Journal of Railway Transportation and Technology
Vol. 3 No. 2 (2024) 1-14
eSSN: 2830-6880

Improving Urban Rail Efficiency: Analyzing Peak and Off-peak Capacity in the Jaipur Metro

Manoj Mittal[1], Anand Kishore Chaturvedi[1]

[1]Department of Mechanical Engineering,
Rajasthan Technical University, Kota, Rajasthan-326001, INDIA

Article Info

Article history:

Received 17 July, 2024
Revised 22 November, 2024
Accepted 25 November, 2024

Keywords:

Cycle time
Passenger ridership
High speed train
Slow speed train
MRT carrying capacity
Peak hours
Off-Peak hours

ABSTRACT

This paper explores the optimization of train ratios for peak and off-peak hours in the Jaipur Metro. The study focuses on the impact of overtaking strategies, where fast trains overtake slow trains at specific locations.
Six models were developed, analyzing various overtaking scenarios in terms of location and frequency. The models considered key factors like cycle time (time between consecutive trains), waiting time at stations, and passenger arrival rates during peak and non-peak hours.
The analysis revealed that strategic overtaking can significantly reduce passenger waiting times, especially during peak hours. Additionally, it allows for more frequent train services without compromising travel times. Stations with high congestion can benefit from increased fast train ratios during peak times to manage passenger flow efficiently.
These findings offer valuable insights for railway planners in the Jaipur Metro. The data-driven approach allows for optimizing train operations and improving passenger experience by reducing waiting times. Moreover, strategic overtaking enhances network efficiency by maximizing capacity utilization during peak hours.
The paper concludes by highlighting the potential for further research, including exploring more complex modeling approaches and integrating the findings with existing scheduling software for implementation. By continuously optimizing train operations, the Jaipur Metro can provide a reliable, efficient, and comfortable public transportation system for its users.

Corresponding Author:

Manoj Mittal
Department of Mechanical Engineering
Rajasthan Technical University, Kota, Rajasthan-326001, INDIA
Email: mmittalgecj@gmail.com

1. INTRODUCTION

As Jaipur experiences rapid population growth and urban expansion, the demand for efficient public transportation is rising significantly. The city's existing infrastructure is approaching its limits, potentially leading to increased congestion and pollution if private vehicle usage continues to grow. To address this challenge, the Jaipur Metro was developed as a sustainable urban mobility solution.

The Jaipur Metro system consists of two corridors spanning 35.666 km, designed to alleviate traffic congestion and provide an environmentally friendly transportation alternative. This study focuses on optimizing the capacity of the Jaipur Metro, with particular emphasis on maximizing passenger flow during peak and off-peak hours. While Mass Rapid Transit Systems (MRTS) like the Jaipur Metro excel at handling large passenger volumes, optimizing train operations for varying demand periods is crucial for maximizing efficiency and passenger experience.

Building upon existing research by Chen et al. on factors influencing metro capacity and Wang et al. on using fuzzy Markov chain theory for capacity measurement, this study aims to identify key factors impacting rail carrying capacity during peak and off-peak hours. Unlike previous studies that primarily considered trains of the same speed, our research uniquely incorporates both slow and fast trains in the analysis, reflecting the real-world operational conditions during non-peak and peak hours.

To understand how overtaking strategies and train mix affect capacity, we developed six models analysing various overtaking scenarios. These models incorporated key factors such as:

- Cycle time (time between trains)
- Waiting times at stations
- Passenger arrival rates for both peak and non-peak hours

Our analysis focused on three primary aspects:

1. Overtaking Strategies: Evaluating the impact of different overtaking scenarios on travel times, passenger waiting times, and overall network capacity.
2. Cycle Time and Waiting Time: Identifying stations with high waiting times and passenger volumes as potential candidates for more frequent overtaking or adjustments in train ratios during peak hours.
3. Passenger Arrival Data: Analysing differences in passenger arrival rates between peak and off-peak hours to inform optimal train ratio adjustments.

This study demonstrates that optimizing train ratios with strategic overtaking strategies can significantly improve passenger experience and network efficiency in the Jaipur Metro. By implementing these findings, railway planners can enhance public transport services and cater to the evolving needs of the city. Additionally, our research acknowledges the importance of factors such as minimum interval between trains (tracking time) and turnaround time when calculating capacity, as emphasized in previous studies.

2. RESEARCH METHOD

This study examines how train mix ratios and overtaking strategies impact rail carrying capacity on an urban rail line, focusing on Jaipur Metro's Corridor-1.

Case Study: Jaipur Metro Corridor-1

- 12.067 km East-West route
- 11 stations (8 elevated, 3 underground)
- Maximum speed: 80 km/h
- Travel times:
    - Low-speed trains: 25 minutes
    - High-speed trains: 15 minutes

2.1 MODELS

Six models were developed to analyse different overtaking scenarios:

1. No overtaking: One fast train between two slow trains
2. Single overtaking: Fast train overtakes at station L7
3. Additional slow train with single overtaking
4. Repeated overtaking of two slow trains
5. Two fast trains overtaking same slow train twice

6. Two fast trains overtaking different slow trains

Model 1 No overtaking:

No Overtaking when one high-speed train operates between two slow trains. when the high-speed train is situated between the two slower ones, neither of the slower trains can surpass or overtake it due to the speed difference. This arrangement creates a situation where the high-speed train essentially acts as a barrier preventing any overtaking maneuver.

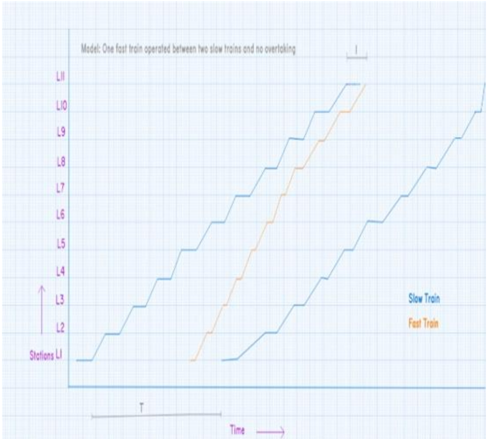

Figure 1 One fast train operated between two slow trains and no overtaking

Model 2 Single overtaking:

Overtaking Once: A high-speed train overtakes slow trains at a designated station (L7) once during the trip. There are no other overtaking points mentioned

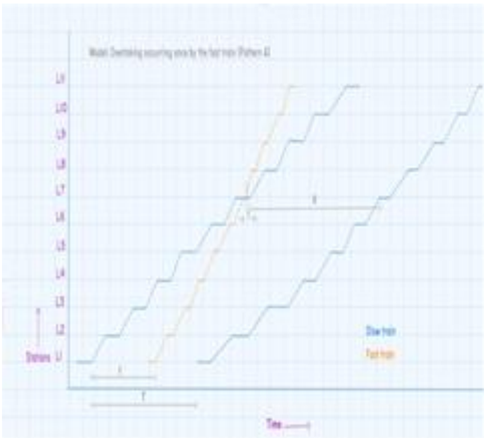

Figure 2 Overtaking occurrence once by the fast trains

Model 3 Additional slow train with single overtaking:

An additional slow train is inserted between an existing slow and fast train pair. The high-speed train continues to overtake the slower trains once at a designated station, and this pattern repeats.

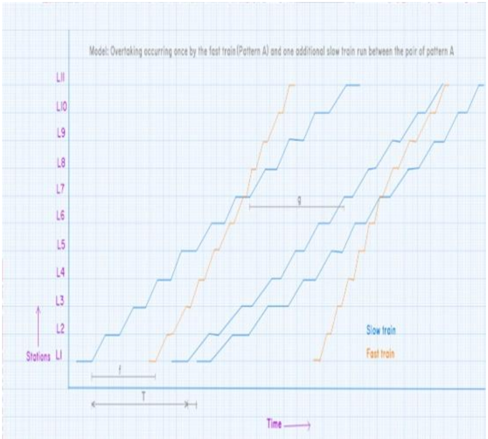

Figure 3 Overtaking occurrence once by the fast train and one additional slow train run between the pair of slow and fast train

Model 4 Repeated overtaking of two slow trains:

The key point is that the high-speed train repeatedly overtakes both slower trains at the same fixed location. This pattern continues throughout the journey, with the high-speed train consistently overtaking the slower pair

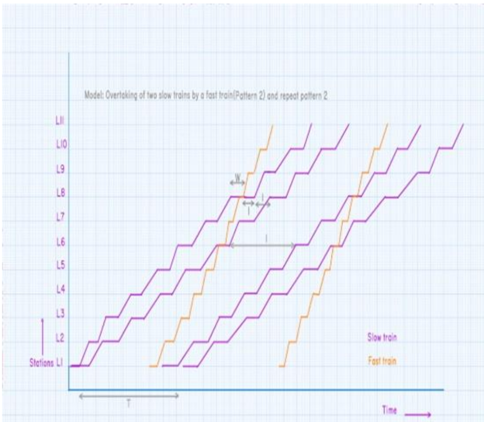

Figure 4 Overtaking of two slow trains by fast trains and repeat this pattern

Model 5 Two fast trains overtaking same slow train twice:

The same slow train is overtaken twice in a specific sequence. The first high-speed train overtakes the slow train at location L6, and then the second high-speed train overtakes the same slow train at location L8. This pattern is repeated throughout the operation.

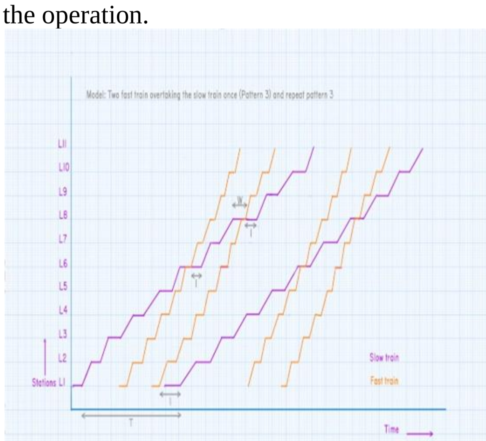

Figure 5 Two fast train overtaking the slow train once and repeat pattern

Model 6 Two fast trains overtaking different slow trains:

Two high-speed trains each overtake a different slow train at designated locations, and this pattern repeats.

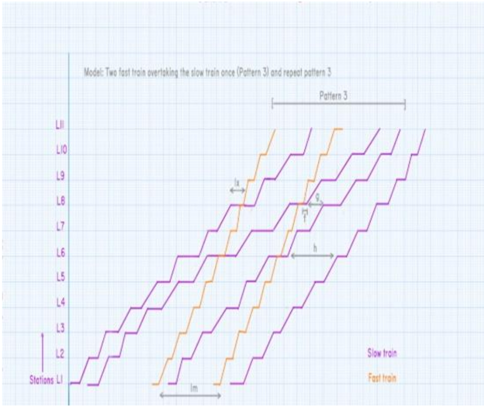

Figure 6 Two fast train overtaking the slow train once and repeat this pattern

2.2 MODEL ANALYSIS

Each model calculates:

- Cycle time (total trip time)
- Maximum carrying capacity (trains per hour)

Analysis considers three scenarios:

- High-speed to low-speed train ratios (p:q) of 1:1, 1:2, and 2:1

2.3 EXPECTED OUTCOMES:

- Overtaking strategies can increase capacity, especially with more high-speed trains
- Optimal train mix depends on peak and off-peak passenger demand
- Models can help optimize schedules and maximize efficiency

2.4 MRT CARRYING CAPACITY

Carrying capacity is calculated using formulas that consider:

- Maximum train frequency
- Cycle time
- Train mix ratios
- Section operating times

The rail carrying capacity can be evaluated by [21,22]:

- Maximum frequency of train (N_{max}) = 3600/ I (Per hour per direction) (1)
- I = maximum {$I_{running}$, $I_{returning}$} (2)
- Nmax = 3600/R (3)
- R= T / (p + q) (4)
- Nmax = (p + q) *(3600/ T) (5)
- Max operating time (I_m) = max {L_{12}, L_{23}, L_{34}, L_{45}, L_{56}, L_{67}, L_{78}, L_{89}, L_{910}, L_{1011}} / V_{AVG} (by all section) (6)

Where,

R trains release in t duration (in seconds) / number of mix trains in t duration, $I_{minimum}$ time interval of two departed trains (in seconds), N is maximum carrying capacity of a line for mix (low-high) mode trains. The rail carrying capacity of a line for mix mode increases as the departing time is reduced and number of trains is increased. n is the slow train stopping frequency. p no of fast train, q no of slow train within Cycle time T and time gap of two mix trains at destination must not be greater than the minimum time gap of departure.

2.5 MODEL FORMULATIONS

Six models were developed to optimize rail carrying capacity during peak and off-peak hours. Each model has a unique formulation for cycle time and maximum carrying capacity, considering factors like overtaking patterns, train ratios, and station stop times. This data-driven approach aims to optimize rail carrying capacity by considering train mix, overtaking strategies, and real-world operational parameters.
These models are designed to improve the efficiency of rail operations and are detailed in the accompanying table 1.

Table 1 Formulation of models

Model	**Formulation (Cycle time)**	**maximum carrying capacity of a line (N_{max})**	**Remark**
Model 1 (No overtaking: one fast train operated between two slow trains)	T = 2. I + n. Zstop	N_{max} = 2*[3600/ (2. I + n. Zstop)]	p:q = 1:1
Model 2 (Overtaking occurrence once by the fast trains)	T = 2. I + n. Z_{stop}	N_{max} = 2*[3600/T}	p:q = 1:1
Model 3 (Adding another slow train between the existing slow and fast trains. Overtaking still occurs once.	T = 3.I + n.Zstop	N_{max} = 3*[3600/ (3.I + n.Zstop)]	p:q = 1:2
Model 4 (Overtaking of two slow trains by fast trains and repeat this pattern)	T = W + 3.I + n. Z_{stop}	N_{max} = 3*[3600/ (W + 3.I + n.Z_{stop})]	p:q = 1:2
Model 5 (Two fast train overtaking same slow train once and repeat pattern)	T = W + 3. I + n. Z_{stop}	N_{max} = 3*[3600/T]	p:q = 2:1
Model 6 (Two fast train overtaking different slow train and repeat pattern)	T = W + I_m + 3.I + g + h	N_{max} = 3*[3600/T]	p:q = 2:1

Where,

Z_{stop} is the waiting time of a train at one station with including accelerating and retardation time, W is waiting time of slow train when fast train is overtaking at particular station. Im is the maximum operation time of all sections (in second), f is departure time gap between 2nd fast and slow train during overtaking, g is departure time gap between 2nd and 3rd slow train during overtaking and his departure time gap between 3rd and next slow train during overtaking.

2.6 IMPACT OF OVERTAKING ON MRT SYSTEM CAPACITY

Our analysis of models 3 and 4 reveals that strategic overtaking can significantly enhance the overall carrying capacity of the MRT system. Key findings include:

- **Optimal Train Ratio**: The overtaking strategy is most effective when the ratio of low-speed to high-speed trains is 2:1.
- **Initial Benefits**: Increasing overtaking frequency initially leads to shorter cycle times, improving system efficiency.
- **Threshold Effect**: However, exceeding two overtakes per cycle results in diminishing returns:
  - Longer waiting times for slower trains
  - Degradation of overall passenger service quality
- **Focus of Study**: Based on these findings, we concentrate on analyzing the impact of up to two overtakes on carrying capacity.

This approach balances the benefits of overtaking with the need to maintain consistent service quality for all passengers. By limiting overtaking events, we can optimize capacity while avoiding the negative consequences of excessive waiting times for slower trains.

3. JAIPUR METRO CORRIDOR-1: AN INVESTIGATION OF PASSENGER CAPACITY

This study focuses on Corridor-1 of the Jaipur Metro system, which runs from Manasarovar to Badi Chaupar along the East-West axis.

Key Characteristics:

- **Number of Stations**: 11
  - 8 elevated stations
  - 3 underground stations
- **Maximum Operational Speed**: 80 km/h
- **Travel Times**:
  - Low-speed trains: 25 minutes
  - High-speed trains: 15 minutes

Operational Parameters:

- **Marshaling Tracks**: 6
- **Minimum Headway**: 10 minutes between departing trains
- **Station Dwell Times** (including acceleration and deceleration):
  - Low-speed trains: 50 seconds
  - High-speed trains: 30 seconds

This corridor serves as a crucial transportation link in Jaipur, connecting major areas along the East-West axis. The study aims to analyze and optimize passenger capacity by considering various operational strategies, including train mix ratios and overtaking scenarios.

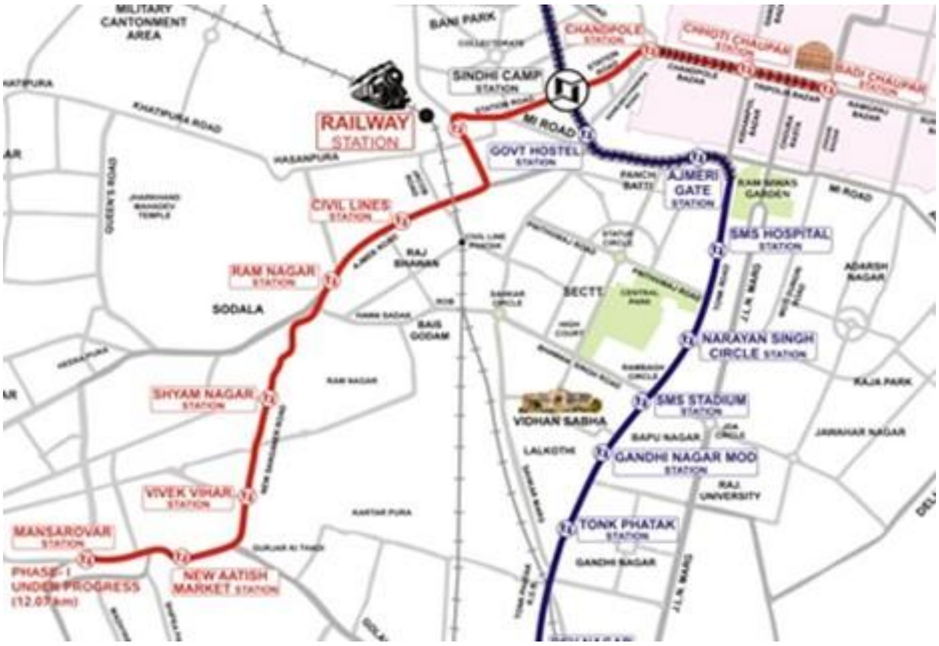

Figure 7 Jaipur Metro Map

Each train operating on corridor-1 has four carriages and boasts a comfortable passenger capacity of 644. To estimate the total passenger carrying capacity of the corridor, we will explore the following formula

$$E_p = (C * A * 60) / D \quad (7)$$

Where,

E_p = Estimated total number of passengers
C = Carry no. of passengers
A = overloading factor
D = Minimum departure time between two trains

Estimated number of passenger (E_p) = (644 X 150% X 60)/10 = 5796 Passengers

3.1 AS PER PROPOSED MODEL MRT RAIL CARRYING CAPACITY

The passenger carrying capacity of Corridor-1 can be measured based on the proposed model. Proposed six models have three basic cases i.e. ratio p:q is 1:1, 1:2 and 2:1 respectively.

Table 1. Ratio of mix (high and low) train flow with carrying capacity

The proportion of mix (high and low) train flow combinations (p: q)	4:1	3:1	2:1	1:1	1:2	1:3	1:4
Carrying capacity (N_{max})	7.89	6.49	5	4.2	4.5	5.8	7

Table 2. Passenger flow during peak and off-peak hours of Jaipur Metro Corridor-1

Station Name	Peak hours (total no. of passengers)	Average Peak hours (passenger/h)	Off-peak hours (total no. of passengers)	Average off-peak hours (passenger/h)
Mansarovar	19924	4981	34224	2852
New Aatish Market	12860	3215	15612	1301
Vivek Vihar	10832	2708	16762	1397
Shyam Nagar	8671	2168	16216	1351
Ram Nagar	7610	1902	16762	1397
Civil Lines	6774	1694	18816	1568
Railway Station	9123	2281	14782	1232
Sindhi Camp	7763	1941	12216	1018
Chand Pole	9280	2320	14672	1223
Choti Chaupar	7335	1834	13284	1107
Badi Chaupar	7520	1880	14484	1207

(1) When p : q = 1:1 and mix trains run during the combined period

Nmax = (p + q) * (3600/ T),
Nmax = 2*[3600 / (2.I + n. Z_{stop})],
Nmax = 2 X [3600 / 2 X 600 + 10 X 50] = 4.24

(2) When p : q = 1:2 and mix trains run during the combined period

Nmax = 3*[3600/ (W + 3. I + n .Z_{stop})] = 3 X [3600/ (90+3 X 600 + 10 X 30 = 4.52

(3) When p : q = 2:1 and mix trains run during the combined period

Nmax = 3*[3600/ (W + 3. I + n .Z_{stop})] = 3 X [3600 / (60+3 X 600+ 10 X 30)] = 5

Hence, Table 2 provides a scientific analysis of how the ratio of high-speed to low-speed trains (running mix) affects the overall carrying capacity of corridor-1. When the number of high-speed and low-speed trains are equal, the carrying capacity is minimized. Conversely, the carrying capacity increases as the ratio of high-speed to low-speed trains rises (and vice versa). This relationship aligns with findings from previous studies [28, 29].

Determining the optimal train mix hinges on actual passenger demand throughout the day. Peak hours may necessitate a higher proportion of high-speed trains to accommodate passenger surges. However, it's crucial to acknowledge that carriages designed for a capacity of 340 passengers can become overloaded by 20% during peak periods, potentially impacting passenger comfort and safety.

3.2 PRACTICAL APPLICATION OF THE MODEL

The proposed model can be implemented in real-world scenarios to optimize train operations. Here's the process:

Demand Measurement: During peak and off-peak hours, the actual number of passengers needing transport is measured.

Capacity Comparison: This measured demand is then compared to the corridor's maximum carrying capacity, as determined in previous sections.

Train Mix Optimization: Based on this comparison, the ideal ratio of high-speed to low-speed trains (running mix) can be identified as shown in Table 2. This ensures efficient service delivery while considering passenger comfort. Peak hours are typically defined as 6:30 AM to 8:30 AM and 4:30 PM to 6:30 PM.

To determine the required number of trains for a specific period (peak or off-peak), the following formula can be used:

$$N_T = N_P / (N_R \times \Upsilon \times N_M)$$

Where,
N_T: Number of trains required for actual demand
N_P: Total number of passengers in that period
N_R: Allowed passenger capacity of a carriage
Υ (gamma): Overloading coefficient (accounts for potential overload)
N_M: Number of marshaling tracks

Table 3 indicates that passenger numbers during peak hours are 25,044, while off-peak hours see 14,446 passengers. Number of marshaling track may be assumed 10 in this study. Hence the required number of trains for each scenario is

- Peak Hours:

$$\mathbf{N_T = 25044 / (340 \times 1.2 \times 10) \approx 6.138}$$

Therefore, the ratio of fast and slow trains 3:1 would be needed during peak hours according to table no.1

- Off-peak Hours:

$$\mathbf{N_T = 14446 / (340 \times 10) \approx 4.248}$$

Thus, the ratio of slow and fast trains 1:1 would be needed during off-peak hours according to table no.1

4. RESULTS AND DISCUSSION

Our analysis of train requirements and capacity data yields valuable insights for optimizing the Jaipur Metro's Corridor-1 operations:

Peak Hours Optimization:

- **Ideal Ratio**: 3 high-speed trains to 1 slow-speed train
- **Benefits**:
    - Maximizes passenger throughput during high-demand periods
    - Reduces overall travel times for commuters
    - Potentially alleviates platform congestion at busy stations

Off-Peak Hours Strategy:

- **Recommended Ratio**: 1 high-speed train to 1 slow-speed train
- **Advantages**:
    - Balances operational efficiency with lower passenger demand
    - Maintains consistent service frequency
    - Potentially reduces energy consumption and operational costs

Dynamic Management Approach:

This model provides a framework for adaptive corridor management:

- **Real-Time Adjustments**: Allows for flexible train mix based on current demand patterns
- **Operational Efficiency**: Optimizes resource utilization across varying traffic conditions
- **Passenger-Centric**: Prioritizes both efficient service delivery and passenger comfort.

By implementing this dynamic approach, Jaipur Metro can enhance its service quality, improve operational efficiency, and better meet the evolving needs of its passengers throughout the day.

5. CONCLUSION

This study on Jaipur Metro's Corridor-1 yielded significant insights into optimizing urban rail operations:

Key Findings**:**

- **Capacity-Demand Relationship**: We established a clear correlation between the corridor's carrying capacity and train requirements during peak and off-peak hours.
- **Model Effectiveness**: Our six proposed models successfully calculated both urban rail carrying capacity and passenger demand.
- **Optimal Train Mix**: We determined the ideal ratio of high-speed to low-speed trains for various demand scenarios, as detailed in Table 2.

Balancing Efficiency and Service Quality:

- **Strategic Overtaking**: While excessive overtaking (more than twice) can negatively impact service, strategic use of overtaking maneuvers remains crucial for capacity optimization.
- **Continuous Challenge**: Optimizing train mix across complex, multi-line metro networks requires ongoing attention and adjustment.

Practical Applications:

The model developed in this study serves as a valuable decision-making tool for metro operators, enabling them to:

- Ensure efficient service delivery
- Prioritize passenger comfort and safety
- Make informed choices about train scheduling and resource allocation

By implementing these findings, Jaipur Metro can enhance its operational efficiency while maintaining a high standard of passenger service, setting a benchmark for urban rail systems in rapidly growing cities.

6. FUTURE RESEARCH AND APPLICATION PROSPECTS

This study on Jaipur Metro Corridor-1 establishes a foundation for further research and practical applications in urban rail optimization. Key areas for future development include:

Research Development:

Model Enhancement:

- Incorporate additional factors such as passenger waiting time and platform capacity constraints
- Explore the integration of machine learning techniques for more accurate predictions

Advanced Demand Forecasting:

- Develop sophisticated models to predict passenger demand patterns
- Account for daily, weekly, and seasonal variations

Network-Wide Optimization:

- Expand the model to consider interactions across the entire Jaipur Metro system
- Develop algorithms for optimizing transfers and connections between lines

Application Prospects:

Dynamic Scheduling System:

- Implement real-time optimization using live passenger data
- Enable automated adjustments to train schedules and compositions

Decision Support Tools:

- Create user-friendly interfaces for transportation planners
- Provide data-driven insights for infrastructure investments and service allocation

Adaptable Framework:

- Refine the model for application in diverse urban rail systems
- Develop a modular structure to accommodate varying operational constraints

By pursuing these research directions and applications, we can significantly enhance the efficiency, reliability, and passenger experience of urban rail systems. This approach will help metro networks like Jaipur's to adapt to evolving urban mobility needs and support sustainable city development.

REFERENCES

1. A. Agarwal, V. Wickramasinghe, and V. Venkatesan, "Feasibility study of Jaipur metro rail project," International Journal of Engineering Research and Technology, vol. 3, no. 4, pp. 2185-2189, 2014.
2. A. Di Graziano et al., "Application of a decision support tool for the risk management of a metro system," International Journal of Rail Transportation, vol. 10, no. 3, pp. 352–374, 2021.
3. A. K. Saxena and N. C. Goel, "Jaipur metro: A sustainable urban transport solution," in International Conference on Transportation Planning and Implementation Methodologies for Developing Countries, Mumbai, India, 2016.
4. A. K. Saxena and N. C. Goel, "Jaipur metro: Enhancing urban mobility and heritage conservation," in International Conference on Urban Transport and the Environment, Seville, Spain, 2017.
5. A. K. Saxena, "Jaipur Metro Rail Project as a Catalyst for Enhancing Heritage Value of Walled City," in Urban Mobility India Conference, Gandhinagar, India, 2016.
6. A. Verma et al., "A Critical Review of India's Urban Governance Reforms and Its Impact on Transport Sector: Case Studies of Bangalore and Jaipur," in Urban Mobility Research in India. UMI 2022. Lecture Notes in Civil Engineering, A. Verma and M. L. Chotani, Eds. Singapore: Springer, 2023, vol. 361.
7. A. Verma et al., "Urban mobility trends in Indian cities: A comparative analysis," Transportation Research Procedia, vol. 48, pp. 3062-3076, 2020.
8. A. Verma et al., "Urban transport policies and initiatives for sustainable mobility: A case study of Jaipur city," Transportation Research Procedia, vol. 48, pp. 2804-2818, 2020.
9. E. Jose et al., "A multi-criteria decision making approach to evaluating the performance of Indian railway zones," Ann Oper Res, vol. 325, pp. 1133–1168, 2023.
10. G. Su et al., "Simulation-Based Method for the Calculation of Passenger Flow Distribution in an Urban Rail Transit Network Under Interruption," Urban Rail Transit, vol. 9, pp. 110–126, 2023.
11. J. Le and J. Teng, "Understanding Influencing Factors of Travel Mode Choice in Urban-Suburban Travel: A Case Study in Shanghai," Urban Rail Transit, vol. 9, pp. 127–146, 2023.
12. J. Li et al., "Integrated optimization of train services plan and passenger flow control on an oversaturated suburban metro line," J. Cent. South Univ., vol. 30, pp. 625–641, 2023.
13. J. Qi et al., "Joint optimization model for train scheduling and train stop planning with passengers distribution on railway corridors," J Oper Res Soc., 2017.
14. Jaipur Metro Rail Corporation, "6th Annual Report 2014-15," Jaipur Metro, Jaipur, India, 2015.
15. Jaipur Metro Rail Corporation, "Annual Report 2022-23," Jaipur Metro, Jaipur, India, 2023.
16. Jaipur Metro Rail Corporation, "Detailed Project Report: Jaipur Metro Rail Project Phase-II from India Gate to Ambabari," Jaipur Metro, Jaipur, India, 2020.
17. M. Parihar, N. Dasari, and K. Bhagwat, "Smart City Solution: Enhancing Capacity Utilization of Mass Rapid Transit System (MRTS) for Economic Viability with Special Reference to Jaipur Metro Rail

Network," in Smart Systems: Innovations in Computing, A. K. Somani et al., Eds. Singapore: Springer, 2022, vol. 235.

18. M. Swami and M. Parida, "Comparative appraisal of metro stations in Delhi using data envelopment analysis in a multimodal context," Journal of Public Transportation, vol. 18, no. 3, pp. 29-51, 2015.

19. P. C. Jasti and V. Vinayaka Ram, "Integrated and Sustainable Benchmarking of Metro Rail System Using Analytic Hierarchy Process and Fuzzy Logic: A Case Study of Mumbai," Urban Rail Transit, vol. 5, pp. 155–171, 2019.

20. P. He et al., "A Local Line Optimization Model for Urban Rail Considering Passenger Flow Allocation," Urban Rail Transit, vol. 10, pp. 160–177, 2024.

21. P. Sharma and J. K. Jain, "Efficiency analysis of Jaipur metro using data envelopment analysis," in International Conference on Recent Advances in Engineering and Technology, Jaipur, India, 2018.

22. P. Sharma and J. K. Jain, "Performance evaluation of Jaipur metro using data envelopment analysis," in International Conference on Recent Trends in Engineering and Technology, Jaipur, India, 2020.

23. P. Sharma and P. Kalla, "Efficiency analysis of Jaipur metro using data envelopment analysis: A comparative study," in International Conference on Transportation Planning and Implementation Methodologies for Developing Countries, Mumbai, India, 2021.

24. P. Sharma and P. Kalla, "Efficiency evaluation of Jaipur metro using data envelopment analysis," in International Conference on Advances in Engineering and Technology, Jaipur, India, 2019.

25. P. Sharma and P. Kalla, "Performance evaluation of Jaipur metro using data envelopment analysis," International Journal of Engineering Research and Technology, vol. 10, no. 1, pp. 341-346, 2017.

26. P. Sharma and P. Kalla, "Study of Performance Efficiencies for Jaipur Metro by Using Data Envelopment Analysis," International Journal of Engineering Research and Applications, vol. 7, no. 3, pp. 66-70, 2017.

27. P. Sharma, J. K. Jain, and P. Kalla, "A study of efficiency measurement of Jaipur metro mass transit system using data envelopment analysis," Innovations Syst Softw Eng., vol. 19, pp. 47–60, 2023.

28. P. Sharma, J. K. Jain, and P. Kalla, "Efficiency measurement of Jaipur metro mass transit system using data envelopment analysis," International Journal of System Assurance Engineering and Management, vol. 12, pp. 1-14, 2021.

29. R. Goel and G. Tiwari, "Access-egress and other travel characteristics of metro users in Delhi and its satellite cities," IATSS Research, vol. 39, no. 2, pp. 164-172, 2016.

30. R. Goel and G. Tiwari, "Promoting low carbon transport in India: A case study of metro rails in Indian cities," Transportation Research Procedia, vol. 25, pp. 3429-3444, 2017.

31. R. Goel and G. Tiwari, "Promoting sustainable transport: A case study of metro rails in Indian cities," Transportation Research Procedia, vol. 48, pp. 2394-2409, 2020.

32. R. Goel and G. Tiwari, "Sustainable urban transport: Case studies of metro rails in Indian cities," Transportation Research Procedia, vol. 62, pp. 577-586, 2022.

33. R. K. Soni and R. Hooda, "Economic viability of Jaipur metro rail project: A critical analysis," International Journal of Management and Social Sciences Research, vol. 6, no. 9, pp. 1-6, 2017.

34. R. K. Soni and R. Hooda, "Jaipur metro rail project: A case study," International Journal of Engineering Research and Applications, vol. 7, no. 6, pp. 1-5, 2017.

35. R. K. Soni and R. Hooda, "Jaipur metro rail project: A sustainable urban transport solution," International Journal of Engineering Research and Applications, vol. 8, no. 6, pp. 1-5, 2018.
36. R. K. Soni, "An Economic Analysis of Mass Rapid Transit System (MRTS) in India with Special Reference to Jaipur Metro Rail in Rajasthan," Journal of Commerce and Trade, vol. 15, no. 1, pp. 86-93, 2020.
37. R. Sharma and P. Newman, "Can land value capture make PPP's competitive in fares? A Mumbai case study," Transport Policy, vol. 64, pp. 123-131, 2018.
38. S. Jain and S. Khare, "Jaipur metro rail project: A sustainable urban transport solution," International Journal of Engineering Research and Applications, vol. 6, no. 4, pp. 1-6, 2016.
39. S. Jain and S. Khare, "Jaipur metro: A step towards sustainable urban transport," International Journal of Engineering Research and Technology, vol. 8, no. 7, pp. 1-6, 2019.
40. S. Jain and S. Khare, "Sustainable urban transport: A case study of Jaipur metro rail project," International Journal of Engineering Research and Technology, vol. 7, no. 5, pp. 1-6, 2018.
41. S. Jain and S. Khare, "Urban transport projects in India: A case study of Jaipur metro rail project," International Journal of Engineering Research and Applications, vol. 5, no. 11, pp. 1-7, 2015.
42. S. K. Sharma and P. Vyas, "Assessment of passenger satisfaction: A study of Jaipur metro," International Journal of Engineering and Management Research, vol. 7, no. 3, pp. 667-672, 2017.
43. S. K. Sharma and P. Vyas, "Customer satisfaction in Jaipur metro: An empirical study," International Journal of Engineering and Management Research, vol. 9, no. 3, pp. 56-61, 2019.
44. S. K. Sharma and P. Vyas, "Service quality assessment of Jaipur metro: An empirical analysis," International Journal of Engineering and Management Research, vol. 8, no. 2, pp. 184-189, 2018.
45. S. K. Sharma, "Evaluation of Metro in Jaipur City, India," International Journal of Engineering Research and Technology, vol. 10, no. 3, pp. 237-242, 2021.
46. S. Mathur, S. Soi, and A. Reengus, "Jaipur: An Emerging Metro City," in Smart Metropolitan Regional Development. Singapore: Springer, 2018, pp. 537-557.
47. S. Swami and M. Parida, "Comparative appraisal of metro stations in Delhi using data envelopment analysis in a multimodal context," Journal of Public Transportation, vol. 18, no. 3, pp. 29-51, 2015.
48. X. Li et al., "Influence of TOD Modes on Passenger Travel Behavior in Urban Rail Transit Systems," Urban Rail Transit, vol. 8, pp. 175–183, 2022.
49. X. Xu et al., "Identifying Station Importance in Urban Rail Transit Networks Using a Combination of Centrality and Time Reliability Measures: A Case Study in Beijing, China," Urban Rail Transit, 2024.
50. Z. Tao et al., "Impacts of Urban Rail Transit on City Growth: Evidence from China," Urban Rail Transit, vol. 8, pp. 121–133, 2022.