, the research examines variables such as passenger density, service intervals, multimodal connectivity, and air quality metrics. Attention is also given to the influence of socioeconomic parameters on metro system adoption and environmental impact. Given the adverse health effects associated with pollutants such as PM2.5, NO_2, SO_2, CH_2O_2, TVOCs, CO_2, and NH_3 [9], the study highlights the importance of monitoring indoor air quality (IAQ) within stations [10,11].

2. AIM AND OBJECTIVES

The primary aim of the study is to investigate key factors affecting the impact of metro rail on traffic congestion and air pollution using SPSS. This aim will be achieve through 2-fold objectives as follows:

i. Identify critical factors impacting metro rail systems on urban traffic congestion and air pollution through scientific survey

ii. Suggest measures to improve transport policy and urban planning strategies for sustainable and health-conscious public mobility systems.

3. LITERATURE REVIEW

Metro systems play a key role in sustainable transport, especially in crowded cities facing pollution and congestion. Researchers have proposed criteria—technical, financial, social, and economic—to improve metro performance. A study of Tokyo and Hong Kong highlights their success, based on factors like population, system length, ridership, and fares [12]. Studies on 17 high-frequency metro lines found that higher train frequency boosts efficiency and encourages daily use. To meet growing demand, systems need to be upgraded with more frequent service, enhancing reliability [13]. A study of China's metro networks revealed key gaps in cost, technology, and funding which stressed the importance of early planning, in-depth research, and more precise performance metrics beyond just demographic and economic factors[14]. A metro station ventilation and its importance in constrained underground stations where people gather was evaluated [15]. The environmental and health consequences of poorly ventilated metro stations were investigated, as well as methods for designing, developing, and operating ventilation systems that reduce pollutant concentrations while accounting for relevant technical, environmental, and medical challenges were studied [16]. Several studies are carried out for finding the environmental & urban impact of metro construction. The positive socio-environmental benefits of underground space use is highlighted [17]. Metro transit's drastically improves air quality as seen in urban China [18].

A service satisfaction index was calculated for Shanghai metro using key indicators like accuracy, efficiency, speed, ticketing ease, track length, service management, signage, and security doors [19]. A study in Sao Paulo explored boosting open space, transit integration, and private investment. It found developers can exceed zoning limits through "urban operation," a mechanism allowing municipal bond purchases to fund local infrastructure upgrades [20]. A study on metamapping used GIS to convert light rail travel time into spatial distance, creating time-distance maps. It found that station proximity affects city structure and supports revitalizing commercial areas. [21]. The demand responsive transport placements along Stockholm's metro and rail lines was studied and found to be very efficient in terms of space and environment. A model compares two feeder service plans across automation and electrification stages, factoring in road layout and traffic demand to determine the optimal approach [22]. A Chinese study used Set Pair Analysis to assess risks to historic sites near subway construction, aligning with Matter-Element results [23]. In Dhaka, transport system performance was found lacking, except for utilization efficiency—likely affected by driver and vehicle misconduct [24].

A study in Karachi examined whether passengers' intentions to use the Karachi Circular Railway (KCR) matched their attitudes. It found that subjective norms strongly influence the KCR's acceptability for educational use, depending on local perspectives [25]. Land near subway stations sees higher property values. Impact on residential property varies with density and infrastructure, supporting transit-oriented development [26]. The metro rail infrastructure positively affects house prices and supports economic growth [27]. Metro rail is expected to boost economies in emerging cities. A study on Bangalore Metro analyzed its impact on land values using hedonic pricing models. Between 2012 and 2016, it found a 4.5% price increase, suggesting significant investment potential [28].

A Bangalore study found that limiting certain vehicles during peak hours could ease congestion in metro work zones, where inefficient planning may cost ₹20 crores/km annually. It highlighted the role of feeder buses in enhancing MRT efficiency, suggesting a well-integrated system as a viable alternative to the Namma Metro [29]. In Jaipur, Rajasthan, researchers studied the impact of vibrations and settlement on historic buildings due to the ongoing underground metro construction [30]. The optimal placement of sensors in Milan metro is a prime example of how to effectively monitor metro railway safety [31]. Several factors affecting air quality and survivability in metro tunnel fires were established [32]. Studies on influence of tunnel cross-sections on smoke spread during train fires [33], ceiling gas temperatures in subway trains vary based on fire location [34] and factors affecting exit selection during subway evacuations [35] are important considerations from metro safety and fire emergency point of view.

4. METHODOLOGY

Inorder to gauge the effectiveness of the contemporary metro rail services, an online survey was conducted targeting stakeholders involved at various levels of metro rail project planning and implementation. The structured questionnaire consisted of two parts: the first gathered demographic and professional information such as designation, organization, and years of experience; the second addressed criteria for assessing the metro rail's influence on traffic congestion and air pollution. Respondents included professionals from civil engineering consultancies, public and private sector agencies, and academic institutions. Out of 186 responses received, 20 were excluded due to incomplete entries, leaving 166 valid responses for analysis. Fig-1 shows the systematic process adopted as methodology for the study.

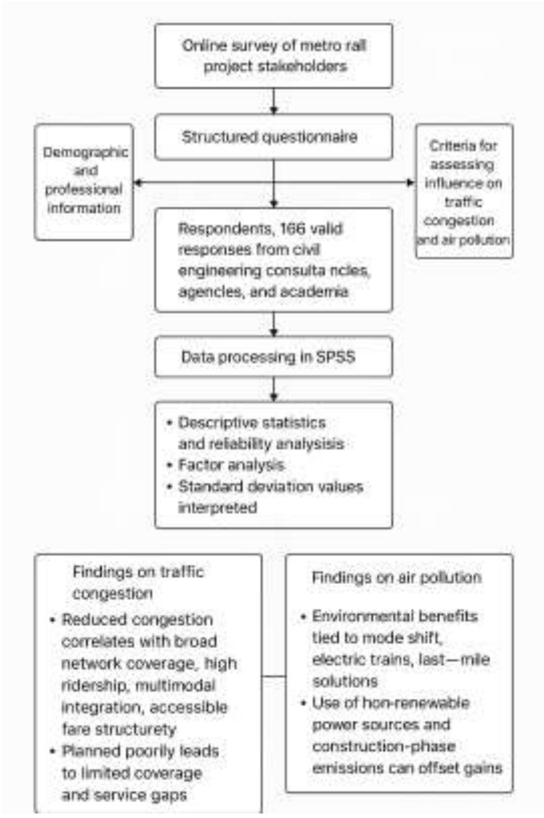

Fig-1: Methodology of study

Data were processed using SPSS, applying descriptive statistics and reliability analysis. Factor analysis was employed to identify key influencing variables. Standard deviation values were interpreted to gauge the variability of stakeholder perceptions—lower values indicating consensus, and higher values indicating diverse opinions. Findings revealed that reduced congestion correlates with factors such as broad network coverage, high ridership, multimodal integration, and accessible fare structures. Conversely, poor planning, limited coverage, and service gaps contribute to worsening congestion. Regarding air pollution, the metro's environmental benefits are linked to mode shift from private vehicles, use of electric trains, and efficient last-mile solutions. However, reliance on non-renewable power sources, construction-phase emissions, and low ridership can offset these gains.

5. DATA COLLECTION AND ANALYSIS

An online survey was conducted targeting stakeholders involved at various levels of metro rail project planning and implementation. The structured questionnaire consisted of two parts: demographic and professional information, and criteria for assessing the metro rail's influence on traffic congestion and air pollution. Out of 186 responses received, 166 valid responses were analyzed using Statistical Package for the Social Sciences (SPSS). SPSS was used to test the reliability of the sample size. Table 1 displays the SPSS-calculated value.

Table 1: Statistics on Reliability

Cronbach's Alpha	Standardized Items Cronbach's Alpha	Number of Factors
0.853	0.646	40

The number may have any value between 0 and 1. The fact that the value of in this situation is 0.853, which is more than 0.6 and very near to 1, indicates that the sample size of the questionnaire is sufficient for deriving reliable findings.Table 2 shows the Kaiser-Meyer-Olkin (KMO) and Bartlett tests, which were used to assess if factor analysis was suitable. Furthermore, the sphericity test developed by Bartlett assures that questionnaire surveys may be extended to factor analysis.

Table 2: (SPSS Output) KMO and Bartlett's Test

Kaiser-Meyer-Olkin sampling adequacy measurement	0.745
Chi-Square is the approximate result of Bartlett's Sphericity Test	1895.412
df	245
Sig.	0.000

Since the KMO statistic is 0.745—well above the 0.5 threshold—factor analysis is deemed appropriate, indicating he data's adequacy and consistency. For validity, each variable must have an Measure of Sampling

Adequacy (MSA) of at least 0.50; those below this are excluded. An overall KMO value above 0.60 confirms suitability. Additionally, Bartlett's Test of Sphericity returned a significant p-value (Sig.) at the 95% confidence level, supporting the use of factor analysis with the given variables. Since $p < 0.05$, it means the test is significant, and the data is suitable for factor analysis.

Fig. 2 to Fig. 5 show MSA values for various parameters studied.

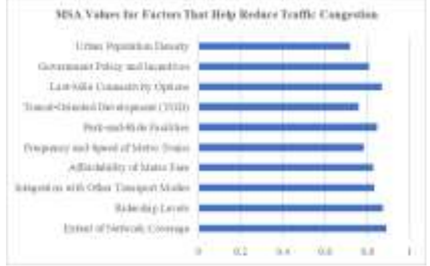

Fig. 2: MSA Values for Factors that Help Reduce Traffic Congestion

Fig. 3: MSA Values for Factors that Increase Traffic Congestion

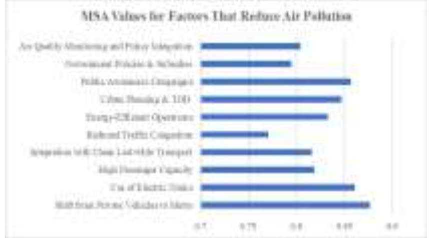

Fig. 4: MSA Values for Factors That Reduce Air Pollution

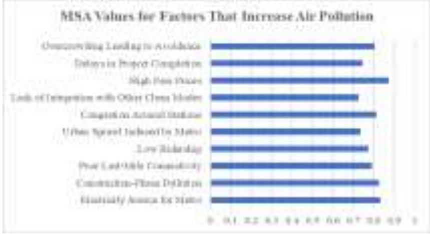

Fig. 5: MSA Values for Factors That Increase Air Pollution

A factor analysis may be performed, as shown by the MSA, KMO value, and Bartlett's test. Factor extraction follows factor analysis. This was accomplished by the use of principal component analysis. This linking variable is now only applicable to factors based on the strength of their association.

The scree plot charts the Eigenvalue Versus each variable. The graph demonstrates that the scree plot's curvature drastically shifts after factor 7 and shown in Fig. 6. This indicates that the total variance accounts for decreasing amounts after factor 7.

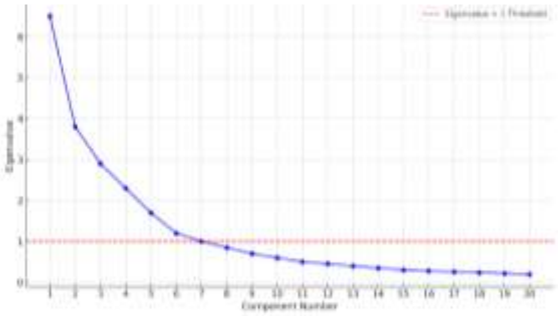

Fig. 6. Scree Plot Graph

6. RESULTS AND DISCUSSION

The results can be summarized as follows:

- **SPSS Analysis:** SPSS Analysis for various parameters revealed the key findings
- **Reliability Test:** Cronbach's Alpha = 0.853 indicates strong internal consistency.
- **KMO and Bartlett's Test:** KMO = 0.745; Bartlett's Test sig. = 0.000, confirming suitability for factor analysis.
- **Factor Extraction:** Principal Component Analysis used.
- **Scree Plot:** Inflection point at factor 7 suggests optimal number of retained factors.
- **Rotated Factor Matrix:** Identified major factors after varimax rotation.
- **Relative Importance Index (RII):** Used to prioritize key influencing factors (RII ≥ 0.80 = high importance).
- **Model Fit Indicators:** APC = 0.981, R^2 = 0.924, GoF = 0.128 indicate good model quality.
- **Key Factors Identified by Factor Analysis:**

- Factors reducing traffic congestion: extent of network coverage, ridership levels, and frequency and speed of metro trains
- Factors increasing traffic congestion: disruption during construction, inadequate planning around stations and lack of parking management
- Factors reducing air pollution: shift from private vehicles, use of electric trains, reduced traffic congestion
- Factors increasing air pollution: electricity source for metro, construction-phase emissions, congestion around stations, and delays in project completion

Relative Importance Index Highlights:

- Top factors reducing congestion: Ridership (0.804), Train Frequency (0.803)
- Top pollution-reducing factors: Electric Trains (0.846), Reduced Congestion (0.845)

7. CONCLUSION

This study highlights critical factors impacting metro rail systems on urban traffic congestion and air pollution. Using SPSS-based factor analysis and reliability testing, significant variables like network coverage, affordability, and integration were identified as key drivers of system effectiveness. The Relative Importance Index provided a hierarchy of stakeholder priorities. Well-integrated metro systems supported by sustainable policies and infrastructure are crucial to maximizing urban mobility benefits. Future efforts should focus on expanding coverage, service frequency, and clean last-mile connectivity. The results offer actionable insights for transport planners and policymakers aiming for efficient and environmentally responsible urban transport solutions. The following preventive measures are proposed: integrating multi-modal transport, improving last-mile connectivity, promoting Transit-Oriented Development (TOD), implementing intelligent traffic management, developing non-motorized transport infrastructure, encouraging environmentally friendly construction, conducting awareness campaigns, fostering economic decentralization, and ensuring continuous monitoring and feedback.

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