

Performance Improvement through Signal Optimization: A Case Study of Ekantakuna Intersection

Riti Shrestha¹, Umanga Man Nyachhon^{2*}, Samyak Shrestha³, Rahul Maharjan⁴,
Sabil Lal Amatya⁵

¹Department of Civil Engineering, Kantipur Engineering College, Tribhuvan University, Nepal, kan078bce069@kec.edu.np

²Department of Civil Engineering, Kantipur Engineering College, Tribhuvan University, Nepal, kan078bce093@kec.edu.np

³Department of Civil Engineering, Kantipur Engineering College, Tribhuvan University, Nepal, kan078bce074@kec.edu.np

⁴Department of Civil Engineering, Kantipur Engineering College, Tribhuvan University, Nepal, kan078bce064@kec.edu.np

⁵Department of Civil Engineering, Kantipur Engineering College, Tribhuvan University, Nepal, kan078bce071@kec.edu.np

Abstract

Traffic congestion has long been one of the most persistent challenges in Kathmandu Valley. Intersections have emerged to be a primary factor contributing to this problem where congestion largely undermines efficiency in daily travel. This study focuses on assessing the present operational conditions at critical junction in the ring road, namely Ekantakuna and exploring measures to improve performance at intersection using SIDRA 8.0. Video graphic survey was conducted for 3 consecutive weekdays. To determine peak traffic periods, a 12-hour volume count was extracted from one day of the data, establishing peak ranges for both morning and evening. From this analysis, volume count within the range was carried out for remaining days and maximum peak hour from the three days was taken for the study. Data collected from the Peak hour which includes; Traffic volume, Back of Queue, Saturation flow etc. were applied for the formulation of model to assess the present condition of intersection and recommend different improvement measures. The current operational performance at Ekantakuna showed an average delay of 72.7 seconds and Level of Service (LOS) of E. Two alternatives were approached among which, Alternative 1 targeted Signal Optimization, reducing average vehicular delay from 72.7 seconds to 53.6 seconds and improving LOS to D. Similarly, Grade-Separated intersection was introduced in Alternative 2, it further reduced Average delay from 72.7 seconds to 40.1 seconds while maintaining an improved LOS of D. The findings from the study conclude that targeted model-based optimization can substantially enhance the operational performance of intersection.

Keywords: Intersection, SIDRA, Signal Optimization, LOS, Average Delay

1. Introduction

An intersection is a shared space designed to facilitate the orderly traffic movement between two or more converging routes. However, these points of convergence often become bottlenecks, characterized by decreased efficiency, increased congestion and delay, and safety concerns. In South Asian urban centers, such as Kathmandu Valley, these challenges are amplified by heterogeneous traffic conditions. Research into traffic behavior in South Asian cities emphasizes that standard traffic models designed for lane-disciplined, car-only environments often fail in heterogeneous conditions. They noted that in countries like Nepal and India, traffic is characterized by a gap-filling behavior where motorcycles and smaller vehicles occupy every available space, rather than following strict lanes [1]. In developing cities, Road traffic jams continue to remain a major problem due to poorly planned networks resulting in elongated traffic congestion [2].

Nepal is one of the fastest urbanizing countries in Asia with more than 5% average growth rate and Kathmandu Valley becoming one of the fastest urbanizing cities [3]. With rapid urbanization, the city has seen unprecedented growth in motorization, resulting in increased traffic congestion, road safety and economic inefficiency. As intersections have proven to be the focal point where the disruptive effects originate, it is very important to manage the performance of intersection. Traditionally, intersections in Nepal have been managed manually by traffic police, which has proven inadequate in handling complex and

* Corresponding author

heterogeneous traffic conditions. At present, signalization serves as the immediate control mechanism however proper signal optimization is needed to enhance the performance of congested junction.

In our context, the intersection at Ekantakuna, located along Ring Road in Lalitpur represents a critical failure point in the valley's transport network. The intersection caters traffic from one of the most congested areas, Satdobato, Bhaisepati, Jawlakhel and Nakkhu Dobato. At present, this junction lacks modern signal systems and traffic police rely on manual control. This reliance on manual control has led to inconsistent traffic flow, excessive delay, long Back of Queue (BOQ) and poor Level of Service (LOS) during peak hours. Given the rising urban congestion, there is an urgent need to evaluate the performance of intersection as several studies highlights the fact that unsignalized intersections in emerging cities are accident hotspots which requires signalization to reduce delays and improve safety [4]. Therefore, this research aims to fill that gap by providing practical recommendations and improvement measures.

2. Literature Review

Traffic Signal optimization has been widely studied as a measure to cut delay substantially and improve intersection efficiency. International research demonstrates that retiming and coordination of signals can significantly bring changes. In Al-Bayda, a study examined four signalized intersections with SIDRA software to evaluate traffic performance during peak hours. Initially, the intersections suffered from long delays and poor LOS ratings which exhibited improvement after applying optimized signal timings. The average delays showed significant drop, i.e., by 32.3% to 44.3% in the morning and 45.8% to 69.5% in the evening. These results highlight how signal optimization can transform congested intersections into more efficient system [5].

Similarly, a different study was conducted in Malaysia at four intersections along with two roundabouts in Kuala Lumpur and Petaling Jaya using SIDRA version 4.0. By analyzing parameters like delay, queue length, travel time, and speed during morning and evening rush hours, researchers found that optimization cut delays substantially. Morning delays fell from 3489 seconds to 1571 seconds, while evening delays dropped from 5093 seconds to 1663 seconds. This showed ultimate reductions of 45% and 33% respectively. These results highlight the measurable benefits of signal optimization [6].

Research in Traffic behavior emphasizes that standard traffic models often fail under heterogeneous condition. However, a study was conducted in Baghdad, showing how SIDRA can be applied in developing cities with heterogeneous traffic. It identified high saturation and long delays which demonstrated SIDRA's ability to reveal inefficiencies in intersections [7]. In the same manner, a study in Karlbala city in Iraq examined intersection performance under heterogeneous traffic conditions relevant to Asian cities. Field data was collected for 7 days from 7 AM to 6 PM in order to final specific peak hour [8].

In the Nepalese context, a case study of Satdobato and Gwarko intersections was conducted and the operational performance under existing conditions was found to be LOS F with an average delay of 226.5 seconds per vehicle at the Satdobato intersection and 201.1 seconds per vehicle at the Gwarko intersection. It was eventually concluded that isolated signal optimization was more beneficial [9]. Similarly, the case study of Thapathali Intersection demonstrated that, the intersections performs at LOS F during weekdays and LOS D during weekends [10]. It was concluded that with geometric enhancements, the performance will be enhanced. The considerations in this study can be reflected for Ekantakuna intersection having similar mixed traffic conditions.

Likewise, a study was conducted that focused on traffic congestion in Kathmandu valley, specifically at Shital Niwas and Kanti Children's Hospital intersections. The results showed that by coordinating the signal systems, the average delay time and maximum queue length were significantly reduced at both intersections [11]. Using SIDRA Intersection 8.0, a study was conducted in Jay Nepal Intersection in Kathmandu which revealed severe over-saturation with unacceptable LOS with an average delay of 119.3 seconds. To address this, the study compared two mitigation measures and incorporating left turning movements into the signal control was vastly superior [12].

A study has been done in the Ekantakuna intersection using VISSIM software and it studied three scenarios among which it suggested the restriction of vehicles from service lanes to main lanes as the best scenario [13]. On that account, it has been observed that for improving intersection performance on Nepalese intersection, software like VISSIM and SIDRA are widely used. However, this study uses SIDRA based modelling for assessing performance of the Ekantakuna intersection. The present research seeks to advance the application of signal optimization along with other measures in Nepalese traffic management.

3. Study Area

Ekantakuna Intersection is located within Bagmati province with coordinates 27.6723N, 85.3111E (Decimal degrees). A busy cross road connecting National highway (NH39) to arterial roads. It's approach legs include Satdobato, located at Southeast side from intersection, Bhaisepati/Petrol pump, entering from the southwest, Nakkhu Dobato intersection, located at northwest approach and Jawlakhel, entering intersection from northeast side. The lane configuration on South east and North west approach consists of four lanes each of lane width 3.75 meters on each direction. South west approach with two lanes of 2.6 meters and North east approach with two lanes of 2.5 meters on each direction. These lane accommodates mix vehicle types including, Car, Motor bike, Public Bus, Multi-axle vehicle, Micro bus etc.



Figure 1. Site Location

4. Methodology

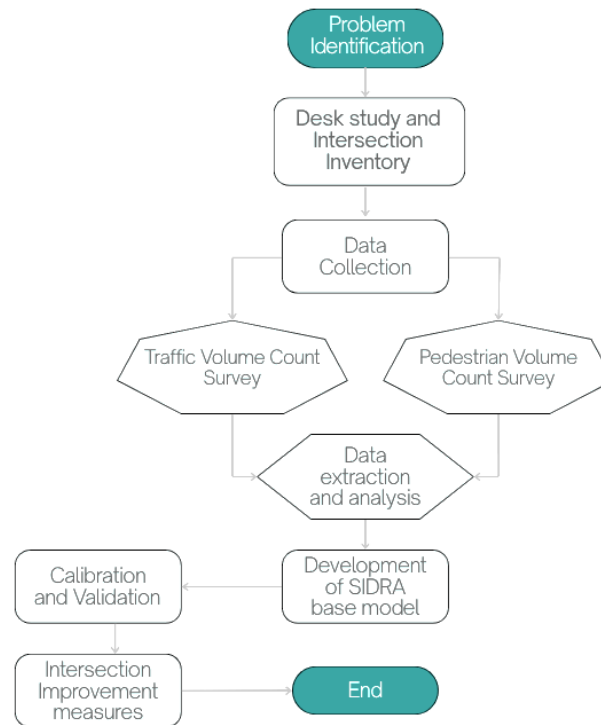


Figure 2. Work Flowchart

Figure 2 illustrates the overall methodological framework of the study. The study started with comprehensive site assessment of the selected study area followed by desk study, during which, details such as; location data, physical features, land use observation, current status of traffic etc. were studied. To ensure research was grounded in the local context, we performed a review on past studies, signal optimization and coordination projects that were conducted across Nepal.

Next, data collection was done through video graphic method, our CCTV cameras were installed at high altitude buildings making sure that it captured all traffic movements. The video graphic survey was carried out for 3 consecutive weekdays from 7:00 AM to 7:00 PM. Once the video was secured, data extraction process was done, the primary task during extraction is classified volume count, for which vehicles were divided into 12 different categories. Vehicles approaching the intersection going through as well as diverting to other directions were counted manually. In addition to this, further required data which includes: approach speeds, BOQ and geometric data were acquired. A base model was then formulated which was infused with all the accumulated data such that it replicates the real world scenario. The model was then calibrated and validated in order to fine-tune said model to best replicated actual conditions as seen presently. Once the model was validated, different strategies were implemented and they were compared to existing condition and significant improvement was noted. The details are provided in the following sections.

4.1 Data Extraction and analysis

4.1.1 Traffic volume and Pedestrian count

Once the recordings were secured, we began to extract traffic volume manually where vehicles were divided into 12 different categories. As every vehicle take up different amounts of space in road, Passenger Car Unit (PCU) factors were applied to the vehicle types. The volume was extracted for 12 hours i.e. from 7:00 AM to 7:00 PM for one of the days in intervals of 15 minutes. Then from 12-hour volume count data, peak range was established for both morning and evening period. Traffic flow was recorded in 15-minute intervals throughout the selected morning and evening windows. The maximum value from three-day peak period data

served as final peak and was used to evaluate peak hour conditions. The analysis revealed the peak hour to be between 9:15 AM to 10:15 AM for Ekantakuna.

Similarly, the volume of pedestrian crossing in the major as well as minor lane for both intersection was counted during the peak hour. Since the pedestrian crossing movement was random, the volume was taken only for those around the periphery of the intersection.

Table 1. Passenger Car Equivalency factor

Vehicle Type	PCU factor
Multi axle	4
Heavy Truck	3
Light Truck	1.5
Big Bus	3
Mini Bus	2.5
Micro Bus	1.5
Car	1
Motor Cycle	0.5
Utility Vehicles	1
Four-Wheeler	1
Tractor	1.5
Three-Wheeler	1
Cycle	0.5

4.1.2 Cruise speed

The speed limit of the road section was 50 kmph. Vehicle speeds were determined by conducting spot speed study and sampled during off peak hours across all intersection legs. The study aimed to collect 50 samples per vehicle category. However, certain classes- specifically, heavy truck, light truck and bus exhibited low frequency in certain approach at the site. The resulting 85th percentile speeds were then integrated into the SIDRA model for performance evaluation. The cruise speeds observed at Satdobato leg was 41 kmph, Nakkhu Dobato leg was 38.71 kmph, Jawlakhel leg was 32.53 kmph and Petrol pump leg was 30.17 kmph.

4.1.3 Back of Queue

Back of Queue (BOQ) data were collected during peak hour operations. The data captures the facility under its most significant stress, ensuring that the resulting values reflect worst-case operational reality rather than average conditions. This sample was distributed evenly across the intersection, with five observations recorded for each of the four lanes and 95th percentile BOQ was taken for validation.

4.1.4 Field measured Saturation flow

The saturation flow at field is measured while there is free flow of vehicle and once the queue is moving steadily. It is typically measured over several cycles to account for variability and data is collected during peak hour when queues are long enough. For lanes with low volume and no formation of queue, field saturation value was considered to be 1950 pcu/hr, which is the default basic saturation flow in SIDRA. In petrol pump approach, highest saturation flow was observed which is 2689 pcu/hr.

4.1.5 Phasing and Signal Timing

Phasing and signal timing data were extracted from video footage. Although the intersection is actively managed by traffic police and there is no presence of traffic signal, this study adopts a signalized framework for modelling purpose treating manual interventions as signalized traffic control. There was randomness of vehicle arrival pattern which made it difficult to separate phase thus, the most frequently occurring phase sequence and duration was selected as the representative for each site. It was observed that Ekantakuna operates on cycle time of 261 seconds across five distinct phases.

Table 2. Existing Phase Timing

Phase:	A	B	C	D	E
Phase time (sec)	47	72	16	56	70
Yellow time:	4	4	4	4	4
Red time:	0	0	0	0	0



Figure 3. Existing Phase Sequence

4.2 Development of SIDRA base model

A base model was created for Ekantakuna intersection such that it replicates the real time scenario of the intersection. It serves as the foundation model and is created in SIDRA using; intersection geometry, traffic volumes, lane movements etc.

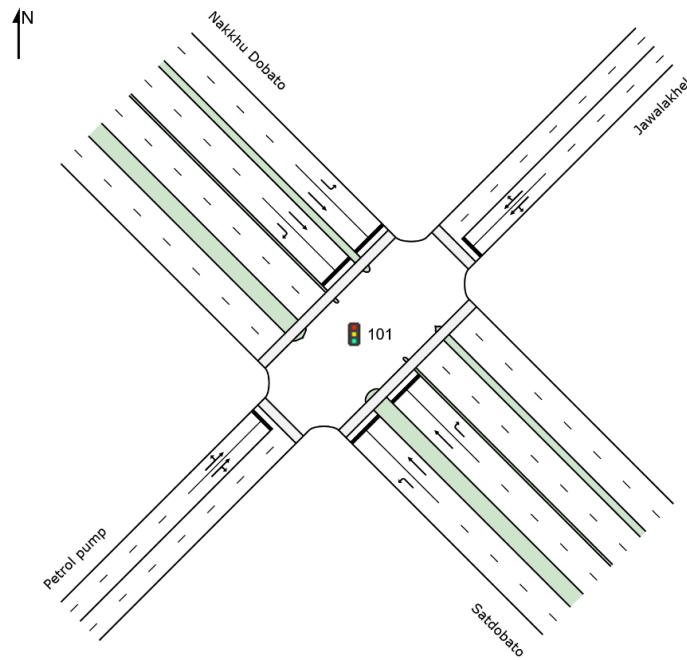


Figure 4. SIDRA base model for Ekantakuna Intersection

4.2.1 Calibration of SIDRA base model

Calibration is the process by which model is adjusted so its output matches observed field data. Calibration is basically about tuning parameters. Calibration involves adjusting parameters related to traffic demand, driver behavior, and intersection geometry so that the performance matched field conditions. In this case, calibration was done using basic saturation flow.

The basic saturation flow of each lane was calculated using empirical formulas derived from Indo-HCM and is compared against field measured saturation flow based on GEH statistics. GEH statistics is developed by Geoffrey E. Havers in the 1970s to assess the goodness of fit between traffic model outputs and real world traffic counts. The value of GEH should be less than 5 as recommended by [14]. If the value of GEH is not less than 5, saturation flow is adjusted through local calibration to match the field measured saturation flow rate and better reflect the actual intersection conditions in base model.

Table 3. Calibration of Basic Saturation flow

LEGS&LANES	Field Saturation flow	Model estimated saturation flow	GEH statistics	Adjusted Saturation flow (PCU/hr) (provided)
Satdobato(L1)	1950	1950	0	1835.76
L2	2603.893	2688	1.635	2530.49
L3	2603.893	2688	1.635	2530.49
L4	2022.594	1975	1.065	1859.62
Jawalakhel(L1)	2085.307	1987	2.179	2018.05
L2	2085.307	1987	2.179	2018.01
Nakkhu Dobato(L1)	1950	1950	0	1835.80
L2	2142.527	1997	3.199	1880.93
L3	2142.527	1988	3.400	1871.52
L4	1950	1950	0	1835.15
Petrol Pump(L1)	2505.38	2688	3.584	2803.74
L2	2505.38	2688	3.584	2803.39

4.2.2 Validation

Once the model calibration is completed, validation begins. This step ensures that model doesn't just work for one specific data set. For this study, validation was done using Back of Queue (BOQ). The field measured BOQ and model estimated BOQ were computed to acceptance criteria of within 20% difference. If the difference is larger, it suggests the model isn't yet ready for making real world infrastructure scenarios [14].

Table 4. Validation using BOQ

Approach	95% BOQ (m)		
	Model Estimated	Field Estimated	Difference %
Satdobato	348.7	304.638	12.63%
Jawalakhel	239.9	194.412	18.96%
Nakkhu Dobato	324.4	260.096	19.82%
Petrol Pump	371.0	297.188	19.89%

5. Performance Analysis

5.1 Performance of network under existing condition

The SIDRA model was developed for Ekantakuna intersection with thorough calibration and validation of relevant parameters. The model was then processed in software in order to analyze the existing performance of the intersection. The overall LOS of intersection was found to be E for vehicular movement and it remained F for pedestrian movement. The operational performance is as mentioned in the table below.

Table 5. Operational Performance of Ekantakuna

Approach	Lane	Demand Flows		Average Delay sec	Level of Service	95% Back of Queue	
		Total veh/h	HV %			Veh	Dist m
Satdobato	Lane 1	1224	1.2	4.2	LOS A	11.9	30.8
	Lane 2	1364	4.1	53.1	LOS D	121.6	348.7
	Lane 3	1364	4.1	53.1	LOS D	121.6	348.7
	Lane 4	709	1.1	163.6	LOS F	107.9	308.9
	Approach	4662	2.9	57.1	LOS E	121.6	348.7
Jawlakhel	Lane 1	840	1.6	88.2	LOS F	91.7	239.9
	Lane 2	596	1.6	89.1	LOS F	65.7	183.7
	Approach	1436	1.6	88.6	LOS F	91.7	239.9
Nakkhu Dobato	Lane 1	142	8.9	7.6	LOS A	3.1	9.6
	Lane 2	915	6.4	81.8	LOS F	102.9	324.4
	Lane 3	910	6.4	81.8	LOS F	102.4	322.9
	Lane 4	53	0.0	123.2	LOS F	6.2	13.7
	Approach	2020	6.4	77.7	LOS E	102.9	324.4
Petrol Pump	Lane 1	1394	0.1	80.4	LOS F	146.8	371.0
	Lane 2	1027	0.2	101.3	LOS F	118.9	309.7
	Approach	2421	0.1	89.3	LOS F	146.8	371.0
Overall Intersection		10539	2.7	72.7	LOS E	146.8	371.0

5.2 Performance of network after signal optimization (Alternative 1)

Signal optimization basically involves finding optimal cycle length that balances green time across approaches to minimize overall delay. In the same manner, the cycle time was optimized and optimum cycle time was 140 seconds distributed across 4 phases. The average delay of intersection reduced from 72.7 seconds to 53.6 seconds whereas the LOS went from E to D. Likewise, the LOS for pedestrian movement remained F. The performance analysis along with phase timing summary and phase diagram using the optimum cycle length is shown below.

Table 6. Performance analysis after Alternative 1

Approach	Lane	Demand Flows		Average Delay (sec)	Level of Service	95% Back of Queue	
		Total(veh/h)	HV %			Veh	Distance (m)
Satdobato	Lane 1	1224	1.2	11.4	LOS B	31.2	81.0
	Lane 2	1364	4.1	64.1	LOS E	100.4	287.9
	Lane 3	1364	4.1	64.1	LOS E	100.4	287.9
	Lane 4	709	1.1	52.4	LOS D	43.2	123.8
	Approach	4662	2.9	48.5	LOS D	100.4	287.9
Jawlakhel	Lane 1	771	1.6	70.3	LOS E	56.5	148.0
	Lane 2	665	1.7	72.0	LOS E	49.4	137.2
	Approach	1436	1.6	71.1	LOS E	56.5	148.0
Nakkhu Dobato	Lane 1	142	8.9	8.3	LOS A	2.5	7.6
	Lane 2	915	6.4	66.2	LOS E	69.6	219.3
	Lane 3	910	6.4	66.3	LOS E	69.3	218.4
	Lane 4	53	0.0	39.3	LOS D	2.5	5.5
	Approach	2020	6.4	61.5	LOS E	69.6	219.3
Petrol Pump	Lane 1	1259	0.1	45.5	LOS D	73.4	185.4
	Lane 2	1162	0.2	47.5	LOS D	68.0	176.7
	Approach	2421	0.1	46.5	LOS D	73.4	185.4
Intersection		10539	2.7	53.6	LOS D	100.4	287.9

Table 7. Phase timing after Alternative 1

Phase	A	B	C	D
Phase Change Time (sec)	0	37	77	101
Green Time (sec)	33	36	20	35
Phase Time (sec)	37	40	24	39
Phase Split	26%	29%	17%	28%

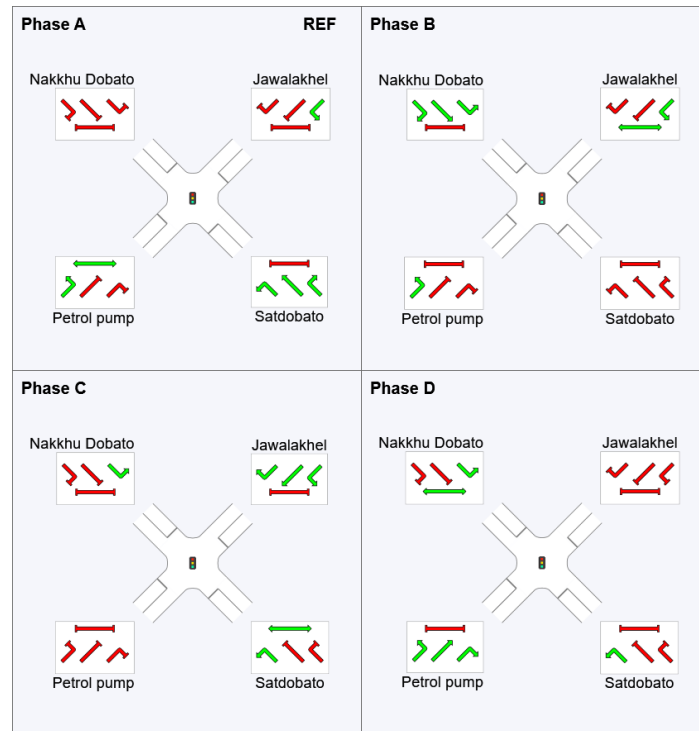


Figure 5. Phase diagram after Alternative 1

5.3 Performance on network after introduction of Grade separated intersection (Alternative 2)

The second alternative explored was the implementation of grade separated intersection. Under this configuration, the traffic flow was segregated with a projected 70% of total volume diverted to overpass/underpass structures whereas 30% of the volume utilized the at-grade lanes. The design basis of 30% flow split through at-grade lanes was established based on the study of Gwarko intersection, which observed a 20% at-grade traffic allocation [9]. To account for the service lane dynamics and localized movements, a conservative 30% at-grade allocation was adopted. To physically represent the footprint of grade separated structure, the median or barrier width was adjusted to match the dimension of Gwarko flyover. The geometric layout of the intersection is shown in the figure below.

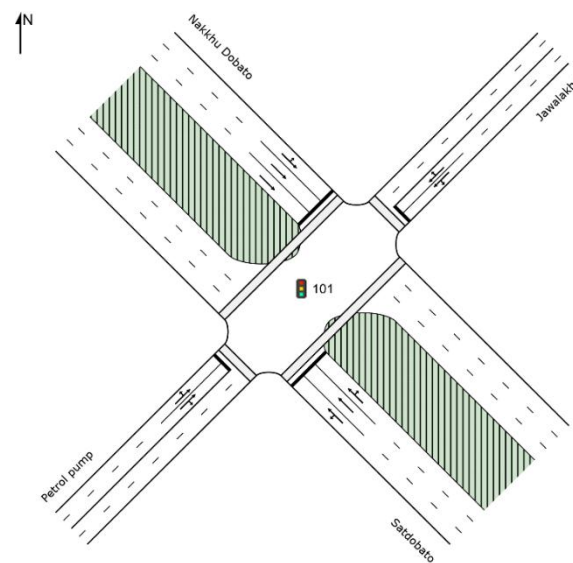


Figure 6. Geometric layout of Ekantakuna intersection with Grade-separated option

The model was allowed to perform at optimized condition which operated at 130 seconds of cycle time and was distributed across 4 phases. There was a substantial reduction in average delay from 72.7 seconds to 40.1 seconds with a drop of LOS from E to D and for pedestrian movement LOS dropped from F to E. The operational performance under this option is presented in the table below.

Table 8. Performance analysis after Alternative 2

Approach	Lane	Demand Flows		Average Delay sec	Level of Service	95% Back of Queue	
		Total veh/h	HV %			Veh	Dist m
Satdobato	Lane 1	1292	1.6	25.7	LOS C	54.0	141.7
	Lane 2	812	9.3	31.0	LOS C	38.5	122.6
	Lane 3	709	1.1	50.7	LOS D	40.7	116.6
	Approach	2814	3.7	33.5	LOS C	54.0	141.7
Jawlakhel	Lane 1	770	1.6	48.5	LOS D	44.0	115.1
	Lane 2	666	1.7	49.0	LOS D	38.3	106.4
	Approach	1436	1.6	48.7	LOS D	44.0	115.1
Nakkhu Dobato	Lane 1	305	9.9	54.9	LOS D	17.8	60.1
	Lane 2	259	10.8	54.4	LOS D	15.2	55.8
	Lane 3	323	10.8	56.4	LOS E	19.7	72.2
	Approach	887	10.5	55.3	LOS E	19.7	72.2
Petrol Pump	Lane 1	1259	0.1	36.0	LOS D	66.7	168.5
	Lane 2	1162	0.2	38.2	LOS D	61.9	160.7
	Approach	2421	0.1	37.1	LOS D	66.7	168.5
	Intersection	7558	3.0	40.1	LOS D	66.7	168.5

6. Comparison of alternative measures with existing condition

The performance changes were accessed by comparing the Level of Service (LOS), Average delay time and Back of Queue (BOQ). At present, Ekantakuna operates at LOS E where average delay of 72.7 second occurs with 371.0 m long formation of queue. With the intention of reducing the delay and BOQ, two alternatives were provided. Alternative 1, signal optimization reduced about 22.4% queue than the original. It also reduced average delay from 72.7 seconds to 53.6 seconds. In the same way, Alternative 2 introduced concept of Grade-separated intersection which reduced about 54.6% queue compared to the original and average delay to 40.1 seconds.

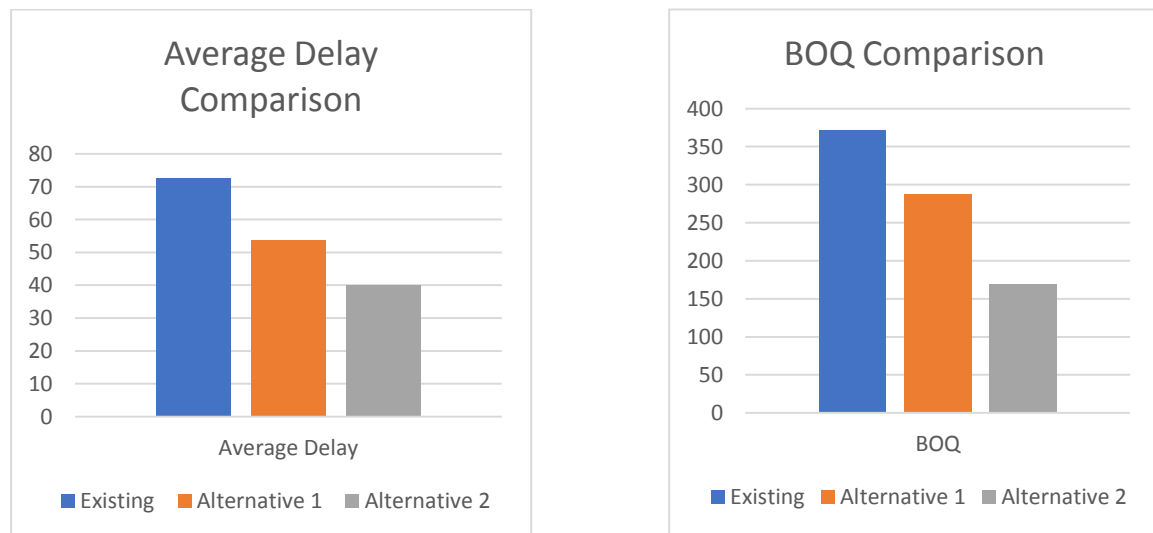


Figure 7. Comparison Chart of Average delay and BOQ

7. Discussion

This study utilizes the SIDRA based signal optimization methodology to enhance the performance of Ekantakuna intersection. The application of SIDRA software, alongside intersection performance metrics (average delay, LOS, BOQ), is well supported by and consistent with recent traffic research conducted in Nepal. A recent study was conducted in Satdobato and Gwarko intersection where, isolated signal optimization was found to be beneficial as compared to coordination of two intersections [9]. Furthermore, a previous micro-simulation study at Ekantakuna intersection using VISSIM software concluded that restriction of vehicles from service lanes to main lanes turned out to be effective [13]. The present study shifts the focus towards signal optimization and advanced geometric interventions rather than movement restrictions. Specifically, this paper explores the operational benefits of both measures which significantly contributes in reducing intersection delays and queue lengths.

8. Conclusion and Recommendations

In conclusion, this study provides comprehensive assessment of the prevailing traffic condition at Ekantakuna which is a currently unsignalized intersection operated solely by traffic police manually. This study explored the operational benefits of optimizing the signal cycle length and also explored advanced grade separated measure. Both approaches contributed to reducing delays and queue lengths, with grade separation measure being more effective. However, optimizing signal cycle length seem to be the most practically implementable short term solution.

Notably, pedestrian LOS was not significantly improved in both alternatives which suggests that signal optimization and grade separated intersections alone are not sufficient, and specific, dedicated strategies for pedestrian walking must be prioritized. Study of pedestrian vehicle interaction is highly recommended for future research. Ultimately, this study aimed to bridge the gap between theoretical traffic models and practical field applications. The study concludes that model based signal optimization can substantially enhance the performance of intersection.

Traffic congestion has been growing at an alarming rate spreading inefficiencies at many intersections in Nepal. Efficient traffic management at urban intersections is a critical component of sustainable transportation systems. Therefore, implementing such strategies can help reduce delay, queues, fuel consumption contributing to improved performance of local traffic.

9. Limitations

- The evaluation is done considering present traffic volume which may not account for future traffic growth.
- SIDRA is a deterministic modelling tool which assumes steady state of traffic which is completely opposite of the traffic conditions in Nepal.

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