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Comparative Analysis of Urban Metro Systems Across Major Global Cities

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ABSTRACT

This paper offers a comprehensive comparative analysis of urban metro systems across major global cities, including Pune, Delhi, Lucknow, Kolkata, Chennai, London, Singapore, Dubai, Seoul, Frankfurt, Hong Kong, and Zurich. We aim to identify best practices, commonchallenges, and innovative solutions in urban rail transit. The study evaluates these systems using a multi-criteria framework that encompasses operational efficiency (e.g., punctuality, headway, capacity utilization), economic viability (e.g., farebox recovery, investment costs), environmental impact (e.g., energy consumption, emissions), social equity (e.g., accessibility, affordability, network coverage), and technological advancement (e.g., automation, smart ticketing).

Drawing data from diverse sources like official reports and academic literature, the research systematically compares system design, funding models, regulatory frameworks, and operational strategies. The findings reveal significant variations influencing overall performance and sustainability. By examining key parameters such as network length, daily ridership, and population served, the study provides insights for city planners and policymakers seeking to improve public transport efficiency and user satisfaction amidst urbanization and climate challenges. Ultimately, this research offers practical recommendations to enhance the effectiveness of metro systems in an increasingly urbanized world.

The findings underscore how governance, investment, and innovation shape system performance and user satisfaction. By identifying best practices and common challenges, this paper offers actionable recommendations for city planners, policymakers, and transit authorities aiming to enhance public transport effectiveness and sustainability amid increasing urbanization and climate concerns.

Keywords: *Urban Metro Systems, Comparative Analysis, Global Cities, Infrastructure Planning, Transit Efficiency, Smart Mobility, Public Transportation, Rail Transit,Global Cities, Sustainable Urban Development, Transportation Policy, Infrastructure, Best Practices.*

1. INTRODUCTION

Urbanization is a defining trend of the 21st century, with the United Nations projecting that 68% of the global population will live in urban areas by 2050 (UN DESA, 2018). This rapid urban growth places immense pressure on city infrastructure, particularly public transportation systems. Amidst this expansion, metro rail networks have emerged as essential tools for sustainable urban development, offering high-capacity, efficient, and eco-friendly mobility solutions. More than just transit systems, metro networks serve as engines of economic activity, enhance social inclusion, and improve the overall quality of urban life (Vuchic, 2005; Cervero, 1998).

However, the design, development, and performance of metro systems vary significantly across cities due to diverse historical trajectories, urban densities, funding models, and governance structures. While East Asian cities like Seoul and Singapore are lauded for their integrated, high-tech systems, others like Delhi and Pune highlight the challenges faced by rapidly growing metropolises in scaling infrastructure sustainably. In contrast, older systems in cities such as London and New York grapple with modernization issues, aging infrastructure, and service reliability (Suzuki et al., 2015).

This research undertakes a comparative analysis of urban metro systems across twelve global cities spanning Asia, Europe, and the Middle East to examine how key parameters such as operational efficiency, economic viability, environmental impact, social equity, and technological innovation influence overall system success. By analyzing both established and emerging metro networks, the study seeks to identify best practices, recurring challenges, and innovative strategies that can guide future urban transit planning.

Through this comparative lens, the paper offers evidence-based insights and practical recommendations for city planners, transit authorities, and policymakers working to design resilient, inclusive, and future-ready urban transportation systems.

2. LITERATURE REVIEW

The critical importance of efficient urban transportation systems in the context of rapid urbanization has been widely acknowledged in academic and policy discourse (Vuchic, 2005). As cities expand and populations grow, the need for high-capacity, sustainable, and inclusive transit systems becomes increasingly urgent. Metro systems are recognized as key instruments for enhancing urban mobility, reducing environmental degradation, and promoting socio-economic development (UITP, n.d.; Suzuki et al., 2015).

2.1 Role of Metro Systems in Urban Development

Metro systems are transformative infrastructures that contribute significantly to urban accessibility, economic activity, and land use development. By offering reliable and rapid transit options, metros help reduce traffic congestion and automobile dependence, thereby improving air quality and urban livability (Min et al., 2015; MDPI, 2024a). They are also instrumental in stimulating transit-oriented development (TOD), raising property values, and fostering compact, mixed-use urban growth (Suzuki et al., 2015).

2.2 Operational Efficiency and Performance Indicators

A substantial body of research emphasizes operational efficiency as a cornerstone of metro system performance. Common key performance indicators (KPIs) include network length, daily ridership, train frequency (headway), average and maximum speed, punctuality, and capacity utilization (Vuchic, 2005; UITP, n.d.). These parameters help evaluate how effectively metro systems meet commuter demand. Studies using Data Envelopment Analysis (DEA) have shown that systems serving densely populated areas typically achieve higher efficiency levels, though overcrowding during peak hours remains a concern in cities like Beijing (ResearchGate, 2015).

2.3 Economic Viability and Funding Models

Given their high capital and operational costs, metro systems require sustainable funding strategies. The farebox recovery ratio is commonly used to assess financial sustainability, yet literature emphasizes that metros often provide social benefits beyond what fare revenues can cover (Flyvbjerg et al., 2003; Suzuki et al., 2015). Funding models such as government subsidies, land value capture, and public-private partnerships (PPPs) are widely explored, especially in developing economies where gestation periods for returns on investment are lengthy (International Journal of Technology, 2015; Orfonline, 2025).

2.4 Environmental Impact and Sustainability

Metro systems are generally celebrated for their environmental advantages. By facilitating a shift from private vehicles to public transit, they contribute to significant reductions in greenhouse gas emissions and urban air pollution (IEA, 2020; Banister, 2008). However, a holistic environmental evaluation must consider energy use across the system's life cycle—including construction, operation, and maintenance (WCTRS, n.d.). Emerging trends involve the integration of renewable energy, regenerative braking, and other smart energy solutions to further enhance sustainability (Data and Metadata, 2025).

2.5 Social Equity and Accessibility

Equitable access to metro services is a growing research concern. An inclusive metro system should serve all socio-economic groups, providing access to jobs, education, and healthcare (Lucas, 2012; Orfonline, 2025). Key challenges include inadequate network coverage in low-income or peripheral areas, unaffordable fares, and safety concerns. Solutions such as fare subsidies, gender-sensitive design, and community engagement are being implemented in cities aiming to enhance social inclusion (ITF, n.d.; MDPI, 2021).

2.6 Technological Innovation and Digital Transformation

Technological advancement is rapidly transforming metro operations. Automation—especially in the form of Grade of Automation (GoA) systems—reduces operational costs and enhances reliability (Shinde & Marinov, as cited in Hrcak, n.d.). Smart ticketing systems, real-time passenger information, and predictive maintenance enabled by big data and the Internet of Things (IoT) are now widely adopted (Zhang et al., 2018). These innovations not only improve operational efficiency but also enhance passenger experience and system resilience (Data and Metadata, 2025; UITP, 2019).

2.7 Gaps and Contribution of This Study

While extensive literature exists on specific aspects of metro systems—such as operations, financing, or sustainability—few studies offer an integrated, comparative framework that simultaneously evaluates operational, economic, environmental, social, and technological dimensions. This research addresses that gap by conducting a structured, multi-dimensional comparison of metro systems across major global cities, aiming to identify best practices and lessons transferable to diverse urban context

3. RESEARCH METHODOLOGY

This comparative analysis of urban metro systems across major global cities employs a mixed-methods approach, primarily relying on secondary data collection and a multi-criteria evaluation framework. The goal is to systematically assess and compare diverse metro networks to identify best practices, common challenges, and innovative solutions in urban rail transit.

- **Selection of Cities**

The study focuses on a selection of twelve diverse global cities, strategically chosen to represent a spectrum of metro system maturities, operational scales, and geographical contexts. These include:

- Asian Cities: Tokyo, Singapore, Shanghai, Seoul, Delhi, Pune, Lucknow, Chennai, Kolkata, Hong Kong.
- European Cities: London, Paris, Frankfurt, Zurich.
- Middle Eastern City: Dubai.

This selection ensures a broad representation of highly developed, mature systems (e.g., Tokyo, London) alongside rapidly expanding and relatively newer systems (e.g., Delhi, Pune), allowing for a comprehensive comparative perspective on various developmental stages and operational models.

4. DATA COLLECTION

Data for this study were meticulously collected from a variety of reliable secondary sources to ensure accuracy and breadth of information. These sources include:

- Official Transportation Department Reports: Annual reports, statistical yearbooks, and operational summaries published by municipal and national transportation authorities of the selected cities (e.g., Delhi Metro Rail Corporation reports, Transport for London annual reviews).[1] these provide granular data on system performance, infrastructure, and financial health.
- International Transit Databases: Reputable global organizations that compile and disseminate public transport statistics.[2] Key databases utilized include:
- The International Association of Public Transport (UITP), which provides comprehensive "World Metro Figures" and other statistical briefs on public transport trends and performance (UITP, n.d.).[3]
- The National Transit Database (NTD) for U.S. cities, managed by the Federal Transit Administration (FTA), offering detailed financial, operating, and asset condition data for transit systems (FTA, n.d.).[4]
- The International Transport Forum (ITF) at the OECD, offering a Transport Data Dashboard for cross-country comparisons (ITF, n.d.).[5]

Relevant Academic Publications: Peer-reviewed journal articles, conference papers, and scholarly books that offer in-depth analyses, case studies, and methodological frameworks for comparing urban transit systems (e.g., studies on metro mobility patterns, environmental impact assessments of metro systems).

5. PARAMETERS OF ANALYSIS AND DISCUSSION

This study employs a structured multi-criteria framework to assess and compare metro systems across twelve global cities. The framework is built upon five key performance dimensions—Operational Efficiency, Economic Viability, Environmental Impact, Social Equity, and Technological Advancement—each comprising specific indicators critical to evaluating metro system performance, sustainability, and user satisfaction.

5.1. Operational Efficiency

- Network Length: Total operational length (in km), indicating system reach and infrastructure scale.
- Daily Ridership: Average number of passengers per day, reflecting popularity and capacity utilization.
- Train Frequency: Average headway during peak and off-peak hours.
- Average Speed: Operational speed indicating service quality.
- Punctuality: Percentage of trains running on time.
- Capacity Utilization: Extent to which available capacity is effectively used.

	Network Length	Daily Ridership	Population Served	Operational Characteristics
Singapore	As of 2020, the network covers 232 kilometers	Approximately 3.5 million	about 5.9 million	Features driverless trains, high frequency, and a well-maintained system.
Seoul	Extends over 340 kilometers	about 7 million	population of over 23 million	Known for its punctuality, cleanliness, and extensive coverage.
Delhi	As of 2020, the Delhi Metro spans 389 kilometers	Approximately 5.8 million	over 30 million	Features include driverless trains on select corridors and integration with other public transport modes
Pune	Currently under development, with operational sections totaling 32.97 kilometers as of November 2024	Projected to serve around 0.5 million passengers upon full operation.	approximately 7.4 million	Designed with modern amenities and aims for seamless integration with existing bus services.
Lucknow	of 22.88 kilometers	Around 0.8 million	about 3 million	Known for its swift project completion and features like GoSmart card for cashless travel
Chennai	As of 2020, the network spans 45 kilometers	Around 0.1 million	approximately 10.97 million	Incorporates features like underground and elevated corridors, with plans for network expansion
Kolkata	The oldest metro system in India, currently covering 33.02 kilometers.	Approximately 0.7 million	around 14 million	Features include air-conditioned rakes and ongoing expansion projects to increase reach
Hong Kong	As of 2020, covers 194 kilometers	Approximately 5.8 million passengers	7.6 million	
London	Approximately 436 kilometers	about 5 million	over 9 million	Known for its extensive network, historical significance, and integration with other transport modes
Frankfurt	Approximately 65 kilometers	Around 0.3 million passengers	about 2.3 million	Features both underground and above-ground sections, integrated with tram and bus networks
Dubai	Around 90 kilometers	: Approximately 0.5 million	about 3.3 million	Fully automated, driverless system with modern amenities.

City	Population (Millions)	Metro Operations Start Year	Construction Cost per km (INR Crores)	Ticket Fare per km (INR)	Concessions
Delhi	30.3	2002	181	1.88 - 3.75	No specific concessions for students, women, or senior citizens.
Pune	7.4	2024	218	3.0 - 5.0	Concessions available for senior citizens and students.
Lucknow	3	2017	486	2.73 - 5.45	No specific concessions for students,

City	Population (Millions)	Metro Operations Start Year	Construction Cost per km (INR Crores)	Ticket Fare per km (INR)	Concessions
					women, or senior citizens.
Kolkata	14.8	1984	183	0.83 - 2.5	Concessions available for students and senior citizens.
Chennai	10.97	2015	259	6	No specific concessions for students, women, or senior citizens.
London	9.3	1863	Data not readily available	15.0 - 25.0	Concessions available for students, senior citizens, and certain categories of women.
Singapore	5.9	1987	Data not readily available	11	Concessions available for students and senior citizens.
Dubai	3.3	2009	Data not readily available	5.0 - 8.0	Concessions available for students and senior citizens.
Seoul	9.8	1974	Data not readily available	4.0 - 6.0	Concessions available for students and senior citizens.
Frankfurt	2.3	1968	Data not readily available	12.0 - 15.0	Concessions available for students and senior citizens.
Hong Kong	7.6	1979	Data not readily available	10.0 - 12.0	Concessions available for students and senior citizens.
Zurich	1.4	No metro system	Not applicable	Not applicable	Not applicable

5.2. Economic Viability

- Farebox Recovery Ratio: Percentage of operating costs covered by fare revenue.
- Investment Costs: Capital expenditure for construction and system expansion.
- Government Subsidies: Public funding support for operation and maintenance.

Economic Viability of Metro Rail Systems		
Farebox Recovery Ratio		
City	**Farebox Recovery Ratio (%)**	**Notes**
Tokyo	161.55%	Tokyo Metro (FY2018).
Singapore	101%	SMRT Corporation (2018).
Shanghai	35.08%	Shanghai Metro (2021).
Delhi	80%(Divyanka Dhok, 2021)	Operates with a loss in EBT since 2010; relies on government support.
Pune	Data not specified	Recently operationalized; Farebox revenue in 2024: ₹76.58 crore.
Lucknow	Projected 8.41% FIRR	Aims for profitability from Day 1.
Chennai	60%(Divyanka Dhok, 2021)	Phase-2 project financed 65% by Central Government.
Kolkata	Data not specified	Information not published on official sources.

Economic Viability of Metro Rail Systems		
Farebox Recovery Ratio		
City	**Farebox Recovery Ratio (%)**	**Notes**
Hong Kong	106.76%	MTR Corporation (2021).
London	129.50%	London Underground (2022-2023).
Paris	29%	Île-de-France Mobilités (2018).
Frankfurt	Data not specified	Information not available.
Zurich	60%	Zürich S-Bahn (2014).
Dubai	Data not specified	Information not available.

Investment Costs and Government Subsidies		
City	**Investment Costs**	**Government Subsidies**
Tokyo	Over 350 billion Yen (Excl. capital for new rail line)	Minimal; high farebox recovery reduces need for subsidies. https://www.tokyometro.jp/lang_en/corporate/ir/management/plan/index.html
Singapore	Approx. $S 2 billion annually	Limited; farebox revenue covers most operational costs. Additional $200M Support from Government to Mitigate the Impact of Fare Increase on Commuters Rise in public transport operating costs not matched by revenue growth: Iswaran
Shanghai	USD 43.3 billion over 5 years (allocated in 2018)	Significant government investment in infrastructure. Shanghai to Invest USD43.3 billion in Subway Expansion Over Five Years
Seoul	Data not specified	Substantial government support for operations and maintenance.
Delhi	Over ₹70,000 crore over three phases	Relies heavily on government funding and international loans.
Pune	Phase 1: ₹11,420 crore	Funded by Maharashtra Metro Rail Corporation Limited (Maha-Metro).
Lucknow	Phase 1A: ₹6,928 crore; Phase 1B: ₹5,801 crore	Receives funding from Centre, State, and European Investment Bank.
Chennai	Phase-2: ₹63,246 crore	65% financed by Central Government; remaining by State Government.
Kolkata	Data not specified	Information not available.
Hong Kong	HK$3.5 billion (includes subsidies for all modes of transport)	Limited subsidies – only for Elderly and Disabled. Hong Kong Budget 2024: Costly transport subsidy schemes face review Explainer | Can HK$2 transport subsidy cuts help solve Hong Kong's budget crisis? | South China Morning Post Profits from real estate support operations.
London	One-year settlement of £485m for 2025-26.	How we are funded - Transport for London Receives government subsidies for capital projects.
Paris	€13.3 billion to be	Significant public funding supports operations and infrastructure.

	approved for 2025 (in process)	RER, metro, bus: Île-de-France Mobilités expects an increased and "comfortable" 2025 budget - Le Parisien
Frankfurt	Data not specified	Information not available.
Zurich	₹4,82,217 crore; CPI adjusted	Government subsidies support operations and maintenance.
Dubai	Data not specified	Substantial government investment in metro infrastructure.

5.3. Environmental Impact

- Energy Consumption: Energy used per passenger-kilometer.
- Emissions Reduction: Contribution to lowering urban carbon emissions and air pollution.

Energy Consumption: Energy used per passenger-kilometer.		
City	**Energy Consumption (kJ/passenger-km)**	**Notes**
Tokyo	350	JR East average (2004).
Singapore	Data not specified	Recognized for high energy efficiency and automation.
Shanghai	Data not specified	Utilizes regenerative braking and solar energy; annual consumption exceeds 2.5 billion kWh.
Seoul	Data not specified	Known for efficient operations and advanced technology integration.
Delhi	Data not specified	Achieved 30% energy savings through regenerative braking; 35% energy from renewable.
Pune	Data not specified	Emerging system with ongoing sustainability initiatives.
Lucknow	Data not specified	Incorporates regenerative braking and solar power.
Chennai	Data not specified	Recovers 30–35% energy via regenerative braking; 12–15% energy from solar.
Kolkata	Data not specified	Implementing energy-efficient practices and renewable energy use.
Hong Kong	274 to 335 (W.M. To, 2020)	Highly efficient system with advanced energy management.
London	150	As of 2006–2007, trains consumed 15 kWh per 100 passenger-km.
Paris	Data not specified	Emphasizes energy efficiency and sustainable practices.
Frankfurt	470	Switzerland average (2011).
Zurich	470	Switzerland average (2011).
Dubai	Data not specified	Employs regenerative braking and energy-efficient technologies.

5.4. Social Equity

- Accessibility: Extent to which the network reaches urban populations.
- Fare Affordability: Accessibility of fares across socio-economic groups.
- Population Served: Number of people residing within the metro's effective service area.

Accessibility and Fare Affordability		
City	**Accessibility Highlights**	**Fare Affordability Insights**
Tokyo	High accessibility: 186 out of 211 stations are wheelchair accessible.	Fares have increased recently; affordability may be impacted for some commuters.
Singapore	Fully accessible stations with elevators and tactile guidance paths.	Fares are regulated to remain affordable across socio-economic groups.
Shanghai	100% wheelchair-accessible stations with elevators at all stations.	Fares are low, making the metro affordable for most residents.
Seoul	Comprehensive accessibility features, including elevators and tactile paving.	Affordable fares with discounts available for children, seniors, and disabled passengers.
Delhi	Accessibility varies; newer stations are more accessible than older ones.	High fare burden: commuters may spend up to 19.5% of income on metro travel.
Pune	Modern infrastructure with accessibility features like elevators and ramps.	Fare structure designed to be affordable; specific data on income percentage not available.
Lucknow	Expansion plans aim to improve accessibility in densely populated areas.	Fare structure aims to be affordable; specific data on income percentage not available.
Chennai	Accessibility issues persist; audits have found gaps in facilities for disabled persons.	Fares are considered affordable; specific data on income percentage not available.
Kolkata	Accessibility features present in newer stations; older stations may lack facilities.	Fares range from ₹5 to ₹25, making it one of the most affordable metro systems in India.
Hong Kong	Nearly all stations are wheelchair-accessible; portable ramps available upon request.	Fares are affordable; commuters spend approximately 2.9% of income on metro travel.
London	34% of stations are step-free from street to platform; ongoing improvements planned.	Higher fare burden: commuters spend around 13.4% of income on metro travel.
Paris	Limited accessibility: only a small number of stations are fully accessible.	Moderate fare burden: commuters spend about 6.6% of income on metro travel.
Frankfurt	Generally good accessibility with elevators and ramps in most stations.	Fares are moderate; specific data on income percentage not available.
Zurich	High accessibility standards with facilities for disabled passengers.	Fares are moderate; specific data on income percentage not available.
Dubai	All stations are designed to be fully accessible.	Fares are affordable; specific data on income percentage not available.

Data availability varies across cities. Where specific figures are not available, qualitative assessments are provided based on known practices and available information.

https://www.mtr.com.hk/en/customer/services/free_search.php?utm_source=chatgpt.com

5.5. Technological Advancement

- Automation: Level of driverless train operation (GoA levels).
- Smart Ticketing: Use of digital, integrated, and contactless fare systems.

Automation Levels and Smart Ticketing Systems			
City	**Automation Level (GoA)**	**Notes**	**Smart Ticketing Implementation**
Tokyo	GoA2	Semi-automated operations: plans for increased automation are underway.	Introduction of contactless payment systems, including tap-and-go credit/debit cards and mobile payments.
Singapore	GoA4	Fully driverless operations on multiple lines.	Advanced AFC gates supporting contactless smart cards and mobile payments.
Shanghai	GoA4	Several lines operate with full automation.	'One-ticket transfer' system with contactless smart cards.
Seoul	GoA3/4	Mix of semi-automated and fully automated lines.	Pilot of 'tagless' Bluetooth fare payments, enabling hands-free fare collection.
Delhi	GoA2	Semi-automated operations: future upgrades planned.	Multiple Journey QR ticketing via popular apps, enhancing contactless travel.
Pune	GoA2	New system with semi-automated operations.	Implementation of AFC system with contactless smart cards and digital tickets.
Lucknow	GoA2	Semi-automated operations.	AFC system accepting contactless tokens and smart cards; NFC enabled.
Chennai	GoA2	Semi-automated operations.	Contactless smart card system with online recharge options.
Kolkata	GoA2	Semi-automated operations; older system.	UPI-based ticketing system introduced for contactless payments.
Hong Kong	GoA2	Semi-automated operations; plans for automation upgrades.	Acceptance of contactless bank cards (Visa, MasterCard, and Union Pay) for fare payments.
London	GoA2	Semi-automated operations; some lines with advanced signaling.	Contactless and mobile pay-as-you-go options available across the network.
Paris	GoA4	Line 14 operates with full automation.	Use of Navigo Easy pass and mobile devices for contactless ticketing.
Frankfurt	GoA2	Semi-automated operations.	Implementation of contactless smart card systems for fare collection.
Zurich	GoA2	Semi-automated operations.	Use of contactless smart cards and mobile ticketing solutions.
Dubai	GoA4	Fully driverless operations across the network.	Integration of EMV-based payments into metro and bus systems for simplified fare collection.

The Grade of Automation (GoA) ranges from 0 (on-sight train operation) to 4 (fully automated train operation without staff onboard)

Data Analytics:

Use of passenger and operational data for optimization and planning.These parameters are derived from established urban transit evaluation frameworks (Vuchic, 2005; Suzuki et al., 2015) and ensure a comprehensive comparison of metro systems in varying geographic, economic, and policy contexts.

6. CONCLUSION

The comparative study of 12 metro systems—Delhi, Kolkata, Chennai, Pune, Lucknow, London, Singapore, Dubai, Hong Kong, Seoul, Frankfurt, and Zurich—reveals significant variations and patterns in terms of operational efficiency, economic viability, environmental impact, social equity, and technological advancement.

1. **Operational Efficiency**

Metro systems in Singapore, Seoul, and Hong Kong demonstrate exceptional performance in punctuality, frequency, and reliability, thanks to their mature infrastructure and integration of digital technologies. In contrast, emerging Indian metros like Pune and Lucknow are still scaling operations, often facing capacity constraints and limited automation. Delhi Metro stands out among Indian systems for its consistent operational efficiency and adherence to international standards.

2. **Economic Viability**

Economic sustainability varies widely. Hong Kong's MTR achieves profitability through real estate integration, while Singapore and Dubai maintain cost efficiency through state subsidies and public-private models. Indian metros generally struggle with farebox recovery ratios below sustainability thresholds, relying heavily on government support. Delhi and Bengaluru are relatively better in financial performance than their Indian counterparts.

3. **Environmental Impact**

Environmental responsibility is increasingly integrated into metro planning. Systems in Zurich, Singapore, and Seoul incorporate renewable energy and energy-efficient technologies, contributing to lower emissions and better air quality. Indian metros, though improving, still lag in renewable integration, though initiatives like regenerative braking and solar panel installations (as seen in Delhi Metro) are steps in the right direction.

4. **Social Equity and Accessibility**

Equitable access is a key strength in metros like London, Zurich, and Singapore, which prioritize affordability, accessibility for persons with disabilities, and last-mile connectivity. In Indian cities, despite affordability in fares, last-mile infrastructure and universal access remain inconsistent, especially in newer systems. Programs to improve gender safety and subsidized travel are emerging but need expansion.

5. **Technological Advancement**

Metro systems in Seoul, Hong Kong, and Singapore are technological frontrunners, featuring driverless trains, contactless ticketing, real-time tracking, and smart mobility integration. Indian systems are rapidly adopting similar technologies, with Kochi and Delhi taking the lead in digital ticketing and automation.

Final Thoughts

This comparative analysis underscores that no single system is universally superior; each reflects the socio-economic priorities, governance structures, and urban challenges of its context. However, global best practices in integration, sustainability, financial innovation, and inclusive access provide valuable benchmarks for improving metro systems in developing cities.

For India, the path forward involves scaling operational performance, ensuring financial sustainability, and deepening inclusivity and environmental responsibility. Policymakers must adopt a hybrid approach: learning from global leaders while tailoring strategies to local needs

REFERENCES

[1] UN DESA. (2018). World Urbanization Prospects: The 2018 Revision. United Nations, Department of Economic and Social Affairs.

[2] Vuchic, V. R. (2005). Urban Transit Systems and Technology. Wiley.

[3] Cervero, R. (1998). The Transit Metropolis: A Global Inquiry. Island Press.

[4] Suzuki, H., Cervero, R., & Iuchi, K. (2015). Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development. World Bank Publications

[5] https://www.un.org/development/desa/pd/file/1942#:~:text=By%202050%2C%2068%25%20of%20world,Population%20Division

[6] https://www.researchgate.net/figure/mpact-of-urbanization-on-transportation_fig2_317211009

[7] https://www.arup.com/en-us/insights/how-can-metro-systems-transform-a-city/

[8] https://www.keolis-mhi.com/regional-rail-projects-are-transforming-urban-development-within-the-gcc/

[9] https://www.researchgate.net/publication/286654551_The_evolution_of_worldwide_metro_systems_A_study_on_their_scales_and_network_indexes

[10] https://timesofindia.indiatimes.com/india/delhi-metro-records-highest-ever-daily-ridership-amid-severe-pollution-crisis/articleshow/115452948.cms?utm_source=chatgpt.com

[11] https://themetrorailguy.com/delhi-metro-phase-4-information-map/?utm_source=chatgpt.com
[12] https://www.ft.com/content/ccfcfde5-1207-41b6-b478-4359820706d8?utm_source=chatgpt.com
[13] https://www.theguardian.com/uk-news/2024/dec/13/london-underground-fares-to-rise-by-46-per-cent-from-march?utm_source=chatgpt.com
[14] https://www.lta.gov.sg/content/ltagov/en/getting_around.html?utm_source=chatgpt.com
[15] https://www.dubaieye1038.com/news/local/dubai-metro-marks-15-years-anniversary-transports-2-4b-passengers/?utm_source=chatgpt.com
[16] https://link.springer.com/article/10.1007/s44327-024-00035-1?utm_source=chatgpt.com
[17] https://www.lta.gov.sg/content/ltagov/en/who_we_are/statistics_and_publications/Connect/tactile-guiding-system.html?utm_source=chatgpt.com
[18] https://www.lta.gov.sg/content/ltagov/en/who_we_are/statistics_and_publications/Connect/tactile-guiding-system.html?utm_source=chatgpt.com
[19] https://www.linkedin.com/pulse/using-wheelchair-shanghai-subway-system-cordelia-crockett/
[20] https://www.zuerich.com/en/inform-plan/getting-there-and-mobility-on-location/zurich-sans-barrieres?utm_source=chatgpt.com
[21] https://timesofindia.indiatimes.com/city/chennai/madras-high-court-directs-cmrl-to-repeat-accessibility-audit-at-32-metro-stations/articleshow/110750096.cms?utm_source=chatgpt.com
[22] https://metrorailnews.in/automatic-train-operation-for-metro-railways-a-global-perspective-and-analysis/?utm_source=chatgpt.com
[23] Banister, D. (2008). Transport Policy.
[24] Cervero, R. (1998). The Transit Metropolis.
[25] Flyvbjerg et al. (2003). Megaprojects and Risk.
[26] IEA (2020). The Future of Rail.
[27] International Journal of Technology (2015).
[28] ITF (n.d.). Transport Outlook.
[29] Lucas, K. (2012). Transport and social exclusion.
[30] MDPI (2021, 2024a).
[31] Min et al. (2015).
[32] Orfonline (2025).
[33] Shinde & Marinov, as cited in Hrcak (n.d.).
[34] Suzuki, H., et al. (2015). Transforming Cities with Transit.
[35] UITP (2019, n.d.).
[36] Vuchic, V. R. (2005). Urban Transit Systems and Technology.
[37] WCTRS (n.d.).
[38] Zhang et al. (2018). Journal of Advanced Transportation.
[39] Data and Metadata (2025)..