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Research Article

Evaluation of Operational Performance of Intersection and Optimizing Signal Timing: A Case Study of the Buspark Intersection in Birgunj Metropolitan

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ABSTRACT

Congestion at key intersections on urban roads is a common occurrence, leading to traffic slowdowns and longer queue lengths. This significant delay leads to higher travel time expenses and diminishes the Level of Service (LOS). Birgunj is the industrial hub of Nepal, sharing its border with India. However, it has encountered multiple difficulties concerning its urban infrastructure, urban transportation network and traffic gridlock. Buspark Junction is located in the Bypass Road connecting Indian border to the East-West highway bypassing the city of Birgunj. The objective of this study is to enhance the traffic flow at the Buspark intersection in Birgunj Metropolitan. This was achieved by assessing the current traffic conditions and implementing various changes to reduce delays and congestion. 72 hours traffic volume data and geometrical characteristics of the intersection were collected and an existing model of the intersection was developed in software 'SIDRA Intersection 8.0'. The validation of the model involved assessing both observed and simulated queue lengths for each approach, and an assessment of the current performance of the intersections was conducted. Two Possibilities were then developed to improvise the performance of the Buspark Junction; signal timing was optimized by changing the cycle lengths (Alternative I) and the continuous left-turning movement was controlled under signal time (Alternative II). The intersection's Level of Service (LOS) was enhanced from E to D as a result of both Alternative I and Alternative II. These modifications led to reductions in the average delay of 34.7% and 38.8%, and also resulted in decreases of 34.7% and 40% in the Back of Queue (BOQ) respectively.

Keywords: Intersection, HCM, SIDRA, LOS, Average Delay, BOQ

Introduction

Traffic congestion at intersection is prevalent and proliferative issue at the urban roads resulting in wide range of negative impacts on individuals, communities, and the environment. One of the most immediate consequences of traffic congestion is the wasted time and productivity of commuters. An inadequately planned intersection can lead to traffic jams, higher vehicle emissions, and an elevated risk of accidents on the road.[1] Congestion has been one of the major problems in the transportation system, especially in urban mobility, where demand exceeds supply. This issue becomes more predominant at junctions, where arrivals and departures in various directions occur. In the meantime, traffic signals serve as a highly effective tool for managing traffic flow. They are frequently employed to regulate potentially conflicting movements of vehicles coming from various directions at significant road intersections simultaneously. This ensures the safety of road users and facilitates the smooth operation of the traffic system, allowing for efficient crossing. Signalized intersections are characterized by the lights determining the order and duration of traffic flows at the intersection.[2] The major challenge regarding the operation of traffic signals is the application of efficient and optimum signal timing; if not done correctly, it might either increase waiting delays or extend queue lengths. A successful signalized intersection relies on three key conditions, as outlined by.[3] First, intersections must be meticulously designed as islands that seamlessly integrate with traffic flows. Second, precise signal orders, often represented through phase diagrams, must be established. Lastly, accurate cycle times must be calculated in alignment with flow volumes. Moreover, to achieve optimal results and heightened effectiveness, it is imperative to implement a device capable of discerning fluctuations in flow patterns. This device ensures the synchronization of cycle times with the dynamic shifts in traffic throughout the day. The pivotal consideration lies in the establishment of an appropriate cycle order and the application of an optimal cycle time. These measures serve to mitigate delays for vehicles.[3]

The Level of Service (LOS) of an intersection is a critical measure used in transportation engineering and planning to assess how efficiently an intersection functions in terms of traffic flow and operational performance. It ranges from ‘A’ to ‘F’, A being the best one and F being the worst. However, [4] suggests that modelers should pay attention to delay, back of queue and degree of saturation rather than just the level of service. Average delay refers to the average amount of time that vehicles or pedestrians must wait at an intersection before they can proceed through it and the “back of queue” refers to the point at which the last vehicle in a line of vehicles waiting at a traffic signal or an intersection comes to a stop. The traffic signal is a highly effective method for controlling intersection traffic by allocating time intervals for vehicle movements.[5]

The intersection was modeled using the SIDRA Intersection 8.0 software, which is a sophisticated micro-analytical tool specifically developed for a wide range of intersection types. SIDRA, short for Signalized & Unsignalized Intersection Design and Research Aid, is a widely utilized software package in traffic engineering. It employs traffic models in conjunction with an iterative approximation approach to generate estimates of Key Performance Indicators (KPIs) like intersection capacity, overall delay, queue lengths, and emission levels. [1,6]

This research focuses on developing a SIDRA intersection model specifically tailored for the high-traffic Buspark junction within the Birgunj Metropolitan area. Subsequently, performance assessment is conducted using metrics such as average delay and queue length. Based on these metrics, diverse alternatives are tested with the aim of enhancing the operational efficiency of the junction.

Research Objective and Scope

The main objective of the study is to assess the current traffic situation at the Buspark Junction in Birgunj, Nepal, and propose solutions to enhance its performance. The ultimate goal is to improve the Level of Service (LOS) by decreasing both the Average Delay and Back of Queue Length (BOQ).

Literature Review

Various approaches are typically employed to address traffic congestion in urban areas. A study was conducted for Satdobato intersection, Nepal which is four-way intersection. Sidra intersection 8.0 software was used 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.[7] A study employed Sidra Intersection 8.0 software to evaluate the operational efficiency of the Jwalakhel roundabout in Lalitpur, Nepal. The analysis revealed that the roundabout was operating at Level of Service (LOS) F, indicating significant congestion, with notably long queues and extended periods of delay for commuters.[8]

At Gaa-Akanbi intersection in Ilorin, Nigeria, improvement of intersection was carries out by using a traffic signal scheme. Sidra was used to find the optimum cycle length and hence the LOS of the intersection was improved to ‘D’ with improved mobility, reduced delays, and decreased fuel consumption and pollutants.[9] The study focused on two signalized intersections in Konya, namely, Kule and Nalçacı–Sille. To enhance traffic flow and service levels, new optimal cycle times were recommended using the Sidra Intersection 5.1 software, employing both American and

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Australian methods. Overall, the suggested cycle times led to reduced delays and improved intersection capacities.[10] The research aimed to enhance the performance of five separate signalized intersections in Erbil city, Iraq. This was achieved by employing two software tools: the Highway Capacity Software (HCS+T7F) and SIDRA Intersection 8. The implementation of SIDRA Intersection 8 led to a notable 21% reduction in delays. To further enhance performance, it is recommended to optimize the intersections based on the insights provided by the SIDRA software.[11]

Pokhrel et al. (2023) obtained the result for reduction in queue length, average delay and improved LOS in both morning and evening peak hours using optimum signal timing and controlled left turning movement with optimum cycle in Sidra. The Left-hand controlled movement with optimum cycle yielded better results improving the LOS to B and C in morning and evening peak hour respectively and reduction in average delay by 78%.[12] In a study conducted by [13] at two intersections in Kathmandu, Nepal (Kanti Children's Hospital and Shital Niwas), three traffic congestion mitigation strategies were compared. They analyzed optimizing cycle length, implementing left-turn control in the optimized cycle, and coordinating signal timing. The results showed a substantial reduction in average vehicle delay: from 106 seconds per vehicle in the existing conditions to 38.6 seconds (optimized cycle), 36.6 seconds (optimized cycle with left-turn control), and 26.6 seconds (coordinated signal). Similarly, at the Kanti Children's Hospital intersection, average vehicle delay decreased from 43.1 seconds to 32.8 seconds (optimized cycle), 27.1 seconds (optimized cycle with left-turn control), and 21.7 seconds (coordinated signal).

Study Area

Birgunj is the major route for interchange of bilateral and third country trade between India and Nepal. The substantial rise in vehicle numbers has resulted in extensive traffic congestion within Birgunj Metropolitan City, leading to day-long delays. Buspark Junction is a four- legged intersection and located in Bypass Road. To the east of the junction is Birgunj Buspark, to the west is Ghantaghar Junction, to the north is Pani Tanki Junction, and to the south is Nagawa Junction, shown in Figure 1. It is a dynamic and vital hub that plays a vital role in transportation, trade, and commerce in the region. The traffic congestion at this intersection is severe and it is expected to grow in a tremendous rate in coming years. The traffic flow in the intersection is mixed traffic condition and the mixed traffic also plays a significant role in the congestion process. Furthermore, due to heavy vehicle and pedestrian flow in the vicinity of the junction, pedestrians have to wait a long time to cross.[14]

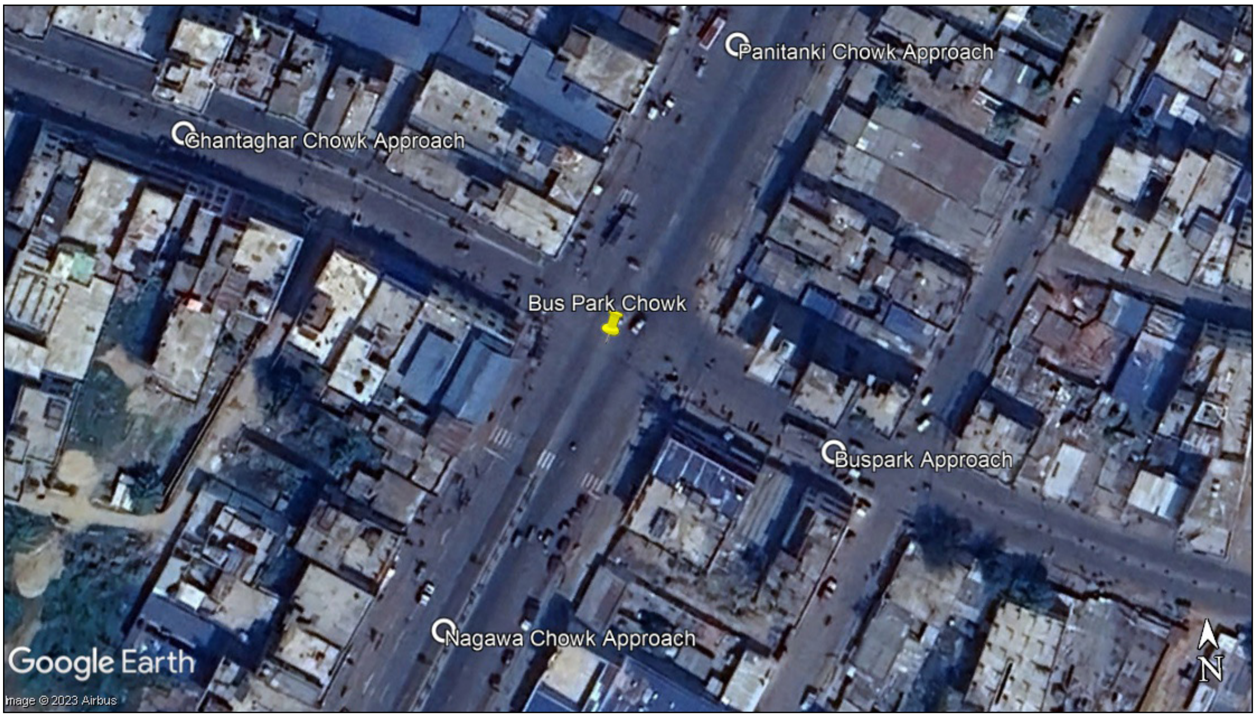

Figure 1.Study Area (Buspark Junction)

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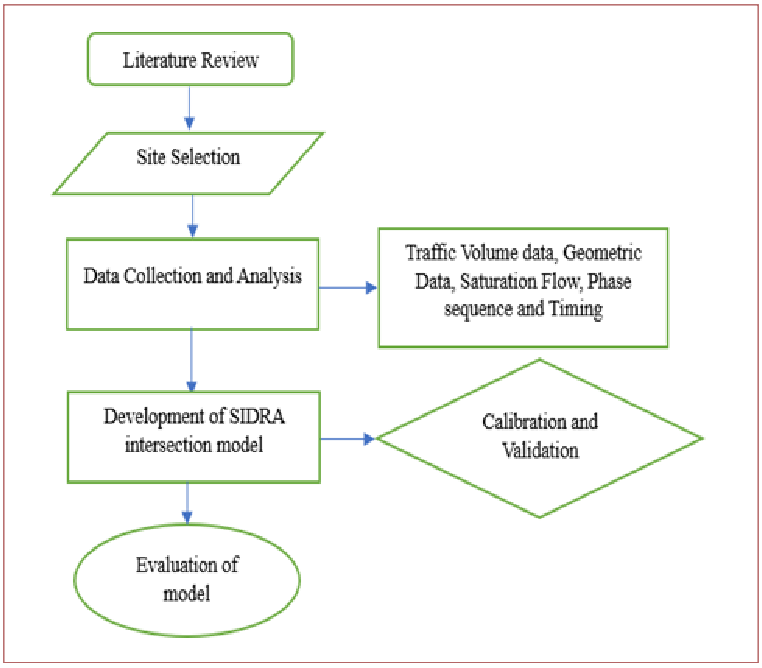

Figure 2.Flowchart Showing Methodological Steps of the Study

Methodology

The methods that have been adopted to accomplish the study can be divided into four measured parts, which are shown in Figure 2.

Literature Review

Various journal articles, reports, and review papers related to signalized intersections and intersection performance were collected and thoroughly reviewed. The primary objective of this literature review was to further develop methodology for completing the task and identify data that are to be collected during the field work. The secondary objective was to identify calibrating parameters and values that assist in the calibration and validation of the SIDRA intersection model.

Data Collection

Classified directional traffic volume data were collected over a 72-hour period in 15-minute intervals. The data collection process began with the installation of cameras at intersection approaches to record directional maneuvers for all legs. Subsequently, video footage was reviewed, and classified directional volume counts were conducted manually. This was facilitated by four trained enumerators who carefully analyzed the video footage. Furthermore, three-day traffic volume data were averaged and multiplied by an equivalency factor according to vehicle type, as indicated in Table 1. This led to the identification of peak hour volume and directional volume in the peak hour, which was used in the development and analysis of the model. Additionally, data related to lane and approach geometry was gathered during the fieldwork. The field data collection also includes the collection of queue length data in all lanes and base saturation flow in peak hour time period for validation purposes.

Table 1.PCU Equivalency Factor for Classified Vehicle

SN	Vehicle Type	PCU Equivalency Factor
1	Car	1.0
2	Heavy Truck	3.0
3	Light Truck	1.5
4	Multi Axle Truck*	4.0
5	Tractor (farm tractor)	1.5
6	Bus	3.0
7	Minibus	2.5
8	Microbus	1.5
9	Utility	1.0

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10	Four Wheel Drive*	1.0
11	Motorcycle	0.5
12	Three wheeler (Auto Rickshaw)	0.75
13	Power Tiller**	1.5

Source: [15]

Model Development

With the help of classified directional traffic volume data and geometry data, the SIDRA intersection model was developed. The model was subsequently calibrated using base saturation flow rate, equivalency factor, phase sequence, phase time, and other parameters as indicated in Table 2. Finally, the model's validation process involved assessing the back of queue length before proceeding with further evaluation. Back of queue length is used to validation due to limitations in measuring the average delay in the field.

Evaluation of Model

The calibrated and validated model was employed to assess the current performance, primarily focusing on average delay and back-of-queue length. Two scenarios were altered in the model to determine if the intersection's performance could be enhanced. These changes involved optimizing signal timing and implementing continuous left turn control, which is absent in the current configuration.

Data Analysis and Results

Traffic Flow Condition

The vehicles were classified into different categories and traffic volume data with 15 minutes intervals of three weekdays were taken. The data was analyzed to obtain a peak hour. The peak hour was found to be 18:30 to 19:30 in the evening, as indicated in Figure 3. Further analysis of the model was done for this peak hour period data.

Model Development, Calibration and Validation

Based on traffic data and geometric data, microscopic analytical model was developed in SIDRA software. There is no presence of operating traffic signal light in this intersection. Thus, the phase sequence and timing for existing scenario were taken according to the traffic operation by traffic police. Calibration within Sidra Solutions software entails the process of refining model parameters and input data to ensure that the outcomes of traffic analysis closely mirror actual traffic conditions, thereby facilitating more precise traffic management and planning. The calibration was done by following parameters in Table.2

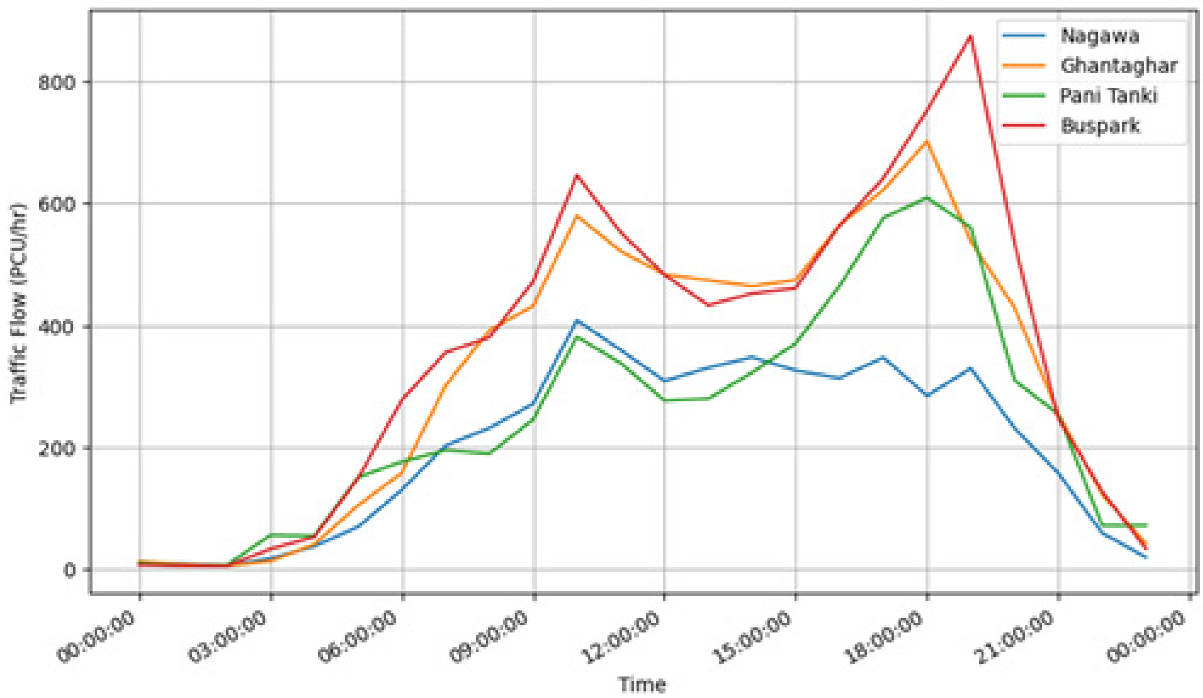

Figure 3.Hourly Variation of Traffic Flow

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Table 2.Calibrating Parameter of SIDRA Model

Parameters	Value	Remarks
Base Saturation Flow	2350	Field measurement using video footages
Lane Utilization Ratio	Program	Program Calculated
Saturation Speed		Program Calculated
Capacity Adjustment	0%	No Capacity Adjustments
Signals		
Buses Stopping	0veh/hr	No bus bays within 75m
Parking Maneuvers	0veh/hr	No Parking Lane

Using the calibrated model, the 95% of BOQ is used as validation for the model. Table 3 shows that the difference between the observed BOQ and SIDRA generated BOQ is not more than 20% in any case.

Existing Performance of Intersection

The degree of saturation of the intersection was found to be greater than 1 i.e., 1.096 which signifies that the intersection is oversaturated. The average delay of the intersection was found to be 66.4 sec/veh with the highest value in Ghantaghar Junction; 83.3 sec/veh. The 95% BOQ of the intersection is 369.4 m. The summary of the intersection along with the phasing is illustrated below in Table 4 and Table 5 respectively.

Alternative Measures I Optimum Cycle Length

The objective of signal length optimization is to find the right equilibrium between ensuring enough green time for vehicles to pass through the intersection or section and minimizing undue waiting times for all road users. The cycle length was optimized to 100 sec by the software considering minimum green time limiting to 15 sec for safety purpose. This reduces the average delay to 43.3 sec/veh and BOQ to 241.2 m with DOS less than 1 i.e., 0.845. Lane and phase summary is illustrated below in Table 6 and Table 7 respectively. The phase sequence proposed is shown in Figure 4.

Table 3.Validation Results of SIDRA Model

Approach	Model	Observed	Difference
South: Nagawa Junction	95.3	88	8%
East: Buspark	358	298	20%
North: Pani Tanki Junction	52	49	6%
West: Ghantaghar Junction	369.4	311	18%

Table 4.Existing Performance of Intersection

Approach	Demand Flows (vehicles/hr)	Deg of Saturation	Average Delay (Sec)	LOS	95 % BOQ (veh)	95% BOQ Length (m)
South: Nagawa Junction						
Lane 1	306	0.353	48.3	LOS D	17.1	95.3
Lane 2	264	0.353	53.5	LOS D	16.1	69.1
Lane 3	50	0.353	58.9	LOS E	3.1	21.2
Approach	620	0.353	51.4	LOS D	17.1	95.3
East: Buspark						
Lane 1	848	0.872	61.8	LOS E	59.2	358.8
Lane 2	167	0.895	83.5	LOS F	13.3	83.6
Approach	1016	0.895	65.4	LOS E	59.2	358.8
North: Pani Tanki Junction						

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Lane 1	130	0.273	46.4	LOS D	7.1	51.4
Lane 2	150	0.273	54.3	LOS D	9	52
Lane 3	118	0.441	66.1	LOS E	7.9	49.9
Approach	398	0.441	55.2	LOS E	9	52
West: Ghantaghar Junction						
Lane 1	787	0.902	65.1	LOS E	57.1	369.4
Lane 2	94	1.096	236.8	LOS F	13.2	89.5
Approach	881	1.096	83.3	LOS F	57.1	369.4
Intersection	2915	1.096	66.4	LOS E	59.2	369.4

Table 5.Existing Phase Timing

Phase	A	B	C	D
Phase Change Time (sec)	0	38	78	117
Green Time (sec)	32	32	31	25
Phase Time (sec)	40	40	39	31
Phase Split	27%	27%	26%	21%

Table 6.Performance of Intersection after Applying Optimum Cycle Length

Approach	Demand Flows (vehicles/hr)	Deg of Saturation	Average Delay (Sec)	LOS	95 % BOQ (veh)	95% BOQ Length (m)
South: Nagawa Junction						
Lane 1	308	0.479	37.3	LOS D	12.4	69.1
Lane 2	252	0.479	42.6	LOS D	11.3	48.4
Lane 3	60	0.479	43.5	LOS D	2.6	16.7
Approach	620	0.479	40.2	LOS D	12.4	69.1
East: Buspark						
Lane 1	848	0.842	41.8	LOS D	39.8	241.2
Lane 2	167	0.845	53.6	LOS D	8.5	53.7
Approach	1016	0.845	43.7	LOS D	39.8	241.2
North: Pani Tanki Junction						
Lane 1	137	0.371	33.6	LOS D	5.5	39.1
Lane 2	143	0.371	43.7	LOS D	6.4	36.6
Lane 3	118	0.437	47.6	LOS D	5.4	34.2
Approach	398	0.437	42.4	LOS D	6.4	39.1
West: Ghantaghar Junction						
Lane 1	760	0.836	41.3	LOS D	35.2	228.2
Lane 2	121	0.836	72.2	LOS E	6.4	42.6
Approach	881	0.836	45.5	LOS D	35.2	228.2
Intersection	2915	0.845	43.3	LOS D	39.8	241.2

Table 7. Phase Timing at Optimum Cycle Length

Phase	A	B	C	D
Phase Change Time (sec)	0	20	49	78
Green Time (sec)	15	22	22	15
Phase Time (sec)	22	29	29	20
Phase Split	22%	29%	29%	20%

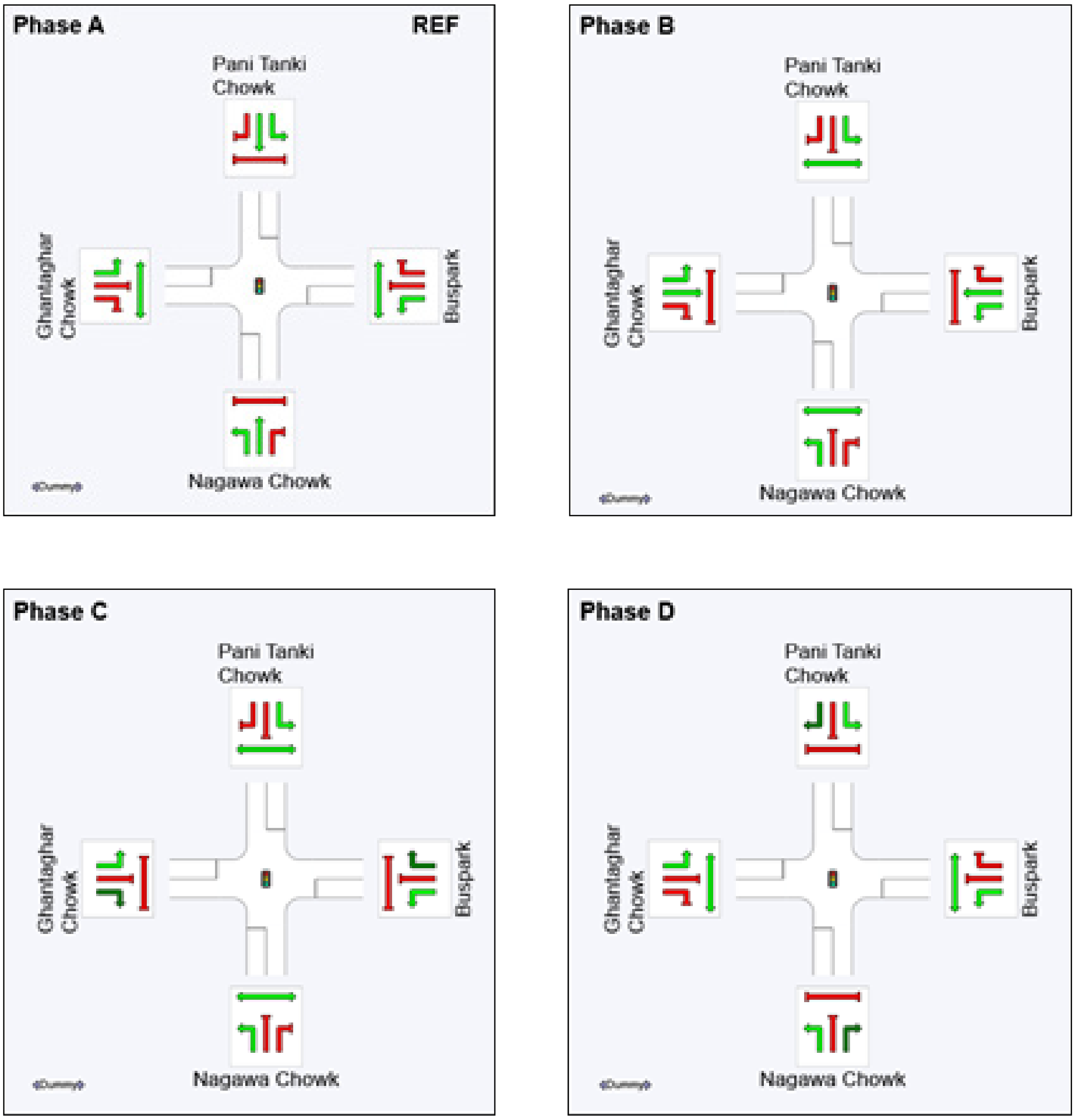

Figure 4.Phase Sequence at Optimum Cycle Length

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Alternative Measures II Left Turn Controlled Optimum Cycle

The left-turn controlled phase sequence ensures reduced conflict with other vehicles, especially when a high number of vehicles from the other direction are approaching. This may potentially reduce delays, especially in cases where there is a limited exit lane. The model was altered controlling the left-hand turn in optimum cycle. This reduces the average delay to 40.6 sec/veh and BOQ to 210.5 m with DOS less than 1 i.e., 0.79. Lane and phase summary is illustrated below in Table 8 and Table 9 respectively. The phase sequence proposed is shown in Figure 5.

Table 8.Performance of Intersection after Applying Optimum Cycle Length with Left Turn Controlled Phase Sequence

Approach	Demand Flows (vehicles/hr)	Deg of Saturation	Average Delay (Sec)	LOS	95 % BOQ (veh)	95% BOQ Length (m)
South: Nagawa Junction						
Lane 1	306	0.456	33	LOS C	9.5	53
Lane 2	250	0.456	40.3	LOS D	10.7	45.8
Lane 3	63	0.456	43.4	LOS D	2.6	16.8
Approach	620	0.456	37	LOS D	10.7	53
East: Buspark						
Lane 1	848	0.714	37	LOS D	34.7	210.5
Lane 2	167	0.791	72.5	LOS E	10	62.9
Approach	1016	0.791	42.9	LOS D	34.7	210.5
North: Pani Tanki Junction						
Lane 1	134	0.347	22.6	LOS C	3.1	22
Lane 2	139	0.347	41.3	LOS D	5.9	33.9
Lane 3	125	0.347	46.6	LOS D	5.4	34.1
Approach	398	0.347	36.7	LOS D	5.9	34.1
West: Ghantaghar Junction						
Lane 1	732	0.682	35.9	LOS D	29.1	188.8
Lane 2	149	0.682	72.7	LOS E	7.7	50.3
Approach	881	0.682	42.2	LOS D	29.1	188.8
Intersection	2915	0.791	40.6	LOS D	34.7	210.5

Table 9.Phase Timing at Optimum Cycle Length with Left Turn Controlled

Phase	A	B	C	D
Phase Change Time (sec)	0	20	49	78
Green Time (sec)	15	22	22	15
Phase Time (sec)	22	29	29	20
Phase Split	22%	29%	29%	20%

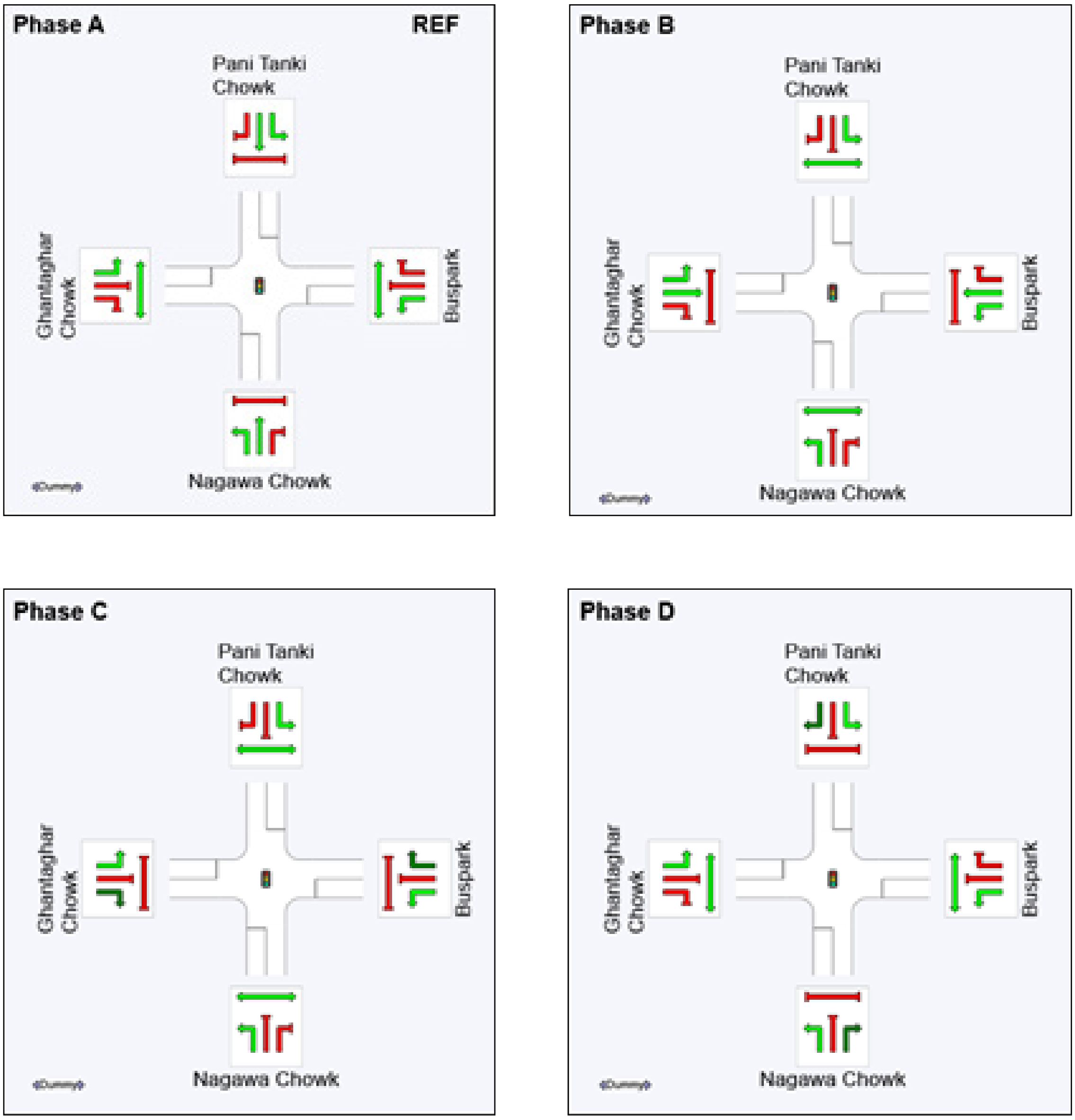

Figure 5.Phase Sequence at Optimum Cycle Length with Left Turn Controlled

Comparison of Existing and Alternatives Measures Performance

Performance changes are assessed by comparing LOS (Level of Service), delay time, and the Back of Queue of the changes to the existing scenario. The intersection's current Level of Service (LOS) is rated as 'E'. After implementing both changes, the intersection's LOS improved to 'D'. Additionally, the average delay at the intersection decreased from 66.4 sec to 43.3 sec due to Change I and to 40.6 sec due to Change II. This represents a 34.7% reduction in average delay per vehicle with Change I (Optimum Cycle Length) and a 38.8% reduction with Change II (Left turn controlled with optimum cycle). Figure 6 represents the visual representation of this comparison.

Whereas, the 95 % BOQ of the intersection reduced from 369.4m to 241.2m and 210.5m from change I and change II respectively. The percentage reduction in BOQ is 34.7% from change I (Optimum Cycle Length) and 43% by change II (Left turn controlled with optimum cycle). The comparison chart is shown in Figure 7.

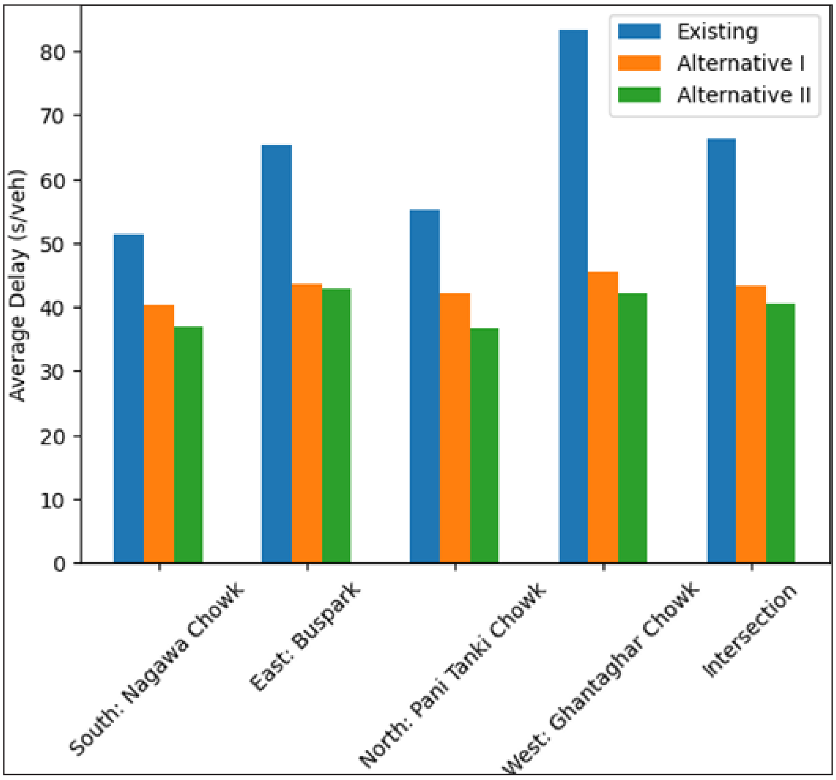

Figure 6.Average Delay Comparison

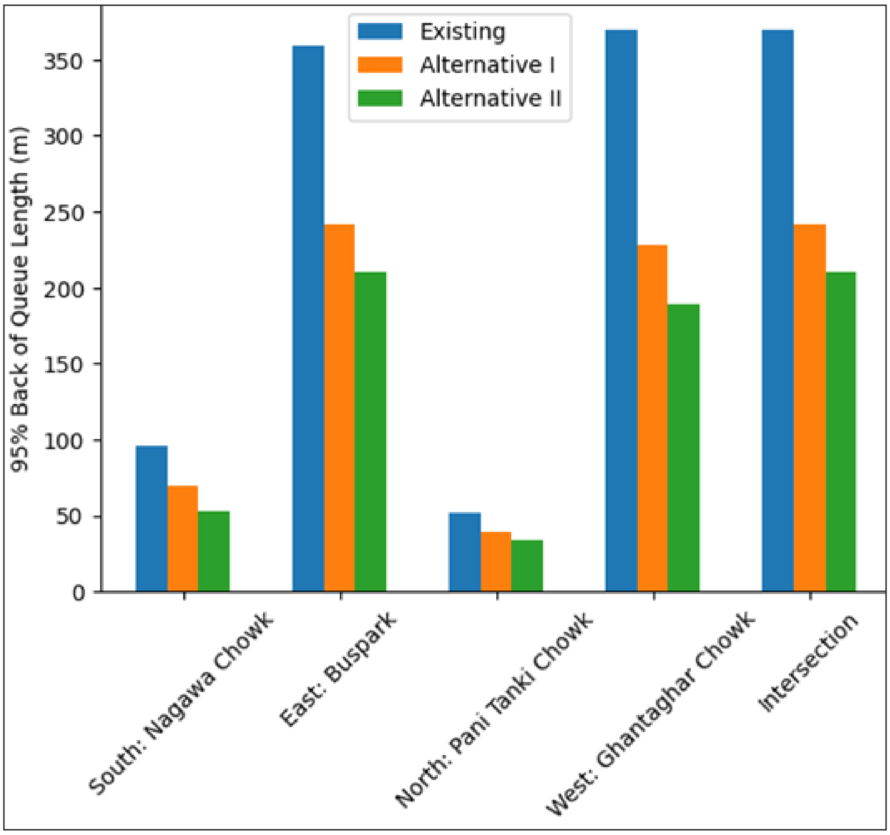

Figure 7.95 % Back of Queue Length Comparison

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Conclusions and Recommendation

The intersection currently operates as an unsignalized intersection under manual control by traffic police, with a Level of Service (LOS) rated as 'E.' This indicates that the current state of the intersection is unsatisfactory and requires immediate improvement. To address this issue, two potential scenarios have been proposed to minimize average delay and the length of the queue, ultimately enhancing the intersection's LOS. The first proposed change involves optimizing the cycle length, while the second change includes controlling left-turn movements in addition to cycle length optimization. Both of these approaches have led to significant reductions in delay and the length of the queue at the intersection. However, when comparing the two alternative scenarios, the second scenario, which incorporates left-turn control alongside cycle length optimization, proves to be more efficient in minimizing average delay and the length of the queue.

This study demonstrates the potential of operational measures to improve the performance of intersections without requiring high investments in further physical improvements. Most intersections in urban areas in Nepal suffer from inefficient operationalization, hence there is a need to explore possible alternatives to reduce delays and queues. This, in turn, helps to reduce pollution by decreasing fuel consumption and provides other economic and environmental benefits.

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