

Evaluating the Feasibility of a Trumpet Interchange at Shibbari Intersection under Current and Future Traffic Growth: A Microsimulation Approach

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ABSTRACT

Traffic congestion at T-intersections in urban areas of developing countries is often intensified by non-lane based, heterogeneous traffic and the presence of dedicated Bus Rapid Transit (BRT) lanes. A trumpet interchange offers a potential solution by eliminating crossing conflicts and improving overall flow efficiency. However, such grade-separated interventions remain uncommon in Bangladesh. This study evaluates the feasibility of introducing a trumpet interchange at the Shibbari intersection, Gazipur, focusing on both current and future traffic conditions. Field data on roadway geometry, traffic volumes, and speeds were collected during peak hours over two weekdays and one weekend. A microscopic simulation model was developed in a micro simulation software to replicate existing conditions and evaluate two scenarios: (1) the current T-intersection (Base Case) and (2) the proposed trumpet interchange. Each scenario was analyzed under present traffic demand a 7% annual traffic growth projection representing future industrial expansion. Results indicate that the existing intersection operates acceptably under current demand but becomes highly congested under future conditions, with vehicle delays exceeding 1200 seconds, stop delays surpassing 1000 seconds, and queue delays reaching 182.9 seconds. In contrast, the trumpet interchange significantly improves performance by reducing conflict points and enhancing capacity. Under future conditions, queue delay at the Shimultoli approach decreases to 21.66 seconds, while Level of Service improves to A-C, although moderate congestion remains during peak periods. Overall operating speeds increase by approximately 23% compared to the base case. These results provide useful guidance for policymakers and urban planners when evaluating the implementation of trumpet interchanges in mixed-traffic environments.

Keywords: Trumpet interchange, BRT lane, micro simulation, traffic growth, intersection congestion.

1. INTRODUCTION

Rapid urbanization in developing countries such as Bangladesh has led to a sharp increase in travel demand, placing substantial strain on urban road networks [5]. As a result, traffic congestion has emerged as a critical issue in many rapidly expanding Bangladeshi cities. Intersections, which serve as the most sensitive components of a road network, frequently experience significant delays and operational inefficiencies, particularly under heterogeneous traffic conditions. Urban roadways in Bangladesh typically accommodate a diverse mix of vehicles including buses, trucks, private cars, auto-rickshaws, and non-motorized transport often operating without strict lane discipline [10]. This coexistence of fast- and slow-moving vehicles within the same space creates irregular traffic flow patterns, increasing the likelihood of disruptions and delays. The absence of effective lane

management and enforcement further intensifies these issues, as vehicles with varying sizes and performance characteristics interact in an unstructured manner, leading to congestion and bottlenecks.

Within Gazipur, the Shibbari intersection stands out as one of the busiest and most congested junctions. Despite its strategic importance as a key access point to major industrial and residential zones, the intersection suffers from poor operational performance. These challenges underscore the urgent need for both policy-oriented and infrastructure-based interventions aimed at enhancing traffic efficiency and ensuring sustainable urban mobility. Compounding the problem is the limited infrastructure at the intersection, which is currently configured as an at-grade T-intersection. In this setup, all traffic movements occur on the same level, resulting in numerous conflict points as vehicles cross and turn across each other's paths.

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The absence of grade-separated facilities significantly restricts capacity and increases delays.

The situation is likely to become more complex with the planned introduction of dedicated Bus Rapid Transit (BRT) lanes through the intersection. Without proper grade separation, BRT operations would intersect with general traffic streams, potentially intensifying congestion and increasing the risk of gridlock. In this context, a modified trumpet interchange has been proposed as a potential solution. This type of grade-separated design is particularly suitable for T-intersections, as it diverts major turning movements onto ramps and elevated structures, thereby eliminating direct crossing conflicts. Implementing such a configuration at Shibbari could facilitate uninterrupted flow along primary corridors, including the BRT route, and substantially reduce delays. However, the adoption of grade-separated interchanges remains limited in Bangladesh's urban environment, raising concerns regarding feasibility, context-specific design adaptations, and cost-effectiveness. Nevertheless, the pressing need to minimize at-grade conflicts provides a strong justification for exploring such solutions.

In summary, the Shibbari intersection is affected by a combination of heterogeneous traffic composition, a high prevalence of slow-moving three-wheelers, and inadequate infrastructure. These factors collectively contribute to severe congestion and operational inefficiencies. Addressing these challenges requires an integrated approach that simultaneously manages traffic composition and enhances intersection design to achieve improved performance and sustainability.

2. LITERATURE REVIEW

Bangladesh's urban traffic operates under heterogeneous "mixed" conditions where diverse vehicle types from cars and buses to auto-rickshaws, cycle-rickshaws, and other non-motorized modes share the same road space without strict lane discipline. Drivers often ignore lane markings and traffic rules, weaving laterally through any available gaps to inch ahead at intersections [9]. Field studies in Dhaka show that average travel speeds drop to as low as 6.1 km/h during peak hours, significantly below global urban standards [16]. Combined with weak enforcement of traffic laws and frequent pedestrian interference (e.g., people crossing roads arbitrarily), this non-lane-based behavior creates numerous conflict points and chaotic maneuvers at both signalized and unsignalized intersections [13].

Consequently, intersections commonly suffer from long delays and frequent stops, along with inefficient use of space as vehicles jostle for position. The absence of proper channelization such as dedicated turning lanes or separate facilities for slower vehicles means that fast-moving and slow-moving traffic intermingle, reducing overall capacity and exacerbating congestion [17]. Similarly, research conducted in Gazipur demonstrates that intersections such as Chowrasta and Shibbari experience persistent gridlock due to heterogeneous vehicle composition. Surveys indicate that over 54% of commuters in Chowrasta lose 4–5 hours daily because of traffic blockages, where electric three-wheelers were identified as a key cause of delay [18]. Similarly, a study on Gazipur Chowrasta confirmed that congestion was chronic due to industrial land use and mixed traffic, with buses, trucks, cars, rickshaws, and easy bikes competing for limited road space [10].

Grade-separated interchanges are special types of road junctions where vehicles move on different levels using bridges or tunnels. This design removes at-grade conflicts and allows vehicles to move without stopping for crossing traffic, leading to continuous traffic flow [14]. Among various types, the trumpet interchange is commonly used where one major highway ends at another. It connects the two roads through a loop ramp that curves around like a trumpet shape [8]. These interchanges help reduce delays and improve safety by lowering the number of conflict points where vehicles would otherwise cross paths. For instance, studies show that building flyovers or interchanges significantly increases intersection capacity and enhances safety by separating traffic streams. A notable example is the 2-kilometer-long Baipail trumpet interchange in Dhaka, completed in 2024. This project was designed to ensure "seamless vehicular movement" at the Ashulia–Nabinagar junction and reduce traffic congestion [2]. Compared to regular at-grade intersections, trumpet and other grade-separated interchanges reduce the need for traffic signals and stops. This leads to fewer delays and higher traffic capacity [3]. Simulation-based studies also support these benefits. For example, research shows that adding a flyover or underpass can double capacity and shorten queue lengths dramatically [4]. In Dhaka, a grade-separated U-loop was found to reduce delays by over 90% compared to a signalized design [3]. As a result, cities like Dhaka have increasingly adopted such structures, including the Mohakhali flyover, to address ongoing traffic congestion [15]. In summary, grade-separated interchanges especially trumpet types are effective solutions for improving traffic flow, reducing delays, and enhancing road safety in both developed and developing urban areas.

3. METHODOLOGY

The research followed several structured steps. First, the research objective was defined, and the study area was selected. A literature review was then conducted to understand existing approaches and identify research gaps. Afterward, field data were collected, including traffic volume, road geometry, GPS-based speed data, and E3W occupancy. A questionnaire survey was also carried out to explore operational challenges and commuter needs. Next, a micro simulation model was developed

and calibrated in PTV VISSIM to represent real traffic conditions. Several alternative scenarios were developed and systematically evaluated to assess their operational performance and identify the most effective solution for enhancing intersection efficiency.

3.1 Study Area: Shibbari Intersection Description

The study was carried out at the Shibbari Intersection in Gazipur City, Bangladesh. Gazipur is an industrial hub located north of Dhaka, hosting numerous factories,

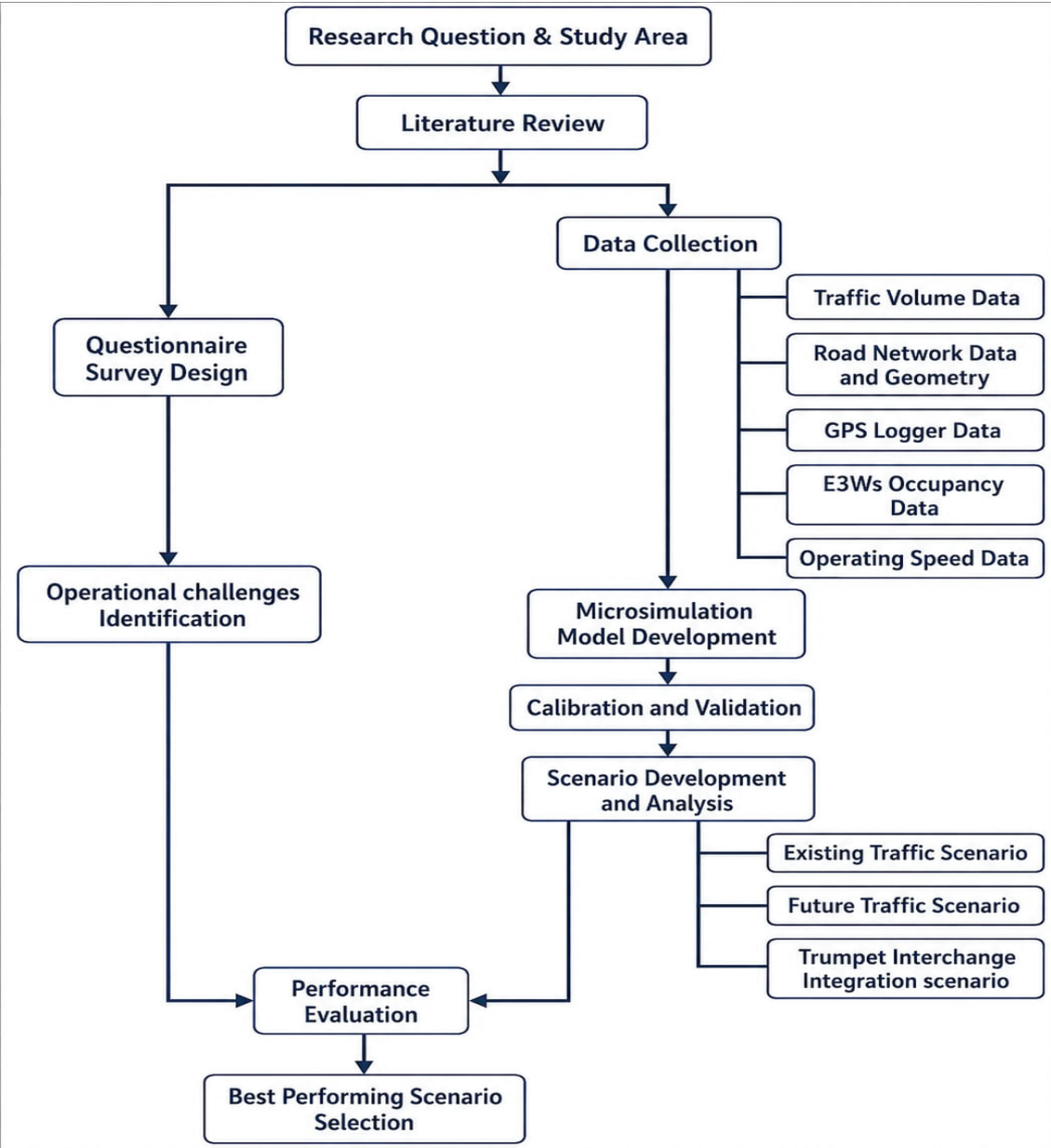


Fig. 1: Flow Chart of Methodology

offices (both government and private), and educational institutions. The Gazipur district spans approximately $23^{\circ}53' - 24^{\circ}21' N$ and $90^{\circ}09' - 92^{\circ}39' E$, placing it near the center of Bangladesh [10]. Shibbari Intersection is about

37 km north of central Dhaka. This strategic urban location connects major highways and contributes to high traffic volumes, making it a relevant case for congestion analysis. The geographic location has been showed in the Fig. 2.

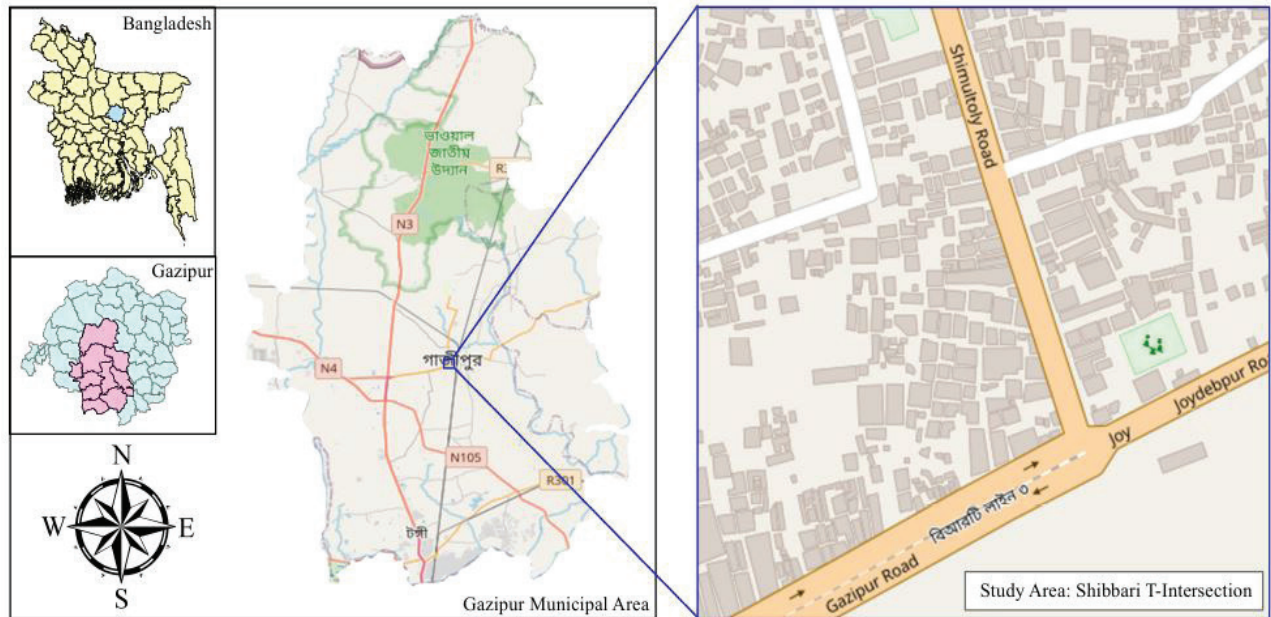


Fig. 2: Birds eye view of the study area: Shibbari Intersection

3.2 Data Collection

Data collection for this research was a challenging but essential task. It was carried out in two main phases. In the first phase, field data was collected from the study area (Shibbari intersection and nearby road links) to accurately build the road network model in PTV VISSIM. In the second phase, after calibration, simulation results were extracted to evaluate the effectiveness of different improvement strategies, especially grade-separated interchange solutions. Field data included traffic volume, vehicle composition, road geometry, E3W occupancy (6 persons, 4 persons and 2 persons capacity type vehicles), and travel speeds. Manual count was used to collect vehicle

flow data during morning (8 am -10 am) and evening (4 pm – 6 pm) peak hours [10]. Additionally, GPS-based logger data was used to find desired speed distribution of several vehicles. Intersection layout and segment lengths were measured using basic instruments like measuring tapes. The calibration and validation were performed following the Florida Department of Transportation (FDOT) Handbook guidelines [20]. Table I summarizes the calibration results for Day 1, and Fig. 4 compares the simulated and observed traffic flows. All GEH values and link flow deviations were within the acceptable limits, confirming that the model accurately represents real-world traffic conditions and is suitable for further scenario analysis.

Table I: Sample Calibration Table for Day 01

Direction	Vehicle /Hr.	Vehicle /600 sec.	Simulation Vehicle /600 sec.	Difference (Veh/hr)	% Difference	GEH
From Shimultoli	684	114.0	113	6	0.88	0.0939
To Shimultoli	426	71.0	77	-36	-8.45	0.6975
From Railgate	980	163.3	160	20	2.04	0.2622
To Railgate	794	132.3	132	2	0.25	0.0290
From Chowrasta	1032	172.0	161	66	6.40	0.8525
To Chowrasta	1468	244.7	203	250	17.03	2.7850

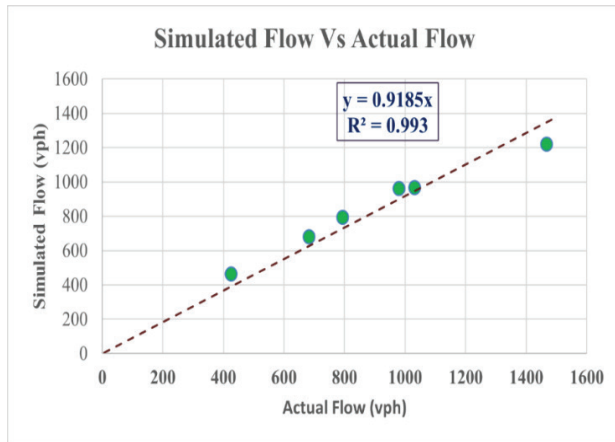


Fig. 3: Comparison between Simulated and Observed Traffic Flows

3.3 Future Traffic Scenario

The base condition scenario assumes that no improvements or geometric changes are made to the existing road network, even as traffic demand continues to grow in future years. According to the Roads and Highways Department (RHD) Pavement Design Guide (2005), the annual traffic growth rate for Regional Roads is 7% [19]. As the study corridor (R310: Joydebpur-Gazipur-Azmatpur-Itakhola Road) is an RHD Regional Road, a 7% annual traffic growth rate was adopted to forecast future traffic demand. Accordingly, projected traffic volumes for the years 2030, 2040, and 2050 were estimated using this growth rate. These projections were applied in the simulation to evaluate the likely increase in congestion and delay if the current infrastructure remains unchanged.

Table II: Traffic with E3Ws under 7% growth rate.

Direction	2025 (Base)	2030	2040	2050
From Shimultoli (veh/hr)	684	959	1,888	3,709
From Railgate (veh/hr)	980	1,375	2,704	5,320
From Chowrasta (veh/hr)	1032	1,448	2,849	5,603

Table II shows that traffic volumes are expected to increase sharply across all approaches under the do-nothing condition. The Chowrasta approach exhibits the highest projected flow, followed by Railgate and Shimultoli. By 2050, total traffic demand is predicted to rise by more than four times compared to the base year, indicating severe congestion if no mitigation measures are implemented.

3.4 Trumpet Interchange Integration Scenario

Here, a modified trumpet interchange is introduced at the intersection to allow uninterrupted vehicle movement through grade separation. The geometric design and lane assignments were prepared using reference studies such

as Indian road congress (IRC) guidelines. The model was built in VISSIM and tested under current and future traffic. The VISSIM simulation was performed using a single simulation run with a fixed random seed of 42. The same random seed was used for all scenarios to ensure consistent and comparable simulation results. Table III briefly compares the IRC-recommended and provided geometric parameters of the proposed trumpet interchange. Most values meet or exceed the standards, confirming the design's suitability. Minor deviations, such as a slightly smaller direct-ramp radius, remain acceptable under site conditions, while overall dimensions ensure safe and efficient traffic operation [11, 12]

Table III: Recommended and Provided Geometric Design Parameters for Trumpet

Description	Recommended Measurement (IRC Guidelines)	Provided Measurement (Design Data)	Reference	Comment
Radius of Loop Ramp	Minimum 30 m	36.2 m	IRC:92-2017, Sec. 6.2.2, Table 6.1	Satisfies standard; adequate for design speed.
Radius of Semi-direct (Direct) Ramp	Minimum 60 m	56.8 m	IRC:92-2017, Sec. 6.2.2, Table 6.2	Slightly below recommended; still acceptable under constrained site conditions.

Description	Recommended Measurement (IRC Guidelines)	Provided Measurement (Design Data)	Reference	Comment
Width of Lane	3.5 m	3.5 m	IRC:86-2018, Sec. 5.4	Standard lane width considered in design.
Length of Curve / Ramp	15–50 m (for 20–80 km/h)	Loop = 170.5 m; Semi-Direct = 64.3 m	IRC:86-2018, Sec. 9.3, Table 9.2	Exceeds minimum requirement; ensures smoother turning movement.
Shoulder Width	Minimum 2 m	2 m	IRC:92-2017, Sec. 6.4	Fully satisfies standard.
Median Width	Minimum 1.2 m	1.2 m	IRC:92-2017, Sec. 6.4	Provided for safety separation between directions.
Approach Road Length	Minimum 90 m	130 m	IRC:92-2017, Sec. 6.5.2, Table 6.4	Adequate for approach alignment and sight distance.
Bridge Length	According to Roadway width	70 m	IRC:92-2017, Sec. 6.6.1	Suitable for grade separation and traffic volume.
Gradient	Maximum 6%	5 %	IRC:92-2017, Sec. 6.3	Within acceptable limit for ramp design.
Vertical Clearance	Minimum 5.5 m	6.5 m	IRC:92-2017, Sec. 6.6.2	Exceeds minimum requirement; ensures full clearance for heavy vehicles.

Fig. 4 shows the adopted geometric measurements of the modified trumpet.

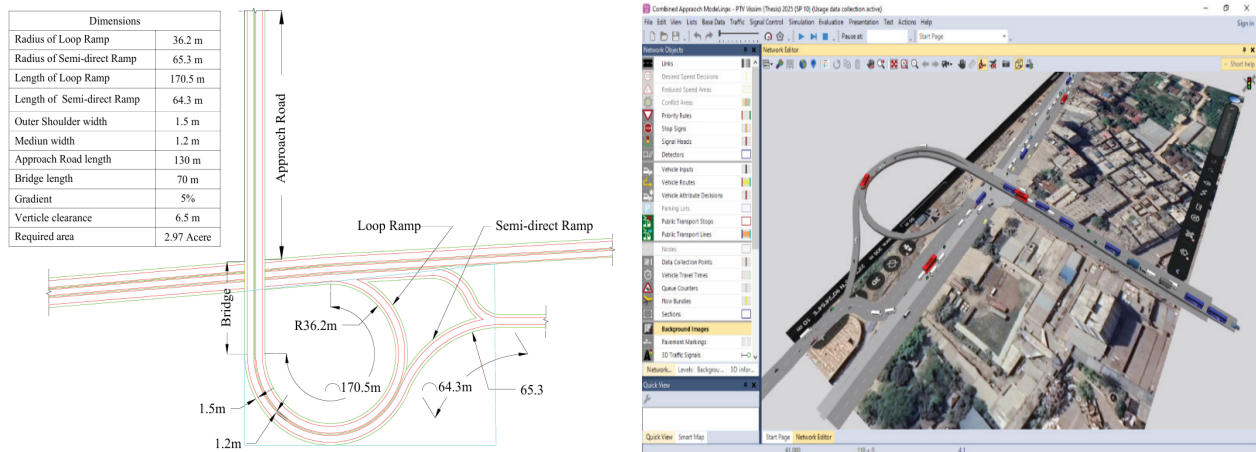


Fig. 4: Graphical representation of modified trumpet interchange

4. RESULTS AND DISCUSSION

4.1 Simulation Results for Existing Conditions

The simulation results for the existing traffic conditions, shown in Table IV, indicate that congestion at the Shibbari intersection increases notably with future traffic growth. Queue delays and occupancy rates rise sharply after 2030, especially on the Shimultoli and Railgate approaches,

while both arithmetic and harmonic mean speeds gradually decrease. By 2050, severe congestion is evident, with delays exceeding 180 seconds and occupancy rates above 90 % on several approaches. These findings suggest that the existing intersection configuration will become highly inefficient under anticipated demand, emphasizing the need for geometric or operational enhancements.

Table IV: Simulation results for existing conditions.

Roadway	Year	Queue delay (all) sec	Speed avg. Arithmetic (all) km/h	Speed avg. Harmonic (all) km/h	Occupancy rate (all)
From Shimultoli	2025 (current)	4.22	14.10	10.79	47.31%
	2030	47.54	9.09	4.30	86.79%
	2040	110.35	8.63	5.27	91.77%
	2050	182.90	7.84	4.74	92.86%
To Shimultoli	2025 (current)	25.84	20.08	18.40	6.92%
	2030	37.00	19.33	17.91	9.15%
	2040	73.59	19.90	18.19	12.79%
	2050	80.66	18.48	17.54	21.54%
From Railgate	2025 (current)	0.31	17.23	15.80	17.82%
	2030	0.62	16.90	14.97	27.07%
	2040	10.53	13.49	10.00	74.64%
	2050	104.62	12.33	9.40	87.02%
To Railgate	2025 (current)	18.35	18.65	17.64	11.06%
	2030	23.17	17.77	16.85	14.52%
	2040	104.19	17.80	16.83	18.95%
	2050	56.23	16.84	16.09	36.39%
From Chowrasta	2025 (current)	0.19	17.11	16.22	15.74%
	2030	0.19	16.98	16.13	20.79%
	2040	50.28	14.42	9.33	83.50%
	2050	31.52	13.91	10.67	80.76%
To Chowrasta	2025 (current)	32.54	17.40	15.86	22.37%
	2030	52.46	17.66	16.24	26.22%
	2040	65.63	16.42	14.92	38.47%
	2050	114.60	16.04	14.61	45.15%

4.2 Simulation Results for Trumpet Interchange Scenario

The findings in Table V indicate that the trumpet interchange substantially enhances traffic performance compared to the existing scenario, especially up to 2030. Queue delays remain negligible in the early years, and average speeds stay relatively high across all approaches.

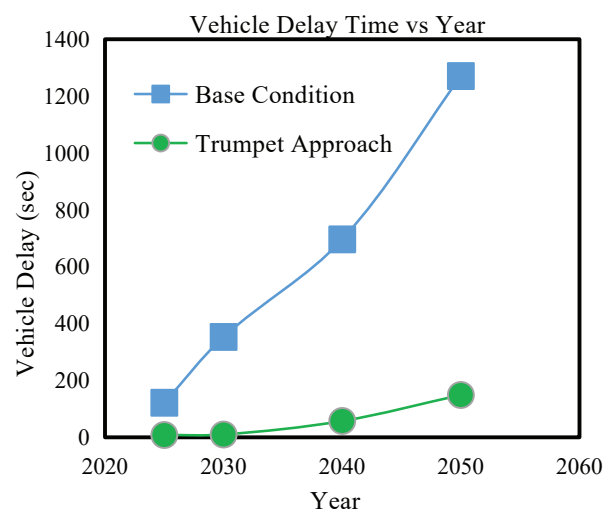
However, as traffic demand grows beyond 2040, queue delays and occupancy rates begin to increase most noticeably on the Railgate and Chowrasta approaches though still at lower levels than in the base scenario. This indicates that the trumpet interchange effectively enhances network efficiency and delays severe congestion under future traffic growth.

Table V: Simulation results for Trumpet Interchange

Roadway	Year	Queue Delay (all) sec	Speed avg. Arithmetic (all) km/h	Speed avg. Harmonic (all) km/h	Occupancy rate (all)
From Shimultoli	2025 (current)	0.05	18.85	17.82	13.02%
	2030	0	18.16	17.17	17.44%
	2040	0.19	16.29	14.78	37.12%
	2050	21.66	11.51	7.29	84.43%
To Shimultoli	2025 (current)	0.49	19.14	18.02	6.44%
	2030	0.55	20.15	18.67	9.15%
	2040	3.14	18.28	16.89	18.06%
	2050	22.84	18.27	17.06	26.48%
From Railgate	2025 (current)	0.11	17.23	15.83	18.12%
	2030	0.35	17.08	15.74	25.58%
	2040	5.71	13.7	8.97	69.72%
	2050	113.37	13.75	10.24	82.09%
To Railgate	2025 (current)	0.68	19	17.88	12.46%
	2030	0.78	18.04	17.01	17.05%
	2040	5.58	17.34	16.52	30.87%
	2050	28.84	16.75	16.07	49.67%
From Chowrasta	2025 (current)	0.78	15.51	14.02	28.90%
	2030	0.45	14.87	13.64	36.39%
	2040	19.18	13.97	8.57	80.95%
	2050	42.44	12.44	8.63	86.54%
To Chowrasta	2025 (current)	15.73	18.31	17.01	20.61%
	2030	18.77	17.41	16.46	28.04%
	2040	51.97	16.62	15.8	44.02%
	2050	151.56	16.69	15.93	47.31%

4.3 Comparative Analysis of Scenarios

Fig. 5 indicates that vehicle delay increases progressively with time in all scenarios due to growing traffic demand. The base condition exhibits the highest rate of delay growth, rising sharply from approximately 120 seconds in 2025 to more than 1200 seconds by 2050, which reflects severe future congestion at the study intersection. In contrast, the trumpet interchange scenario substantially reduces vehicle delay throughout the analysis period. Although delay still increases gradually over time, the values remain considerably lower than those of the existing condition, indicating improved traffic operation and roadway efficiency.

**Fig. 5:** Comparative analysis of scenarios with respect to vehicle delay

The trend in Fig. 6 Stop Delay Time vs Year shows a consistent increase in stop delay across all scenarios as traffic demand increases. The base condition experiences the highest and fastest growth, exceeding 1000 seconds by 2050, indicating worsening congestion and frequent stoppages. In contrast, the trumpet interchange scenario maintains significantly lower stop delay throughout the analysis period, demonstrating its effectiveness in improving traffic flow and reducing intersection congestion.

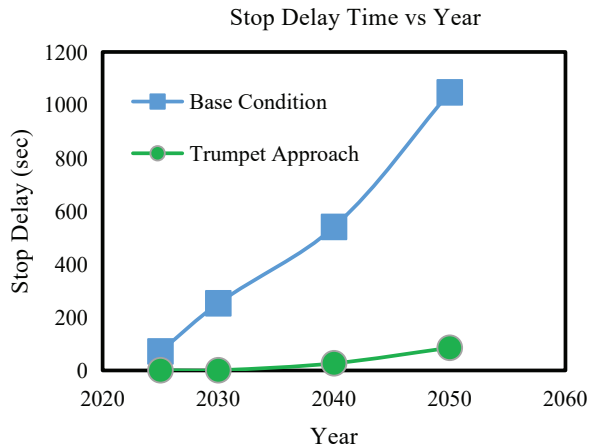


Fig. 6: Comparative analysis of scenarios with respect to stop delay

The Level of Service (LOS) distribution under the base condition shows a gradual decline over time. In 2025, most traffic movements operate at LOS A, reflecting smooth traffic flow. However, as traffic volume increases, the number of movements at LOS E and LOS F grows sharply, becoming dominant by 2050. This trend signifies that the existing intersection layout cannot handle future traffic demand efficiently and will experience severe congestion and unstable operations without substantial improvements. This condition is illustrated in Fig. 7.

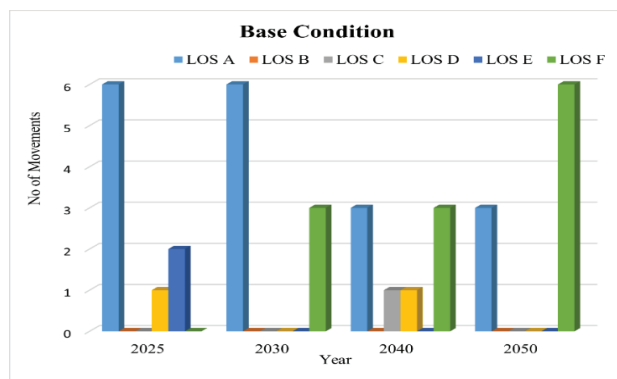


Fig. 7: Comparative analysis of scenarios with LOS under base condition

The Level of Service (LOS) results for the trumpet interchange scenario indicate a significant improvement in traffic performance compared to existing conditions. Up to 2030, all movements operate at LOS A, indicating free-flow conditions achieved through grade separation and reduced conflict points. Even by 2050, most movements still perform at LOS A-C, with only a few shifting to LOS E-F. This demonstrates that the trumpet interchange significantly enhances capacity, minimizes intersection delays, and sustains high operational efficiency over the forecast period. This condition is illustrated in Fig. 8.

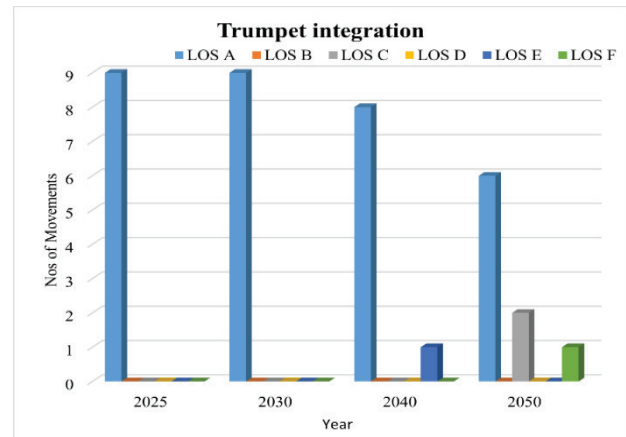


Fig. 8: Comparative analysis of scenarios with LOS under trumpet condition

The findings of this study are consistent with previous research on grade-separated intersections. Similar to earlier studies, the proposed trumpet interchange reduced traffic delays and improved traffic flow by eliminating at-grade conflict points [3], [4], [14], [15]. These findings also support the effectiveness of grade-separated facilities in heterogeneous traffic conditions commonly found in developing countries [9]. Compared with previous studies in Bangladesh [6], [17], this study further evaluates the long-term operational performance of a trumpet interchange under projected traffic growth and a dedicated BRT lane.

5. CONCLUSION

This study investigated traffic congestion at the Shibbari intersection in Gazipur and evaluated the effectiveness of a proposed trumpet interchange under existing and future traffic conditions. Simulation results for the existing condition indicate a substantial increase in delays as traffic grows. By 2050, vehicle delays exceeded 1200 seconds, stop delays surpassed 1000 seconds, and queue delays on the Shimultoli approach reached 182.9 seconds, with occupancy rates above 90.

The trumpet interchange scenario showed improved performance by eliminating traffic conflict points through grade separation. In 2050, Shimultoli's queue delay was 21.66 seconds, and average speeds remained around 11.5 km/h, though stop delays and occupancy rates still increased beyond 80%. LOS remained at A to C levels, but signs of congestion were still present.

Overall, the findings indicate that the trumpet interchange provides a more sustainable long-term solution for mitigating congestion at the Shibbari intersection under projected traffic growth conditions. The study highlights the potential applicability of grade-separated interchange facilities in mixed and heterogeneous traffic environments commonly observed in developing countries such as Bangladesh. This study assessed the feasibility of the proposed trumpet interchange only from a traffic operational perspective. Construction cost, land acquisition, right-of-way requirements, and BRT-related implementation feasibility were beyond the scope of this study and should be considered in future research.

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