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Intersection Efficiency Improvement through Signal Optimization: A Case Study of Pushpalal Chowk (Mahendra Chowk), Butwal

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Abstract

Traffic congestion has emerged as a major challenge in Butwal, Nepal, driven by rapid urbanization, population expansion, and a growing number of vehicles. Puspalal Chowk, a critical junction linking important routes such as Siddhartha Highway and the Butwal-Bhairahwa road, faces heavy traffic volumes, resulting in frequent congestion. This study aims to optimize the traffic signal system at Puspalal Chowk using SIDRA Intersection 8.0 software. Data was gathered over a 72-hour period, and the intersection's geometric features were manually documented. A model was created in SIDRA 8.0 to evaluate traffic conditions during peak hours (morning, afternoon, evening and night) following signal optimization. The findings reveal notable improvements, with reductions in average delays and queue lengths, especially during peak traffic times. The optimized signal timing plans enhanced the Level of Service (LOS) at the intersection, underscoring the effectiveness of signal optimization in improving traffic flow and alleviating congestion.

Keywords: Congestion, Intersection, Signalized Intersection Design and Research Aid (SIDRA), Signal Optimization

1. Introduction

Traffic congestion has become a growing concern in Nepal, particularly in urban areas, as the country experiences rapid urbanization, population growth, and an increasing number of vehicles. The combination of inadequate infrastructure, poor traffic management systems, and a lack of effective transportation planning has led to severe traffic bottlenecks, especially in major cities like Kathmandu, Pokhara, and Butwal.

Butwal a bustling city located in Rupandehi District serves as a major economic, educational and transportation hub in the western region. The city encounters heavy traffic volume since it serves as a transitional hub for mountainous region of the country to the Terai region. Pushpalal chowk is one of the busiest junction, it perceives an extensive amount of traffic from private automobiles, lorries, buses, and motorbikes. The crossroad frequently encounters tumultuous traffic owing to inadequate signaling systems and insufficient enforcement of traffic regulations. Common instances of such subpar designs are traffic congestion, accidents, and bottlenecks, especially at crossings. Intersections pose significant risks of collisions due to conflicting movements of vehicles approaching from different directions. Intersections play an important role in managing conflicts and merging traffic streams (Sandesh Acharya, 2024).In intersections like these with heavy traffic volume non optimized signal timing fail to prioritize high volume movements creating bottlenecks and congestion (Rahman, 2005).

The success of signalization at intersections hinges on several critical factors, including proper signal timing, accurate traffic data, intersection design, conflict management, and user compliance. Inadequate signal timing may lead to increased crash rates. For instance, deficient clearance intervals—periods that cover both the yellow and all-red phases of a traffic signal—can result in abrupt stops by drivers, potentially causing rear-end collisions (PAUL ZADOR, 2018). Additionally, Level of service (LOS) is used to evaluate the overall effectiveness of signal timing, categorizing traffic conditions from free flow to heavy congestion. A successful signal timing plan aims to achieve a higher LOS, indicating smoother traffic operations.

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This study aims to assess the performance of the Butwal city intersection, focusing on signal optimization, while identifying potential areas for further research to address traffic-related challenges. In Butwal, like any other cities of Nepal traffic management prominently depends on Traffic Police, Traffic police is solely responsible for navigating and controlling the traffic movement. The implementation of traffic signals can provide more efficient regulation of conflicts from all directions, ensuring both road user safety and a smoother flow of traffic. Traffic signal control is an important tool in traffic flow management as it is considered as one of the most effective ways to reduce traffic congestion at intersections (Myungeun Eom, 2020) .

2. Literature Review

Intersection efficiency is critical to urban traffic management because badly planned intersections generate bottlenecks that increase emissions, delays, and congestion (Niraj Bohara, 2024). Rising car ownership and fast urbanization have increased traffic in Nepal, yet many crossings are still un-signalized, creating a chaotic flow of traffic and increasing the danger of accidents. According to studies, because of underestimated gaps and failure-to-yield accidents, un-signalized junctions are associated with greater collision rates, especially side-impact and right-angle wrecks (Elvik, 2009). The necessity of installing traffic control devices is highlighted by Tiwari (Tiwari, 2015), this study also affirms that an increase in traffic flow directly raises accident rates at uncontrolled intersections.

Unsignalized junctions in areas like Butwal, Nepal spots Drivers and pedestrians frequently rely on unofficial rules and gestures to navigate when there are inadequate traffic signals and signs, which raises the danger of accidents (Pradhan, 2018). (Timalsena, 2017) measures these inefficiencies, pointing out that protracted delays result in large losses in human capital hours. Without marked crosswalks, synchronized signals, or unambiguous phasing, pedestrian safety has been seriously jeopardized, according to public perception surveys underscoring the societal consequences of subpar infrastructure.

One important tactic to reduce intersection inefficiencies is signal optimization. While a study conducted in Indian cities discovered that customized signal layouts in Indian cities reduced delays by 20–30% and fuel usage by 10–15% (Chaudhary, 2014) similarly, an early research showed that optimal timing lowers delays and queue lengths (Park, 2007). Recent case studies in Nepal confirm these advantages, while (Dhakal, 2023) employed SIDRA software to suggest infrastructure and timing modifications for Satdobato intersection, highlighting its potential for diverse traffic circumstances, (Hemant Tiwari, 2023) demonstrated that signal coordination increased the Level of Service (LOS) at two Nepalese intersections.

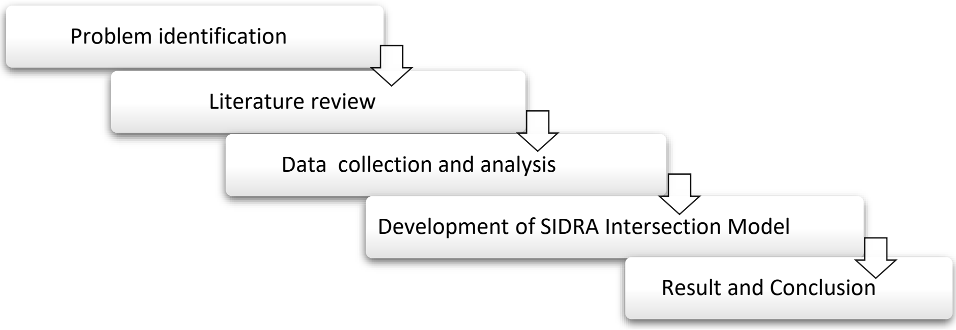
Microsimulation techniques like SIDRA provide useful solutions for locations with limited data, such as Nepal. In a case study of Kathmandu adjusting cycle lengths and phasing, SIDRA was used to improve LOS from "D" to "C" and this cut down on delays by 20% at a major crossroad in Nepal. The program is especially useful for developing nations because of its ability to predict mixed traffic, including pedestrians and motorcyclists (Shakya, 2020). These results provide practical insights for Nepalese cities while adapting approaches to local restrictions and aligning with global evidence.

3. Study Area

Figure 1. Study Area

The Pushpalal chowk intersection intersection is a four-legged intersection located in Butwal with Traffic Chowk on North, Buspark on South, Amarpath on North-West and Nepalgunj on West. The lane configuration on the north-south approach consists of three lanes in each direction, with lane widths of 4 meters. North-West approach consists of the lane width of 5m on each direction while the west approach consists of two lanes of 4m lane width on each direction. These lanes accommodate a mix of vehicle types, including public buses, private vehicles, motorcycles, and non- motorized traffic.. However, the intersection faces challenges such as high traffic volumes, congestion, and safety concerns, necessitating improvements in infrastructure and traffic management to enhance efficiency and safety ((DoR)., 2019).

4. Methodology



The process started with the installation of cameras at intersection approaches to capture directional movements for all entry points. High-resolution cameras were strategically positioned at all four intersection approaches to record vehicle movements continuously. Four trained analysts manually reviewed the video recordings to classify and count directional traffic volumes Directional traffic volume data, categorized by type, was gathered over a 72-hour period in 15-minute intervals. The data, averaged over three days and adjusted using vehicle type equivalency factors (as shown in Table 1), were used to determine peak hour volumes and directional traffic patterns. Furthermore, fieldwork collected information on lane and approach geometry, as well as queue lengths during peak hours, to validate the model.

Table 1. PCU equivalency factor.

S.N	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	Micro Bus	1.5
7	Car	1
8	Motorcycle	0.5
9	Utility vehiclrs	1
10	4 wheel dirve	1
11	Tractor	1.5
12	Wheeler	1
13	Power Trailer	1.5

5. Traffic Flow Analysis

Based on the analysis of the three-day traffic volume data, the intersection's peak hours were identified across four specific time periods: morning (7:00-8:00), afternoon (15:00-16:00), evening (16:30-17:30) and night (8:00-9:00). The traffic data reveals that the Bus Park to Nepalgunj direction consistently carries the highest traffic volumes across all peak hours, with morning traffic at 1,056 vehicles, peaking in the afternoon at 1,476 vehicles, and maintaining high volumes in the evening (900 vehicles) and night (1,163 vehicles). The Traffic Chowk to Bus Park leg also sees significant traffic, reaching 1,051 vehicles at night, though it remains steady at 935 vehicles in the afternoon and evening. However, traffic from Traffic Chowk to Amarpath is minimal, with only 25-88 vehicles recorded across different times of day, indicating it as a less traveled route.

The Pushpalal Chowk intersection handles a total Average Daily Traffic (ADT) of 93,244 vehicles and 88,468 PCUs, with traffic distributed unevenly across its four legs. The Bus Park leg manages the highest traffic, with an ADT of 38,454 vehicles and 36,702 PCUs, underscoring its role as a primary transit hub. Nepalgunj leg follows closely, handling 23,803 vehicles and 24,580 PCUs, indicating substantial traffic flow. Amarpath experiences moderate traffic, with an ADT of 7,015 vehicles and 4,203 PCUs. Traffic Chowk itself handles 23,972 vehicles and 22,983 PCUs, contributing significantly to the intersection's traffic load.

6. Development of the SIDRA Intersection Model

The validation of the SIDRA intersection model at the Pushpalal Chowk intersection in Biratnagar involved assessing critical parameters such as back-of-queue length, base saturation flow rate, equivalency factor, phase sequence, and phase timing. The back-of-queue length refers to the maximum length of vehicles waiting at the signalized intersection during peak traffic times (Elżbieta Macioszek, 2021). After input of data into SIDRA, such as traffic volumes, geometric design details, signal timing, saturation flow rates, and peak hour factors, it processes this information using mathematical models and algorithms. The software performs capacity analysis to determine lane capacities, estimates delays for vehicles and pedestrians, predicts queue lengths, and evaluates the likelihood of queue spillover. Based on these calculations, SIDRA assigns a Level of Service (LOS) grade (A to F) and provides key performance indicators like delay, queue length, and throughput.

6.1. Signal Optimization and Phasing

This intersection lacks any type of traffic control measures and completely depends on driver-to-driver conversations for smooth flow of traffic. Phasing refers to the division of a traffic signal cycle into specific intervals. In this study, phasing was successfully implemented for morning, afternoon, evening, and night to address the unique traffic patterns and demands during each period.

6.2. Performance at peak hour at morning after optimization

After optimization during morning peak hours, the Pushpalal Chowk intersection handles a total demand flow of 6,472 vehicles per hour (vh/hr) with an average delay of 24.8 secs and operates at LOS C, indicating acceptable overall performance. The South approach Buspark performs well with an overall LOS B, though Lane 2 experiences LOS D and Lane 3 has a significant queue distance of 445.2 meters. The North approach Traffic Chowk shows mixed performance: Lane 1 operates excellently LOS A, but Lanes 2 and 3 face severe delays, with Lane 2 at LOS F and Lane 3 at LOS E. The Northwest approach Amarpath operates efficiently at LOS B with moderate delays and queue distances. However, the West approach Nepalgunj struggles, operating at LOS D with high delays and a maximum queue distance of 721.9 meters in Lane 2.

Table 2. Performance of intersection at morning peak hour after optimization

Morning	Demand Flows Total (vh/hr)	Average Delay (secs)	Level of Service (LOS)	95% Back of Queue Distance (m)
South : Buspark				
Lane 1	1388	5.7	LOS A	56.9
Lane 2	258	45.4	LOS D	124.4
Lane 3	1137	19.3	LOS B	445.2
Approach	2783	15	LOS B	445.2
North :Traffic Chowk				
Lane 1	916	0.3	LOS A	23.4
Lane 2	89	93.1	LOS F	67.1

Lane 3	312	77.7	LOS E	210.4
Approach	1317	24.9	LOS C	210.4
Northwest : Amarpath				
Lane 1	411	18.9	LOS B	121.4
Approach	411	18.9	LOS B	121.4
West : Nepalgunj				
Lane 1	695	31	LOS C	333.6
Lane 2	1266	44.9	LOS D	721.9
Approach	1961	40	LOS D	721.9
Intersection	6472	24.8	LOS C	721.9

Table 3. Phase timing at morning peak hour after optimization

Phase	A	B	C	D
Phase Change Time (sec)	0	18	42	60
Green Time (sec)	15	21	15	37
Phase Time (sec)	18	24	18	40
Phase Split	18%	24%	18%	40%

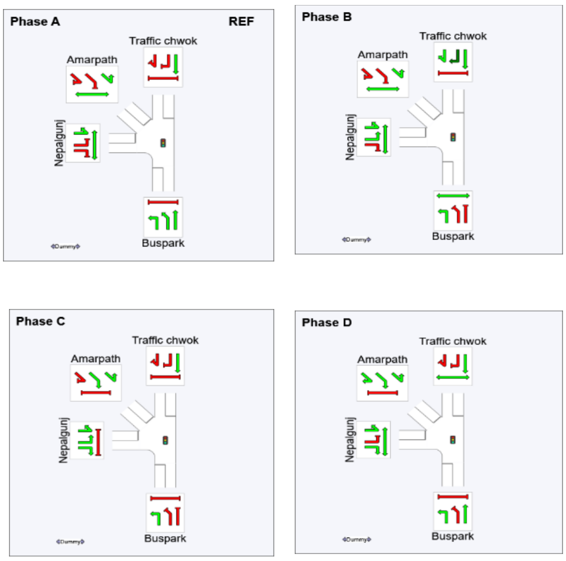


Figure 2. Phase sequence for Pushpalal Chowk intersection for morning peak hour

6.3. Performance at peak hour at afternoon after optimization

During afternoon peak hours, the intersection experiences significant delays, averaging 35.6 seconds with an overall LOS D. While the South approach maintains moderate delays 18.1 seconds, LOS B, the North approach suffers from severe congestion in Lanes 2 and 3 155.1 and 155.6 seconds, LOS F, and the West approach faces high delays in Lane 2 i.e 70.1 seconds, LOS E. Despite some lanes performing well, the intersection requires targeted improvements, particularly in the North and West approaches, to reduce delays and enhance traffic flow.

Table 4. Performance of intersection at afternoon peak hour after optimization

Afternoon	Demand Flows Total (Vh/hr)	Average Delay (secs)	Level of Service (LOS)	95% Back of Queue Distance (m)
South : Buspark				

Lane 1	1001	5.6	LOS A	21.8
Lane 2	229	33.9	LOS C	78.3
Lane 3	927	27.6	LOS C	277.1
Approach	2158	18.1	LOS B	277.1
North :Traffic Chowk				
Lane 1	1014	0.4	LOS A	21.9
Lane 2	170	155.1	LOS F	138.3
Lane 3	176	155.6	LOS F	148.1
Approach	1360	39.8	LOS D	148.1
Northwest : Amarpath				
Lane 1	327	31.5	LOS C	98.8
Approach	327	31.5	LOS C	98.8
West : Nepalgunj				
Lane 1	408	12.4	LOS B	54
Lane 2	1245	70.1	LOS E	746.5
Approach	1654	55.8	LOS E	746.5
Intersection	5499	35.6	LOS D	746.5

Table 5. Phase timing at afternoon peak hour after optimization

Phase	A	B	C	D
Phase Change Time (sec)	0	18	37	55
Green Time (sec)	15	16	15	22
Phase Time (sec)	18	19	18	25
Phase Split	23%	24%	23%	31%

6.4. Performance at peak hour at evening after optimization

After optimizing traffic flow during peak hours, the evening and nighttime conditions show a mix of improvements and ongoing challenges. In the evening, Buspark struggles with heavy congestion: Lane 1 moves relatively well with an 11.9-second delay and a Level of Service (LOS) B, but Lanes 2 and 3 are severely backed up, with delays hitting 101 seconds and an LOS F, bringing the overall delay to 59 seconds and an LOS E. Meanwhile, North: Traffic Chowk fares better, with Lane 1 nearly delay-free at 0.4 seconds and an LOS A, though Lanes 2 and 3 see moderate delays of around 32 seconds and an LOS C, keeping the overall delay low at 10 seconds with an LOS A. Over in the Northwest: Amarpath, traffic is manageable, with Lane 1 facing a 30.1-second delay and an LOS C. However, Nepalgunj in west is hit hard, with Lane 1 at 46.6 seconds and an LOS D and Lane 2 at a staggering 155.3 seconds and an LOS F, pushing the overall delay to 129.1 seconds and an LOS F.

Table 6. Performance of intersection at evening peak hour after optimization

Evening	Demand Flows Total (vh/hr)	Average Delay (secs	Level of Service (LOS)	95% Back of Queue Distance (m)
South : Buspark				
Lane 1	1217	11.9	LOS B	229.4
Lane 2	740	101	LOS F	466.7
Lane 3	624	101	LOS F	392.8
Approach	2581	59	LOS E	466.7
North :Traffic Chowk				
Lane 1	1126	0.4	LOS A	24.6
Lane 2	250	32.9	LOS C	64.7

Lane 3	224	32.6	LOS C	67.1
Approach	1600	10	LOS A	67.1
		Northwest : Amarpath		
Lane 1	559	30.1	LOS C	154.4
Approach	559	30.1	LOS C	154.4
		West : Nepalgunj		
Lane 1	437	46.6	LOS D	170.1
Lane 2	1376	155.3	LOS F	1040.4
Approach	1813	129.1	LOS F	1040.4
Intersection	6553	63.9	LOS E	1040.4

Table 7. Phase timing at evening peak hour after optimization

Phase	**A**	**B**	**C**	**D**
Phase Change Time (sec)	0	18	36	54
Green Time (sec)	15	15	15	15
Phase Time (sec)	18	18	18	18
Phase Split	25%	25%	25%	25%

6.5. Performance at peak hour at night after optimization

By nighttime, things ease up a bit. At Buspark, the traffic in Lane 1 flows smoothly with a delay of 5.7-second and LOS A, while Lanes 2 and 3 observe moderate delays of around 37 seconds and LOS D, resulting in an overall delay of 21.2 seconds and LOS C. Traffic Chowk's Lane 1 remains efficient with a 4.4 second delay and an LOS A, but Lanes 2 and 3 slow down significantly, with delays of 61.1 and 59.2 seconds and an LOS E, bringing the overall delay to 21.2 seconds and an LOS C. In Amarpath, Lane 1 has a 33.2-second delay and an LOS C, while Nepalgunj shows moderate congestion, with Lane 1 at 13.8 seconds and an LOS B, Lane 2 at 28.3 seconds and LOS C, and an overall delay of 22.5 seconds and an LOS C. The traffic at night time is generally smoother.

Table 8. Performance of intersection at night peak hour after optimization

Night	Demand Flows Total (vh/hr)	Average Delay (sec)	Level of Service (LOS)	95% Back of Queue Distance (m)
		South : Buspark		
Lane 1	1029	5.7	LOS A	30.8
Lane 2	539	37.4	LOS D	237.4
Lane 3	451	37.1	LOS D	183.1
Approach	2019	21.2	LOS C	237.4
		North :Traffic Chowk		
Lane 1	647	4.4	LOS A	104.5
Lane 2	115	61.1	LOS E	67.1
Lane 3	166	59.2	LOS E	91.9
Approach	928	21.2	LOS C	104.5
		Northwest : Amarpath		
Lane 1	392	33.2	LOS C	154.1
Approach	392	33.2	LOS C	154.1

West : Nepalgunj				
Lane 1	535	13.8	LOS B	94.5
Lane 2	785	28.3	LOS C	295.4
Approach	1320	22.5	LOS C	295.4
Intersection	4659	22.6	LOS C	295.4

Table 9. Phase timing at night peak hour after optimization

Phase	**A**	**B**	**C**	**D**
Phase Change Time (sec)	0	18	36	54
Green Time (sec)	15	15	15	15
Phase Time (sec)	18	18	18	18
Phase Split	25%	25%	25%	25%

7. Result and Conclusion

The signal optimization at Pushpalal Chowk using SIDRA 8.0 improved intersection efficiency, reducing average delays to 24.8 seconds (LOS C) in morning peaks and 22.6 seconds (LOS C) at night, though challenges persisted in high-traffic lanes like Buspark Lane 2 (45.4-second delay, LOS D) and Nepalgunj Lane 2 (721.9-meter queue). Afternoon and evening peaks saw heavier congestion (35.6–63.9-second delays, LOS D–E), particularly in conflicting movements, underscoring the need for dynamic signal adjustments and lane capacity upgrades. The study confirms signal optimization's efficacy in mixed-traffic contexts but highlights the necessity of complementary measures—such as adaptive signaling and stricter enforcement—to address residual bottlenecks, aligning with global best practices for sustainable urban mobility.

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