Journal of Transportation Technologies, 2026, 16(4), 361-375
https://www.scirp.org/journal/jtts
ISSN Online: 2160-0481
ISSN Print: 2160-0473

Operational Evaluation of a Compact 120 m Median U-Turn Offset: A Microsimulation Case Study of an Existing Urban Corridor

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How to cite this paper: Badwes, A. (2026) Operational Evaluation of a Compact 120 m Median U-Turn Offset: A Microsimulation Case Study of an Existing Urban Corridor. *Journal of Transportation Technologies*, **16**, 361-375.
https://doi.org/10.4236/jtts.2026.164020

Received: July 7, 2026
Accepted: August 14, 2026
Published: August 17, 2026

Abstract

As rapidly urbanizing cities face increasing car dependency, traditional intersections often reach saturation, necessitating unconventional geometric interventions. This study evaluates the operational efficiency of an unsignalized Median U-Turn (MUT) configuration, specifically investigating the impact of imbalanced offset distances on a high-volume urban corridor in Riyadh, Saudi Arabia. The research evaluates a compact 120 m crossover representing the lower bound of AASHTO recommendations against a conventional imbalanced configuration featuring offsets of 864 m for the Northbound approach and 1.37 km for the Southbound approach. Utilizing PTV Vissim microscopic simulation under a peak demand of 2,415 veh/hr, the methodology analyzes movement-specific dynamics through a 600 second analysis interval scaled to hourly performance. Findings demonstrate that the unsignalized MUT configuration with an imbalanced 120 m offset provides satisfactory operational performance, achieving a system-wide average delay of only 11.11 seconds per vehicle (LOS A). Critically, despite the high Southbound demand of 1,119 veh/hr, the maximum observed queue of 26.63 m utilized only 22.2% of the available 120 m storage length. These results empirically suggest that extreme distances of 864 m and 1.37 km are operationally redundant for this corridor. Implementing the compact 120 m MUT design reduces the additional travel distance for U-turning vehicles by up to 2.4 km per trip by replacing the existing long crossover configuration. The simulation results demonstrate that the proposed 120 m MUT operates efficiently under the observed traffic demand, providing evidence that a compact offset is operationally feasible while improving land-use efficiency without compromising operational stability.

Keywords

Intersection Design, Median U-Turn, Traffic Delay, Level of Service, Offset Distance Optimization

1. Introduction

Urban intersections represent critical nodes within road networks, where multiple traffic streams converge, diverge, and cross. Inefficient intersection design often leads to increased control delay, traffic congestion, higher fuel consumption, and elevated crash risk, particularly in rapidly growing cities. Unsignalized MUT design intersections, while effective in regulating conflicting movements, may introduce substantial delay during peak hours if not properly designed or if geometric and operational constraints are ignored.

In recent years, transportation agencies have increasingly explored alternative intersection designs such as Median U-Turn (MUT) intersections as cost-effective solutions to improve operational performance without extensive right-of-way acquisition. These alternatives aim to reduce conflict points, minimize signal phases, and enhance traffic flow continuity, especially under high directional traffic demand.

Riyadh, Saudi Arabia, has experienced significant growth in vehicular traffic due to urban expansion and increased car dependency. Despite this growth, applied case studies evaluating alternative intersection designs using real field data remain limited within the local context. Most existing studies focus on theoretical design guidelines, while fewer evaluate the operational feasibility of compact MUT designs using empirical traffic data and microscopic traffic simulation.

Therefore, this study aims to evaluate the operational performance of a real MUT intersection with unbalanced offset distances in both sides of the main road located on Ash Shaikh Hasan Road in Riyadh as shown in **Figure 1** by analyzing existing unbalanced MUT offset conditions with the balanced MUT with 120 m offset for both sides of main road as alternative intersection design.

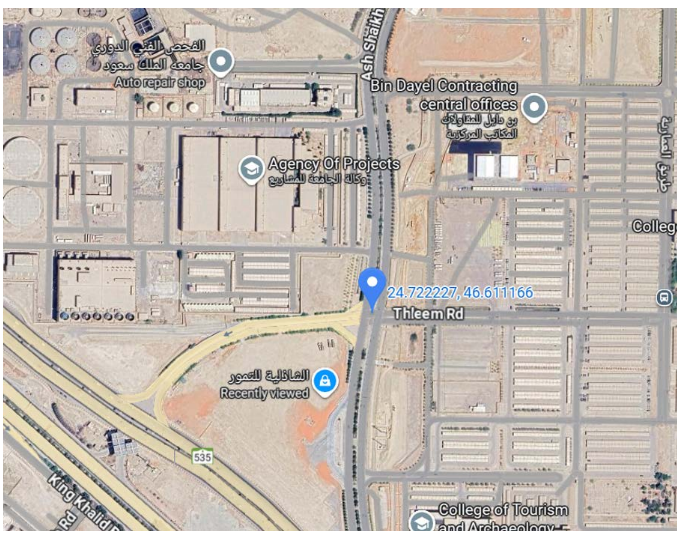

Figure 1. Satellite view of the intersection location.

2. Literature Review

Urban intersections are among the most critical elements of road networks, as they directly influence traffic flow efficiency, safety, and travel reliability. Inefficient intersection operations often lead to excessive delays, increased fuel consumption, and higher emissions, particularly in rapidly urbanizing cities. Prior studies emphasize that intersection bottlenecks account for a disproportionate share of urban congestion and travel time losses [1]. Intersection of geometric design and control type significantly affects operational performance. Conventional signalized intersections may perform adequately under balanced traffic demand but tend to degrade rapidly under high volumes or unbalanced turning movements. Researchers highlight that poor geometric layouts exacerbate queue spillbacks and signal inefficiencies [2].

The Highway Capacity Manual (HCM) has long been the primary analytical framework for evaluating intersection performance. It provides standardized methodologies for estimating capacity, control delay, and level of service (LOS). Numerous studies confirm the robustness of HCM procedures when applied to field-collected traffic data [3]. Several empirical studies have applied HCM-based analyses to diagnose operational deficiencies in urban intersections. These studies demonstrate that control delay and LOS are reliable indicators for comparing alternative intersection designs under identical traffic demand conditions [4].

Despite their widespread use, conventional signalized intersections exhibit notable limitations under heavy traffic volumes. Studies report increased delays, frequent signal failures, and inefficient phase utilization, especially when left-turn demands are high [5]. To overcome the shortcomings of traditional intersections, transportation agencies have explored alternative designs such as roundabouts, Median U-Turn (MUT) intersections, and displaced left-turn intersections. These designs aim to reduce conflict points and improve traffic progression [6]. The MUT intersection modifies left-turn movements by rerouting them to downstream median openings, thereby eliminating direct left turns at the main intersection. This configuration reduces signal phases and improves throughput [7]. Multiple studies have shown that MUT intersections significantly reduce control delay and improve LOS compared to conventional signalized intersections. The reduction in signal phases leads to shorter cycle lengths and improved progression along arterial corridors [8]. Roundabouts are another commonly proposed alternative intersection design. While they perform well under moderate volumes, studies show that their operational efficiency declines under high traffic demand and unbalanced flows, limiting their applicability in dense urban environments [9]. Signalized intersections are often used where one approach carries significantly lower demand. However, under high arterial volumes, their performance is constrained by limited capacity and increased delays on minor approaches [10].

Operational delay directly translates into increased vehicle operating costs, fuel consumption, and emissions. Several studies highlight those alternative intersections, particularly MUT designs, offer substantial economic benefits by minimizing idle time and stop-and-go conditions [11]. Rapid motorization and population growth in Middle Eastern cities have intensified congestion at urban intersections. Studies conducted in Saudi Arabia indicate that traditional signalized designs struggle to accommodate rising demand [12].

The authors found that the new double contraflow intersection outperforms conventional signalized intersections by significantly reducing average delay and queue lengths, particularly under high left-turn demand. Compared with other alternative intersection designs, the double contraflow configuration provides more efficient signal phasing and higher throughput. The results indicate improved operational performance in terms of travel time and level of service at moderate to heavy traffic volumes. However, the authors noted that successful implementation depends on proper signal control, clear signage, and adequate driver familiarity [13]. The authors found that the "Shifting Movements" intersection design significantly reduces control delay and improves traffic progression compared to conventional signalized intersections. By relocating and reorganizing turning movements upstream of the main intersection, the design decreases conflict points and allows simpler signal phasing. The results showed notable reductions in queue lengths and travel time under moderate to high traffic demand. However, the authors emphasized the need for clear signing, pavement markings, and driver education to ensure safe and effective operation [14]. The authors found that the U-turn design with advance left-turn significantly improves traffic flow sustainability by reducing intersection delay and queue lengths compared to conventional signalized intersections. The advance left-turn strategy enhances capacity utilization and smooths traffic progression under high turning volumes. Results indicated lower travel times and improved level of service, particularly during peak periods. The study also highlighted reduced stop-and-go conditions, contributing to lower fuel consumption and emissions [15].

Despite the extensive body of research demonstrating the operational advantages of MUT intersections, practical implementation does not always conform to established geometric design recommendations. In several existing applications, crossover locations are determined by site-specific constraints rather than operational efficiency, resulting in excessively long and asymmetric offsets that may increase travel distance without providing measurable traffic benefits. The present study addresses this practical gap through a real-world case study of an existing MUT intersection in Riyadh, Saudi Arabia, where the northbound and southbound U-turn crossovers are located at substantially different distances, with one crossover reaching to 1 km from the main intersection. Rather than comparing different intersection types, this research evaluates whether the minimum offset distance recommended by AASHTO (120 m) can adequately accommodate the observed traffic demand while maintaining satisfactory operational performance. Using microscopic traffic simulation, the study assesses the feasibility of replacing the existing land-intensive configuration with a compact 120 m MUT design and examines whether the excessive crossover distances currently implemented are operationally justified.

3. Methodology

3.1. Study Area Description

The study area is a MUT urban intersection located on Ash Shaikh Hasan Road, near the College of Engineering at King Saud University in Riyadh, Saudi Arabia where Figure 2 shows the real intersection inside the campus. The intersection serves mixed traffic demand, including commuter traffic associated with university activities and surrounding urban land uses. The posted speed limit along the major approaches is 60 km/h, and the intersection currently operates under restricted movement conditions due to median barriers.

The geometric configuration consists of northbound (NB), southbound (SB), eastbound (EB), and westbound (WB) approaches, each accommodating through and turning movements. Due to its strategic location and high directional traffic demand during morning peak hours, the intersection experiences recurrent congestion, making it a suitable candidate for operational performance evaluation.

Figure 2. Picture of the location of the intersection.

3.2. Data Collection

Traffic data was collected through manual field observations to establish the baseline operational demand as shown in Figure 3. The observation period was specifically targeted at the Morning Peak Period (7:30 AM - 9:30 AM). This two-hour window was selected because it represents the critical saturation state of the intersection, characterized by the highest directional volumes associated with university and commuter activities. The data collection procedure involved:

1) Selecting a vantage point that allowed clear visibility of all intersection approaches.

2) Recording the number of vehicles approaching each leg of the intersection.

3) Classifying traffic volumes by direction (NB, SB, EB, WB).

4) Computing average hourly traffic volumes based on observed counts.

Following standard engineering practices for operational analysis, vehicle counts were recorded in 15-minute intervals to capture the Peak Hour Factor (PHF) and temporal variations in demand. Traffic was disaggregated by approach (NB, SB, EB, WB) and movement type (Left, Through, Right) to ensure high-fidelity inputs for the HCM 2010 lane-group evaluation. By focusing on the peak-period saturation flow, the study ensures that the recommended alternative designs are robust enough to handle the maximum daily stress on the road network.

Figure 3. Collecting the data from the site.

3.3. Data Preparation

The study focuses on design of the intersection which is located on Ash Shaikh Hasan Ash Shaikh Road near to college of engineering in King Saud University in Riyadh. **Table 1** presents the raw traffic volume data collected at the study intersection on Ash Shaikh Hasan Road during the morning peak period. Vehicle counts were recorded at 15-minute intervals between 7:30 and 9:30 AM for all four approaches: northbound (NB), southbound (SB), eastbound (EB), and westbound (WB). The results indicate that the highest traffic demand occurs on the northbound and southbound approaches, reflecting the dominant directional flow along the main corridor. Over the two-hour observation period, total volumes reached 1,647 vehicles for the northbound approach and 1,316 veh for the southbound approach, corresponding to average hourly volumes of 824 veh/h and 658 veh/h, respectively. In contrast, the eastbound and westbound approaches experienced substantially lower traffic demand, with average hourly volumes of 105 veh/h and 285 veh/h, respectively. This pronounced imbalance in directional traffic demand highlights the operational challenges at the intersection and underscores the need for evaluating alternative intersection designs capable of efficiently accommodating heavy through movements while minimizing delay and operational inefficiencies.

Table 1. Number of vehicles per hour approaching each bound in the intersection (raw data).

Time interval	No. vehicle (NB)	No. vehicle (SB)	No. vehicle (EB)	No. vehicle (WB)
7:30 - 7:45	267	181	17	89
7:45 - 8:00	237	185	21	92
8:00 - 8:15	225	147	17	63
8:15 - 8:30	152	145	16	57
8:30 - 8:45	158	124	23	50
8:45 - 9:00	171	159	21	63
9:00 - 9:15	215	163	37	83
9:15 - 9:30	222	212	57	73
Total	1647	1316	209	570
Average volume/h	824	658	105	285

Table 2 presents the adjusted traffic volumes used as simulation inputs after applying the traffic diversion associated with the existing MUT configuration. The adjusted volumes were derived from the observed field traffic counts by reassigning movements that cannot be performed directly at the main intersection because of the median closure. Vehicles requiring indirect left-turn movements were redirected through the existing downstream U-turn crossover in accordance with the current geometric layout, while maintaining the total observed traffic demand. This redistribution increased the effective demand on the southbound, eastbound, and westbound approaches, whereas the northbound approach remained unchanged at 824 veh/h. Consequently, the adjusted hourly volumes became 1,119 veh/h, 147 veh/h, and 343 veh/h for the southbound, eastbound, and westbound approaches, respectively. These effective approach volumes were subsequently adopted as the input demand for the VISSIM microsimulation model and the HCM 2010 operational analysis.

Table 2. Number of vehicles approaching each bound in the intersection (after diversion).

Time interval	No. vehicle (NB)	No. vehicle (SB)	No. vehicle (EB)	No. vehicle (WB)
7:30 - 7:45	267	308	24	107
7:45 - 8:00	237	315	29	110
8:00 - 8:15	225	250	24	76
8:15 - 8:30	152	247	22	68

Continued

8:30 - 8:45	158	211	32	60
8:45 - 9:00	171	270	29	76
9:00 - 9:15	215	277	52	100
9:15 - 9:30	222	360	80	88
Total	1647	2238	294	685
Average volume/h	824	1119	147	343

Table 3 present the distribution of traffic volumes by movement type (left-turn, through, and right-turn) for each approach based on the adjusted average hourly flows. This movement-level disaggregation is a critical step in the methodological framework, as HCM-based operational analysis is performed at the lane-group level rather than total approach volumes. The results indicate that left-turn movements dominate the northbound and westbound approaches, while through movements are predominant on the southbound approach, reflecting strong directional demand along the major corridor. These movement-specific volumes were subsequently used to define lane groups, identify critical movements, and convert traffic flows into through-vehicle equivalents. Consequently, the data in Table 3 directly underpins the calculation of critical lane volumes, signal phasing decisions, and control delay estimation for the evaluated intersection design alternatives.

Table 3. Number of vehicles in in each direction (left-through-right).

Approach	Average volume/h	V right	V left	V through
No. vehicle NB	824	124	494	206
No. vehicle SB	1119	56	392	671
No. vehicle EB	147	15	29	103
No. vehicle WB	343	71	257	15

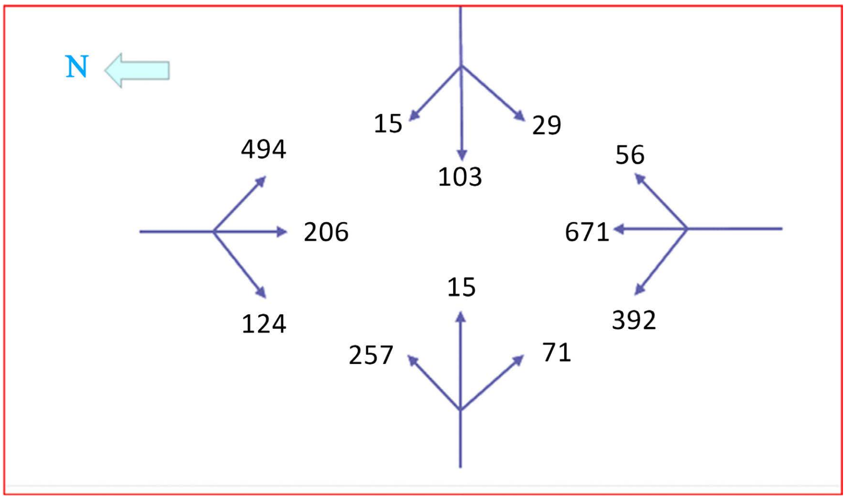

Figure 4. Number of vehicles in each direction (left-through-right).

Figure 4 illustrates the movement-specific traffic volumes presented in Table 3, providing a clear visual representation of left-turn, through, and right-turn demands at each approach. The figure highlights the dominance of left-turn movements on the northbound and westbound approaches and the high through-movement demand on the southbound approach. This visual interpretation facilitates the identification of critical movements and competing traffic streams at the intersection. Combined with the numerical data, Figure 4 was used to define lane groups and determine critical lane volumes in accordance with HCM 2010 procedures.

3.4. Existing Geometric Configuration

To ensure the practical relevance of the simulation analysis, a high volume four-leg MUT intersection located within the urban arterial network of Riyadh, Saudi Arabia, was selected as the baseline case study. The current infrastructure incorporates a MUT configuration characterized by significant asymmetrical longitudinal offsets, dictated by existing site-specific constraints and land-use requirements. As illustrated in Figure 5, the existing geometry features a crossover for the Northbound approach situated at a longitudinal offset of 862 m. In contrast, the Southbound approach features a substantially more extended offset of 1.37 km. These existing distances are considerably larger than standard theoretical recommendations, leading to a potential increase in Vehicle Kilometers Traveled (VKT) and associated environmental externalities.

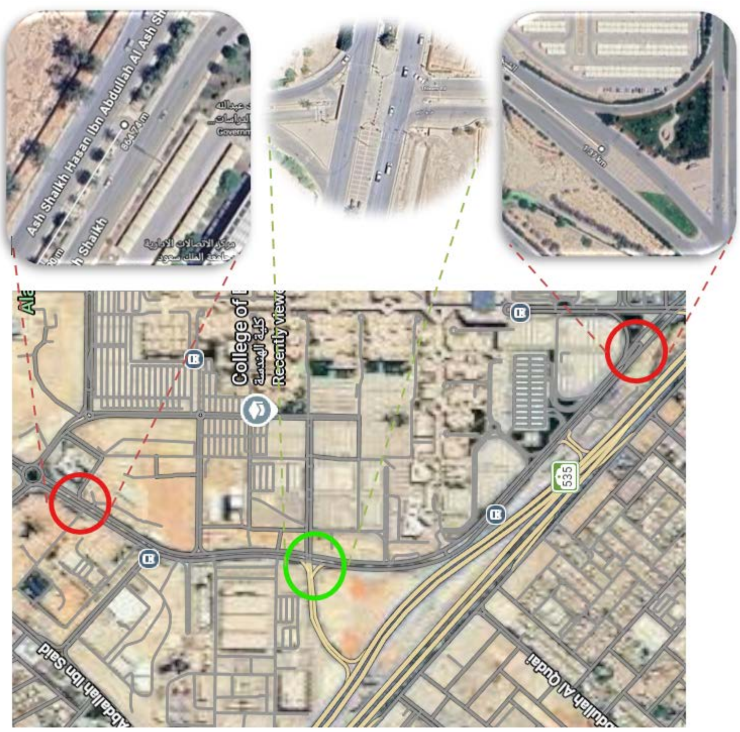

Figure 5. Schematic view of the South approaches MUT crossover at 1.37 km and North approaches MUT crossover at 862 m longitudinal offset.

To isolate the influence of crossover offset distance, all geometric characteristics, traffic demand, routing decisions, priority rules, and operational conditions of the existing MUT intersection were kept unchanged. The only design parameter modified in the simulation was the longitudinal distance between the main intersection and the U-turn crossover, which was reduced from the existing 862 m and 1.37 km offsets to the minimum AASHTO-recommended value of 120 m.

3.5. Model Development

The simulation model was developed focusing on the geometric optimization of the Median U-Turn (MUT) configuration. For the initial design phase, a U-turn offset distance of 120 meters from the main intersection was selected. This distance represents the lower bound of the functional range recommended by AASHTO standards, which typically suggests offsets between 120 m and 180 m (400 to 600 feet) to balance operational efficiency with spatial constraints. By selecting the 120 m minimum threshold, the model aims to test the lowest bound feasibility; if this compact design can successfully manage the projected peak hour volumes specifically the heavy Southbound demand of 1,119 veh/hr and Northbound flow of 824 veh/hr, it would prove that more expansive and land-intensive designs (such as the 864 m offset) are unnecessary for this specific corridor. The following **Figure 6** illustrates the VISSIM network layout, lane configurations, and vehicle routing used to validate this 120 m design.

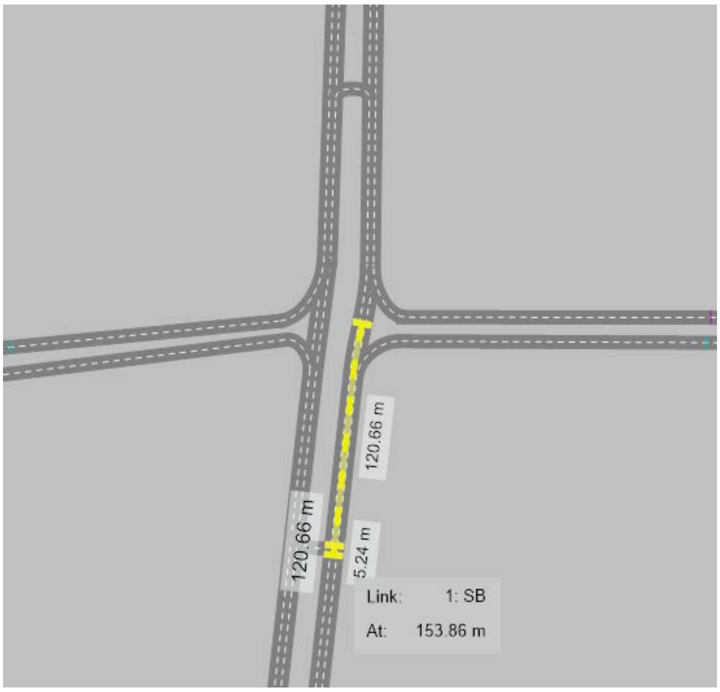

Figure 6. VISSIM model layout with 120 m MUT offset.

3.6. Model Calibration and Validation

The microsimulation model was developed in PTV Vissim using the Wiedemann

74 car-following model to represent driver behavior. The simulated geometry replicated the existing MUT intersection layout, where the left lane on the major road served through movements only, while the right lane accommodated both through and right-turn movements. The existing MUT storage lengths were approximately 50 m on one approach and 30 m on the opposite approach. Vehicle routing followed the existing MUT operating pattern, whereby indirect left-turn movements were redirected through the downstream U-turn crossover. To facilitate mandatory lane changes before reaching the crossover, lane-changing behavior was initiated approximately 200 m upstream. Since the intersection operated without traffic signals, vehicle interactions were controlled using VISSIM Conflict Areas, with priority assigned to vehicles traveling on the major roadway, while vehicles entering from minor approaches or performing U-turn maneuvers yielded to acceptable gaps. The traffic composition consisted primarily of passenger cars, reflecting the dominant traffic demand generated by employees and students traveling to and from the nearby university area.

Table 4. Calibration of the VISSIM model using the GEH statistics.

Movement	Simulated	Real	GEH
1	516	671	6.39
2	336	392	2.94
3	72	103	3.31
4	24	15	2.04
5	170	206	2.67
6	42	51	1.32
7	210	257	3.08
8	426	494	3.17

The VISSIM model was executed using five independent simulation runs with different random number sequences generated from an initial random seed of 42. A warm-up period of 2 minutes was applied to eliminate the influence of initially empty network conditions before performance measures were recorded. Operational performance was then evaluated over a 600-second (10-minute) analysis interval, and the resulting traffic volumes and performance measures were converted to equivalent hourly values to validate with the observed peak-hour traffic demand. The reported results represent the average values obtained from the five simulation runs. The simulated traffic volumes were calibrated against the observed field traffic counts using the Geoffrey E. Havers (GEH) statistic, which is widely accepted as a standard measure for validating traffic microsimulation models. Eight traffic movements were tested between the simulated and observed volumes. The calibration results showed that seven out of the eight movements (87.5%) as shown in Table 4 achieved GEH values below the commonly accepted threshold of 5.0, indicating a good agreement between the simulated and observed traffic flows. Only one movement produced a GEH value of 6.39, which is only slightly above the recommended threshold and may be attributed to normal variability in traffic demand and driver behavior. Overall, the calibration results demonstrate that the developed VISSIM model provides a satisfactory representation of the existing traffic conditions and is therefore considered suitable for evaluating the operational performance of the proposed 120 m MUT configuration.

4. Results

Figure 7 presents the operational delay for each approach of the MUT 120 m design. The results show that all approaches operate with high efficiency. The Southbound (SB) approach, despite carrying the highest volume of 1,119 veh/hr, maintains a low delay of 8.05 seconds, confirming that the MUT configuration effectively handles heavy through-movements. The Eastbound (EB) approach shows the highest delay at 18.39 seconds, which is still well within the limits for a high Level of Service (LOS B). Overall, the uniform low delay values across the network demonstrate that the 120m offset does not create any significant bottlenecks or congestion points.

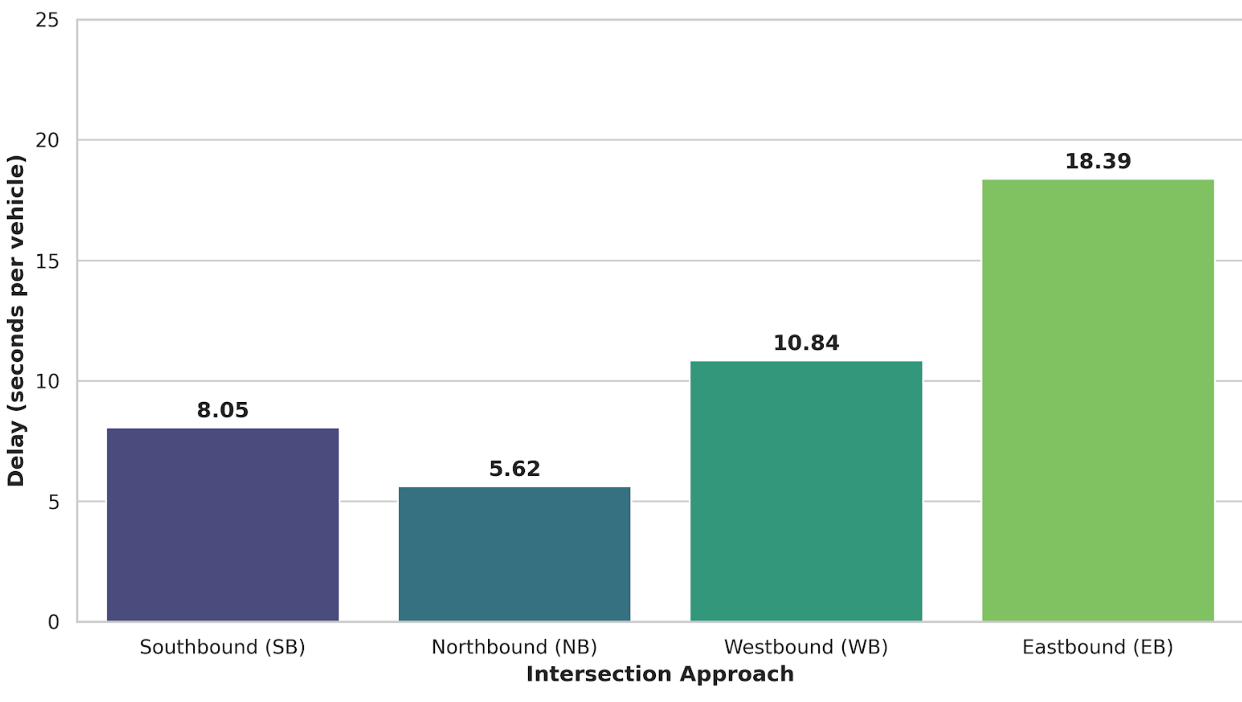

Figure 7. Weighted Average Delay (s/veh) across the Four Intersection Approaches.

In Table 5 the total input demand (2,415 veh/hr), this confirms the intersection is being tested under high-load, peak-hour conditions. The system capacity sufficient verdict proves that geometry can manage the throughput without failing. Average intersection Delay (11.11 s/veh) This is the most important number for a traffic engineer. A delay under 10 seconds typically corresponds to Level of Service (LOS) A. It shows that the MUT design allows for a very fluid movement of traffic, even with the prohibition of direct left turns. Maximum queue length (26.63 m). This row directly answers the Safety question. Since the U-turn is 120 m away, and the longest queue only reaches 26.63 m, the design has a massive safety margin. Storage Reservoir Utilization 22.19%: This percentage is derived by dividing the max queue by the available offset distance. It shows that 77.8% of the U-turn Lane remains empty, proving that an 864 m offset would be entirely unnecessary and wasteful of land. Travel Distance Saving (1,360 m/veh). This is the Environmental/Economic argument. By placing the U-turn closer, you reduce the extra travel distance for every left-turning vehicle from 1,600 m down to 240 m.

Table 5. Operational performance and geometric efficiency for the 120 m MUT offset.

Movement	Travel Time (sec)	Travel Distance (m)	Veh delay (sec)
1: SB to NB	16.15	178.67	3.82
2: SB to WB	49.83	408.02	11.14
3: EB to WB	49.7	355.77	11.41
4: EB to SB	49.24	381.22	9.12
5: NB to SB	13.19	159.76	2.22
6: WB to EB	56.95	374.65	17.32
7: WB to NB	62.23	410.77	14.68
8: NB to EB	55.1	382.32	19.13

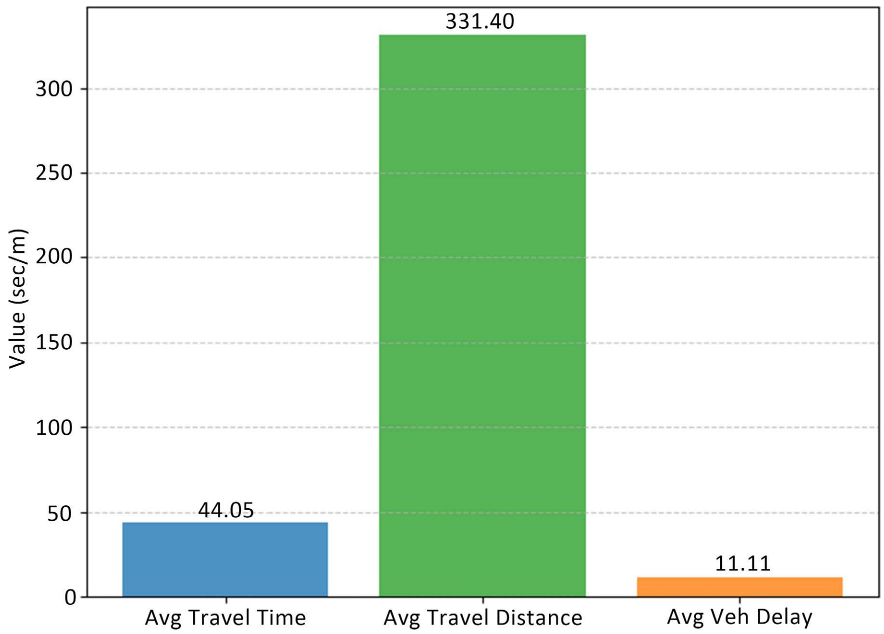

Figure 8. Summary of average traffic performance parameters.

Figure 8 illustrates the aggregate operational performance of the intersection by calculating the mean values for travel time, travel distance, and vehicle delay across all observed movements. By consolidating these metrics into a single representative index, the chart provides a baseline for the intersection's overall traffic efficiency. Notably, the average vehicle delay serves as a critical performance indicator, quantifying the quality of service and reflecting the impact of current traffic control configurations on the general flow of vehicles.

5. Discussion

The 120 m offset effectively manages the heavy 2,415 veh/hr demand, maintaining a system-wide LOS A with just 11.11 seconds of delay. Crucially, the Southbound maximum queue of 26.63 meters occupies less than a quarter of the available storage, proving that more expansive 1.37 km offsets are operationally redundant. This compact design optimizes land use without compromising throughput. By reducing the U-turn loop, the configuration significantly lowers vehicle travel time along the corridor.

6. Conclusions

The study validates that a 120-meter unsignalized MUT offset is sufficient for high-volume urban traffic in Riyadh. This compact geometry eliminates the need for imbalanced, land-intensive crossovers exceeding 1 kilometer while ensuring zero spillback risk. Implementing this design saves up to 2.4 kilometers per trip for U-turning vehicles, directly improving network efficiency and fuel economy. These findings offer municipal planners a cost-effective, space-saving framework for managing saturated corridors.

Acknowledgements

I would like to thank King Saud University for providing access and permission to collect empirical traffic data at the intersection inside the campus of the University.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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