Proceedings of 13th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2023 Month: April Volume: 13

Performance Evaluation and Improvement of an Intersection : A Case Study of Thapathali Intersection

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Abstract
The Thapathali Intersection located in Kathmandu Valley is a crucial junction connecting the city to Lalitpur and other major intersections like Maitighar and Tripureshwor. Given its high traffic volume, there is a need for a detailed analysis of the current operational performance of the intersection and the exploration of new solutions to improve its efficiency. A video-based survey was conducted over a period of 5 days including 3 weekdays and 2 weekends to gather data. The manual vehicle count was performed using custom manual counting software and the data was analyzed. The peak hour traffic volume during the weekdays was 5,593 PCU in the morning and 4,883 PCU in the evening, while the weekend traffic volume was 4,652 PCU in the morning and 4,547 PCU in the evening. On average, motorcycles constituted 70.58% of the total traffic. The simulation model of the intersection was developed using the traffic analysis software SIDRA for both weekdays and weekends. After the models were calibrated and validated using the 95th percentile back of queue (BoQ), the performance of the intersection was evaluated under the current traffic policed controlled scenario. The analysis revealed average delays of 99.6 seconds/vehicle and 35.1 seconds/vehicle for weekdays and weekends respectively, with level of service (LoS) F and D and average speeds of 16.6 kmph and 24.7 kmph respectively. Six alternative models were proposed for weekdays and weekends through lane reconfiguration and phasing and timing reconfiguration. The LC3-2 model with a performance index of 1888.8 and average delay of 24.1 seconds/vehicle was found to be the best option for weekdays, while the LC6-2 model with a performance index of 1394.4 and average delay of 18.1 seconds/vehicle was the best option for weekends. The future performance of the intersection was evaluated for the time periods of 3, 5 and 10 years, indicating that the weekday model will maintain LoS E till 2027 and the weekend model will maintain LoS E till 2032. It is recommended to perform a geometric upgradation of the intersection after 2032 with addition of lanes and reconfiguration phase timing so that the intersection operates under LoS of C and B for weekdays and weekends respectively.

Keywords
Intersection, Peak hour volume, SIDRA, Back of Queue (BoQ), Delay, Level of Service (LoS), Performance Index (PI)

1. Introduction

It is common knowledge to the people of Kathmandu Valley that its road traffic is suffering from congestion the main reasons being rapid population increase, haphazard urban sprawl, and inadequate urban infrastructures and planning [1]. The congestion of roads and public transport are taking place even in the off-peak hours. Especially, the intersections and nearby areas are getting serious hits due to congestion affecting the day-to-day activities of the citizens. The problems seen at such intersections are severe traffic congestion, increasing traffic accidents, a substantial amount of vehicle emissions, degradation of urban amenities, etc.

Traffic congestion is a condition where the demand exceeds the capacity of the transport infrastructure which is characterized by slow traffic speeds, longer travel times, and long vehicle queues. If the number of vehicles using a road or intersection exceeds its capacity, it can lead to congestion as the traffic flow slows down. The problem of traffic congestion is even worse for developing countries like Nepal due to restricted rights of way, limited financial resources, and lack of advanced technology.

An intersection refers to a point where two or more roads meet or cross each other. The operating efficiency of a highway and the safety thereof depend on the number and types of intersections en-route and the efficiency of the design of these intersections[2].

Intersections play an important role in managing conflicts and merging traffic streams. The geometric and traffic studies and assessments can be done at a selected intersection which leads to determining if the intersection is operating well in its capacity or if traffic flow exceeds the capacity. Travel time and delay analysis is a major part of the intersection study. The analysis of traffic congestion often highlights delay as a significant issue at intersections. Conducting a study of intersection delays is a useful tool for assessing the operational effectiveness of an intersection in managing traffic flow.

2. The Problem statement and the objective of the study

2.1 Problem Statement

The total number of motor vehicles plying across the country reached nearly 3.1 million as of mid-May, according to a data of Department of Transport Management (DoTM)[3]. The escalating number of vehicles in the Kathmandu valley, driven by the improvement of the economy and living standard of the population, has necessitated the need for wider road networks with advanced traffic control systems. However, the increasing population and haphazard urban sprawl have imposed limitations on land acquisition for road widening. Urban road networks have relatively medium and large intersections which are usually closely spaced. As a result, there is more traffic congestion, especially during peak hours. Kathmandu lacks even a single flyover, and the majority of traffic lights that could help control traffic are inoperable. The majority of the busy crossroads have traffic cops directing the traffic. This has necessitated the implementation of efficient, state-of-the-art traffic management systems to mitigate congestion. One such intersection is Thapathali, which is equipped with channelizing islands and staged pedestrian crossings, however, during peak hours, traffic congestion is observed to extend beyond nearby intersections such as Maitighar and Tripureshwor. The Thapathali intersection experiences a significant volume of vehicular traffic due to the presence of government offices beyond the Maitighar intersection, as well as the proximity of two major hospitals (Norvic and Maternity Hospital) to the east of the intersection. Additionally, the presence of a large commercial shopping center (Bhatbhateni Supermarket) beyond the Tripureshwor intersection and proximity to the Kalimati Market also contribute to the high volume of trip generation at this intersection. Thus, an in-depth performance evaluation and improvement study must be conducted at the Thapathali intersection to improve the traffic flow.

2.2 Objectives

The primary objective of this study is to provide a current picture of the status of traffic in a signalized intersection of Thapathali in terms of degree of saturation (DoS), level of service (LoS), delay, queue length, and average travel speed and then provide multiple probable solution measures to improve the current situation.

1. To identify the current traffic situation and LoS at the intersection by evaluating travel time and delays after the calibration and validation of the microsimulation model.
2. To provide possible solutions and alternatives to improve the existing condition of the intersection by making a comparative analysis among the alternatives based on travel time, delay & queue length.

3. Literature Review

3.1 Traffic Signal Optimization

When optimizing signal control at isolated intersections, the emphasis is usually on optimizing cycle length, green signal ratio, and phase sequence. However, insufficient attention is paid to phase design when traffic conditions change over time. Inadequate phase design can undermine the effectiveness of subsequent signal timing optimization. Moreover, effective signal control at isolated intersections is a prerequisite for coordinated signal control at arterial intersections. Therefore, optimizing the phase design of isolated intersections is crucial.[4].

In general, it was found that optimizing cycle lengths is more beneficial than optimizing splits. It can decrease the total amount of delay and the total travel time and increase the average speed. It may also decrease fuel consumption but may increase the amount of hydrocarbon and carbon monoxide emissions[5].

The inefficient operation of traffic signals is a common problem certainly experienced by all network users. Traffic control signals that are improper or unjustified can cause a range of negative consequences, including excessive delays, increased disobedience of traffic laws, higher usage of less adequate routes, and a significant increase in rear-end collisions[6].

If designed and timed correctly, a traffic signal can facilitate the smooth and efficient movement of people and vehicles in an orderly manner. Besides this, traffic signals can maximize the volume of movements served at the intersection hence increasing the capacity. Tthey can help reduce the frequency and severity of certain types of crashes while ensuring appropriate levels of accessibility for pedestrians and side street traffic[7].

Traffic signal retiming is a highly cost-effective method for enhancing traffic flow and represents a basic strategy for mitigating congestion. Implementing up-to-date signal timing can lead to a range of benefits, such as shorter commute times, improved air quality, lower frequency and severity of certain types of crashes, and decreased driver frustration[8].

3.2 Performance Evaluation

Synchro and SimTraffic models were created in assessing and optimizing signal timing plans for a signalized intersection with separate models for the afternoon and off-peak periods. After optimizing the existing signal timing plan, using Synchro's "Optimization by Intersection Splits", it was found that the intersection average delay decreases in the orders of 9 to 11% for the off-peak and 4 to 5% for the PM-peak. Using Synchro's "Optimization by Cycle Length", it was found that the delays decrease in the orders by 30 to 35% both for the off-peak and the PM-peak hours[5].

According to Abojaradeh et al.'s study, which used the HCM (Highway Capacity Manual) and HCS (Highway Capacity System) computer systems to analyze traffic at a signalized intersection, the delay was found to be 473 seconds per vehicle, with a Level of Service (LoS) of F. They proposed 4 different alternatives and found 4th alternative i.e., the construction of two overpasses to reduce LoS to LoS-C with a delay of 27 sec/veh[9].

Kumar and Dhinakaran determined control delay for five isolated signalized intersections using guidelines by HCM 2000 and didn't find a good correlation between observed and predicted delay. So, they accounted field measured control delay for defining LoS[10]. Shrestha and Marsani conducted an evaluation of the New Baneshwor Intersection using VISSIM and proposed five alternatives for reducing congestion. They found that the most effective solution was the fifth alternative, which involved three-phase signal planning with a flyover and the provision of a U-Turn at a distance of 300 meters. This solution was able to decrease the Level of Service (LoS) from F to C.Based on travel time and delay reduction using five comparative models, it was found that the third alternative, three-phase signal planning with a flyover by providing a U-Turn, effectively reduced delay and travel time by 81.92% and 80.1% during morning and evening peak times, respectively, while maintaining a LoS C. In addition, traffic in areas such as Maitighar, Tinkune, Old Baneshwor, and Sankhamul Lane decreased by a minimum of 60% during both morning and evening peak times. This solution was deemed the most technically efficient to be implemented[11].

3.3 SIDRA Intersection

SIDRA Intersection software is a powerful and comprehensive tool for analyzing and designing individual intersections and networks. It uses a micro-analytical approach and can model separate movement classes such as light vehicles, heavy vehicles, buses, bicycles, large trucks, light rail/trams, and more. The software can estimate a range of performance measures including capacity, level of service, delay, queue length, stops for vehicles and pedestrians, fuel consumption, pollutant emissions, and operating costs[12].

The SIDRA Intersection software is an advanced micro-analytical traffic analysis tool developed by the Australian Road Research Board (ARRB) for signalized intersections. It is a powerful tool that provides detailed and accurate analysis of traffic flow and performance, including capacity, level of service, delay, queue length, and more[13].

In addition to analyzing signalized intersections, the SIDRA Intersection software can be utilized in various other traffic scenarios, such as those involving uninterrupted traffic flow and merging analysis, due to its adaptable nature[14].

The calibration of model parameters in the HCM version of the SIDRA Intersection software is dependent on the highway capacity manual[15].

In their study, Darma et. al. utilized the HCM methodology and conducted a delay analysis of signalized intersections using both SIDRA and Transyt-7F software. Their research showed that factors such as cycle time, inter-green time, number of phasing, number of lanes, and LTOR (Left turn on red) have a notable impact on delay at intersections[16].

The main finding of the model comparison study was that for intersections with low traffic demand and some geometric negotiation, SIDRA tended to calculate higher average delay statistics than VISSIM. Upon closer examination, it was revealed that SIDRA automatically factors in geometric delay in its calculation of average vehicle delay, while VISSIM's equivalent statistic disregards geometric delay when coded with reduced speed areas and accounts only for genuine control delay. This highlights a fundamental discrepancy between the two packages in the way they report a performance measure that is frequently evaluated in TIAs[17].

Irtema et al. conducted a study in the study area and observed that the morning period yielded better results in terms of delay, queue, journey time, and speed as compared to the evening period, based on practical measurements obtained[18].

Ali et al. employed the SIDRA Intersection software to assess the traffic flow conditions in Nicosia city of Cyprus, and the results indicated that the level of service was poor, leading to slow speeds and substantial delays during both morning and evening peak hours[19].

Mohammed and his team utilized SIDRA to evaluate the operational effectiveness of Jordan intersection, where they found that the intersection is operating at LoS D, with an average delay of 35 sec/veh and a degree of saturation of 0.996 v/c[20].

Figure 1: Drone Image of Thapathali Intersection.

Shrestha and Dhungel conducted a study using SIDRA Intersection 5.1 to assess the operational performance of the Old Baneshwor Intersection in 2018, as well as explore potential improvements for the intersection up until 2028. The intersection was found to be at LoS F, with a DoS of 1.16 and an average delay of 98.3 sec/veh under current traffic police control. Among the six alternatives considered, the sixth option was found to be the most effective, with the lowest PI of 116.5 and the least delay of 32.6 sec/veh. Furthermore, the sixth option with a minor geometric upgrade was deemed sufficient for the intersection's needs until the year 2028[21].

Aslan et al. conducted a study to investigate the impact of signal coordination on delay times using both SIDRA and VISSIM. The results revealed that by implementing coordination between the first and second intersections of Marmul Street prior to its geometric redesign, the overall vehicle delays in the system were reduced by up to 3.36 %[22].

4. Methodololgy

4.1 Study Area

For this research study, the study area selected is the Thapathali Intersection at the position of 27.690678°N, 85.317625°E. The two main roads Prashuti Griha Marg – Tripura Marg and Thapathali Road – Kupondole Road cross at this intersection. It is a 4-legged intersection with non-operating traffic signals rather managed by traffic police. The south leg is towards Kupondole (Kupondole Leg), the east leg toward Maternity Hospital Road (Maternity Road Leg), the north leg is towards Maitighar (Maitighar Leg), and the west leg towards Tripureshwor (Tripureshwor Leg).

4.2 Data Collection

To perform an intersection analysis, it is necessary to gather data on geometric characteristics, traffic characteristics, and signal control characteristics. The majority of the data relating to these categories is obtained through primary sources such as videographic surveys and field observations. The video of traffic flow at the Thapathali intersection for 5 Days from 01/06/2022 to 05/06/2022 which included three weekdays and two weekends were recorded. The following data were collected:

a. Intersection geometry which includes lane type, lane traffic control, lane discipline, etc.

b. Classified counts of vehicles

c. Peak period and Off-peak period observations

d. Current signal timing and phasing data

e. Cruise Speeds data

f. Back of Queue data

Other data such as approach leg distances & lane widths were obtained from the measure tool available in QGIS, passenger car units (PCUs), basic saturation flow, vehicle class growth rates, vehicle dimensions, queue space & vehicle occupancy were adopted as secondary data.

4.3 Intersection Modelling

For the analysis of raw data obtained from traffic flow video, other field observations and other secondary sources, a computer-based micro-analytical software called SIDRA Intersection was employed. A wide range of data was required to be fed into the software such as Intersection data, movement definitions (user-defined in addition to Light and Heavy Vehicle movements), lane geometry, lane movements, traffic volumes, and existing phasing and timing data. With these data, a model of the Thapathali intersection was created in SIDRA Intersection.

Intersection and Approach Data The number of approaches with their distance and leg geometry.

Movement Definition Vehicle classes with their pcu values and origin-destination movement. The PCU value for each vehicle class were adopted from the Kathmandu Valley Intelligent Traffic System Project (KVITSP) [23].

Table 1: PCU Factors

SN	Vehicle Class	PCU Factor
1	Light Vehicles (LV)	1.5
2	Heavy Vehicles (HV)	3
3	Buses (B)	3
4	Mini Buses (mB)	2.5
5	Micro Buses (uB)	1.5
6	Cars (C)	1
7	Jeeps (J)	1
8	Tempos (T)	0.75
9	Motor Cycles (MC)	0.25

Lane Detailing Lane congifugration which includes no. of approach and exit lanes, their widths, type of traffic control for each lanes. Lane discipline which indicate directional movement of each vehicle class. Lane data which includes saturation flow for each lane.

Volume Data The peak hour volume obtained from the classified vehicle count for 15 minutes interval.

Vehicle Movement Calibration Data related to vehicle movement such as cruise speed, queue space, vehicle dimension, etc.

Phasing and Timing The cycle and phase timing as assigned by the traffic police were observed for the particular peak hour considered from the recorded footage.

4.4 Calibration and Validation of Model

4.4.1 Calibration of Model

The calibration target in terms of queue length in the traffic simulation model is to achieve the difference between simulated and observed queue lengths to be within 20%[24]. Thus, calibration was performed used 95th percentile back of queue. The field data of Day-1 and Day-2 was fed to SIDRA as input and a simulation run was performed to obtain the simulated queue length for the weekday model. Similarly, field data of Day-4 was used to obtain the simulated queue length for the weekend model. A comparison between the observed and simulated queue lengths is made for the calibration of the model as shown in table 2.

4.4.2 Validation of Model

The weekday model and weekend model was validated by comparing the simulated 95th percentile back of queue as obtained from the models with the observed 95th percentile back of queue as observed in the field with Day-3 and Day-5 data respectively.

Table 2: Queue length comparison

Day	Leg	Mean	95th % BoQ		%
		BoQ	Obs.	Sim.	Diff.
1	South	323	415	438	5.6
1	North	382	438	425	3.0
1	West	252	388	365	5.8
2	South	344	463	499	7.7
2	North	249	350	361	3.3
2	West	255	365	373	2.1
3	South	475	543	501	7.8
3	North	453	544	529	2.7
3	West	375	448	423	5.7
4	South	74	93	87	5.9
4	North	51	78	81	3.8
4	West	106	171	157	8.1
5	South	244	330	365	10.5
5	North	327	532	518	2.7
5	West	317	494	506	2.4

5. Data Analysis

5.1 Intersection Model & Lane Detailing

The Thapathali intersection is a 4-legged intersection with non-operating traffic signals, rather controlled by traffic police. The two main roads Prashuti Griha Marg – Tripura Marg and Thapathali Road – Kupondole Road intersect to form the Thapathali Intersection. The legs in this intersection are:

- The south leg is Kupondole road towards Kupondole (Kupondole Leg),
- The east leg is Prashuti Griha Marga towards Norvic and Maternity Hospital (Maternity Road Leg),
- The north leg is Thapathali road towards Maitighar (Maitighar Leg),
- The west leg is Tripura Marg towards Tripureshwor (Tripureshwor Leg).

The Kupondole Leg has 5 lanes with an approach length of 530 m, the Maternity Road Leg has 2 lanes with an approach length of 320m, the Maitighar Leg has 4 lanes with an approach length of 520m and the Tripureshwor Leg has 4 lanes with an approach length of 500m. Figure 2 shows the model formed in SIDRA which represents the actual intersection close to reality with the existing number of approach and existing lanes and their lane disciplines.

The Kupondole leg features 3 approach lanes and 2 exit lanes where left most approach lane serves as a bypass lane for left turn movements. The Maternity Road leg has a single approach lane and a single exit lane with the single approach lane used only for left-turn traffic movements. The Maitighar leg comprises 2 approach lanes and 3 exit lanes whereas the second exit lane is of type short lane. The Tripureshwor leg has 3 approach lanes and 3 exit lanes where the first approach lane is functioning as a bypass lane for left turn movements only and the second approach lane is a short lane acting as a pocket lane to accommodate traffic on the stopped condition while the second exit lane is also of type short lane. The lane control for each lane was configured as "Continuous" if the traffic movement is not controlled either by the device or traffic police or "Signals" if the traffic movement is controlled either by the device or traffic police.

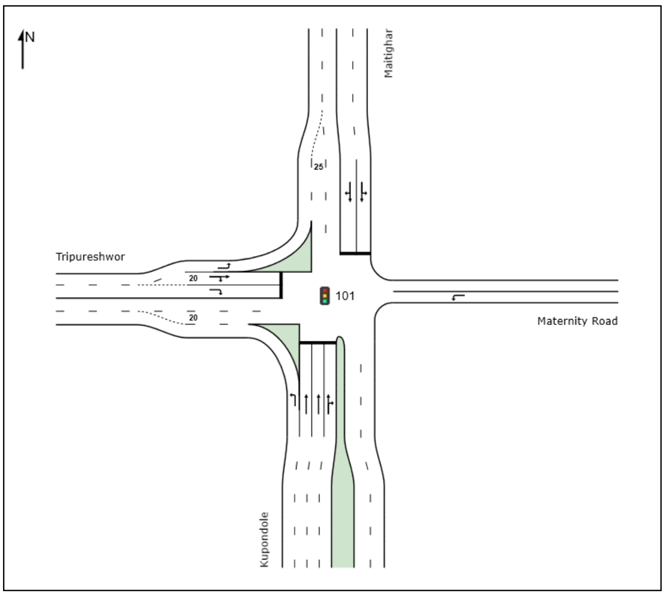

Figure 2: Intersection site layout in SIDRA.

5.2 Traffic Volume

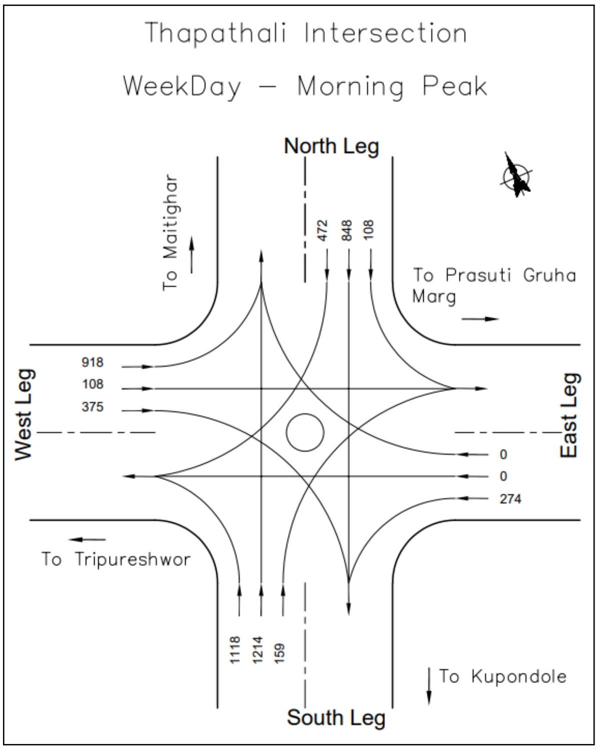

Figure 3: Weekday-Morning Peak Hour Volume

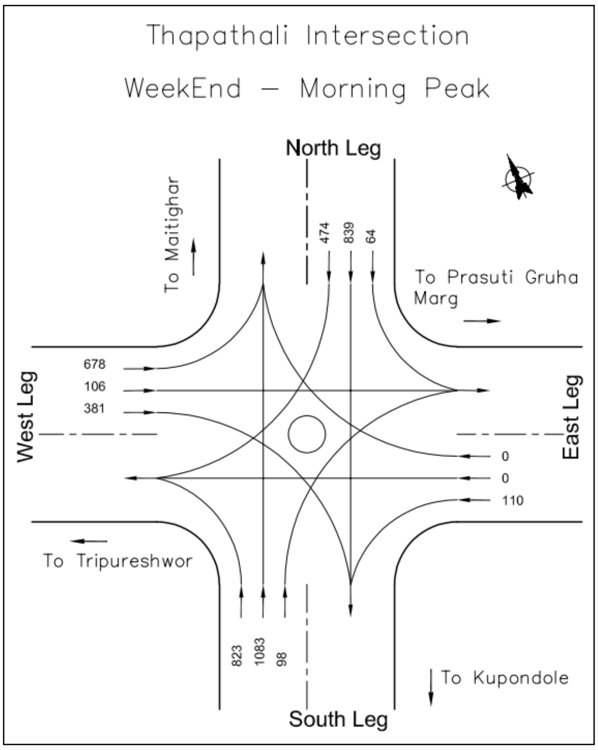

Figure 4: Weekend-Morning Peak Hour Volume

For both weekday and weekends, it was observed that the traffic demand is higher in the morning peak hour compared to the evening peak hour. For weekdays, during the morning peak hour period, Kupondole (South leg) had 2,491 PCU, Maternity Road (East leg) had 274 PCU, Maitighar (North leg) had 1,427 PCU, and Tripureshwor (West leg) had 1,401 PCU which is shown in figure 3 where during the evening peak hour period, Kupondole (South leg) had 1,782 PCU, Maternity Road (East leg) had 315 PCU, Maitighar (North leg) had 1,559 PCU, and Tripureshwor (West leg) had 1,227 PCU. For weekends, during the morning peak hour period, Kupondole (South leg) had 2,002 PCU, Maternity Road (East leg) had 110 PCU, Maitighar (North leg) had1,376 PCU, and Tripureshwor (West leg) had 1,165 PCU which is shown in figure 4 where during the evening peak hour period, Kupondole (South leg) had 1,727, Maternity Road (East leg) had129 PCU, Maitighar (North leg) had 1,443 PCU, and Tripureshwor (West leg) had 1,249 PCU.

5.3 Vehicle Composition

The identified vehicle classes during the classified vehicle count are Multi-Axle trucks, Heavy trucks, Light trucks, Standard Buses, Mini Buses, Micro Buses, Cars/Taxis, Utility vehicles, Four-Wheel Drives, Motorized three-wheeler (Tempos), and Motorcycles. The analysis of classified vehicle count demonstrated that the primary mode of travel through the intersection is the Motorcycle vehicle class holding 71.4%, 75.6%, 72.5%, 66.6%, and 70.2% composition during Day-1, Day-2, Day-3, Day-4, and Day-5 respectively with a 5 days average composition of 70.65% while Car/Taxi vehicle class has the second highest composition with 14%, 16.8%, 17.8%, 22%, and 19% composition during Day-1, Day-2, Day-3, Day-4, and Day-5 respectively with a 5 days average composition of 17.92%. However, the analysis does not consider the Bicycle and Rickshaw vehicle classes.The individual vehicle composition at the intersection for weekdays and weekends is displayed in table 2.

Table 3: Vehicle Composition in %

VC	Day1	Day2	Day3	Day4	Day5	Avg.
MT	0.01	0.01	0.00	0.01	0.00	0.01
HT	0.13	0.06	0.02	0.17	0.09	0.09
LT	0.12	0.11	0.50	0.39	0.27	0.28
SB	1.61	1.30	0.35	1.06	0.98	1.06
MB	0.19	0.43	1.27	0.30	0.40	0.52
UB	2.58	2.22	1.85	2.35	1.62	2.12
C/T	14.05	16.79	17.73	21.99	19.06	17.92
UV	2.05	1.31	1.92	2.36	2.05	1.94
FW	6.81	4.41	2.96	3.69	4.23	4.37
3W	1.07	1.09	1.00	1.15	1.15	1.09
MC	71.36	72.53	72.38	66.50	70.13	70.58

5.4 Cruise Speed

Manual Short-Base Method for speed survey as described in ORN-11 published by Overseas Centre Transport Research Laboratory [25] was employed to carryout cruise speed survey. The output of the study for the approach legs of the intersection is summarized in table 3 and the 85th percentile speed, which is considered to exclude extremely fast drivers and gross measuring error, is shown graphically in figure 6.

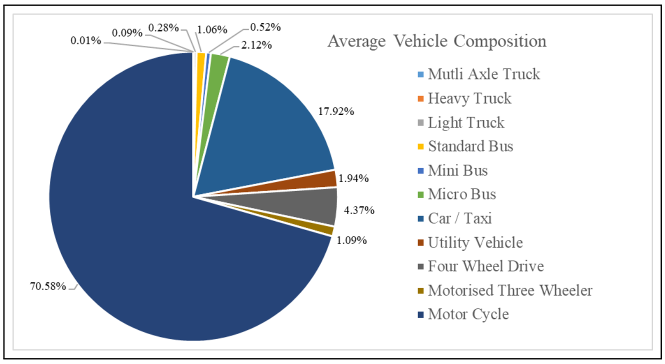

Figure 5: Average Vehicle Composition at the Intersection

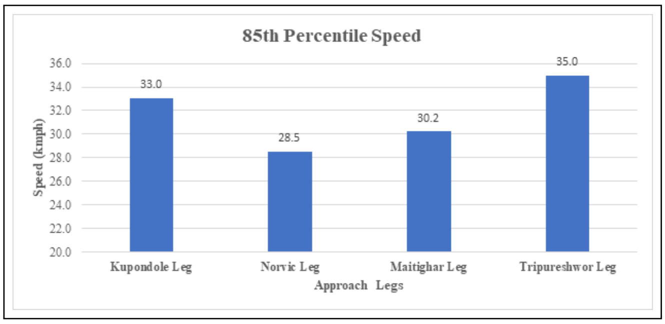

Figure 6: 85th Percentile Speed

Table 4: Summary of Speed Survey

Particular	South	East	North	West
Min. Speed	13.0	14.2	17.2	15.7
Max. Speed	37.9	32.7	37.8	39.1
No. of Obs.	96	97	105	104
Mean Speed	26.5	24.7	26.2	29.9
95th % Speed	35.2	29.5	33.1	37.2
85th % Speed	33.0	28.5	30.2	35.0

5.5 Phasing & Signal Timing

The phase timing for peak hour and off-peak periods for each day were determined through the extraction of data from video recordings of traffic flow during various events, resulting in the calculation of an average value for each phase. A summary of the peak hour phase timing for each day from Day-1 to Day-5 is shown in table 4.

Table 5: Summary of Phase Timing

	Average Duration (sec)				
Phase	Day1	Day2	Day3	Day4	Day5
P1	74	62	83	9	17
P2	121	111	160	25	34
P3	73	58	53	17	27
P4	57	47	77	12	12
P5	116	103	140	27	39
Sum	441	381	513	90	130

5.6 Current Operation Performance

A model of the Thapathali intersection was created for the morning peak hour after collecting a large amount of data from primary and secondary sources, and the model was calibrated and validated appropriately.

5.6.1 Weekday

The average of 3 week-days vehicle count and phase timing for the morning peak hour was used to prepare the week-day model. After processing the model with SIDRA, various performance statistics were extracted. During week-days, the total demand flow is 12740 veh/h with a degree of saturation of 2.215 and an average delay per vehicle of 99 seconds. The overall intersection has a level of service of F as the worst performing approach is Tripureshwor leg with LoS of F, the highest control delay of 209.1 sec, and the highest 95th percentile BoQ of 694.5 m.

5.6.2 Weekend

Similar to week days, the average of 2 weekend days' vehicle count and phase timing for the morning peak hour was used to prepare the weekend model. After processing the model with SIDRA, various performance statistics were extracted.During week-days, the total demand flow is 9884 veh/h with a degree of saturation of 1.353 and an average delay per vehicle of 35.1 seconds. The overall intersection has a level of service of D as the worst performing approach is Tripureshwor leg with LoS of F, highest control delay of 60.5 sec, and highest 95th percentile BoQ of 170 m.

The performance statistics for the weekday and weekend model of the Thapathali intersection at the present are summarized in table 6.

Table 6: Intersection Operational Performance

Model	WeekDay	WeekEnd
Demand Flows (veh/h)	12740	9984
DoS (v/c)	2.215	1.353
Avg. Delay (sec)	99.6	35.1
LoS	F	D
95% BoQ	694.5	170
Avg. Speed (Kmph)	16.6	24.7
Performance Index (PI)	5416.6	1711.1

5.7 Evaluation of Different Options

Lane reconfiguration along with phase reconfiguration was adopted to generate 3 different lane configuration each with 3 different phase plannings resulting into 9 options for both the weekday and weekend model of the intersection which are listed below.

Option 1-3: Three approach lanes with exclusive through turn, shared through and right turns, and exclusive right turns were proposed for the Kupondole leg with 3, 4, 5 Phase configuration.

Option 4-6: Three approach lanes with an exclusive left turn with continuous control, shared through and right turns and exclusive right turn where the widths of exit lanes were reduced to accommodate the addition of the third lane was proposed for the Maitighar leg with 3, 4, 5 Phase configuration.

Option 7-9: Addition of a short lane to the approach lane, while removing the existing short lane from the exit lanes, and to have three approach lanes that include an exclusive through turn short lane, a shared through and right turns full-length lane, and an exclusive right turn short lane was proposed for the Tripureshwor leg with 3, 4, 5 Phase configuration.

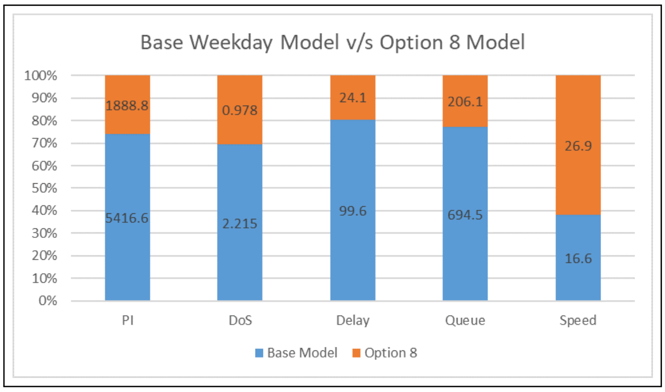

Figure 7: Base model v/s Option 8 model for weekdays

Each option set are catered towards the three leg of the intersection and each phase configuration in the option set were adopted as supported by the SIDRA Intersection after observing systems adopted for the most of the intersections inside the Kathmandu valley.

5.7.1 Weekday

Option 8 with the least performance index of 1888.8 is chosen as the best option for the weekday model. This option has a degree of saturation of 0.978, an average delay of 24.1 sec, LoS of C, 95th percentile queue length of 206.1 m, and an average travel speed of 26.9 kmph. The phase timings adopted for this option is shown in table 7.

Table 7: Phase Timing for Weekday's Option 8

Phase	A	B	C	D
Change Time (sec)	0	21	33	63
Green Time (sec)	18	9	27	24
Phase Time (sec)	21	12	30	27
Phase Split (%)	23	13	33	30

The performance statistics for the best option for the weekday model of the Thapathali intersection are shown in figure 7.

5.7.2 Weekend

Option 8 with the least performance index of 1394.4 is chosen as the best option for the weekend model. This option has a degree of saturation of 0.845, an average delay of 18.1 sec, LoS of B, 95th percentile queue length of 50.9 m, and an average travel speed of 26.1 kmph. The phase timings adopted for this option is shown in table 8.

Table 8: Phase Timing for Weekend's Option 8

Phase	A	B	C	D
Change Time (sec)	0	13	30	57
Green Time (sec)	10	14	24	20
Phase Time (sec)	13	17	27	23
Phase Split (%)	16	21	34	29

The performance statistics for the best option for the weekend

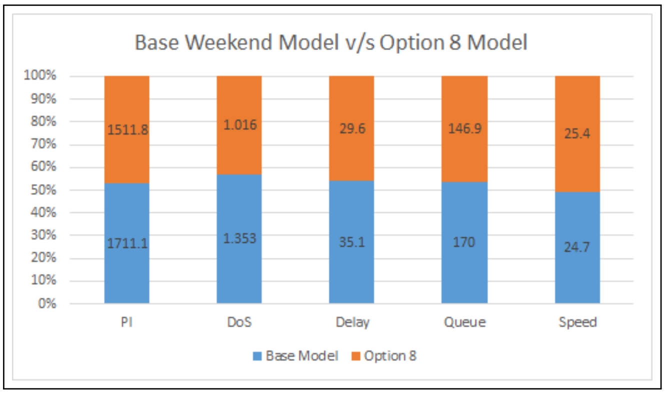

Figure 8: Base model v/s Option 8 model for weekends

model of the Thapathali intersection are shown in figure 8.

5.8 Evaluation for Future Years

For the base year 2022, it is evaluated that options 8 are the best options for the weekday and weekend model of the intersection. Furthermore, these best options for the weekday and weekend models were analyzed for the future design period of 3, 5, and 10 years resulting in years 2025, 2027, and 2032 respectively. The growth rate for each vehicle class was adopted from the KVITSP[24] as shown in table 9.

Table 9: Growth Rate

	Growth Rate (%)		
Vehicle Class	(2022-26)	(2026-30)	(2030-35)
LV	3.5	2.8	2.2
HV	0	0	0
B	0	0	0
mB	3.5	2.8	2.2
uB	4.5	3.6	2.8
C	5.2	4.1	3.3
J	4.6	3.7	3
T	0	0	0
MC	7	5.6	4.5

5.8.1 Weekday

The future growth analysis for the weekday model results that by the year 2027, the intersection will perform with LoS E with DoS of 1.252, an average delay of 71.7 sec/veh, a 95th percentile queue length of 392.3 m, and an average travel speed of 19.4 kmph. But, after the year 2032, the intersection will perform at LoS F. The demand flows, degree of saturation, average delay, and 95th percentile queue all will increase. A year-wise comparison of the performance statistics of the weekday model is shown in table 10.

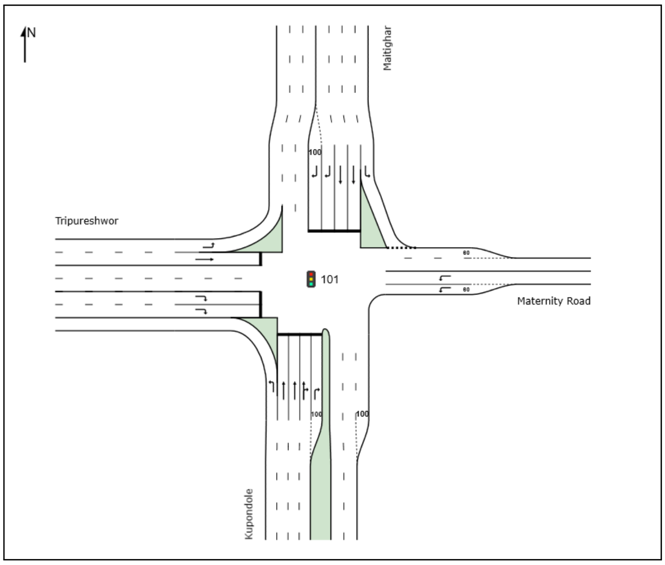

Figure 9: Geometric Enhancement Proposed

Table 10: Performance Statistics for Weekday Model

	2022	2025	2027	2032
Cycle Time (sec)	90	90	90	90
PI	1888.8	2931.2	3727.3	4533.9
Demand (veh/h)	12740	15344	16965	18405
DoS (v/c)	0.978	1.143	1.252	1.350
Avg. Delay (Sec)	24.1	49.8	71.7	91.8
95% BoQ (m)	206.1	310.5	392.3	480.6
Avg. Speed (Kmph)	26.9	22.0	19.4	17.5

5.8.2 Weekend

The future growth analysis for the weekend model results that by the year 2027, the intersection will perform with LoS D with DoS of 1.137, an average delay of 51.2 sec/veh, a 95th percentile queue length of 259.9 m, and an average travel speed of 21.9 kmph. But, after the year 2032, the intersection will perform at LoS F. The demand flows, degree of saturation, average delay, and 95th percentile queue all will increase. A year-wise comparison of the performance statistics of the weekday model is shown in table 11.

Table 11: Performance Statistics for Weekend Model

	2022	2025	2027	2032
Cycle Time (sec)	65	70	70	70
PI	1394.4	2115.1	2699.3	3346.8
Demand (veh/h)	9884	11873	13117	14182
DoS (v/c)	0.845	1.041	1.137	1.229
Avg. Delay (Sec)	18.1	36.3	51.2	69.6
95% BoQ (m)	136.9	207.9	259.9	324.3
Avg. Speed (Kmph)	28.1	24.2	21.9	19.7

5.8.3 Geometric Enhancements

To improve operational efficiency, it is recommended to consider geometric improvements, such as the addition of full-length lanes, short lanes, and bypass lanes. The proposed geometric enhancement for the Thapathali intersection for 2032 onwards is depicted in figure 9.

The proposed enhancement for the Kupondole leg involves the addition of two 100m short lanes on both the approach and exit lanes. On the Maternity road leg, the proposal includes the addition of two 60m short lanes on both the approach and exit lanes. For the Maitighar leg, the enhancement plan includes the addition of one bypass lane to Maternity road, one full-length lane, and one 100m short lane on the approach side, and one full-length lane on the exit side. The Tripureshwor leg proposal includes the addition of two full-length lanes for right-turn movements and one exit lane, which will be positioned between the through-turn movement approach lane and the right-turn movement approach lane.

After processing the model in SIDRA with optimum cycle timing option, it was observed that the intersection during weekdays will operate under LoS C and PI of 1870.7 with DoS of 1.036, average delay of 26 sec/veh, 250.3 m of 95th percentile BoQ and average travel speed of 26.3 kmph and during weekends will operate under LoS B and PI of 1511.9 with DoS of 0.895, average delay of 18.2 sec/veh, 188.6 m of 95th percentile BoQ and average travel speed of 28.2 kmph. For both the weekdays and weekends, a 4 phase planning were adopted. The phase timings adopted for the weekday and weekend are shown in table 12 & 13 respectively.

Table 12: Phase Timing for Weekday of 2032

Phase	A	B	C	D
Change Time (sec)	0	14	34	67
Green Time (sec)	11	17	30	15
Phase Time (sec)	14	20	33	18
Phase Split (%)	16	24	39	21

Table 13: Phase Timing for Weekend of 2032

Phase	A	B	C	D
Change Time (sec)	0	15	37	72
Green Time (sec)	12	19	32	20
Phase Time (sec)	15	22	35	23
Phase Split (%)	16	23	37	24

6. Conclusions

i) The initial performance evaluation of the intersection demonstrated that during weekdays the intersection was performing at LoS F with degree of saturation of 2.21, average delay of 99.6 sec/veh, and average travel speed of 16.6 kmph. While during weekends, the intersection was performing at LoS D with degree of saturation of 1.353, average delay of 35.1 sec/veh, and average travel speed of 24.7 kmph.

ii) Out of 9 options proposed for the weekday model, the option 8 model (Tripureshwor Leg's lane reconfiguration with 4 phase timing plan) with a performance index of 1888.8, LoS C, degree of saturation of 0.978, average delay of 24.1 sec/veh, and average travel speed of 26.9 kmph is the best option.

iii) Out of 9 options proposed for the weekend model, the option 8 model (Tripureshwor Leg's lane reconfiguration with 4 phase timing plan) with a performance index of 1394.4, LoS B, degree of saturation of 0.845, average delay of 18.1 sec/veh, and average travel speed of 28.1 kmph is the best option.

iv) On analysis of the performance of the intersection for future design period of 3, 5 and 10 years, it was revealed that intersection during weekdays will operate under LoS E with average delay of 71.2 sec/veh till 2027 and during weekends it will operate under LoS E with average delay of 69.6 sec/veh till 2032.

v) With geometric enhancements like addition of full length lanes, short lanes, and bypass lane, the performance of the intersection will be enhanced. In the analysis of the intersection during 2032 with proposed geometric enhancements it was observed that during weekdays the intersection will have improved performance with LoS C, degree of saturation of 1.036, and average delay of 26 sec/veh under 4 phase timing configuration while during weekends the intersection will have improved performance with LoS B, degree of saturation of 0.895, and average delay of 18.2 sec/veh under 4 phase timing configuration.

7. Recommendations

- Considerable research effort was invested in conducting 16-hour traffic flow counts over a 5-day period. To save time and enhance efficiency, the deployment of a machine learning-powered software solution could be used to automate the traffic counting process.
- The current analysis of the intersection was performed in isolation and did not consider the impact of neighboring intersections. To enhance the accuracy and comprehensiveness of future research, it is recommended to conduct a network-level analysis that incorporates the Maitighar Intersection, the Thapathali Intersection, and the Tripureshwor Intersection.
- The current intersection model was developed using saturation flow values obtained from the Indo-HCM equations. To improve the model's accuracy, a separate saturation flow study could be conducted at the intersection.
- The model calibration and validation process currently relies solely on the 95th percentile back of queue as a variable measure. To enhance the model's accuracy, saturation flow and degree of saturation could be used as additional variables for calibration and validation.

Acknowledgments

The authors express their gratitude to the Department of Roads for supplying pertinent data and materials, as well as to all those who contributed directly or indirectly to the successful completion of this research.

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