ISSN: 2633-4828 Vol. 6 No.4, December, 2024

International Journal of Applied Engineering & Technology

MITIGATING URBAN TRAFFIC CONGESTION IN PUNE USING MOVABLE TRAFFIC DIVIDERS AND INTELLIGENT CONTROL SYSTEMS

Prof. A. N. Bhirud[1] , Mahajan Shivam D.[2] , Gavit Amarjit A.[3] , Shembade Balaji T[4] and Thorat Suraj S.[5]

[1]Assistant Professor, Department of Civil Engineering, Imperial College of Engineering and Research, Wagholi, Pune-412207

[2,3,4,5]UG Student, Department of Civil Engineering , JSPM'S Imperial College of Engineering and Research, Wagholi, Pune-412207

ABSTRACT

Urbanization and rapid vehicular growth in metro cities have led to a severe imbalance between traffic volume and static road infrastructure, resulting in persistent congestion, increased travel time, and frequent accidents. Pune, one of India's fastest-growing cities, faces acute traffic congestion despite ongoing mitigation efforts. Traditional solutions like road widening are increasingly ineffective due to spatial constraints and induced traffic demand. This paper explores the dynamics of recurring traffic congestion in Pune, emphasizing its identification, measurement, and mitigation. The study proposes an innovative approach using ***movable traffic dividers*** *to dynamically reconfigure lane capacity in response to real-time traffic conditions. In addition, a* ***hierarchically intelligent traffic control system*** *is suggested for managing and optimizing urban traffic flows. By leveraging data from metro counts and congestion mapping, the proposed system aims to maximize the efficiency of existing infrastructure without the need for physical expansion. The combination of adaptive traffic lane systems and intelligent control can offer sustainable solutions to urban mobility challenges in Pune and other similar cities.*

Keywords: *Traffic Congestion, Pune, Movable Traffic Divider, Urban Transport, Intelligent Traffic Control, Metro Count, Dynamic Lane Allocation, Smart City Mobility*

1. INTRODUCTION

1.1 Background of Urban Traffic Growth

With increasing urbanization and economic development, metropolitan cities worldwide have witnessed an exponential surge in vehicular population (Jadhav & Bhirud, 2015), (Bhirud & Revatkar, 2016). This has led to growing traffic demands on city roads, which often outpace infrastructure development. The imbalance between the growth in motor vehicles and static road infrastructure contributes to severe traffic congestion, particularly during peak hours (Zhao et al., 2013). In India, urban mobility has become a complex challenge, with cities like Delhi, Mumbai, and Pune experiencing rapid motorization without proportional growth in road capacity (MoUD, 2014).

1.2 Significance of Traffic Management in Growing Metro Cities

Efficient traffic management is crucial for economic productivity, public safety, and environmental sustainability. Poorly managed traffic systems lead to longer commute times, increased fuel consumption, air pollution, and road accidents (Singh & Rajan, 2015). According to the World Bank (2019), urban congestion can reduce city productivity by up to 10%, making it imperative for planners to adopt innovative solutions for smoother mobility. As cities evolve, adopting intelligent transport systems (ITS) and flexible infrastructure becomes key to building resilient urban ecosystems (Kumar & Bansal, 2021).

1.3 Traffic Scenario in Pune: Current State and Challenges

Pune, known for its IT hubs and academic institutions, has seen a dramatic rise in private vehicle ownership—particularly two-wheelers and cars—over the last decade. However, the road infrastructure has not expanded at the same rate, resulting in severe congestion at major junctions and arterial roads (Patil & Deshmukh, 2020). Encroachments, inadequate public transport coverage, and lack of lane discipline further exacerbate the traffic situation. Despite several flyovers and BRTS corridors, the city's traffic woes remain unresolved, highlighting the urgent need for alternative congestion management strategies (PMC, 2021).

2. LITERATURE REVIEW

2.1 Studies on Traffic Congestion and Urban Infrastructure Limitations

Several studies underline the growing gap between traffic demand and available infrastructure in rapidly urbanizing cities. A study by Rodrigue (2020) emphasizes that increasing road length alone is not sufficient to reduce congestion due to induced demand—newly built roads attract more traffic over time. Similarly, Mitra et al. (2018) note that traditional infrastructure planning in Indian cities fails to accommodate multi-modal transport needs, creating bottlenecks in urban networks (Ambrule & Bhirud, 2017; Bhirud & Patil, 2016).

2.2 Traditional Methods of Congestion Mitigation (e.g., Road Widening)

Historically, urban congestion was tackled through physical expansion—such as road widening, construction of flyovers, or creation of expressways. While these interventions provide temporary relief, they often become ineffective due to land scarcity and the rapid rebound effect (Downs, 2004; Litman, 2017). Studies by Agarwal and Singh (2019) on Indian urban roads show that road widening projects rarely produce long-term decongestion benefits, particularly in land-constrained cities.

2.3 Recent Innovations in Dynamic Traffic Management

Recent developments have shifted toward **adaptive and data-driven traffic management**. Intelligent Transportation Systems (ITS), sensor-based signal control, and dynamic lane allocations are being adopted globally to improve efficiency (Zhou et al., 2016). In cities like Seoul and Singapore, real-time traffic flow data is used to adjust signal timings and lane directions, significantly reducing congestion (World Economic Forum, 2020). These methods provide better adaptability and responsiveness than static systems.

2.4 Use of Movable Traffic Dividers in Other Urban Areas

Movable or retractable traffic dividers are used in several countries to dynamically adjust lane availability based on peak direction flows. For instance, cities like Los Angeles and Auckland have implemented reversible lanes using movable barriers to reallocate road space without requiring new construction (Mohan & Kapoor, 2019). These systems optimize road utility by catering to directional traffic variations during peak hours. Research by Chen and Liu (2017) supports that dynamic median barriers can reduce traffic delays by up to 25% in high-density corridors.

2.5 Hierarchical and Intelligent Control Systems in Traffic Regulation

Hierarchical control models categorize traffic control functions at multiple levels—local, regional, and central—allowing for coordinated and intelligent traffic flow optimization (Papageorgiou et al., 2015). These models integrate sensors, cameras, and AI algorithms to regulate signals and dynamically manage road capacity. Recent studies by Joshi et al. (2022) demonstrate that smart hierarchical systems can enhance urban mobility by minimizing bottlenecks, improving safety, and reducing carbon emissions.

3. Methodology

3.1 Data Collection Methods: Metro Count, Surveys, and Traffic Flow Monitoring

To analyze traffic congestion and develop a suitable mitigation strategy, a combination of **quantitative and qualitative data collection methods** was employed.

- **Metro count devices** were installed at major junctions and arterial roads across Pune to collect real-time vehicular data, including vehicle type, count, and average speed during peak and non-peak hours (Joshi et al., 2022).
- **Structured surveys** were conducted among commuters, traffic police, and transport planners to gather opinions on congestion hotspots and potential solutions.
- **Manual and camera-based traffic flow monitoring** was conducted over 30 days across 12 key intersections to observe volume-to-capacity ratios, traffic delays, and queuing lengths (PMC, 2021).

This triangulated approach ensured the robustness and reliability of the dataset used in this study.

3.2 Traffic Congestion Analysis Parameters

Congestion analysis was based on key traffic performance indicators (TPIs), including:

- **Volume-to-Capacity (V/C) ratio**
- **Average vehicle delay (seconds/vehicle)**
- **Travel time index (TTI)**
- **Queue length and intersection delay**
- **Level of Service (LOS) classification** as per IRC guidelines (IRC SP-41:1994; Zhou et al., 2016)

Data were averaged over multiple peak periods (morning: 8–11 AM, evening: 5–8 PM) and weekdays to ensure consistency and representativeness.

3.3 Identification of High Congestion Zones in Pune

Using the collected data, congestion zones were identified by:

- Mapping V/C ratios on GIS layers,
- Overlaying accident frequency data from the Pune Traffic Police database, and
- Applying spatial clustering using **ArcGIS and QGIS** platforms.

High-congestion zones included **Swargate Junction, Shivajinagar, Katraj Chowk, Deccan Gymkhana, and Hadapsar**, which consistently displayed congestion levels exceeding acceptable thresholds (Patil & Deshmukh, 2020).

3.4 Simulation or Case Study Areas for Movable Divider Application

Based on congestion mapping, **pilot study locations** for movable divider application were shortlisted:

- **Sinhgad Road (Warje to Swargate)**
- **Hadapsar Bypass**
- **JM Road to FC Road stretch**

These sites were selected due to their:

- High directional traffic volume imbalance during peak hours,
- Sufficient width to accommodate movable medians, and
- Minimal grade-separated intersections.

Simulation modeling was conducted to predict lane demand variability and to optimize divider movement intervals.

3.5 Tools and Technologies Used for Modeling (e.g., MATLAB, VISSIM)

Traffic modeling and evaluation were conducted using:

- **PTV VISSIM** for microsimulation modeling of lane flows and dynamic divider integration.
- **MATLAB** for algorithm development to automate divider movement logic based on real-time congestion data.
- **GIS tools** (ArcGIS, QGIS) for spatial traffic visualization and hotspot analysis.

- **Google Maps API** and **Pune Smart Traffic Monitoring Dashboard** were used to validate real-time congestion feedback and travel time indices.

This hybrid methodology supports the empirical validation of the proposed intervention under various traffic scenarios.

4. TRAFFIC CONGESTION IN PUNE

4.1 Analysis of Vehicle Growth vs Infrastructure in Pune

Between 2011 and 2021, Pune experienced over a **120% rise in registered vehicles**, with two-wheelers accounting for nearly 70% of the fleet (RTO Pune, 2022). However, the city's road network expanded by only 14% during the same period. The mismatch between vehicle growth and road availability has overwhelmed arterial and sub-arterial roads (Kumar & Bansal, 2021).

The **vehicle per km road density** in Pune is now among the highest in India, leading to reduced travel speed and increased emissions (World Bank, 2019).

4.2 Peak Hour Traffic Behavior and Patterns

Peak congestion in Pune typically occurs during:

- **Morning commute (8:00–11:00 AM)** and
- **Evening return (5:00–8:00 PM)**

Key observations from metro count and camera data:

- Roads like **Karve Road, Sinhgad Road, and Pune-Solapur Highway** exhibit lane saturation during peak periods.
- Directional imbalance is significant; for instance, inbound traffic during mornings is nearly **40% higher** than outbound in specific corridors like Hadapsar to Swargate (Joshi et al., 2022).
- Traffic violations (e.g., signal jumping, lane cutting) further reduce operational capacity.

4.3 Spatial and Temporal Congestion Mapping

Using temporal data and spatial overlays:

- Heat maps were created for **hourly congestion severity**.
- **Accident-prone zones** and **intersection bottlenecks** were identified through high-frequency incident reports.
- Areas with consistently high **travel time indices (>2.5)** include **Swargate**, **Chinchwad**, and **Kharadi Bypass**.

GIS-based **congestion index layering** revealed that over **32% of Pune's road length operates at LOS E or F** during peak hours, indicating severe congestion (PMC, 2021).

4.4 Challenges in Implementing Traditional Solutions

The following limitations were observed in existing infrastructure improvement strategies:

- **Limited Right of Way (RoW)** due to dense development along roads.
- **Legal and social barriers** to land acquisition for road widening.
- **Cost escalations** and **delay in construction** of flyovers or elevated corridors.
- **Environmental concerns** in sensitive zones such as riverbanks and green belts.

Additionally, expanding infrastructure often **induces further traffic** (Downs, 2004), making it a short-term fix rather than a sustainable solution.

5. PROPOSED SOLUTION: MOVABLE TRAFFIC DIVIDERS

5.1 Concept and Working Mechanism

Movable traffic dividers, also known as *dynamic median barriers* or *lane changers*, are designed to allow the flexible reallocation of lanes according to directional traffic demand. These systems use **automated barrier transfer machines (BTMs)** or **manual sliding mechanisms** that shift the position of a concrete or metal median barrier across lanes (Chen & Liu, 2017).

The working mechanism includes:

- A **mechanically guided track or wheeled mechanism** that repositions the divider.
- Predefined **divider shifting schedules** during morning and evening peak hours.
- **Traffic sensor data** to trigger real-time adjustments based on flow thresholds.

This flexibility ensures efficient usage of road space without requiring permanent infrastructure expansion.

5.2 Benefits in Dynamic Lane Allocation

Movable dividers help dynamically balance traffic volumes in congested corridors with **asymmetrical directional demand**. Key benefits include:

- **Increased throughput** by optimizing underutilized lanes.
- **Improved safety** due to physical separation of opposing traffic flows.
- **Cost-effectiveness** as it avoids land acquisition and permanent construction (Mohan & Kapoor, 2019).
- **Scalability and reversibility** for different corridors and event-specific traffic changes.

A study by Zhou et al. (2016) reported **up to 20–30% reduction in travel time** on routes using reversible lanes with movable dividers.

5.3 Cost, Feasibility, and Operational Considerations

The feasibility of implementing movable dividers in Pune was assessed based on:

- **Lane width availability** (minimum of 3.5 meters per lane),
- **Low presence of encroachments and footpaths** in the divider zones,
- **Manual operation cost** (INR 8–12 lakhs per km annually) vs **automated BTM costs** (INR 50–70 lakhs one-time with minimal O&M),
- **Environmental impact** (minimal), and
- **Public acceptance** based on pilot survey data.

The system is especially feasible on **wide four-lane and six-lane urban corridors**, where lane reconfiguration is possible without major civil works.

5.4 Implementation Strategy in Identified Congestion-Prone Areas

Based on analysis in Chapter 4, the following strategy is proposed:

- **Pilot Implementation Corridors**:
  - Swargate–Katraj (Sinhgad Road)
  - Pune–Solapur Highway (Hadapsar Bypass)
  - University Road–Shivajinagar

- **Schedule-Based Deployment**:
  - Morning (7:30 AM – 10:30 AM): More inbound lanes
  - Evening (5:30 PM – 8:30 PM): More outbound lanes
- **Monitoring & Evaluation**:
  - Deploy temporary movable medians for 6 months.
  - Assess volume/capacity ratio improvements and travel time reductions.

With local traffic police and PMC coordination, a **phased deployment model** with mid-term performance review is advised.

6. HIERARCHICAL INTELLIGENT CONTROL SYSTEM

6.1 System Architecture: Sensors, Controllers, and Decision Nodes

The proposed intelligent traffic management system consists of multi-layered architecture:

- **Local Control Layer**: Real-time traffic data from cameras, infrared sensors, and radar-based detectors at intersections.
- **Mid-Level Controller**: Regional coordination of traffic signals and lane controls across 2–3 zones.
- **Central Traffic Command Center (CTCC)**: Makes macro-level decisions using AI and historical traffic data analytics (Papageorgiou et al., 2015).

Each node communicates bidirectionally for adaptive and predictive traffic regulation.

6.2 Integration with Traffic Signals and Surveillance

Integration is achieved through:

- **IoT-based signal controllers** connected to a central database.
- **Closed-circuit cameras (CCTV)** using object recognition to detect traffic violations, lane occupancy, and congestion.
- **Automatic Number Plate Recognition (ANPR)** systems to track repeat violations and manage enforcement.

Pune's existing smart traffic infrastructure under the **Smart City Mission** offers a foundation for integrating the proposed control system (PMC, 2021).

6.3 Adaptive Traffic Signal Timing and Lane Direction Control

Using real-time traffic data, the system:

- Adjusts **signal timing dynamically** using algorithms based on queue lengths and vehicle flow (Zhou et al., 2016).
- Coordinates with **movable dividers** to optimize lane direction changes.
- Prioritizes **emergency vehicles and public transport**, improving response time and commuter efficiency.

Simulation studies suggest **up to 25% reduction in average vehicle delay** when compared to fixed-time signal systems (Joshi et al., 2022).

6.4 Communication Infrastructure and Real-Time Traffic Data Utilization

A robust communication framework is critical. This includes:

- **Fiber-optic backbone** linking intersection controllers to the CTCC.

- **Cloud-based storage and analytics** for historical traffic data modeling.
- **Mobile app and dashboard interface** for public updates and adaptive routing suggestions.

Data from the metro count sensors, mobile GPS feeds (e.g., Google Maps APIs), and traffic cameras enable **predictive congestion management** and public alerts in advance of disruptions.

7. RESULTS AND DISCUSSION

7.1 Impact Assessment through Simulation or Pilot Study

A pilot simulation was conducted using **PTV VISSIM** for three high-traffic corridors in Pune: **Swargate–Katraj**, **Hadapsar Bypass**, and **University Road–Shivajinagar**. The implementation of **movable traffic dividers** and **adaptive signal control** was simulated for both morning and evening peak hours.

Key findings from the simulation:

- **Average travel time reduced by 22–28%** across the three routes.
- **Queue lengths reduced by 35%** during peak inflow directions.
- **Lane utilization improved**, particularly in unidirectional high-flow periods.
- The **level of service (LOS)** improved from E/F to C/D on major intersections (Zhou et al., 2016; Joshi et al., 2022).

These results demonstrate the feasibility and effectiveness of dynamic lane allocation integrated with intelligent control.

7.2 Comparative Analysis: Before and After Implementation

Parameter	Before	After (Simulated)	Improvement
Average Vehicle Delay (s/veh)	180 seconds	128 seconds	↓ 29%
Peak Hour Volume Capacity	0.94	0.72	↑ 23% efficiency
Travel Time Index (TTI)	2.4	1.7	↓ 29%
Lane Utilization (%)	61% (avg.)	84% (avg.)	↑ 37%

This comparative analysis confirms that the **combined strategy of movable dividers + ITS** can significantly optimize traffic operations without road expansion.

7.3 Public Perception and Usability Studies (if applicable)

A survey was conducted among 450 commuters and 50 traffic officials:

- **78% of commuters** agreed that flexible lanes would ease congestion.
- **66% preferred intelligent signal systems** over traditional timers.
- **Traffic police officers** expressed concerns about enforcement during lane shifts but supported the automation aspect for long-term control (PMC, 2021).

However, **27% expressed safety concerns**, particularly regarding accidents during lane switching. This underscores the need for **clear signage**, **public education**, and **gradual deployment**.

7.4 Expected Challenges in Large-Scale Deployment

While the results are promising, several challenges are expected:

- **Cost of automation and BTM machines** for larger networks.
- **Public resistance to change**, especially in informal traffic environments.

- **Inter-agency coordination** between PMC, traffic police, and Smart City cell.
- **Real-time data integration delays** due to incomplete sensor coverage.

In highly dense areas like **Dhole Patil Road or Peth areas**, **limited road width** and **pedestrian conflict** may hinder divider deployment (Patil & Deshmukh, 2020).

8. RECOMMENDATIONS AND POLICY IMPLICATIONS

8.1 Guidelines for Scalable Implementation in Pune and Other Cities

Based on findings, the following guidelines are recommended:

- Begin with **pilot corridors** that meet width and traffic criteria.
- Adopt a **modular rollout approach**, assessing performance in quarterly cycles.
- Use **dynamic scheduling algorithms** based on live data (Chen & Liu, 2017).
- Develop **Standard Operating Procedures (SOPs)** for divider movement and traffic rerouting.

Such guidelines can serve as templates for implementation in cities like **Nagpur**, **Hyderabad**, and **Ahmedabad**, facing similar congestion profiles.

8.2 Suggested Government and Civic Engagement Strategies

Policy success requires multi-stakeholder engagement:

- **PMC and Traffic Police**: Lead regulatory and operational coordination.
- **Urban transport agencies**: Integrate systems with public transport flow.
- **Citizens' groups and RWAs**: Participate in education and feedback loops.
- **PPP Models**: Invite private sector in supply, installation, and data analytics.

Campaigns should focus on:

- **Awareness about lane switching rules**,
- **Safe usage of reconfigured roads**, and
- **Compliance monitoring via CCTVs and AI enforcement tools** (Papageorgiou et al., 2015).

8.3 Integration with Smart City and Sustainable Urban Mobility Plans

The solution aligns with:

- **National Urban Transport Policy (NUTP)** goals of demand management and efficient mobility.
- **Smart City Mission objectives** on intelligent traffic systems and digital governance.
- **Sustainable Urban Mobility Plans (SUMPs)** for Pune and Tier-2 cities, promoting non-infrastructure heavy strategies.

Integration can be achieved by:

- Embedding divider and signal control into **Pune's Integrated Traffic Management System (ITMS)**,
- Creating a **city-wide digital traffic twin** for real-time decision-making, and
- Using **performance-based funding** from national programs like AMRUT or 15th Finance Commission Urban Reforms Grant.

8. RECOMMENDATIONS AND POLICY IMPLICATIONS

8.1 Guidelines for Scalable Implementation in Pune and Other Cities

To ensure the scalability of **movable traffic dividers** and **intelligent traffic control systems**, the following guidelines are proposed:

- **Site Selection Criteria**:
  - Minimum of four-lane road width.
  - Asymmetrical traffic volume during peak hours.
  - Low encroachment or commercial obstruction on footpaths and medians.
- **Operational Guidelines**:
  - Establish predefined **time-based lane shift schedules** (e.g., AM: 3 inbound, 1 outbound; PM: reversed).
  - Employ **automated or semi-automated barrier movers** depending on corridor volume.
  - Develop **emergency override mechanisms** for ambulance/fire brigade paths.
- **Performance Evaluation**:
  - Use **KPIs** such as travel time index (TTI), average queue length, and vehicle throughput.
  - Conduct **monthly reviews** for adjustment of divider schedules and control strategies (Kumar & Bansal, 2021).

Cities such as **Nagpur**, **Indore**, and **Ahmedabad**, which show similar congestion patterns, could adopt these models under the guidance of **NUTP** and **Smart City governance structures**.

8.2 Suggested Government and Civic Engagement Strategies

Implementation success hinges on multi-tier participation:

- **Government bodies**: PMC, Pune Traffic Police, and the Smart City Department should co-lead operations and infrastructure integration.
- **Community awareness**:
  - Conduct **public campaigns** about lane-changing safety and divider operation.
  - Introduce **feedback portals** for citizens to report implementation issues.
- **Incentivize private partnerships**:
  - Encourage private firms for supplying automated divider systems under **PPP (Public-Private Partnership)** models.
  - Leverage CSR funds from local industries for funding traffic improvement tech (Papageorgiou et al., 2015).
- **Enforcement tools**:
  - Use **CCTV and AI-based detection** for monitoring violations during lane switching.
  - Collaborate with **RTOs and enforcement units** to penalize dangerous driving behaviors.

8.3 Integration with Smart City and Sustainable Urban Mobility Plans

The proposal aligns with key smart city and urban mobility principles:

- **Smart City Mission**: Emphasizes integration of intelligent transport systems (ITS), public participation, and infrastructure optimization.

- **SUMP Frameworks**: Focus on **non-expansionist**, **sustainable**, and **data-driven mobility solutions** that reduce emissions and congestion.

Integration strategy includes:

- Embedding the project into **PMC's Integrated Traffic Management System (ITMS)**.
- Leveraging **existing sensor infrastructure** and AI-based analytics from the Smart City Command and Control Centre.
- Collaborating with national programs like **AMRUT** and **15th Finance Commission Grants** to secure funding and capacity-building support (MoHUA, 2022).

9. CONCLUSION

9.1 Summary of Key Findings

This study investigated the chronic problem of **urban traffic congestion in Pune** and proposed a dual-layered solution using **movable traffic dividers** and a **hierarchical intelligent control system**. Simulation and pilot data revealed:

- A **20–30% reduction in travel time**,
- **Improved lane utilization and service levels**, and
- **Public acceptance exceeding 70%**.

These findings indicate that **space-efficient, technology-backed traffic regulation** can offer substantial improvements over traditional infrastructure expansion.

9.2 Limitations of the Study

Despite promising results, certain limitations exist:

- The **pilot study was simulation-based**; real-world dynamics like weather, driver behavior, and pedestrian interference were not fully captured.
- Financial estimates were based on **average market rates** and may vary during actual procurement.
- **Sensor coverage** in Pune is still incomplete, limiting real-time adaptability.

Future research should include **field implementation trials** and **multi-junction corridor coordination** to validate model predictions under real-time conditions.

9.3 Scope for Future Research

This study opens avenues for further exploration:

- Development of **AI-powered real-time lane reallocation algorithms**.
- **Integration with public transit flow models** (e.g., PMPML bus lanes).
- Studying **environmental impact** and **carbon reduction potential** due to smoother traffic flow.
- **Scalability assessment** for Tier-2 and Tier-3 cities with different traffic cultures and infrastructure limitations.

A long-term vision involves the creation of **digital twins of urban traffic systems**, allowing predictive modeling and proactive congestion management.

REFERENCES

1. Agarwal, R., & Singh, P. (2019). *Urban traffic decongestion strategies in Indian cities: A critical review*. Journal of Urban Transport, 34(2), 112–124.

2. Ambrule, V. R., & Bhirud, A. N. (2017). Use of artificial neural network for pre design cost estimation of building projects. Interational Journal on Recent and Innovation Trends in Computing and Communication, 5(2), 173-176.

3. Bhirud, A. N., & Patil, P. B. (2016). Application of building information modeling for the residential building project. International Journal of Technical Research and Applications, 4(3), 349-352.

4. Bhirud, A. N., & Revatkar, B. M. (2016). Effective implementation of ERP in infrastructure construction industry. International Journal of Technical Research and Applications, 4(2), 246-249.

5. Chen, Y., & Liu, L. (2017). *Dynamic lane management using movable barriers in urban road networks*. International Journal of Transport Systems, 25(4), 298–312.

6. Downs, A. (2004). *Still stuck in traffic: Coping with peak-hour traffic congestion*. Brookings Institution Press.

7. IRC SP-41:1994. (1994). *Guidelines for the Design of At-Grade Intersections in Rural and Urban Areas*. Indian Roads Congress.

8. Jadhav, O. U., & Bhirud, A. N. (2015). An analysis of causes and effects of change orders on construction projects in Pune. International journal of engineering research and general science, 3(6), 795-799.

9. Joshi, M., Sharma, T., & Kulkarni, S. (2022). *AI-enabled adaptive signal control systems in Pune*. Journal of Urban Mobility, 18(1), 65–78.

10. Kumar, A., & Bansal, R. (2021). *The role of traffic management systems in sustainable urban development*. Urban Studies Review, 45(3), 221–236.

11. Litman, T. (2017). *Generated traffic and induced travel: Implications for transport planning*. Victoria Transport Policy Institute.

12. Mitra, S., Roy, A., & Das, S. (2018). *Multi-modal transport challenges in Indian metros*. Transport Policy Journal, 60, 53–62.

13. Mohan, P., & Kapoor, S. (2019). *Application of movable traffic dividers in Indian urban roads: A feasibility study*. Indian Journal of Civil Engineering, 40(1), 44–52.

14. MoHUA (Ministry of Housing and Urban Affairs). (2022). *Sustainable urban transport planning guidelines*. Government of India.

15. MoUD (Ministry of Urban Development). (2014). *Urban Mobility India: Annual Report*. Government of India.

16. Papageorgiou, M., Diakaki, C., & Dinopoulou, V. (2015). *Advanced traffic management systems and coordinated control strategies*. Transportation Research Part C, 61, 1–27.

17. Patil, A., & Deshmukh, R. (2020). *GIS-based congestion hotspot identification in Pune*. Journal of Indian Urban Infrastructure, 12(3), 141–153.

18. PMC (Pune Municipal Corporation). (2021). *Comprehensive mobility plan for Pune*. PMC Transportation Department.

19. Rodrigue, J. P. (2020). *The geography of transport systems* (5th ed.). Routledge.

20. RTO Pune. (2022). *Annual report on vehicle registrations (2011–2021)*. Regional Transport Office, Pune.

21. Singh, S., & Rajan, S. (2015). *Economic impacts of traffic congestion in Indian cities*. National Transport Research Conference Proceedings.

22. World Bank. (2019). *Mobility and productivity in Indian cities*. World Bank Group.

23. World Economic Forum. (2020). *Global smart mobility report*. World Economic Forum.

24. Zhou, J., Wang, Z., & Zhang, T. (2016). *Dynamic traffic management systems: Advances and challenges*. Transportation Research Procedia, 21, 93–101.