# Enhancing Intersection Performance in Heterogeneous Urban Traffic through SIDRA-Based Optimization

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**Abstract:** Urban intersections are critical nodes in transportation networks where conflicting traffic streams interact, often leading to congestion, safety risks, and operational inefficiencies. These challenges are particularly severe in developing cities with mixed-traffic environments characterized by heterogeneous vehicle compositions, poor lane discipline, and high pedestrian activity. This study investigates the operational performance of a major signalized intersection in Ahmedabad, India, using a combination of field data and analytical simulation. Comprehensive geometric and traffic datasets, including turning movement counts, vehicle composition, and phasing information, were collected during peak hours and calibrated in SIDRA Intersection software. Performance indicators such as average delay, queue lengths, degree of saturation, and Level of Service (LoS) were evaluated under existing conditions and compared with multiple optimized signal phasing and geometric improvement scenarios. Results show that the existing intersection operates at an overall LoS D, with average delays exceeding acceptable thresholds, primarily due to unchannelized approaches and shared turning lanes. Among the simulated alternatives, a lead–right phasing strategy combined with auxiliary turning lanes and improved channelization produced the most significant improvements, reducing average delays by more than 40% and upgrading the intersection to LoS B. The findings demonstrate that targeted optimization of geometry and signal control can substantially enhance intersection efficiency, improve safety, and mitigate environmental impacts by reducing vehicle idling. The proposed methodology provides a scalable framework for similar urban intersections in mixed-traffic conditions across developing regions, supporting evidence-based traffic management and sustainable mobility planning.

## 1. Introduction

Urban road networks are heavily reliant on traffic intersections, which serve as critical points where different traffic streams converge. These intersections are often the most challenging in terms of both safety and operational efficiency. The overall performance of intersections plays a pivotal role in shaping the efficiency of a city's transport network, impacting factors like travel time, mobility, and road safety. In rapidly growing urban centers, especially in cities like Ahmedabad in Gujarat, the increasing number of vehicles has led to severe congestion at key intersections, contributing to delays, fuel consumption, air pollution, and frustration among drivers. With the city's rapid growth and rising vehicle ownership, the demand on the busiest intersections continues to increase, pushing existing traffic control measures to their limits. Thus, it has become crucial to analyse and optimize the performance of these intersections to ensure effective urban mobility in the long term. Over the past few decades, research on intersection performance has expanded significantly. Early studies focused on the application of analytical tools like SIDRA, which were used to assess the efficiency of roundabouts, signalized intersections, and stop-controlled junctions under varying traffic loads. These studies established key relationships between traffic volume, turning movements, and intersection capacity, demonstrating that the effectiveness of traffic control strategies is heavily influenced by traffic demand. For example, roundabouts were found to perform well in moderate traffic but tend to struggle under heavy congestion, where signalized intersections might offer better performance. These findings emphasized the importance of adapting intersection control types to meet traffic demands, a lesson that continues to be relevant in cities like Ahmedabad, where demand often exceeds capacity during peak periods.

Subsequent research broadened the scope of analysis by introducing microsimulation models like VISSIM and AIMSUN, which allowed for more detailed simulations of driver behavior, vehicle interactions, and lane usage. These models showed that while analytical tools like SIDRA are efficient for early-stage evaluations, microsimulation can offer a more accurate reflection of real-world conditions when properly calibrated. However, discrepancies still arose, especially under mixed-traffic conditions, highlighting the need for local data calibration. This issue is particularly pertinent to Indian cities like Ahmedabad, where traffic is diverse and includes a mix of two-wheelers, three-wheelers, and pedestrians, which traditional Western models may not adequately represent. The role of intersection geometry and auxiliary features such as slip lanes, left-turn storage lanes, and flyovers has also been a focus of research. For instance, while free-flow slip lanes can reduce delays in certain cases, their benefits can diminish or even reverse when pedestrian activity is high. This is particularly relevant in dense urban environments like Ahmedabad, where the presence of pedestrians and non-motorized vehicles must be carefully factored into the design. Similarly, grade-separated infrastructure, such as flyovers, has not always delivered the anticipated improvements in traffic flow. Congestion frequently persists at at-grade intersections beneath flyovers, suggesting that solutions should be multimodal, integrating both vehicle and pedestrian needs rather than solely focusing on vehicular capacity.

Recent studies have also examined driver behavior, showing that varying levels of compliance with traffic rules can significantly affect the performance of an intersection. This is especially true in Ahmedabad, where non-compliance with traffic signals, lane discipline, and pedestrian crossings frequently disrupt the smooth flow of traffic. Incorporating such behavioral factors into simulation models is essential for creating realistic and effective traffic management solutions. In the past few years, there has been a noticeable shift toward mixed-traffic delay modeling, data-driven optimization, and the development of hybrid control strategies. Innovations such as using smartphone GPS trackers to measure delays in mixed traffic have provided more affordable and effective ways to collect reliable data. Additionally, regression-based models for designing left-turn storage lanes have been proposed to address issues of spillback that are often misestimate by traditional software. Other studies have explored hybrid strategies, combining features like tunnels with roundabouts or introducing metering signals at congested roundabouts, which have been shown to reduce delays and improve the overall Level of Service (LOS). These findings emphasize the need for flexible, adaptive solutions tailored to specific traffic conditions rather than adopting a one-size-fits-all approach.

This study draws on these insights to examine the busiest intersection in Ahmedabad, representing a common traffic bottleneck found in rapidly urbanizing cities. The intersection exemplifies the challenges faced by urban areas: increasing vehicle numbers, diverse traffic types, inadequate infrastructure, poor lane discipline, and heavy pedestrian volumes. By applying advanced analytical methods and integrating global research, this study aims to assess the operational performance of the intersection, identify critical issues, and propose solutions that balance traffic flow, safety, and environmental impact. Ultimately, the research will contribute both to local traffic management practices in Ahmedabad and to the broader understanding of how intersection models can be adapted to Indian traffic realities.

## 2. Need of Study

### 2.1 Rapid Increase in Vehicle Numbers

Ahmedabad, a rapidly growing metropolitan city, has witnessed an explosive rise in motor vehicle registrations, with over 4.5 lakh registered vehicles in 2020, up from just 79,000 in 2002. This growth is not limited to private vehicles but also reflects the surge in demand for commercial and industrial transport, as evidenced by a 15% increase in passenger vehicle sales in 2023. The surge in vehicles has created substantial pressure on the city's already overstretched infrastructure. As the number of vehicles continues to rise, the existing roadways—especially intersections—are struggling to accommodate the growing traffic volume. This has led to significant congestion, long delays, and frequent bottlenecks, particularly at key junctions across the city [1].

### 2.2 Traffic Congestion and Increased Travel Time

Ahmedabad has been ranked 7th in India for traffic congestion, with a traffic congestion index of 49.27 in 2023. The city’s average travel time of 29 minutes for every 10 kilometers is considerably slower than other urban centers, reflecting the inefficiency of the traffic system. A significant portion of these delays occurs at major intersections, where vehicle queues build up, and signal timings often fail to keep up with the heavy traffic load. In particular, intersections like Sal Cross Road and Pakwan Crossroads see high volumes of vehicles and pedestrians, leading to gridlock during peak hours. This level of congestion directly affects mobility, economic productivity, and environmental sustainability, as increased fuel consumption and emissions are direct consequences of inefficient traffic flow. Hence, improving traffic flow at intersections is not just a matter of convenience but also a critical step in reducing overall congestion and environmental impact [2], [3].

### 2.3 Impact on Public Safety

High traffic volumes and poorly designed intersections lead to an increased risk of accidents. In Ahmedabad, poor lane discipline, traffic signal violations, and uncontrolled pedestrian crossings contribute to accidents at key junctions. The safety of pedestrians is especially compromised, as many intersections lack sufficient crosswalks or pedestrian-friendly infrastructure. In areas like ISKCON and SG Highway, where vehicle and pedestrian traffic intersect, accidents are frequent due to the lack of proper traffic control and pedestrian facilities. To mitigate these issues, intersection modifications are urgently needed to incorporate dedicated pedestrian walkways, overbridges, and better crosswalk designs. This will not only improve the safety of pedestrians but also ensure smoother traffic flow for vehicles, reducing the likelihood of accidents and improving overall road safety [4].

### 2.4 Need for Adaptive Traffic Management

The introduction of adaptive traffic control systems (ATCS) at major intersections is another crucial modification to consider. These systems can adjust signal timings based on real-time traffic conditions, helping to optimize traffic flow and reduce congestion. In cities like Ahmedabad, where traffic patterns change drastically throughout the day, adaptive signals can help maintain an even flow, reducing unnecessary delays at intersections. This will not only help shorten travel times but also improve the efficiency of public transport systems like BRTS, which rely on smooth intersections to provide timely services. Adaptive traffic systems can help alleviate congestion at intersections, significantly enhancing overall urban mobility [5].

### 2.5 Benefits of Intersection Modifications

- Reduced Traffic Congestion: The most immediate benefit of intersection modifications is the reduction in congestion. By optimizing signal timings and redesigning road geometries, vehicles can pass through intersections faster, reducing overall travel time across the city.

- Improved Road Safety: Modifying intersections can lead to a significant reduction in road accidents. This includes introducing dedicated lanes for left-turning vehicles, eliminating bottlenecks, and improving pedestrian crossings to ensure safety for all road users.
- Better Environmental Outcomes: Reducing congestion will cut down on vehicle idle times, leading to lower emissions and fuel consumption. This is crucial for sustainable urban development and reducing Ahmedabad's overall environmental footprint.
- Enhanced Economic Productivity: Faster traffic flow translates into improved efficiency for businesses and residents alike. Reduced congestion means better connectivity between key commercial areas, making Ahmedabad a more attractive place for both businesses and residents to thrive [6].

## 3. Literature Review

The modern analytical treatment of intersection performance done by Akcelik et al.in 2001 evaluation of roundabout operations using SIDRA**,** which explored how design geometry and turning movements influence overall efficiency. The study demonstrated that single-lane roundabouts could handle moderate traffic effectively but became strained under high left-turn proportions, while multi-lane roundabouts performed better in such conditions. At very high volumes, however, signalized intersections outperformed roundabouts in terms of delay and reliability. These results provided early evidence that control type effectiveness depends strongly on demand regimes, setting the stage for subsequent comparative research [7]. In 2008 A. Vlahos et al. studied, the conversion of all-way stop-controlled intersections into roundabouts was investigated using SIDRA alongside field-calibrated data from Delaware and Maryland. Results revealed dramatic reductions in delay (by more than 65%), shorter queues, and improved emissions performance following conversion. The study also identified a threshold volume of around 2,350 vehicles per hour, beyond which signalized intersections deliver better performance. This “crossover point” offered practitioners a quantitative guideline for determining whether to maintain stop control, implement a roundabout, or install signals [8]. By H. Al-Ghandour et al. in 2012, research expanded to include microsimulation of roundabout slip lanes. An evaluation of single-lane roundabouts with different slip-lane exit types—free-flow, yield, and stop control—showed that free-flow slip lanes minimized delay under low pedestrian volumes, while stop-controlled slip lanes sometimes increased delays by nearly 66% during heavy right-turn flows. Pedestrian activity significantly altered performance outcomes, highlighting the importance of multimodal considerations in roundabout design and operations [9]. A comparative study by Z. Chen and D. Lee in 2013 examined SIDRA and VISSIM models at a signalized intersection in Xi’an, China. While SIDRA offered rapid setup and faster output generation, VISSIM’s predictions more closely matched observed field delays, with errors around 10% compared to SIDRA’s 15%. The research demonstrated that while SIDRA is suitable for policy and preliminary evaluation, microsimulation tools like VISSIM are better suited for detailed operational analysis requiring higher precision [10]. A study done by T. Ranjitkar et al in 2014, SIDRA was used to evaluate the operational performance of intersections with different control types under varied demand and turning ratios. The findings showed that priority intersections performed best under light demand, roundabouts were optimal at moderate flows, and signals became necessary under heavy demand. Emission modeling revealed that oversaturated signals generated higher pollutants than roundabouts, confirming the environmental advantages of circular designs in certain contexts [11]. That same year, the Al Jame’ Roundabout in Oman was analysed by M. A. Muley and S. Al-Mandhari, where extreme congestion produced average control delays above 190 seconds per vehicle and queues approaching a kilometer in length. Sensitivity testing identified inscribed diameter as the most critical geometric parameter affecting capacity, and results suggested that a signalized conversion would likely be necessary to achieve sustainable improvements [12].

A case study done by P. Chinsomboon in 2015, on flyover-bridge intersections in Thailand highlighted the persistent problems at grade even after constructing elevated crossings. The study reported that crash costs remained high—averaging 9.3 million Baht annually across sites—due to conflicts and congestion at surface-level intersections beneath flyovers. The findings emphasized that grade separation alone is insufficient, and comprehensive safety and operational strategies are required to address both vertical and horizontal movement conflicts [13]. Researchers Z. Chen and D. Lee in 2016, turned their attention to the accuracy of different software packages when applied to congested, multilane roundabouts. A case study in Anchorage, Alaska compared SIDRA, RODEL, and VISSIM outputs with video-based field data. Results showed that all three tools overestimated capacity prior to calibration and underestimated delays and queues, especially under unbalanced traffic conditions. The study reinforced the need for calibration against local conditions to ensure credible modeling outcomes [14]. In the same year, signalized intersections were analyzed by S. Akmaz and M. Çelik using both the Australian SIDRA method and the U.S. Highway Capacity Manual (HCM). The comparison revealed that HCM generally predicted higher delays (+11%) and lower capacities (−7%) than SIDRA, though both frameworks achieved better results when cycle timings were optimized [15]. In 2017, Adelaide's dual-signal roundabout was analyzed by K. Taylor and J. Young with both SIDRA and AIMSUN. The study found that maximum queue predictions were accurate to within 95% of field observations across both tools. However, approach-specific results for delay and LOS (Level of Service) varied, demonstrating that modeling assumptions about gap acceptance and lane use can heavily influence outputs. The research concluded that triangulating findings from both analytical and microsimulation tools provides more reliable evaluations of complex intersection forms [16].

Study done by S. AlKheder et al. in 2020, driver behavior emerged as a critical factor in performance evaluations. A Kuwait-based study surveyed 804 drivers and combined the results with SIDRA modeling. It revealed that while most drivers understood roundabout rules, compliance was poor, leading to ineffici5encies and safety risks. SIDRA scenarios demonstrated that introducing metering signals on heavy approaches or modifying geometry could improve performance, particularly in congested urban settings where driver non-compliance is prevalent [17]. S. R. Sushmitha and K. V. R. Ravishankar in 2021 study in India used smartphone GPS applications (OSM tracker) to measure control delay at signalized intersections in mixed traffic. The researchers developed a non-linear model that outperformed both HCM and INDO-HCM estimates, capturing the effects of heterogeneous vehicle composition dominated by two- and three-wheelers. This offered a cost-effective, accurate alternative for delay measurement and calibration in developing regions [18]. In Kabul, Afghanistan, another 2021 study done by A. A. Noori used SIDRA to optimize the Sara-e-Shamali intersection. Lane reassignments and cycle-time adjustments produced significant reductions in delay and improvements in LOS, showing the practical value of simulation in resource-constrained and rapidly urbanizing areas [19]. In 2022, further refinements to modeling techniques were introduced by H. Ramadan and M. Hassan. Their study developed delay models for various lane assignments at signalized intersections in heterogeneous conditions, demonstrating that dedicated left-turn lanes and better lane distribution greatly reduce delays. The predictive models developed provided practitioners with tools to evaluate intersection design alternatives under mixed-traffic realities [20]. A separate study done by M. Ramadan et al. in the same year proposed a framework for selecting intersection control types in urban areas. It concluded that two-way stop control is effective below 1,000 vehicles per hour, roundabouts are preferable between 1,000 and 4,200 vehicles per hour, and signals are necessary above 4,300 vehicles per hour. These thresholds confirmed earlier empirical findings while offering clear quantitative guidance for practitioners [21]. A. A. Yasin et al. in 2023 presented study on evaluation of the Elba-House Road intersection in Amman, Jordan, applied SIDRA to one of the busiest corridors in the city. Baseline data revealed extreme congestion, with delays exceeding 280 seconds per vehicle and LOS F. Testing of alternatives demonstrated that introducing a hybrid tunnel–roundabout configuration reduced delays to around 13 seconds per vehicle and improved LOS to B. This case demonstrated the transformative impact of combining grade-separated and surface-level improvements [22]. In Malaysia, R. Rahmat et al., compared SIDRA outputs with the Malaysian Highway Capacity Manual (MHCM) at the Kempas intersection. Field data showed that SIDRA more accurately predicted delay and queue length than MHCM, particularly under heavy traffic conditions. The study concluded that while national manuals offer regulatory consistency, SIDRA provides more precise operational insights and should be prioritized when accuracy is critical [23]. Also in 2023, an investigation done by A. Hussein et al. on the Palestine intersection in Baghdad focused on left-turn storage lane design. Field observations combined with SIDRA 8.0 analysis showed that insufficient storage frequently caused spillback into through lanes. While SIDRA offered useful estimates, it often overestimated queues at high saturation and underestimated them at lower levels. Regression models developed in the study provided more reliable storage length calculations, recommending coverage of the 95th percentile queue with an additional buffer [24]. W. Ahmida et al. presented study on an evaluation of four intersections in Al-Bayda City, Libya, demonstrated the challenges posed by rapid urban expansion. LOS values across the sites ranged from D to F under existing conditions, with severe delays during peak hours. Improvement strategies modeled with SIDRA included signal cycle optimization, lane additions, and geometric widening. These measures reduced delays by 32–69% and improved LOS to B–C. The findings emphasized that even modest operational and geometric changes can yield major improvements in congested, resource-limited urban contexts [25].

## 4. Methodology of Study

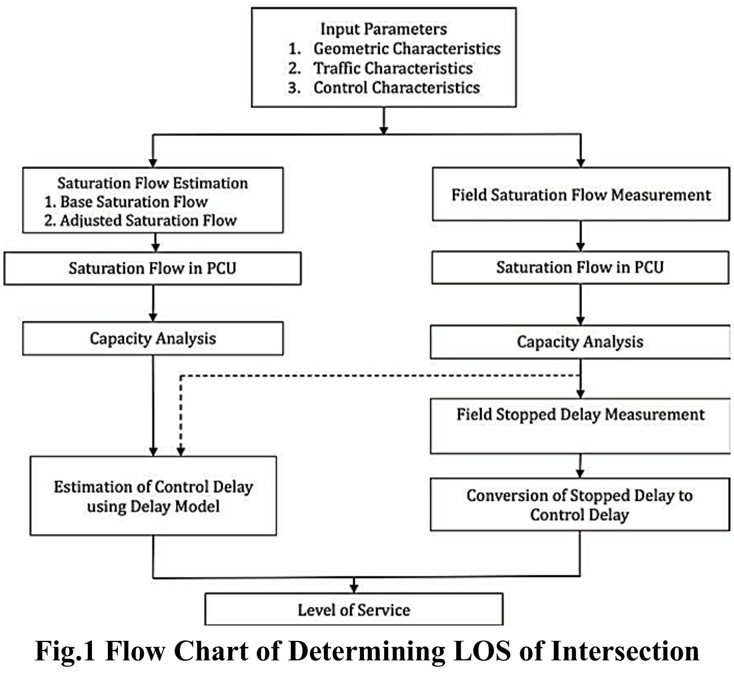


**Fig.1 Flow Chart of Determining LOS of Intersection**

The study begins with the selection of high-demand intersections, focusing on the busiest junctions to capture peak traffic conditions. In Ahmedabad, this includes junctions such as Sal hospital cross-road. Once the sites are identified, a comprehensive dataset is collected, encompassing geometric, traffic, and signal-related information. Geometric parameters include lane widths, number of lanes, presence of turn pockets, and approach configurations. Traffic data involves vehicle composition—two-wheelers, three-wheelers, cars, light and heavy commercial vehicles, and buses—along with turning movements (left, through, right) and peak-hour traffic volumes. Signal parameters such as cycle lengths, green times, and offsets are also recorded. Field observations complement these measurements, capturing lane usage, queue lengths, pedestrian movements, and driver compliance with signals. This ensures a realistic representation of traffic conditions for subsequent analyses.

Following data collection, lane grouping and demand flow analysis are performed. Vehicles are allocated to specific lanes based on observed traffic patterns, and flow rates are adjusted using peak-hour factors and special conditions like right-turn-on-red (RTOR) manoeuvres. This step ensures that traffic demand is accurately represented for capacity calculations. Capacity estimation and volume-to-capacity (v/c) ratio determination are then carried out. Saturation flow rates are calculated using basic equations and adjusted with correction factors to account for heavy vehicle proportions, pedestrian interference, lane widths, and local traffic characteristics. The resulting capacities and v/c ratios provide insight into intersection performance under existing conditions and highlight potential bottlenecks.

The methodology continues with performance evaluation, using both analytical and simulation-based tools such as SIDRA. Key performance measures include average delay per vehicle, queue lengths, level of service (LOS), progression adjustments, and back-of-queue analysis to detect potential spillback effects. Additionally, scenario testing and optimization are conducted, exploring alternative signal timings, lane reallocations, adaptive traffic control strategies (ATCS), and hybrid intersection designs, including tunnels, roundabouts, or slip lanes. These interventions are evaluated for their effectiveness in improving traffic flow, reducing delay, and enhancing safety.

**4.1 Study Area Selection**

The intersection selected for analysis should meet the following criteria:

- High traffic demand during morning and evening peak hours**.**
- Evidence of congestion such as long queues, high delays, or lane blockages.
- Strategic location with significant land-use impacts (e.g., proximity to hospitals, schools, markets, or business centers).
- Availability of sufficient observation points for videographic or manual surveys.

This ensures that the selected site reflects realistic challenges for capacity and Level of Service (LOS) evaluation.

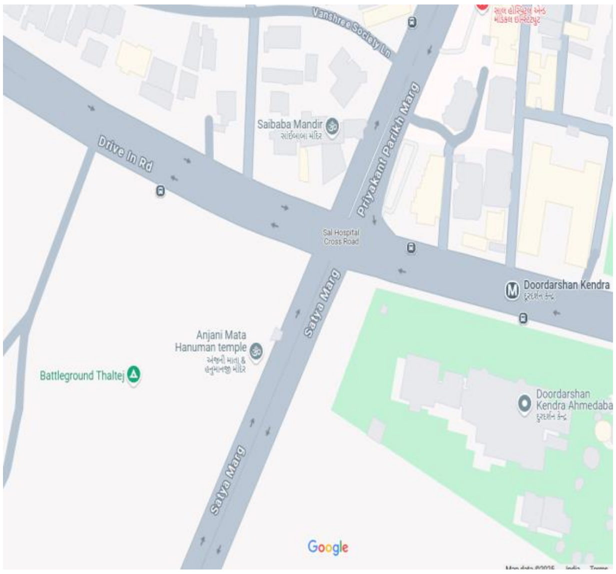


**Fig. 2 Location of Study area (Google map)**

## 4.2 Data Collection

To comprehensively evaluate intersection performance, two major categories of data are collected:

### 4.2.1Geometric Data

- Number of legs and approach/exit lanes.
- Lane widths, type (exclusive/shared), and control (signalized, stop/yield).
- Entry angle, entry radius, turning radii, and approach lengths.
- Presence of channelizing/bypass lanes, medians, or pedestrian facilities.
- Inscribed circle diameter / island diameter (for roundabouts).
- Gradient, sight distance, and availability of auxiliary lanes (left-turn/short lanes).
- Signal phasing plan, cycle length, and clearance intervals (for signalized intersections).

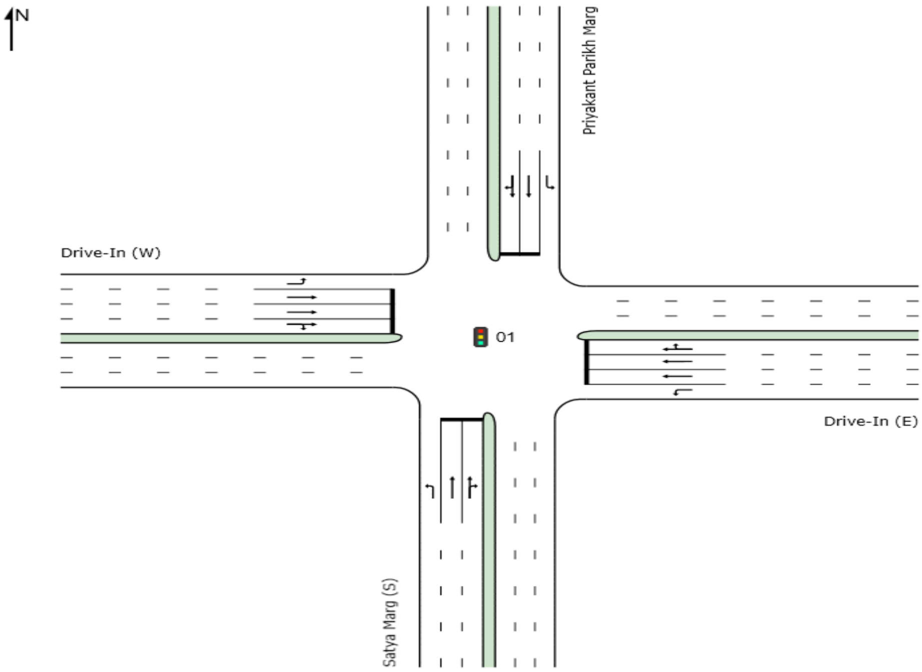


**Fig. 3 Geometric Layout of Intersection**

### 4.2.2 Traffic Data

- Classified turning movement counts (TMCs) for each approach: left, through, right turns.
- Vehicle categories: cars, motorcycles, three-wheelers, buses, minibuses, trucks, non-motorized (bicycles/rickshaws).
- Passenger Car Unit (PCU) conversion using Indo-HCM guidelines.
- Data collection via video recording during peak periods:
    - Morning Peak: 8:00–10:00 a.m. (work/school start).
    - Evening Peak: 6:00–8:00 p.m. (home-return).
    - Counts aggregated at 15-minute intervals.
- Manual verification of unusual driver behaviors: forced merging, gap violations, disobedience of signals, pedestrian conflicts.
- Cruise speeds on each leg using short-base method (stopwatch or video frame count).
- Queue lengths (95th percentile back of queue) observed directly and validated against simulation outputs.

| Approach | Movement | Car | Auto Rickshaw | LCV | Buses | Truck | T/W |
|---|---|---|---|---|---|---|---|
| **Drive-In (East)** | Left | 153 | 25 | 10 | 4 | 6 | 180 |
| | Through | 201 | 103 | 13 | 90 | 9 | 453 |
| | Right | 75 | 24 | 10 | 5 | 0 | 105 |
| **Priyakant Parikh Marg** | Left | 65 | 20 | 9 | 3 | 1 | 61 |
| | Through | 115 | 90 | 106 | 10 | 5 | 389 |
| | Right | 19 | 36 | 20 | 21 | 2 | 81 |
| **Drive-In (West)** | Left | 82 | 30 | 12 | 6 | 2 | 105 |
| | Through | 201 | 42 | 21 | 7 | 3 | 412 |
| | Right | 52 | 25 | 10 | 2 | 1 | 110 |
| **Satya Marg** | Left | 152 | 36 | 9 | 4 | 3 | 312 |
| | Through | 511 | 208 | 94 | 50 | 10 | 701 |
| | Right | 135 | 18 | 8 | 9 | 2 | 203 |

Table 1 Summarized Average Traffic Volume data with each leg turning movement counts

The classified turning movement count shows traffic composition at a four-legged intersection. On the Drive-In (East) approach, through movements dominate with 453 vehicles, while left and right turns record 180 and 105 vehicles respectively. Priyakant Parikh Marg carries lower flows, with 389 through, 61 left, and 81 right-turn vehicles. Drive-In (West) also has significant through traffic at 412 vehicles, compared to 105 left and 110 right turns. Satya Marg experiences the heaviest movement, with 701 through vehicles, 312 left turns, and 203 right turns. Two-wheelers and cars are the major contributors across all approaches, followed by auto-rickshaws.

The turning movement analysis across the four approaches highlights the predominance of through traffic compared to left and right turns. On the Drive-In (East) approach, the through movement is highest at 869 vehicles, followed by 378 left and 219 right-turning vehicles. The Priyakant Parikh Marg approach shows a relatively lower demand, with 715 through, 159 left, and 179 right-turning vehicles. The Drive-In (West) approach registers a` balanced distribution with 686 through and 516 right-turning vehicles, while left turns are comparatively fewer at 237. The Satya Marg approach carries the largest through movement with 1,574 vehicles, alongside 516 left and 375 right turns. Overall, the chart indicates that through traffic dominates across all approaches, particularly at Satya Marg, which represents the critical movement corridor of the intersection.

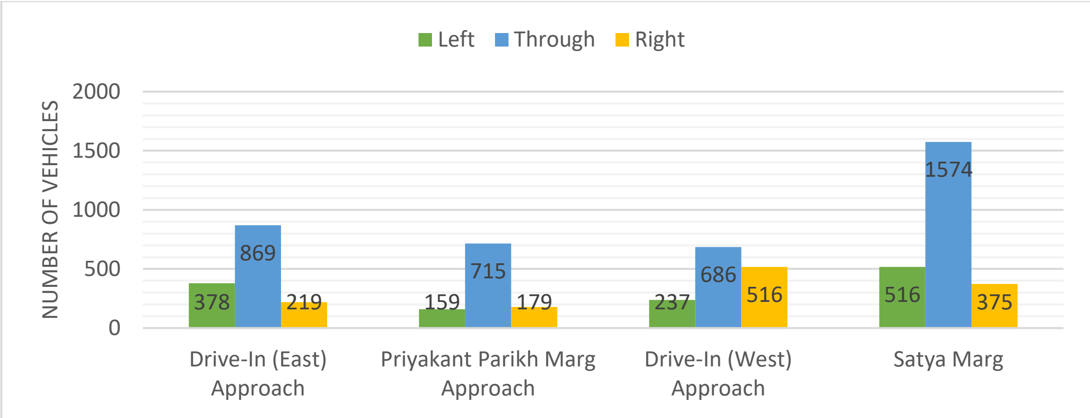


**Fig 4 Graphical Representation of Average Turning Movements at each approach**

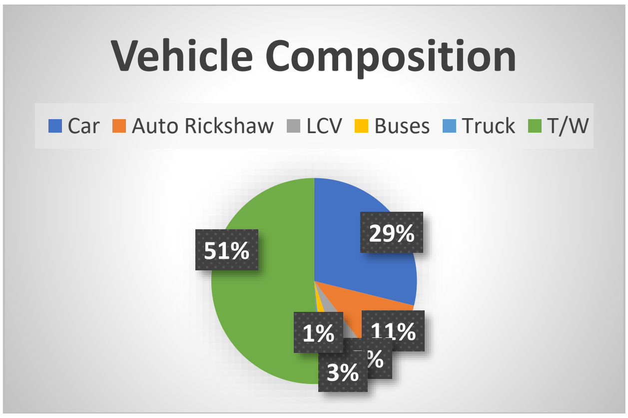


**Fig. 5 Graphical Representation of Average Vehicle Composition at the Intersection**

The vehicle composition analysis, as illustrated in the pie chart, indicates that two-wheelers dominate traffic flow, accounting for 51% of the total volume. Cars form the second largest category with 29%, followed by auto-rickshaws at 11%. Light commercial vehicles (LCVs) contribute 5%, while buses and trucks represent relatively smaller shares of 3% and 1%, respectively. This distribution highlights the prevalence of two-wheelers and private cars, which together constitute about 80% of the total traffic, underscoring the mixed nature of traffic with a significant presence of smaller, fast-moving vehicles compared to heavy vehicles.

**4.2.3 Phasing and Signal Timing Data**

Phasing and signal timing information was obtained from manually from traffic signal lights. Since the sequence of phases constant within each cycle, it was difficult to establish exact timings as it is heterogeneous condition. In addition, videographic surveys during evening periods faced visibility constraints; hence, only the morning peak hour was selected for detailed analysis. For model calibration, the phase sequence that occurred most consistently during the morning peak was considered as the representative pattern. The frequently repeated sequences are presented in Tables 2, while Figures 6 show the corresponding phase arrangements generated by SIDRA software.

| Phase | A | B | C | D |
|---|---|---|---|---|
| Cycle (s) | 212 | | | |
| Green Time (s) | 33 | 63 | 33 | 63 |
| Amber (s) | 3 | 3 | 3 | 3 |

| All Red (s) | 2 | 2 | 2 | 2 |
|---|---|---|---|---|
| Phase Plan (s) | 38 | 68 | 38 | 68 |

**Table 2 Phase Sequence and timing at Intersection**

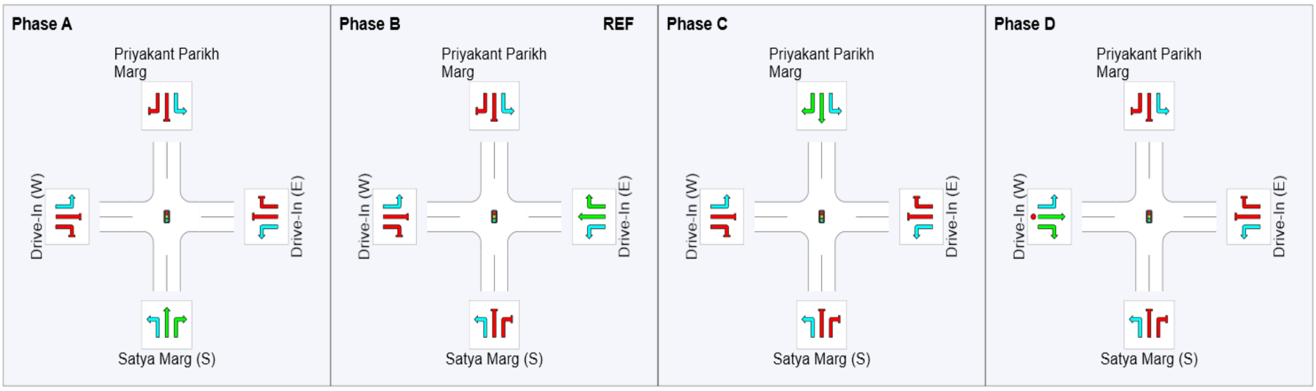


**Fig. 6 Phase Pattern at Intersection**

## 5. Result and Analysis

### 5.1 Performance Analysis Under Existing Condition

SIDRA models were developed for the selected intersection after detailed calibration of relevant parameters using field-observed data. Once calibrated, the models were simulated in SIDRA Intersection to assess lane-wise performance under the prevailing geometric design and signal timing conditions. The summarized operational results are presented in the respective tables for intersection. Overall, intersections were observed to operate at a Level of Service (LoS) D, with average intersection delays exceeding 54.8 seconds per vehicle. Lane-specific LoS for individual approaches is further illustrated in the corresponding figures, highlighting critical movements with the highest delays.

**Lane Use and Performance**

| | Demand Flows Total veh/h | Demand Flows HV % | Cap. veh/h | Deg. Satn v/c | Lane Util. % | Average Delay sec | Level of Service |
|---|---|---|---|---|---|---|---|
| South: Satya Marg (S) | | | | | | | |
| Lane 1 | 543 | 1.4 | 3066 | 0.177 | 100 | 5.6 | LOS A |
| Lane 2 | 1030 | 3.8 | 1140 | 0.904 | 100 | 50.5 | LOS D |
| Lane 3 | 1022 | 3.5 | 1131 | 0.904 | 100 | 52.8 | LOS D |
| Approach | 2595 | 3.2 | | 0.904 | | 42.0 | LOS D |
| East: Drive-In (E) | | | | | | | |
| Lane 1 | 392 | 1.1 | 2716 | 0.144 | 100 | 4.1 | LOS A |
| Lane 2 | 441 | 10.5 | 493 | 0.894 | 100 | 77.5 | LOS E |
| Lane 3 | 441 | 10.5 | 493 | 0.894 | 100 | 77.5 | LOS E |
| Lane 4 | 254 | 3.1 | 285 | 0.894 | 100 | 86.7 | LOS F |
| Approach | 1527 | 6.8 | | 0.894 | | 60.2 | LOS E |
| North: Priyakant Parikh Marg | | | | | | | |
| Lane 1 | 167 | 2.5 | 2562 | 0.065 | 100 | 4.4 | LOS A |
| Lane 2 | 517 | 2.1 | 586 | 0.883 | 100 | 73.3 | LOS E |
| Lane 3 | 456 | 6.4 | 516 | 0.883 | 100 | 76.6 | LOS E |
| Approach | 1140 | 3.9 | | 0.883 | | 64.5 | LOS E |
| West: Drive-In (W) | | | | | | | |
| Lane 1 | 249 | 3.4 | 2672 | 0.093 | 100 | 4.2 | LOS A |
| Lane 2 | 314 | 1.5 | 355 | 0.886 | 100 | 82.3 | LOS F |
| Lane 3 | 314 | 1.5 | 355 | 0.886 | 100 | 82.3 | LOS F |
| Lane 4 | 304 | 1.5 | 343 | 0.886 | 100 | 85.1 | LOS F |
| Approach | 1182 | 1.9 | | 0.886 | | 66.5 | LOS E |
| Intersection | 6444 | 3.9 | | 0.904 | | 54.8 | LOS D |

**Table 3 Operational Performance of Intersection under Existing Condition**

| | Approaches | | | | Intersection |
|---|---|---|---|---|---|
| | South | East | North | West | |
| LOS | D | E | E | E | D |

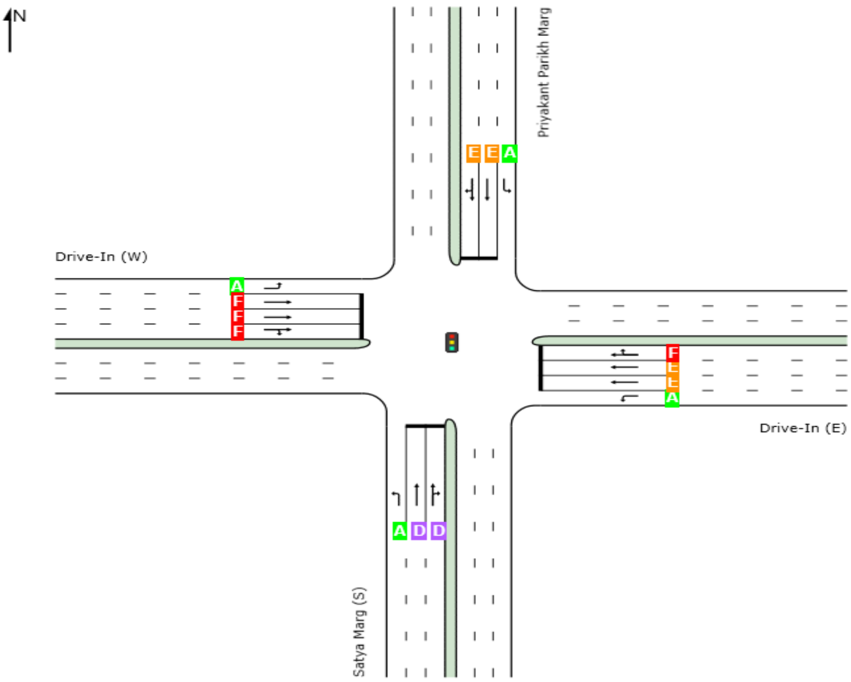


**Fig 7 Lane-wise LoS of different approaches of intersection under Existing Condition**

### 5.2 Operational Performance of Intersection after Optimizing Signal Phasing and Geometric Configuration

To evaluate operational improvements, multiple signal timing and phasing alternatives were simulated under pre-timed control, including the existing configuration with optimized timing, split phasing, lead–right phasing, and a design-based phasing scheme. The alternatives were compared primarily on the basis of average delay and back of queue. Results indicated that while complete clearance of vehicles was not achieved under any scenario, the optimized phasing configuration provided the lowest average delay and shortest queue lengths. Among the tested alternatives, the lead–right turn phasing strategy with a four-phase cycle structure emerged as the most efficient, achieving a substantial reduction in overall delay. Lane-by-lane analysis further revealed variability in performance, with certain approaches operating at lower Levels of Service (LoS) compared to others. Similarly, for another intersection, the optimized version of the existing signal phasing was found to yield the best results, demonstrating reduced delays and improved approach-level LoS. In general, the findings highlight that context-specific optimization of phasing plans can significantly improve intersection performance compared to current operations.

| | Approaches | | | | Intersection |
|---|---|---|---|---|---|
| | South | East | North | West | |
| LOS | B | B | B | B | B |

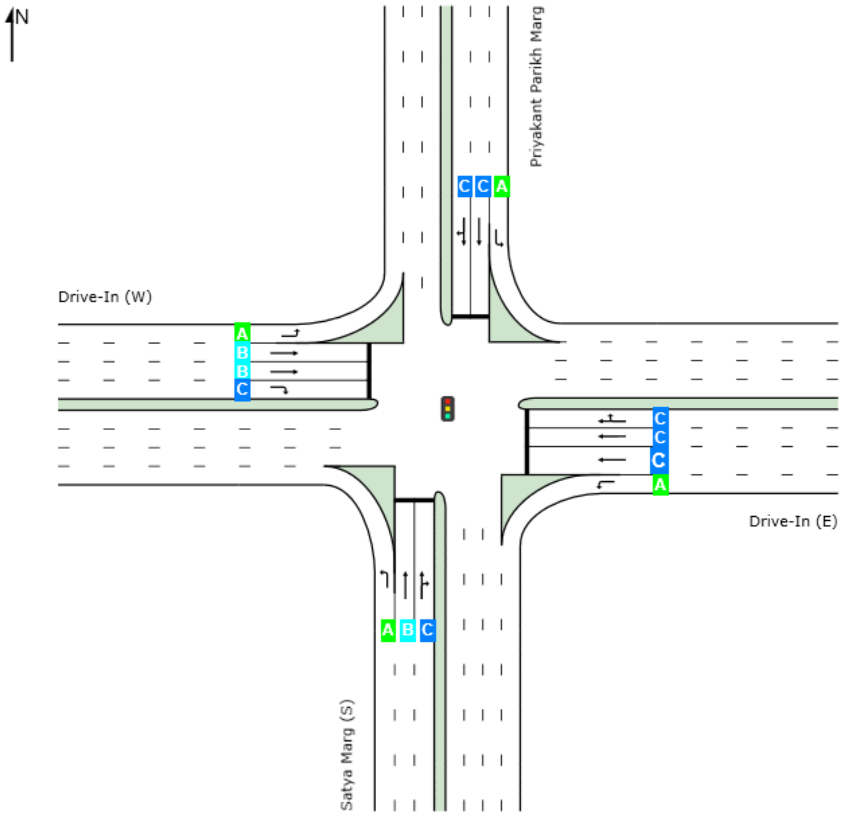


**Fig 8 LOS of Different Lanes after Optimizing Signal Phasing and Geometry of Intersection**

## 6. Conclusion and Recommendations

### 6.1 Geometry and Lane Configuration

- Existing Intersection Layout:
  - The approaches generally consist of unchannelized movements, with fewer dedicated turning lanes.
  - Turning movements (particularly right turns) are not fully segregated, resulting in conflicts between through and turning traffic.
  - Lane utilization is uneven, with some approaches constrained by limited lane width and absence of auxiliary lanes.
- Optimized Intersection Layout:
  - Introduction of channelized lanes and designated turning bays improves movement discipline.
  - Additional lanes are provided on critical approaches (e.g., Drive-In East/West and Satya Marg South), ensuring separation of through and turning streams.
  - Auxiliary left-turn lanes and properly defined approach geometry are incorporated, minimizing conflict points.

### 6.2 Traffic Control and Lane Movements

- Existing Intersection Layout:
  - Lane movements are mixed, with shared lanes accommodating both through and turning traffic.
  - This mixed arrangement increases delay due to blocking, especially where left- or right-turn vehicles obstruct through flow.

  - Signal phasing is less effective due to lack of geometric segregation.
- Optimized Intersection Layout:
  - Clear designation of exclusive left-turn and through lanes results in smoother movement distribution.
  - Signal phases can be more efficiently utilized as conflicts between turning and through traffic are reduced.
  - The overall alignment is more structured, supporting effective pre-timed or actuated signal operation.

**6.3 Level of Service (LoS)**

- Existing Intersection Layout:
  - Approach-level LoS is poor, ranging between D and E.
  - Intersection-level LoS is D, indicating high delays and unstable flow conditions.
  - Specific legs such as Drive-In (W) and Priyakant Parikh Marg (N) experience particularly severe congestion with LoS E or F for certain movements.
- Optimized Intersection Layout:
  - Significant improvement is observed across all approaches, with each achieving LoS B or better.
  - Intersection-level LoS improves from D (existing) to B (optimized).
  - Lane-specific analysis shows majority of approaches achieving LoS A–C, demonstrating balanced capacity utilization and reduced control delays.

**6.4 Performance Improvements**

- Existing Intersection Layout:
  - High average delays due to shared lanes and limited geometric capacity.
  - Long queues during peak hours, particularly in east–west directions.
  - Irregular vehicle discharge because of mixed flows.
- Optimized Intersection Layout:
  - Delay reduction due to dedicated lane movements and channelization.
  - Reduced back of queue lengths as turning traffic is separated from through lanes.
  - Enhanced operational efficiency with cycle lengths better matched to demand.
  - Improved safety due to fewer conflict points and more predictable lane discipline.

**6.5 Geometric Enhancements**

- Addition of auxiliary lanes, especially exclusive left-turn channels, in the optimized design.
- Wider approach cross-sections in optimized design accommodate higher volumes.
- Channelization reduces driver confusion and enforces proper turning radii.
- Signal heads and phasing plans can be better aligned with geometric design, ensuring systematic clearance of queues.

**6.6 Key Findings**

- The methodology proposed in this study can be applied to optimize intersections experiencing heterogeneous traffic conditions, particularly in developing countries. For the intersection analyzed, adopting optimized signal settings with the most effective cycle length plan from isolated models is generally recommended. Furthermore, as traffic patterns are subject to change following major infrastructure interventions, periodic reassessment of signal timing is essential to maintain efficiency.
- The existing intersection suffers from operational inefficiencies due to unchannelized approaches, shared lanes, and lack of geometric clarity, resulting in LOS D–E.

- The optimized intersection demonstrates the effectiveness of geometric reconfiguration, lane channelization, and signal timing coordination, upgrading the performance to LOS B.
- The comparative results underline that geometric improvements coupled with optimized signal control can transform an intersection from oversaturated conditions to stable and efficient operation.

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