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IMPROVEMENT OF AN UNSIGNALIZED INTERSECTION THROUGH SIGNAL OPTIMIZATION AND GEOMETRIC ENHANCEMENT: A CASE STUDY OF MILAN CHOWK, BUTWAL

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ABSTRACT

In fast-growing Nepali urban centres, unsignalized junctions frequently struggle to handle mixed traffic volumes. Many of these locations are controlled only informally by traffic police, which produces irregular operations, high delays, and lengthy queues. Milan Chowk, a four-arm junction on the Mahendra Highway (NH-01) in Butwal, Nepal, experiences repeated peak-hour congestion and therefore offers a useful setting for testing systematic improvements. The present work examines the current operation of Milan Chowk and evaluates remedial measures with SIDRA Intersection software. Classified volume counts were gathered across a continuous 72-hour window; morning and evening peak periods were then extracted from the 15-minute summaries for detailed modelling. Existing police-regulated conditions formed the baseline. Two upgrade options were tested: Alternative I (cycle-length optimisation only) and Alternative II (added approach lanes on the north and south arms together with optimised cycle lengths). Performance was judged by average control delay, level of service (LOS), and 95th-percentile queue length. Cycle-length optimisation by itself (Alternative I) failed to relieve congestion adequately, especially in the evening peak when the junction remained at LOS F. The combined scheme of Alternative II performed markedly better. Cycle times of 110 s (morning) and 130 s (evening), paired with the extra lanes, cut average delay by 21 % in the morning and 45 % in the evening relative to Alternative I and reduced the 95th-percentile queue by as much as 56 %. The findings indicate that, at a high-demand unsignalized junction such as Milan Chowk, geometric capacity expansion must accompany carefully optimised signal timing if an acceptable level of service is to be reached; signal timing alone is insufficient.

Key Words: Average delay, Back of queue, SIDRA, Intersection, Level of Service, Congestion

1. Introduction

1.1 Background

An intersection is the location at which two or more roads cross at grade, permitting vehicles and pedestrians to change routes. Because traffic on one approach must yield or stop for traffic on another, these points regularly become the principal sources of delay and congestion within urban networks. Consequently they are widely recognised as critical bottlenecks. The time and resource losses that arise from intersection delays are substantial (Azimi, et al., 2015). Congestion also raises fuel use, intensifies air and noise pollution, and reduces economic productivity, quality of life, and the orderly behaviour of road users (Kumarage, 2004).

In Nepal the problem has grown especially acute in rapidly expanding cities such as Kathmandu, Biratnagar, Birgunj and Butwal. Accelerated urbanisation, population increase, higher vehicle ownership and incomplete transport planning all contribute to the trend (Singh, et al., 2025). The great majority of unsignalized junctions continue to depend on traffic-police control during peak periods. Officers adjust their decisions according to instantaneous volumes, congestion levels and pedestrian activity. Although such manual intervention can temporarily shorten extreme delays, it remains susceptible to human error, fatigue, misjudgement and unforeseen events, producing inconsistent operations. The method is also difficult to expand because simultaneous oversight of several busy junctions becomes increasingly impractical at peak times (Acharya, et al., 2025).

Butwal, situated in Rupandehi District of Lumbini Province, ranks among Nepal's most rapidly expanding urban centres and functions as a principal economic, educational and transport hub for the western region. Substantial traffic volumes pass through the city because it links the surrounding hill districts with the Indian border at Sunauli. Milan Chowk is one of Butwal's busiest junctions and lies inside a lively commercial zone that contains retail shops, restaurants, educational consultancies and other service premises.

SIDRA Intersection is a specialised traffic-analysis package that employs a lane-based micro-analytical modelling framework to evaluate intersections, roundabouts, interchanges and networks. It models individual lane movements, yielding precise estimates of operational performance and congestion while also supporting the design of signal timings and coordinated control schemes. Built on decades of research, SIDRA Intersection is internationally recognised and routinely applied by traffic engineers and planners for evidence-based analysis and network optimisation (Akcelik, 2025).

The central aim of the present study is to improve traffic movement at Milan Chowk. Under present conditions the junction is controlled manually by traffic police during peak hours, an arrangement that can generate elevated delays and irregular flow. The work therefore develops and tests a signalised scheme intended to minimise delay and raise overall junction performance.

1.2 Literature Review

Unsignalized junctions constitute a widespread difficulty in cities worldwide, and Nepal is no exception. Numerous investigations have examined the analysis and optimisation of urban intersections. Earlier work has demonstrated the value of packages such as SIDRA and VISSIM for designing, analysing and evaluating intersections, roundabouts and road networks. Those studies illustrated how parameters including queue length, level of service (LOS), degree of saturation and delay can be improved through signal optimisation, thereby reducing congestion and enhancing flow. The literature reviewed below was consulted to identify effective optimisation approaches.

In Nicosia, Turkey, the performance of four signalised intersections and two roundabouts during peak hours was assessed with SIDRA Intersection 5. Evaluation criteria comprised level of service, delay, delayed travel speed, performance index, operating cost, fuel consumption and carbon-dioxide emissions. Results indicated poor levels of service, low speeds and extremely high delays (up to 9 318.9 s). Fuel use reached nearly 1 431.6 L/h and CO_2 emissions 3 594.7 kg/h. The severe peak-hour congestion was attributed primarily to the limited capacity of the two-lane roads. The authors recommended staggered and varied working hours to redistribute demand temporally (Ali, et al., 2018).

Delay at five signalised intersections in Erbil City, Iraq, was examined with Highway Capacity Software (HCS+T7F) and SIDRA Intersection 8. After optimisation the average delay declined; the SIDRA delay model produced a 21 % reduction relative to the un-optimised condition (Omar & Hussein, 2022).

At the Gaa-Akanbi junction in Ilorin, Nigeria, a three-phase signal with a 150 s cycle was designed in SIDRA Intersection 8.1. Amber time was set at 6 s for every phase and green times were 48 s, 46 s and 38 s. The proposed timing improved mobility, reduced delay, and lowered fuel consumption and emissions (Oguntayo, et al., 2023).

Performance of the unsignalized Buspark Intersection in Birgunj Metropolitan City was evaluated and signal timing optimised. Two alternatives were tested on a junction operating at LOS E: variation of cycle length and restriction of continuous left-turning movements. Both options raised the level of service from E to D and cut average delay by 34.7 % and 38.8 %, respectively; back-of-queue lengths fell by 34.7 % and 40 % (Luitel, et al., 2023).

At Kanchanbari, Biratnagar, field data were calibrated and validated in SIDRA Intersection. Two improvement options—cycle-length optimisation and left-turn control—were examined. Both reduced delay and queue length, the second proving more effective (Acharya, et al., 2024).

At Traffic Chowk, Butwal, signal timing was optimised to raise operational efficiency and shorten waiting times. Existing conditions yielded LOS C overall, yet the Purano Buspark approach deteriorated to LOS F during peaks, underscoring the need for refined management. The authors concluded that optimised signal schedules combined with tactical directional control are required to lower average vehicle delay (Sapkota, et al., 2025).

Signal optimisation at Pushpalal Chowk, Butwal, produced average delays of 24.8 s (LOS C) in the morning and 22.6 s (LOS C) at night. The study also recommended adaptive signalling and stricter enforcement to address remaining bottlenecks (Singh, et al., 2025).

Although most earlier applications of SIDRA focused on isolated junctions, the software has also been shown capable of analysing closely spaced or coordinated pairs. Coordination between two Nepalese junctions substantially reduced maximum queue length and average delay (Tiwari, et al., 2023). Comparable gains in level of service and back-of-queue length were recorded when the Pulchowk and Shahid Chowk junctions in Bharatpur were evaluated under coordinated control (Acharya, et al., 2025). These results confirm that SIDRA can represent traffic interactions between neighbouring junctions and is not restricted to isolated sites.

VISSIM has likewise been employed to assess capacity on urban multi-lane highways. On the four-lane divided section between Yari Chowk and Mangalgadhi Chowk in Birendranagar Municipality, default VISSIM parameters overestimated speed and capacity. The discrepancy between simulated and observed capacity fell from 10.40 % to 0.56 % after calibration of standstill distance (CC0) and headway time (CC1) (Luitel, et al., 2024).

A comparison of VISSIM and SIDRA at the West Wenhua Road–Chanchun Road junction in Xianyang City found SIDRA simpler to operate, while VISSIM produced lower mean error (10.18 % versus 14.78 %). The authors concluded that VISSIM is preferable when precise average-delay estimates are required, whereas SIDRA is advantageous when delay values serve mainly as reference data (Tianzi, et al., 2013).

2. Methodology

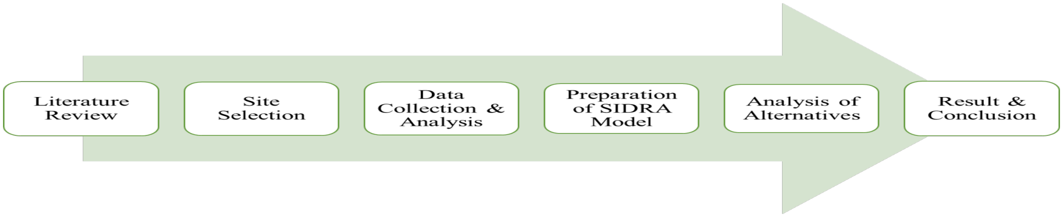

Figure 1 Methodological Framework

The methodological framework of the study is illustrated in Figure 1.

2.1 Study Area

Milan Chowk is a four-legged junction located inside Butwal sub-metropolitan city, Rupandehi district. Traffic approaches from Rajmarga Chauraha (south), Buspark (north), Sukhanagar (east) and Tinkune (south-west). The south and north arms were treated as the major approaches because of the heavy volumes carried by the Mahendra Highway (NH-01). Lane widths measured 3.5 m on the major arms and 3 m on the minor arms. Approach distances were 540 m (Chauraha), 810 m (Buspark), 340 m (Sukhanagar) and 260 m (Tinkune). The layout and satellite view of the junction appear in Figures 2 and 3.

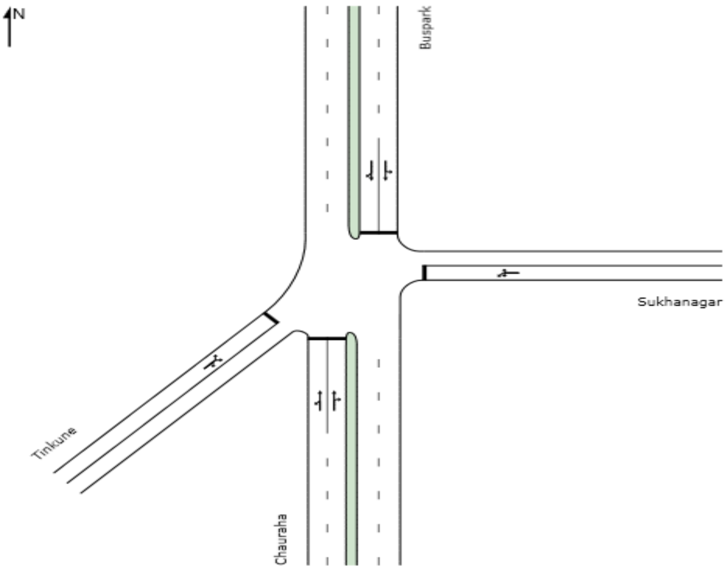

Figure 2: Pictorial Representation of the study area.

Figure 3 Satellite Image of the study area

2.2 Data Collection and Analysis

Video cameras were installed at the junction and recorded traffic continuously for three days in 15-minute intervals. The recordings were subsequently reviewed and vehicles classified by direction to obtain directional flows. The three-day classified counts were averaged and converted to passenger-car units by means of the equivalency factors listed in Table 1, yielding peak-hour volumes and the corresponding peak periods. Geometric data (lane widths and approach lengths) were measured on site.

Table 1 PCU Equivalency factor (Department of Roads, 2016)

S. No.	Vehicle Type	PCU Equivalency Factor
1	Multi-axle Truck	4
2	Heavy Truck	3
3	Light Truck	1.5
4	Big Bus	3
5	Mini Bus	2.5
6	Microbus	1.5
7	Car	1
8	Motorcycle	0.5
9	Utility Vehicles	1
10	4 Wheel Drive	1
11	Tractor	1.5
12	3 Wheeler	1
13	Power Tiller	1.5

Preparation of SIDRA Model

Earlier validation studies have confirmed that SIDRA Intersection can reproduce key performance measures—back-of-queue length, saturation flow rate, passenger-car equivalency factors, phase sequence and signal timings. Back-of-queue length, representing the maximum queue that forms during peak demand, is especially informative because it captures demand fluctuations more sensitively than average delay. By incorporating measured volumes, vehicle mix and observed timings, the software simulates lane-by-lane operations and thereby evaluates both existing and alternative configurations.

The model allows engineers to quantify operational efficiency and to test, in a virtual environment, revised timings, phase orders or lane arrangements before any physical works are undertaken. This capability supports evidence-based decisions aimed at improving flow, reducing congestion and delay, and enhancing safety.

Calibration & Validation of model

An analytical model of the junction was constructed in SIDRA Intersection from the measured geometry and traffic data. Although the site is formally unsignalized, police officers regulated traffic during peaks; the observed phase sequence and control intervals were therefore supplied as model inputs. Calibration employed back-of-queue length, saturation flow, passenger-car factors, phase sequence and phase durations. Validation consisted of comparing the simulated 95th-percentile back-of-queue with field observations.

The discrepancy between observed and modelled queue lengths remained inside 20 %, confirming that the model is sufficiently accurate for subsequent analysis and optimisation.

Table 2 Calibrating Parameters

Parameters	Value	Remarks
Base Saturation Flow	2250	On-site Measurement
Lane utilization Ratio		Program calculated
Saturation Speed		Program calculated
Capacity Adjustment	0%	
Buses stopping	0 veh/hr	No bus bays within 75m
Parking Maneuvers	0 veh/hr	No parking Lane

Table 3 Validation Result of SIDRA Model

Time	Model	Observed	Difference
Morning	856	753	11.36%
Evening	933	796	11.72%

3. Analysis of Alternatives

Two alternatives were examined in order to evaluate possible performance gains.

Alternative I: Optimization of cycle time

(1) Performance at morning peak hour

After cycle-length optimisation the junction processed a total demand of 4 476 veh/h, experienced an average delay of 41.2 s and operated at LOS D—indicating still-inadequate performance. The optimised cycle length was 120 s. Detailed results appear in Table 4; phase timings and the phase diagram are given in Table 5 and Figure 4.

Table 4: Performance of Intersection at morning peak hour after Alternative I.

Approach	Demand (Veh/hr)	Capacity (Veh/hr)	Average Delay (Sec)	Level of Service	95% Back of Queue (m)
South: Chauraha					
Lane 1	1525	2561	0.7	LOS A	0
Lane 2	125	121	143	LOS F	53.9
Approach	1650		11.5	LOS B	53.9
East: Sukhanagar					
Lane 1	504	673	53.7	LOS D	140
Approach	504		53.7	LOS D	140
North: Buspark					
Lane 1	1533	2568	0.8	LOS A	0
Lane 2	130	122	160.9	LOS F	62.3
Approach	1663		13.3	LOS B	62.3
SouthWest: Tinkune					
Lane 1	659	599	176.3	LOS F	342.9
Approach	659		176.3	LOS F	342.9
Intersection	4476		41.2	LOS D	342.9

Table 5 Phase timing at the morning peak hour after Alternative I.

Phase	A	B	C
Phase Change Time (Sec)	0	13	84
Green Time (sec)	8	66	31
Phase Time (sec)	13	71	36
Phase Split	11%	59%	30%

(2) Performance at evening peak hour

In the evening peak the junction performed poorly, recording an average delay of 119.4 s and LOS F while handling 4 912 veh/h. The cycle length remained 120 s. Results are summarised in Table 6; phase timings and the phase diagram appear in Table 7 and Figure 4.

Table 6 Performance of Intersection at evening peak hour after Alternative I.

Approach	Demand (Veh/hr)	Capacity (Veh/hr)	Average Delay (Sec)	Level of Service	95% Back of Queue (m)
South: Chauraha					
Lane 1	1401	2314	0.7	LOS A	0
Lane 2	175	134	337	LOS F	153
Approach	1576		38	LOS D	153
East: Sukhanagar					
Lane 1	667	578	207.2	LOS F	416.2

Approach	Demand (Veh/hr)	Capacity (Veh/hr)	Average Delay (Sec)	Level of Service	95% Back of Queue (m)
Approach	667		207.2	LOS F	416.2
North: Buspark					
Lane 1	1592	2295	1.1	LOS A	0
Lane 2	143	137	132.3	LOS F	66.6
Approach	1735		11.9	LOS B	66.6
SouthWest: Tinkune					
Lane 1	934	679	393.7	LOS F	742.1
Approach	934		393.7	LOS F	742.1
Intersection	4912		119.4	LOS F	742.1

Table 7 Phase timing at evening peak hour after Alternative I.

Phase	A	B	C
Phase Change Time (Sec)	0	15	77
Green Time (sec)	10	57	38
Phase Time (sec)	15	62	43
Phase Split	13%	52%	36%

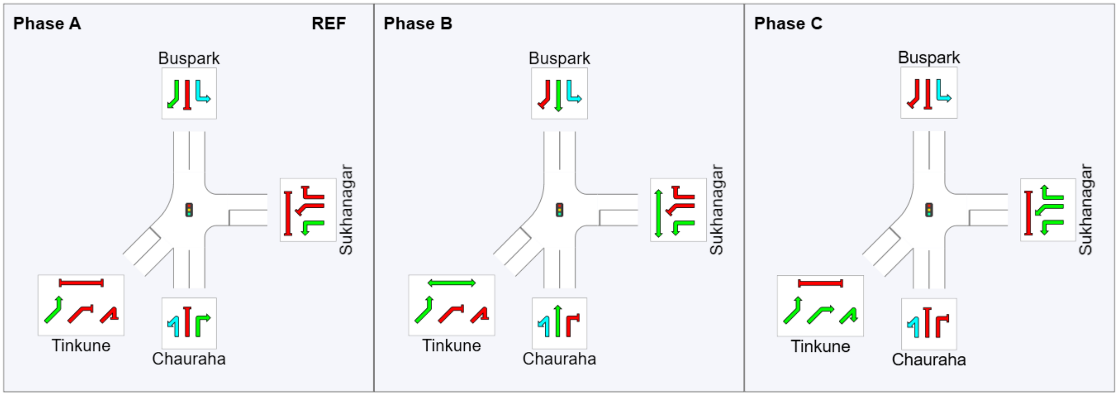

Figure 4 Phase sequence at morning and evening peak hours after Alternative I.

3.2 Alternative II: Geometric Improvement with optimized cycle time

Addition of lanes on the north (Buspark) and south (Chauraha) approaches (Figure 5), together with cycle-length re-optimisation, produced a clear improvement in performance.

(1) Performance at morning peak hour

During the morning peak the level of service rose from LOS F to LOS C and average delay fell to 32.4 s. The cycle length that minimised delay was 110 s. Detailed results are presented in Table 8; phase timings and the phase diagram are given in Table 9 and Figure 6.

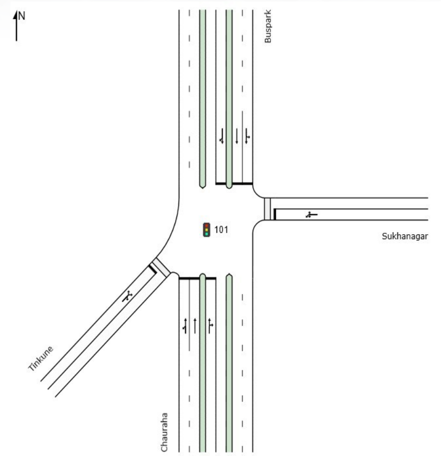

Figure 5 Intersection layout after geometric improvement.

Table 8: Performance of Intersection at Morning peak hour after Alternative II.

Approach	Demand (Veh/hr)	Capacity (Veh/hr)	Average Delay (Sec)	Level of Service	95% Back of Queue (m)
South: Chauraha					
Lane 1	746	1132	26	LOS C	119.4
Lane 2	779	1182	25.4	LOS C	125.2
Lane 3	125	189	59.4	LOS E	27.9
Approach	1650		28.2	LOS C	125.2
East: Sukhanagar					
Lane 1	504	696	39.5	LOS D	101.5
Approach	504		39.5	LOS D	101.5
North: Buspark					
Lane 1	746	1129	26.1	LOS C	118.7
Lane 2	788	1193	25.4	LOS C	123.8
Lane 3	130	190	58.6	LOS E	30.1
Approach	1663		28.3	LOS C	123.8
SouthWest: Tinkune					
Lane 1	659	752	48.1	LOS D	149.6
Approach	659		48.1	LOS D	149.6
Intersection	4476		32.4	LOS C	149.6

Table 9 Phase timing at the morning peak hour after Alternative II.

Phase	A	B	C
Phase Change Time (Sec)	0	17	71

Green Time (sec)	12	39	34
Phase Time (sec)	17	54	39
Phase Split	15%	49%	35%

(2) Performance at evening peak hour

After geometric widening and cycle-length re-optimisation the junction improved from LOS F to LOS E, with average delay reduced to 65 s. The cycle length that minimised delay was 130 s. Detailed results appear in Table 10; phase timings and the phase diagram are shown in Table 11 and Figure 6.

Table 10: Performance of Intersection at evening peak hour after Alternative II.

Approach	Demand (Veh/hr)	Capacity (Veh/hr)	Average Delay	Level of Service	95% Back of Queue (m)
South: Chauraha					
Lane 1	677	808	44.6	LOS D	170.5
Lane 2	724	864	43.3	LOS D	178.3
Lane 3	175	172	124.8	LOS F	89
Approach	1576		52.9	LOS D	178.3
East: Sukhanagar					
Lane 1	667	780	46	LOS D	200.3
Approach	667		46	LOS D	200.3
North: Buspark					
Lane 1	736	775	68.4	LOS E	250.5
Lane 2	850	896	63.8	LOS E	257.6
Lane 3	149	157	93.6	LOS F	59.1
Approach	1735		68.3	LOS E	257.6
SouthWest: Tinkune					
Lane 1	934	926	93.1	LOS F	373.8
Approach	934		93.1	LOS F	373.8
Intersection	4912		65	LOS E	373.8

Table 11 Phase timing at evening peak hour after Alternative II

Phase	A	B	C
Phase Change Time (Sec)	0	21	71
Green Time (sec)	15	46	54
Phase Time (sec)	20	51	49
Phase Split	15%	39%	45%

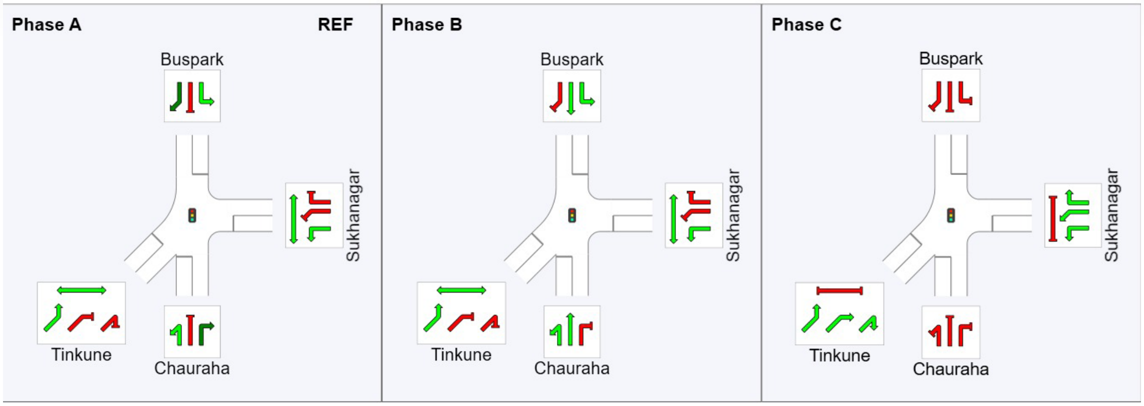

Figure 6 Phase sequence at morning and evening peak hours after Alternative II.

4. Result & Discussion

Table 12 Result obtained after analysis of alternatives

Alternative: A.M./P.M.	LOS	Average Delay (Sec)	95% Back of queue (m)	Cycle Time (Sec)
AI: Morning	D	41.2	342.9	120
AII: Morning	C	32.4	149.6	110
AI: Evening	F	119.4	742.1	120
AII: Evening	E	65	373.8	130

Comparison of the two alternatives (Table 12) clearly demonstrates the combined influence of cycle-length optimisation and geometric enlargement on junction efficiency. Under Alternative I (cycle optimisation only) a 120 s cycle was applied in both peaks. Acceptable performance was obtained in the morning (LOS D, 41.2 s average delay), yet the evening peak remained severely congested (LOS F, 119.4 s average delay and excessive queues). The result shows that cycle-length adjustment alone cannot accommodate high demand when geometric capacity is constrained.

Alternative II added approach lanes on the north and south arms and re-optimised the cycle lengths. The morning cycle shortened to 110 s, producing an average delay of 32.4 s and LOS C. In the evening a longer 130 s cycle was required; average delay fell to 65 s and LOS improved from F to E. Substantial reductions in 95th-percentile queue length occurred in both peaks, reflecting greater storage capacity and smoother progression. Overall, the results confirm that cycle-length optimisation yields its greatest benefit when supported by adequate geometric capacity, particularly at junctions characterised by pronounced directional demand imbalance.

5. Conclusion

Operational performance of the unsignalized Milan Chowk junction in Butwal, Nepal, was assessed with SIDRA Intersection and two improvement schemes were evaluated. The findings show that cycle-length optimisation by itself is insufficient to produce substantial gains under high demand, especially in the evening peak. Although Alternative I achieved a modest delay reduction in the morning, it could not relieve the severe evening congestion caused by limited approach capacity.

The combined strategy of Alternative II—geometric widening together with optimised cycle times—proved markedly more effective. Cycle lengths of 110 s (morning) and 130 s (evening) delivered clear reductions in average delay, queue length and overall congestion while raising the level of service on all approaches. The study emphasises that cycle-time selection must reflect peak-period demand variation and that longer cycles may be necessary during high-demand intervals to keep queuing within acceptable limits.

For rapidly urbanising cities such as Butwal, the upgrading of unsignalized junctions through capacity expansion and scientifically derived signal timing can yield significant operational, environmental and economic benefits. The methods and results presented here offer a practical reference for traffic engineers and planners confronting comparable junction-performance problems in Nepal and other developing urban contexts.

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