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Enhancing Urban Traffic Flow Through Signal Optimization: A Case Study of Traffic Chowk, Butwal

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Abstract

The continuous growth of urban traffic at intersections creates critical challenges because many cities cannot develop their infrastructure fast enough to accommodate rising vehicle numbers. The research behind this investigation studied Traffic Chowk, Butwal, Nepal to optimize traffic flow and signal timing with the purpose of boosting operational efficiency and reducing vehicle waiting times. A traffic volume study was conducted to analyze vehicle movement patterns and SIDRA Intersection modeling to evaluate intersection performance. This evaluation establishes that most areas at the intersection provide Level of Service C but Purano Buspark faces peak-hour LOS F congestion which requires optimized traffic management along with adaptive signal controls for urban sustainability goals. Smart traffic control systems demonstrate critical importance for developing areas because they reduce congestions while enhancing roadway efficiency.

Keywords: Traffic congestion, Optimized traffic management, SIDRA Intersection model, Traffic volume analyses, Peak hour.

1. Introduction

Modern transportation systems face major difficulties because of delayed transportation at urban intersections coupled with heavy traffic flow. Higher traffic numbers actively lead to intersection congestion which results in reduced vehicle speed and extended journey times and enlarges waiting queues of vehicles at stoplights. The problem affects rapidly growing cities in developing nations specifically since limited land becomes scarcer and transportation increases while infrastructure planning remains inadequate. Traffic congestion impacts urban residents deeply because it leads to high stress levels combined with disrupted routines which results in blood pressure elevations and emotional problems that cause reduced abilities to manage their frustration levels. Efforts to maintain proper traffic flow with installed traffic signals tend to be ignored after the completion of installation tasks.

Effective traffic management strategies are necessary since cities continue expanding and their vehicular populations grow because they guarantee smooth movement and shorten travel times and enable better road safety. Traffic signal design represents an effective solution to enhance intersection efficiency because it establishes systematic methods of controlling vehicle and pedestrian movements through signalized phases. Traffic signals developed through proper design achieve three functions that decrease congestion and make transportation systems more efficient: they control vehicle traffic movements and eliminate conflicts and maximize intersection capacity. Also, improving the timing of traffic signals can increase the ability of vehicles entering or exiting main roads from smaller roads, and help prevent congestion at intersections (Pokhrel et al.,).

The high population growth in cities has resulted in heavy intersection traffic congestion which creates excessive waiting times and longer travel duration for vehicles. An increase in vehicle purchase causes intersections to reach capacity levels primarily during peak times. Road conditions in Butwal, Nepal remain critical because vehicles struggle to navigate smoothly due to combined traffic types alongside old-fashioned traffic controls and poor driving rules enforcement. The traffic signals operating at Traffic Chowk function poorly for handling daily variations in vehicle movement. Travel becomes unpleasant for drivers and

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pedestrians because the improper timing of the traffic signals causes stopping intervals along with delayed queues throughout the day. Overflowing congestion occurs primarily during peak hours because the signals operate without adjusting their timing according to traffic patterns. The local traffic characteristics led to choosing phase sequences during this research that presented optimal delays for vehicles and addressed operational limitations within current traffic patterns. The optimization framework made purposeful signal phase duration changes and sequencing modifications to fulfill operational demands which included extended pedestrian clearance periods together with staged left-turn operation scenarios. Such minor adaptive changes create a localized enhancement in both safety levels and operational efficiency. A practical approach for implementation at traffic management locations was established while using present local resources to accomplish this goal without needing extensive infrastructure modifications.

The research aims to develops solutions for these obstacles through analysis of traffic flow together with signal timing optimization at Traffic Chowk. The research adopts a data-driven method for traffic signal design that works to decrease vehicle delays and decrease congestion to achieve better intersection traffic operations which contribute to urban transportation sustainability.

1.1. Study Area

Traffic Chowk stands in the central region of Butwal within Nepal as a premier junction which judges as the most active and vital traffic intersection throughout the city. The four-legged junction carries signal control functions between Goal Park to the north and Puspalal Chowk to the south as well as Purano Film Hall to the east and Purano Buspark to the west. This main transportation center offers space for buses serving the public and vehicles of the private sector along with motorcycles and pedestrians at its intersection point. Heavy congestion at this crossing happens every day because it serves as an essential connecting point for both city and country-based traffic during all hours. The constant heavy flow of vehicles at Traffic Chowk causes delays so proper management strategies are needed to boost mobility and control congestion.

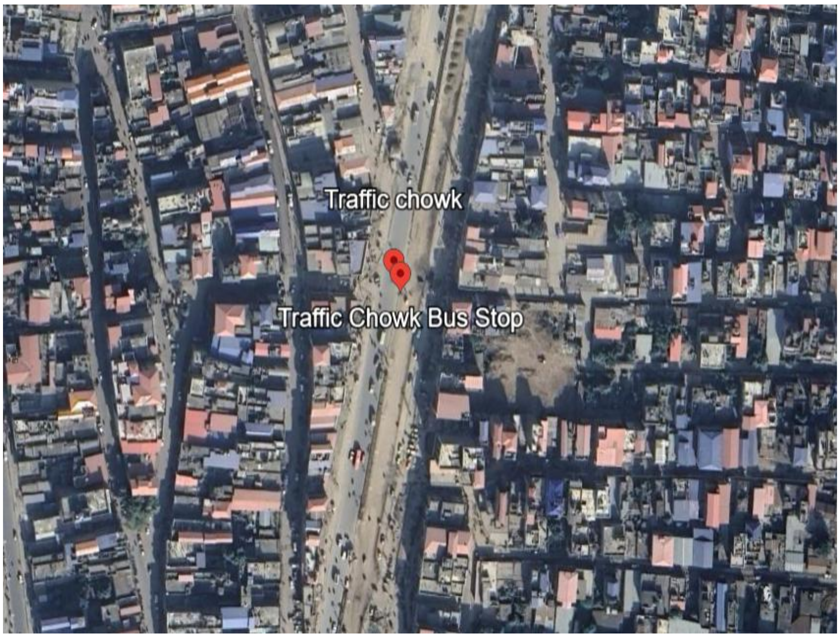

Figure 1. Traffic Chowk (Source: Google)

2. Literature Reviews

Managing traffic at signalized intersections is a significant challenge in urban transportation, as congestion leads to delays, increased fuel consumption, and pollution. Researchers have explored various methods to optimize traffic signals and improve intersection efficiency (Robertson, 2024) introduced the Transyt and Scoot traffic signal control systems, which dynamically adjust signal timing based on real-time traffic conditions. These systems have influenced modern adaptive traffic management strategies, allowing signals to respond to fluctuating traffic demands rather than relying on pre-set cycle times. A tool like simulation is very helpful in traffic engineering to analyze the complex dynamic behavior of a traffic stream. Simulation can be defined as the imitation of real-world systems or processes for conveniently acquiring the information through analogous traffic flow models (Qadri et al., 2020). A comprehensive review by (Eom & Kim, 2020) emphasized the importance of efficient signal scheduling, demonstrating that proper phase design and green time allocation can significantly improve traffic flow and reduce delays. Another study on urban congestion prediction (Yao et al., 2025) highlighted the complex and non-linear nature of congestion, influenced by factors such as vehicle volume, road conditions, driver behavior, and weather. These findings suggest that traditional fixed-time signal plans may be inadequate in handling dynamic urban traffic conditions, reinforcing the need for intelligent and adaptive control systems. The traffic volume study was performed to determine the number, movement, and classification of vehicles at this intersection using the manual method of traffic count, while the geometric survey of the intersection was done using tape and Total Station (Tiwari et al., 2023).

In recent years, artificial intelligence (AI) and data-driven traffic signal optimization techniques have gained increasing attention. Reinforcement learning (RL) has emerged as a promising approach to optimizing traffic light timing. According to (Guo et al., 2019), RL-based traffic signals continuously learn from past traffic patterns and adjust signal timings in real-time to minimize congestion. This approach has shown significant improvements over traditional methods, as it can adapt to sudden changes in traffic volume and reduce overall travel delays. Similarly, a study by (Darmaji et al., 2024) applied graph theory to traffic signal optimization, where researchers modeled vehicle movement patterns to determine the most efficient phase sequences. Their findings indicated that graph-based optimization could significantly reduce congestion, particularly at complex intersections with multiple conflicting traffic movements. Another innovative approach involves integrating Visible Light Communication (VLC) into traffic control systems. (Cao et al., 2024) explored the use of VLC technology, where vehicles and traffic signals communicate using LED lights, allowing real-time traffic data exchange. This technology has the potential to enhance coordination between multiple intersections, leading to smoother traffic flow and reduced delays, particularly in urban areas with high traffic densities.

In addition to AI-driven solutions, traditional traffic signal optimization methods remain relevant. The Highway Capacity Manual (HCM) is widely used to evaluate intersection performance, providing guidelines for determining optimal signal timing and phase splits. A study by (Mishra et al., 2022) found that combining HCM-based analysis with crowd-sourced data from GPS and mobile applications provided an economical and effective way to monitor and manage traffic congestion. Similarly, a study by (Bindzar et al., 2024) examined how intersection design affects traffic performance, showing that adjusting lane configurations, signal timing, and cycle lengths can significantly improve efficiency. These findings highlight the importance of integrating both conventional and advanced methods to develop smart traffic management systems. While AI-based solutions offer adaptability and efficiency, traditional optimization techniques provide a structured framework for traffic engineers to implement practical and cost-effective improvements.

Several studies have utilized SIDRA Intersection and VISSIM software to analyze and improve intersection performance in Kathmandu, Nepal. These tools have been employed to model traffic flow, assess current conditions, and propose optimization strategies. A study was conducted for Satdobato intersection, Nepal which is four-way intersection using Sidra intersection 8.0 software to optimize signal timing by adjusting cycle lengths and controlling continuous left-turn movements within the signal timing which subsequently reduced average delays and BOQ traffic (Civil Engineer, Traffic & Transport Unlimited Solution (TATUS) Lalitpur, Nepal. & Luite, 2023). While these studies primarily utilized SIDRA Intersection for micro-analytical traffic evaluation, VISSIM has also been applied in the context of Kathmandu's traffic analysis.The present study illustrates the effectiveness of utilizing VISSIM software in evaluating the capacity of urban multi-lane highways under varied traffic conditions (Luitel et al., 2024). (Chettri, 2023) focused on calibrating car-following parameters in VISSIM for traffic in Kathmandu, specifically at the Putalisadak intersection. This research aimed to enhance the accuracy of traffic simulations by adjusting VISSIM's parameters to better reflect local driving behaviors.Studies have demonstrated its utility in calibrating unsignalized intersections under heterogeneous traffic conditions (Paudyal et al., 2025).

Overall, the combination of intelligent traffic management strategies, real-time data exchange, and optimization models is crucial in addressing urban congestion. Future research should focus on integrating AI-driven models with traditional traffic engineering principles to create a more efficient and adaptive transportation system. Also, various studies highlight those signalized intersections, when optimized, can significantly enhance road safety by controlling traffic movement and minimizing conflicts between vehicles and pedestrians. For safety purposes, the standards also include provisions for traffic signs (Tiwari & Luitel, 2023).

3. Methodology

The procedures followed for evaluating the intersections are presented in Fig. 2.

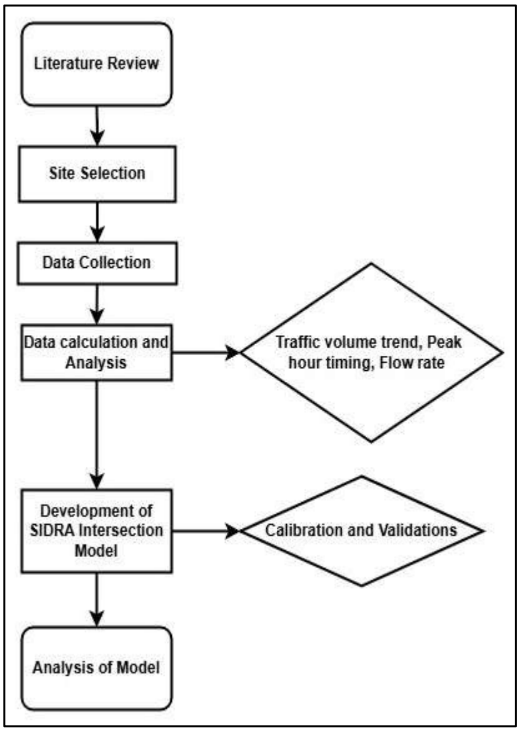

Figure 2. Methodological flowchart

3.1. Site Selection

The selection process for sites concentrated on identifying congested intersections within Butwal. Selection criteria based on intense traffic patterns and persistent road blockages and historic traffic accidents produced the candidate areas. Researchers visited the locations to assess physical and geometric aspects during site surveys. The evaluation found Traffic Chowk intersection suitable because of its problematic traffic issues and urgent need for improvement.

3.2. Data Collection

For the 72-hour duration researchers obtained directional traffic volume data through 15-minute data collection periods. Each camera at the intersection watched all directions across the approaches to capture vehicular activity. The four trained enumerators performed manual traffic direction classification work on the video recordings for data collection purposes. Measures of peak traffic flow patterns and volumes were calculated through the average data collected over three days while using vehicle type equivalency factors from Table 1. The queue lengths measurements were obtained from video recordings taken during busy hours at every junction. We manually extracted maximum back-of-queue length data from video inspections conducted in specific time intervals. The observed lane characteristics and approach conditions as well as peak hour queue lengths served as validation data during field surveys.

Table 1. PCU equivalency Factor

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 Triller	1.5

3.3. Data Analysis

The traffic analysis showed four major congestion periods across three days starting at 7:00 AM in the morning followed by 10:15 AM in the late morning and concluding with 12:00 noon in the afternoon and 18:30 PM in the evening. The Puspalal Chowk to Golpark path received the most significant traffic among all routes as it recorded 1,015 vehicles in late morning and sustained high numbers throughout day time. Nighttime traffic from Puspalal Chowk to Purano Buspark reached 226 vehicles but other time periods exhibited lower figures and Purano Film Hall received only minimal vehicles (28–80 vehicles). Throughout the afternoon period traffic at Golpark to Puspalal Chowk reached its peak volume which exceeded 1,170 vehicles. The number of vehicles conducted on the Purano Buspark to Puspalal Chowk trip grew from 105 in the morning to 280 during the evening period. The minimal approach to Purano Film Hall resulted in overall low traffic volumes that showed little change throughout the day. Research data shows how congestion needs specific management strategies at Puspalal Chowk and Goalpark and Purano Buspark.

3.4. Development of the SIDRA Intersection Model

A validation of the SIDRA Intersection model at the Traffic Chowk intersection concentrated on essential parameters which include queue length alongside saturation flow rate together with phase sequencing and signal timing. The model functioned by replicating vehicle movements along with peak traffic findings to create performance and congestion evaluation outcomes. The queue length measurement served to identify how extreme congestion became during peak traffic times by showing the maximum number of waiting vehicles. The model served to evaluate diverse signal timing scenarios and different lane structures for determining peak performance improvements at the intersection.

3.5. Calibrations and Validations of the Model

Field-based queue length data served as input to calibrate the simulation model through parameter adjustments of saturation flow rates alongside headways and reaction time values until the observed-simulated conditions aligned properly. The validation used 95th percentile queue data points collected from peak morning and evening periods according to studies showing these times to have maximum traffic congestion. A thorough investigation focused on these two peak periods because they exhibited sustained high traffic volumes despite initial studies of four peak periods. Model accuracy and reliability for signal optimization proved true based on the successful match between observed and simulated queue length data. Table 2 contained all parameters which were employed to conduct the calibration process. Table 3 shows a summary comparison between the observed and simulated queue lengths across different approaches during peak periods.

Table 2. Calibrating parameters.

Parameters	Value	Remarks
Base Saturation Flow	1950	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. Observed vs. Simulated Queue Lengths

Time Period	Observed Length(m)	Simulated Length(m)	% error
Morning peak	330.23	303.8	8.7%
Evening peak	407.51	383	6.4%

3.6. Phase and Signal analysis

The signal timing design is always recommended to design for various time of day and for this scope of works, it is carried out for four time of day; morning peak, afternoon peak, evening peak and night peak. Four phase system is adopted for this intersection. The cycle time for all peak hours is 75 sec. Research focused on the morning hours from 7:00 AM to 9:00 AM and the evening hours from 5:00 PM to 7:00 PM for analysis because these times had the most vehicles and congestion. Signal optimization did not require attention during the midday and night hours because traffic remained lower compared to other periods. The phase diagrams for morning and evening peak hours are shown in Figure 3 and Figure 4 respectively.

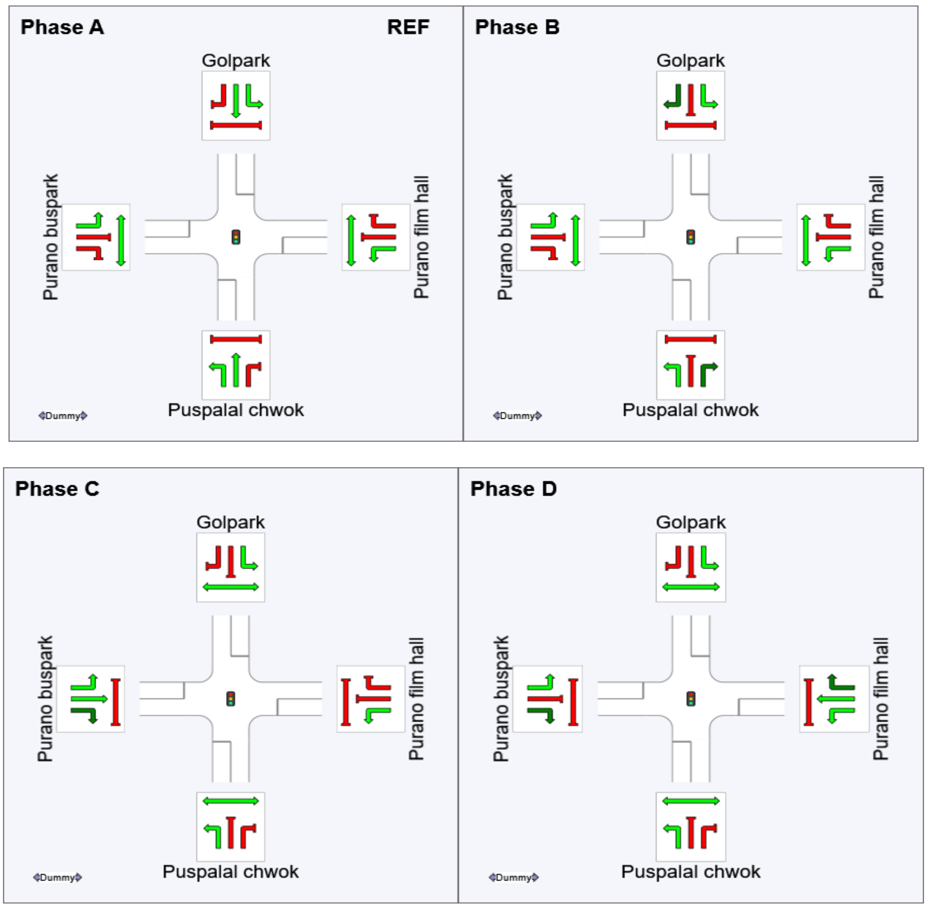

Figure 3. Phase sequence at morning peak hour

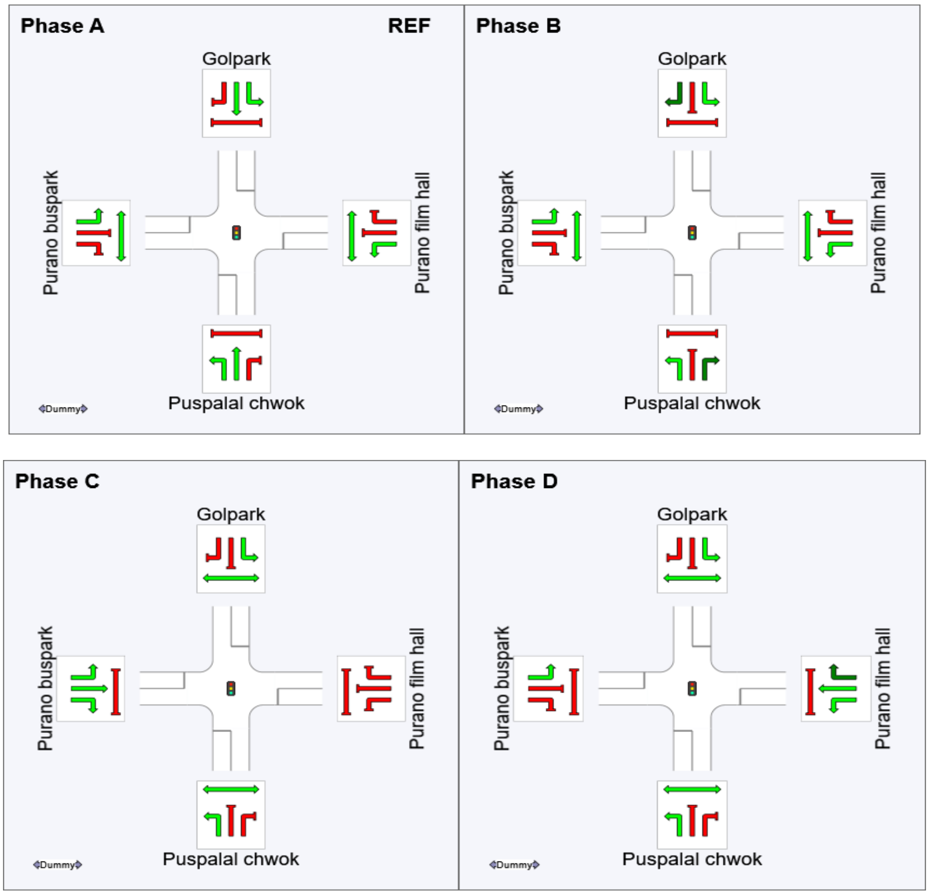

Figure 4. Phase sequence at evening peak hour

3.7. Performance of Intersection at Morning Peak Hours

The table contains operational traffic statistics for lanes located at South (Puspa Lal Chowk) and East (Purog Film Hall) in addition to North (Goalpark) and West (Purono Buspark). Vehicles per hour flow rates are combined with seconds of average delays and LOS measurements along with 95th percentile queue distance figures that measure in meters. The traffic flow LOS scale reaches from C through D which signifies that several lanes experience moderate to heavy delays during operations. The intersection level displays the maximum demand flow rate of 3756 veh/hr accompanied by an average delay duration of 32.4 seconds at Level of Service C. The queuing situation at Puspa Lal Chowk stands out most prominently because Lane 303.8 meters records the longest queue.

Table 3. Performance of intersection at morning peak hour

Approach	Demand Flows Total (veh/hr)	Average Delay (sec)	Level of Service (LOS)	95% Back of Queue Distance(m)
		South:Puspalal Chowk		
Lane 1	743	30.6	LOS C	303.8
Lane 2	598	32.2	LOS C	202.2
Lane 3	383	36.7	LOS D	133.2
Approach	1723	32.5	LOS C	303.8
		East: Purano film hall		
Lane 1	211	25.4	LOS C	68.4
Approach	211	25.4	LOS C	68.4
		North: Goalpark		

Lane 1	539	34.2	LOS C	194.6
Lane 2	524	34	LOS C	189.6
Lane 3	148	54.4	LOS D	58.8
Approach	1211	36.6	LOS D	194.6
		West: Purano Buspark		
Lane 1	612	26.5	LOS C	259
Approach	612	26.5	LOS C	259
Intersection	3756	32.4	LOS C	303.8

Table 4 represents the phase details.

Table 4. Phase timing at morning peak hour

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%

3.8. Performance of Intersection at Evening Peak Hours

The intersection reached Level of Service 'C' during the evening peak period under current operational conditions. The approaches at LOS C were the standard while LOS D levels occurred in certain lanes at Puspalal Chowk and Goalpark. The measurements showed the intersection ran 32.8 seconds of average delay while locating the maximum queue length at 383 meters. The current traffic performance shows stability but particular approach lanes within Puspalal Chowk and Goalpark demonstrate longer delays which need further analysis for improvement.

Table 5. Performance of intersection at evening peak hour

Approach	Demand Flows Total (veh/hr)	Average Delay (sec)	Level of Service (LOS)	95% Back of Queue Distance(m)
		South:Puspalal Chowk		
Lane 1	847	31.5	LOS C	383
Lane 2	671	33	LOS C	262.2
Lane 3	101	50	LOS D	34.9
Approach	1619	33.3	LOS C	383
		East: Purano film hall		
Lane 1	169	31.4	LOS C	53.2
Approach	169	31.4	LOS C	53.2
		North: Goalpark		
Lane 1	513	29.7	LOS C	169.1
Lane 2	507	29.7	LOS C	167.3
Lane 3	106	49.6	LOS D	42.3
Approach	1125	31.6	LOS C	169.1
		West: Purano Buspark		
Lane 1	552	34.2	LOS C	286
Approach	552	34.2	LOS C	286

Intersection	3465	32.8	LOS C	383

Table 6 represents the phase details.

Table 6: Phase timing at evening peak hour

Phase	**A**	**B**	**C**	**D**
Phase Change Time (sec)	0	22	44	62
Green Time (sec)	19	19	15	15
Phase Time (sec)	22	22	18	18
Phase Split	28%	28%	23%	23%

4. Discussion

Traffic flow and delay reduction achieved significant results at Traffic Chowk, Butwal through modified signal sequence planning along with green time distribution and a 75-second cycle span which maintained Level of Service C in most movements. The static nature of signal timing proves insufficient for diversifying traffic flow resulting in adaptive traffic signal control (ATSC) becoming essential for traffic developments. Short-term success from SIDRA modeling needs long-term solutions that include advanced infrastructure improvements and enhanced traffic enforcement as well as intelligent traffic system technologies to maintain sustainable city transportation systems.

5. Conclusion

The research investigates the critical traffic jams that originate from rising vehicle numbers and deficient traffic signals together with weak law implementation at Traffic Chowk in Butwal. The research team examines intersection performance through SIDRA Intersection model data analysis which determines traffic flow details and signals problems that exist at peak times. The evaluation shows the intersection maintains Level of Service C as its normal condition but the Purano Buspark approach during afternoon hours reaches grade LOS F. The research highlights the necessity to combine optimized traffic signal scheduling and tactical direction to enhance intersection management and minimize delays in vehicles while promoting better city transportation. Traffic operations become smoother and waiting times decrease together with transportation efficiency increasing when the signals apply data-based optimization approaches to minimize congestion levels. The research thus helps sustainable urban traffic planning through practical methods that boost intersection effectiveness and increase road capacity.

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