

Evaluating the performance of Signalized intersection using SIDRA software: A case study in Bahir Dar city, Ethiopia

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ABSTRACT

The paper presents a comprehensive evaluation of signalized intersections in Bahir Dar City, Ethiopia, focusing on their performance using SIDRA software. Signalized intersections are crucial for urban traffic management, affecting transportation efficiency and safety. The study employs field observations, traffic counts, and intersection geometries to assess traffic flow, delay, and level of service. Key findings indicate inadequacies in split signal phasing and suggest a preference for roundabouts in some cases. By implementing improvements such as phasing time adjustments and signal replacement with roundabouts, significant enhancements in average delay, queue length, and overall quality of service are observed. Specifically, the Depo Intersection is highlighted as problematic, with initial performance metrics indicating higher delay and queue length compared to post-improvement outcomes. The analysis underscores the benefits of replacing signalized intersections with roundabouts, demonstrating notable reductions in delay and queue length. SIDRA software facilitates a detailed examination of intersection performance, emphasizing the importance of optimization techniques in urban traffic planning. Recommendations for enhancing intersection performance include increasing traffic enforcement, modifying geometry, and adjusting signal timing. Furthermore, the potential of intelligent transportation systems and adaptive signal control techniques is suggested for future research to further improve traffic efficiency and safety in Bahir Dar City.

1. Introduction

Bahir Dar is the capital city of the Amhara region and a developing city in Ethiopia, with a mix of pedestrians, bicycles, and motorized vehicles such as Bajaj, taxis, buses, and trucks. The city has several straight roadways with a variety of intersection controls such as roundabouts and traffic signal intersections, among others. Signalized intersections are critical components of urban transportation systems, regulating traffic flow and ensuring safety for road users. In rapidly growing cities like Bahir Dar in Ethiopia, the efficient operation of signalized intersections is essential for addressing traffic congestion and improving overall mobility. However, assessing the performance of these intersections requires detailed analysis considering various factors such as traffic volume, signal timing, and geometric design. Previous studies have highlighted the importance of signalized intersections in urban traffic management and the need for effective evaluation methods.

Researchers have employed various approaches, including analytical models, simulation software, and field studies, to assess intersection performance. SIDRA software has emerged as a popular choice due to its ability to simulate complex traffic scenarios and provide detailed performance metrics. Studies in similar contexts have identified factors influencing intersection performance, such as signal timing, geometric design, and traffic demand patterns. A range of studies have utilized SIDRA to evaluate intersection performance. (Ranjitkar, Shahin, & Shirwali, 2014) compared priority controlled, roundabout, and signalized intersections, finding that each performed best under different traffic conditions. (Akcelik, 1984) described the extensive output of SIDRA-2, including performance measures such as delay, number of stops, and queue length. (Sisiopiku & oh, 2001) found that roundabouts are particularly effective for heavy through and left-turning traffic volumes. (Mohammed, Jony, Shakir, & Ambak, 2018) used SIDRA to assess the performance of an unsignalized intersection, identifying the need for further development.

This project will primarily a comprehensive evaluation of signalized intersections in Bahir Dar City using SIDRA software, a powerful tool for traffic analysis and simulation where it is located in depo. Depo signalized intersections would be evaluated in terms of capacity, saturation, average queue length, maximum queue length, and delay, as well as check their performance following roundabout replacement.

1.1. Statement of the Problem

Different control mechanisms, such as traffic signals, are preferred to control traffic in urban areas with limited right of way and high accident rates at roadway junctions. However, incorrect traffic forecasting and/or traffic signal installation can result in a long queue, a traffic crash, congestion, and delays on the roads. Due to the rapid growth of population and vehicle numbers in Bahir Dar, installing the signal intersection or replacing other control mechanisms based on the appropriate input data will continue to be a problem. As a result, it is critical to conduct an evaluation and comparison study of operational performance between roundabouts and signalized intersections in order to utilize effective and efficient traffic flow and overcome the associated economic impact.

1.2. The Purpose of the study

The general objective of this study is to evaluate the performance or service quality of roadway signalized intersections in Bahir Dar city at Depo location and plan to improve the intersection using other control mechanism.

2. Literature Review

2.1. Intersection traffic control

One crucial component of controlling traffic flow is the use of intersection traffic control devices. During emergencies and special occasions, skilled workers often utilize manual traffic control, which involves granting vehicles the right-of-way. In order to improve visibility and prevent traffic bottlenecks, an intelligent traffic junction control machine has been designed. It consists of a lifting device that allows the height of signal indication lamps and camera assemblies to be adjusted (Araghi, Khosravi, Johnstone, & Creighton, 2013) Presetting traffic flow and conflict relationships, creating phase parameters for the signal lamp, refining phase sequences, and regulating the traffic signal using signal timing techniques are all part of the proposed intersection traffic signal control method (Benhamza & Seridi, 2015). keeping an eye on line lengths and modifying intervention reference values, a traffic light control device has been developed to increase the efficiency of vehicle passing at junctions (Yousef, Al-Karak, & Shatnawi, 2010). In order to reduce traffic congestion at the intersection and provide rear-end

vehicles with real-time traffic information, an intersection traffic control system containing two traffic signal light devices has been designed (De Schutter & De Moor, 1998).

The purpose of intersection traffic control devices is to minimize traffic jams and maximize traffic flow. Priority control, traffic light control based on stop lines, and traffic light control based on lane connections are only a few of the control mechanisms used (Araghi, Khosravi et al. 2013). The Intelligent Traffic Intersection Control Machine is a control device that can modify signal phases and times to optimize intersection traffic in response to changing traffic circumstances. To assess traffic flow data and make well-informed decisions on traffic control, intelligent algorithms are employed. (Benhamza and Seridi 2015) During emergencies and special events, manual traffic control by skilled professionals, such police officers, is also thought to be an effective approach for managing traffic (Zhong, Liu, & Lv, 2022).

2.2. Intersection performance measures

When evaluating the past and present performance of signalized crossings, intersection performance metrics are crucial. Data on intersection performance is gathered using automated traffic signal performance measures (ATSPMs), yet the amount of data gathered can be deluged. In order to overcome this, an approach that uses ATSPM data to summarize intersection-level performance was created. Using k-means cluster analysis and expert input, the system employs a number of performance measures, including platoon ratio, split failures, arrivals on green, and red-light infractions, which are then scaled and classified. (Wang, Schultz, Macfarlane, & McCuen, 2022). Furthermore, a framework for multimodal signal timing was created to take into account the requirements of bicycles, pedestrians, and passengers in transit vehicles. The framework's performance measures, which were implemented at Arlington, VA intersections and resulted in better performance along the corridor, include vehicle delay, crosswalk delay, crossing stress, and bus delay (Cesme et al., 2023). The performance of continuous flow intersections (CFIs) can be assessed using connected car trajectory data, negating the necessity for on-site data collection (Saldivar-Carranza, Li, Taylor, & Bullock, 2022).

A variety of techniques can be employed to assess intersection performance. Analyzing the performance using measures of effectiveness (MOEs) including queue length, delay time, and saturation level is one method. This can be accomplished by employing software such as Vissim (Ashqer et al., 2023) to gather and analyze traffic flow data at the intersection. Another technique uses real-time MOE estimation based on vehicle trajectory data gathered by drone flights.

Using the Vissim software, this technique enables the tracking of individual vehicle movements inside street networks while accounting for various traffic situations (Schroeder et al., 2014). Furthermore, it is possible to forecast the operational performance of road intersections and continuously monitor traffic conditions by utilizing Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication technologies (Nematichari, Pechlivanoglou, & Papagelis, 2022). In addition, computer vision techniques can be used for more thorough examination of crossings by tracking cars and pedestrians, predicting the number of turning movements, and modeling actual traffic patterns (Radjawane & Lao, 2023) Factors affecting intersection performance.

A range of factors influence intersection performance, including vehicle-pedestrian interaction, speed limit, and human reactions (Son, 2017) found that pedestrian interference can significantly worsen performance, leading to lower transportation efficiency, increased energy consumption, and higher safety risk. Son (2017) highlighted the impact of driver reaction time and signal location on efficiency and safety. (Dukiya & Ajiboye, 2011) emphasized the role of traffic control systems and intersection design in reducing delay, time wastage, and traffic conflicts. Li (2019) proposed a multi-objective optimization method for improving performance, considering vehicle conflicts and pedestrian interference. These studies collectively underscore the complex interplay of factors in intersection performance and the need for comprehensive optimization strategies.

3. Methodology

This research adopts a case study approach to evaluate signalized intersections in Bahir Dar City. The study area is selected based on traffic volume, intersection complexity, and strategic importance. Data collection includes field observations, traffic counts, and intersection geometries. SIDRA software is used to model and simulate intersection operations under different scenarios, allowing for the analysis of traffic flow, delay, and level of service. The methodology aims to provide a comprehensive understanding of intersection performance and identify areas for improvement.

3.1. Description of study area

Bahir Dar City, located in the northwestern part of Ethiopia, serves as the capital of the Amhara Region. Situated on the southern shore of Lake Tana, the city is a significant economic, cultural, and administrative hub in the region. With a rapidly growing population and expanding urbanization, Bahir Dar faces numerous transportation challenges, including traffic congestion, safety concerns, and inefficient transportation infrastructure.

The study of signalized intersection, one of the city's signalized intersections is located at the Depo intersection. Georgis to Depo Approach Leg(South), Noc to Depo Approach Leg(West), Geter menged to Depo Approach Leg(North), and Felege Hiwot Hosipital to Depo Approach Leg(East) are the four approaches. As shown in Figure 1 below depicts a plain view of the intersection.



Figure 1. Depo Signalized intersection

3.2. Data collection

Field observations were made on the selected roads of Bahir Dar city at the Depo location, which is a signalized intersection, to select intersections for the study and to determine the peak hour. Because traffic and geometric data are critical to achieving the project's goals, it was determined that it was necessary to collect traffic movement data using video cameras and to extract traffic volume within their movement direction, as well as to collect geometry data such as lane width, median width, and approach lane length, among other things.

3.2.1. Traffic data collection

Visual inspections are conducted to determine the peak flow period time at the intersection in order to get a clear picture of the site and the flow condition. At a chosen intersection, two-hour traffic count surveys measuring movements of traffic through (T), left turns (LT), right turns (RT), and U-turns (UT) were conducted at 15-minute intervals during the working day on Monday from 2:00 am to 3:00 am and on Tuesday from 5:00 am to 6:00 am. The four consecutive 15-minute intervals with the highest overall volume were found to be the peak hour. For usage in the, the maximum traffic volume in each direction was noted. Following examination of the data, several traffic categories were transformed into comparable passenger car unit (PCU) values based on the direction of travel. Data from the approaches or legs of the passenger car unit's traffic volume are also required for the analysis. When gathering the data, the intersection's site characteristics, traffic volume, and vehicle categorization should all be taken into account.

In this study, various aspects including geometric condition and control condition must be observed in order to determine the parameter such as lane number, lane usage, and approach of the leg. Traffic counts are created for both automobile and pedestrian traffic since they both have a significant impact on how well intersection's function. There is a mixed volume of pedestrian, Bajaj, and bicycle traffic in Bahir Dar. Thus, the following are counted: Bajaj, bicycles, pedestrians, light (cars, taxis, minibuses, pickups), and heavy (buses, trucks, trucks, and trailers). Passenger vehicles should be used instead of mixed traffic for intersection analysis and design.

3.2.1.1. Passenger car unit (PCU)

Passenger car units are utilized to illustrate the varied effects of mixed vehicle types on saturation flows by transforming a traffic stream made up of several vehicle kinds into an equivalent traffic stream made up exclusively of passenger vehicles. Saturation flows, on the other hand, are determined by the number and kind of vehicles in the traffic stream. Therefore, in order to normalize the saturation flow to a common base of passenger car units per hour (pcu/hr), passenger car units (pcu) are commonly assigned to various vehicle classifications. As a result of the PCU value being influenced by vehicle features, traffic flow, highway, environment, and control, the research on passenger car equivalency of bus and truck vehicles in Ethiopia is also included in SIDRA software heavy vehicles. As a result, the vehicle can be converted to a PCU using the information as shown as in Table 1 and the Ethiopia road authorities 2013 geometric design manual in Table 2.

Table 1. Executed PCEs for Trucks and Buses (ET) in General Terrain

Vehicle	PCE by type of Terrains	
	Level	Rolling
Trucks and buses, ET	2.5	3.0

Source (Girum T.,2016)

SIDRA INTERSECTION defines a Heavy Vehicle as any vehicle with more than two axles or dual tyres on the rear axle for the purposes of intersection analysis. Heavy Vehicles include buses, trucks, semi-trailers (articulated vehicles), cars towing trailers or caravans, tractors, and other slow-moving vehicles. Other vehicles are classified as Light Vehicles (cars, vans, small trucks). According to this, buses and trucks are classified as heavy vehicles. The SIDRA intersection software also requires the PCU value of heavy vehicles, as well as the percentage and converted flow for the total vehicle class. To determine the peak hour average number of vehicles (in pcu) and pedestrians of the intersection in each 15-minute intervals of peak flow period are shown in Table and Figure 4 below

Table 2. Passenger car unit value (ERA 2013)

Vehicle	Pcu value
Pedestrian	0.15
Bicycle	0.2
Motor cycle	0.25
Bicycle with trailer	0.35
Bajaj	0.4
Motor cycle with trailer	0.45
Small animal-drawn cart	0.7
Bullock cart	2.0

Source: Ethiopia road authorities 2013 road geometric manual

Table 3. Average number of vehicles (in pcu) and pedestrians

Time	Average number of vehicles	Average number of pedestrians
2:00-2:15	470.6	420
2:15-2:30	479.7	441
2:30-2:45	509.95	468
2:45-3:00	495.7	442

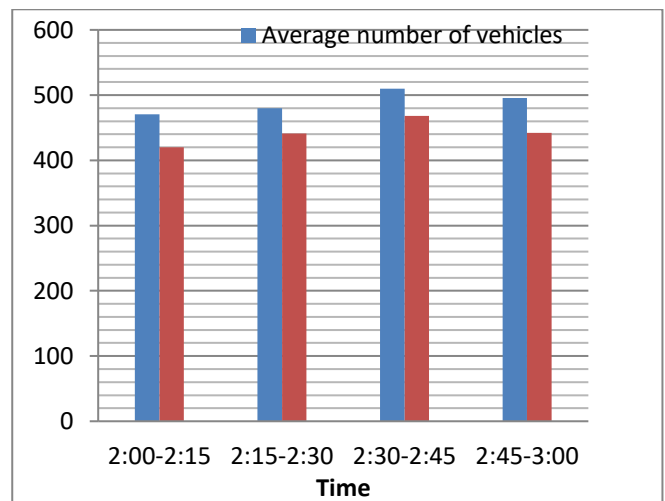


Figure 2. Time related to the average number of vehicle and pedestrian

A Figure 2 shown as the time from 2:30-2:45 am is the 15-minute interval which has higher traffic volume than other 15-minute intervals of peak flow period (2:00-3:00 am) and both vehicles and pedestrians traffic decreases from this time.

3.2.2. Geometric data

As per the requirement of the SIDRA Intersection, the collected geometric data include: number of lanes, lane width, configurations of lanes, median width, Approach distance and grade. These data were measured with in a tape meter.

Table 4. Geometric Data for signalized intersection for Depo

Approaches	Number of lanes	Lane width(m)	Median width(m)	Approach Distance(m)
Georgis to Depo Approach Leg	3	3.5	2.9	131
Noc to Depo Approach Leg	2	3.3	2.7	216
Geter manged to Depo Approach Leg	3	3.5	2.9	138
Felege Hiwot Hospital to Depo Approach Leg	2	3.3	4.8	142

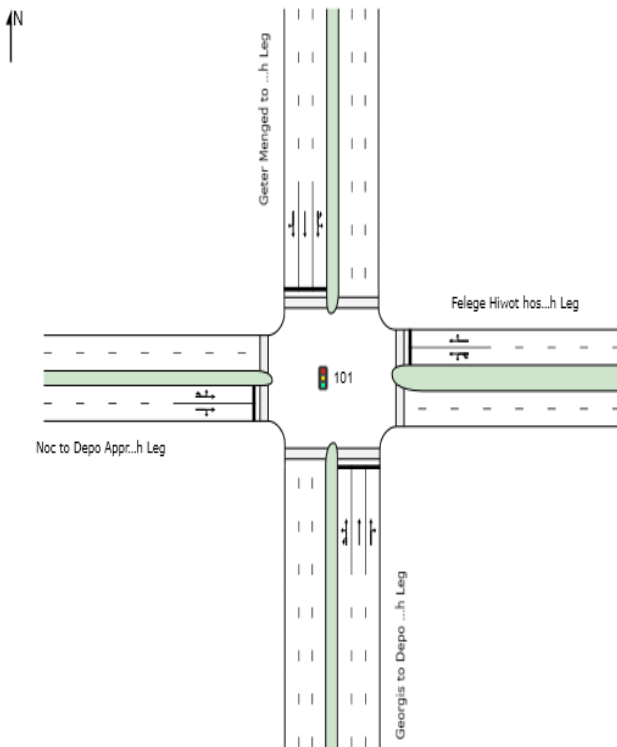


Figure 3a. Layout of signalized intersection in Depo location

3.2.3. Signal time data

The signal time of the existing signalized intersections; cycle time, allocated green time for each approach, all red and any other allocated signal timing is taken from the field visit. The signal timing of the route corridor is as summarized in the Table 5 below.

Signals - Fixed Time Isolated Cycle Time = 110 seconds (Site User-Given Phase Times)
 Phase sequence: split phasing
 Reference Phase: Phase B
 Input Phase Sequence: B, A, D, C

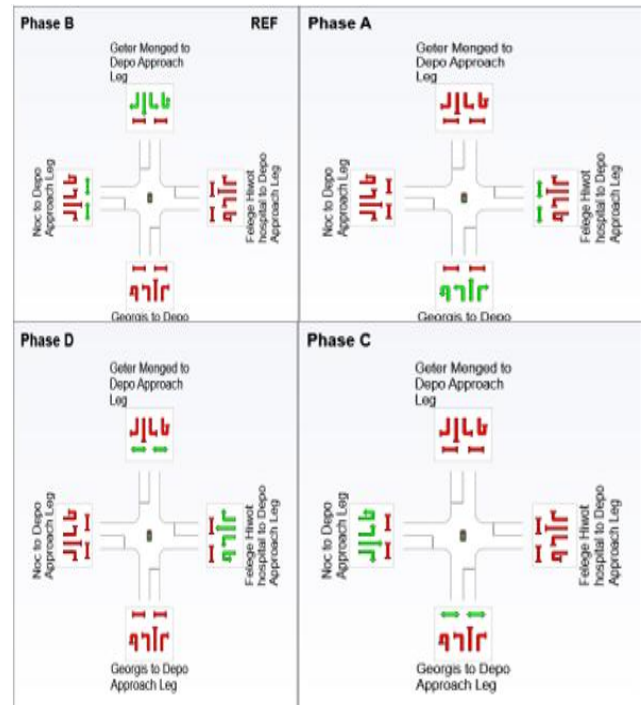


Figure 3b. Traffic Signal Phases at Intersection

Table 5. Depo intersection signal Timing data

Name	Phase Time	Green Time	Yellow Time	All-Red Time
	sec	sec	sec	sec
B	30	25	3	2
A	30	25	3	2
D	25	20	3	2
C	25	20	3	2

4. Results and Discussion

The analysis of signalized intersections in Bahir Dar City reveals several key findings. Traffic flow patterns vary significantly between intersections, influenced by factors such as land use, road hierarchy, and signal timing. Delay and queuing lengths exceed acceptable thresholds during peak hours, indicating suboptimal intersection performance. Through simulation experiments, potential improvements in signal timing and geometric design are identified, which could enhance traffic efficiency and reduce congestion

4.1. Performance analysis of traffic signal at Depo location

The performance of Depo signalized intersection is measured based on delay, degree of saturation, queue length and capacity by SIDRA intersection analyzing software and the detail result and level of service are shown in Table 6. In the analysis of intersection performance of traffic signal by using SIDRA INTERSECTION 8 input and output data are used.

4.2.1. Level of service of traffic signal

The level of service for Depo traffic signal is shown below in the Figure 4. and Table 6.

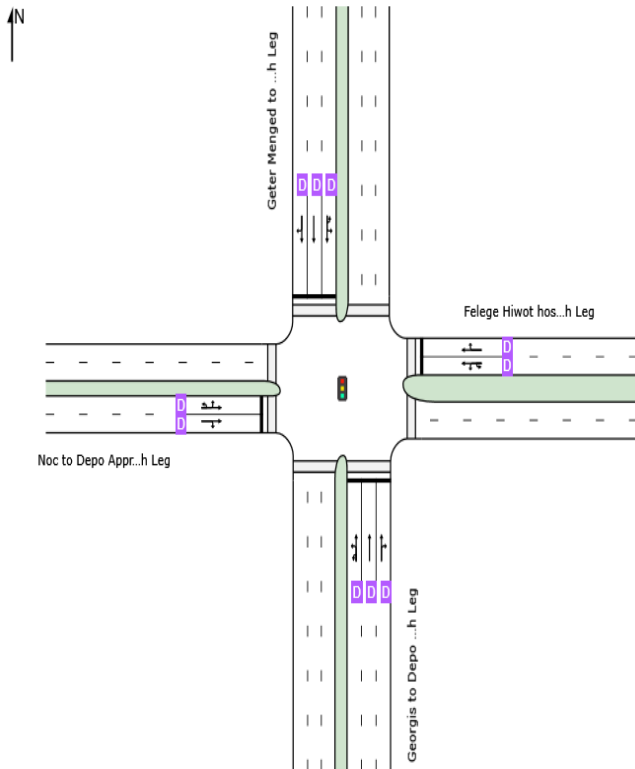


Figure 4. Level of service at depo location of intersection

Table 6. Output summary of Depo signalized intersection

	Approaches				Intersection
	South	East	North	West	
LOS	D	D	D	D	D

The capacity analysis result indicates that each approach's level of service (LOS) was D. As a result, both this approach's and the intersection's overall level of service are D. This is explained by the fact that there will be some waiting time in the event of an increasing phasing time without the arrival of a vehicle in the case of a signalized intersection with low traffic flow. I was working on the current intersection to enhance the functionality of the Depo signalized intersection. I had to replace the existing signal with a roundabout or adjust its phasing into two phases.

4.3. Analysis results of traffic signal depo intersection for improved their phases

Signal data for two phasing
 Phase Sequence: Two-Phase
 Reference Phase: Phase A
 Input Phase Sequence: A, B
 Movement Class: All Movement Classes

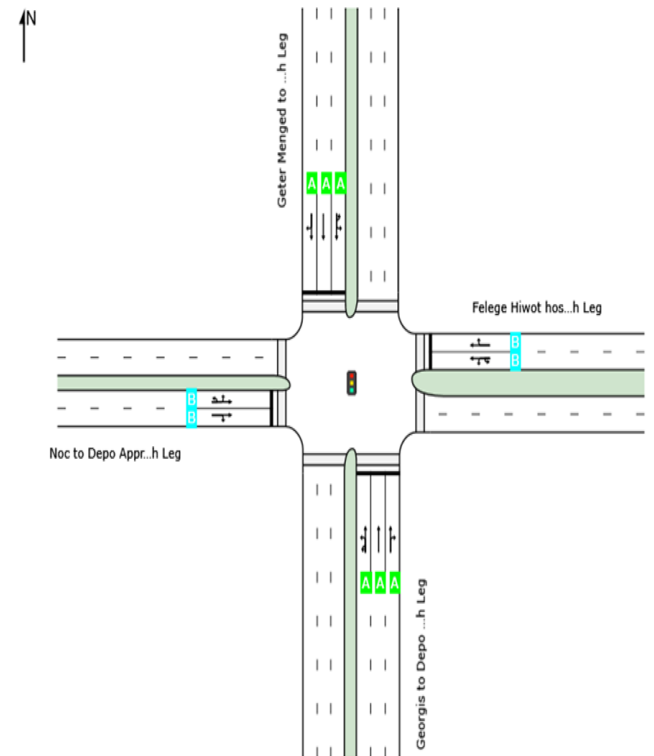
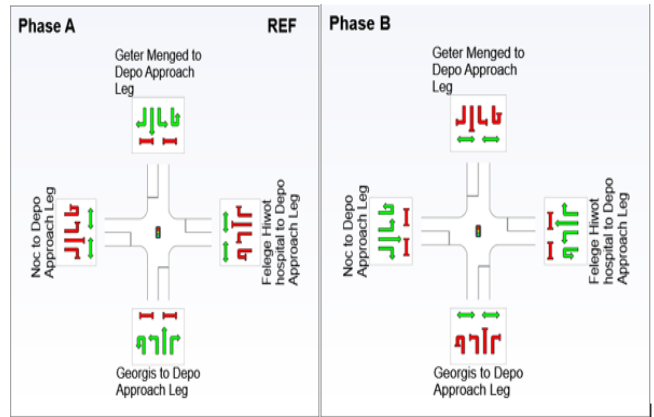


Figure 5. Level of service of traffic signal for improved phase times

Table 7. Output summary of signalized intersection after improved their phases

	Approaches				Intersection
	South	East	North	West	
LOS	A	B	A	B	B

The capacity analysis's outcome indicates that the hospitals in Noc and Felegehiwote were ranked B, while the level of service (LOS) on Georgia and the Getermerged Approach was rated A. In order to change the phase times for major and minor approach roads and to determine whether the intersection's performance may enhance the timing and phasing of the major road, the level of service for both this approach and the intersection as a whole is B. And based on the outcome, the intersection's degree of service has improved from D to B.

4.3. Analysis results of traffic signal depo intersection for replaced by roundabout

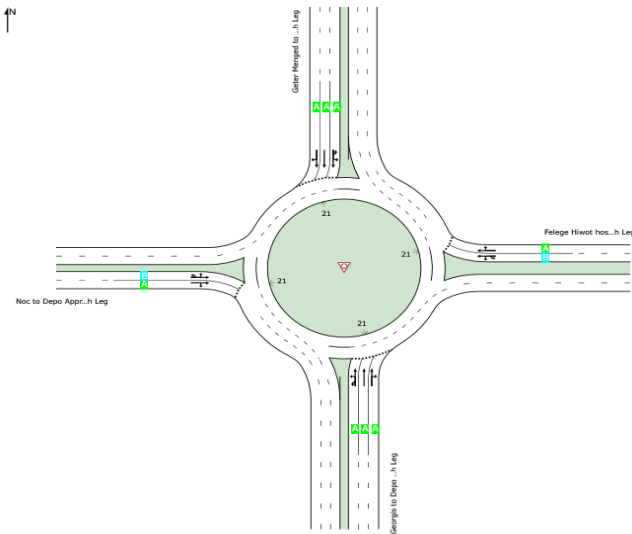


Figure 6. Level of service of roundabout for improved

Table 8. Output summary of replaced by roundabout

	Approaches				Intersection
	South	East	North	West	
LOS	A	A	A	A	A

Because of the full range of services available when the roundabout replaces the signalized intersection, the answer is A. Following the replacement of the signalized roundabout with a roundabout, the depo intersection's performance measure values are all generally at their best. The approach's degree of saturation, delay, and queue length are all significantly lower than they were before to replacement, when the approach's level of service was D due to the high waiting times that occurred before each approach lane's high traffic flow.

5. Conclusion

The results of analysis for the three alternative intersection performance evaluations under this study are summarized in Table 9. The performances were measured in terms of v/c ratio or degree of saturation, average control delay per vehicle and level of service. LOS was applied using the HCM 2010 Manual. Detailed analysis results of SIDRA Intersection Output.

Table 9. Summarized Result of Analyses for the intersections before and after the improvement

Intersection	Average Delay(se c)	Queue Length(m)	LOS	95% Back of Queue (veh.)
Signalized intersection	43.7	94.9	D	13.2
After improvement replaced by two phases	11.4	30.2	B	4.3
After improve of the intersection (replaced by round about	4.8	11.8	A	1.6

The Depo Intersection has major issues, according to the results of the current intersection performance analysis. Prior to improvement, the intersection's average delay and queue length were greater than their respective outcomes after improvement. In order to replace the signal in the roundabout and improve the intersection by adjusting the phasing time. At last, the intersection's average delay, wait time, and quality of service have all improved. As a result, the Depo signalized major intersection performance analysis results show that some of the intersections are either in poor condition or are overloaded during peak hours.

The main elements influencing intersection performance are: insufficient split signal phasing and, generally speaking, the absence of a signal in favor of a roundabout. The implementation of roundabout scenario (intersection treated as a modern roundabout) indicates superior performance at the junctions than the current condition, according to the results of the intersection capacity analysis carried out using SIDRA. The current status, which entails a move from D to A, is marginally worse than the suggested roundabout level of service. As seen above, when comparing the signalized intersection to the roundabout, it was discovered that the Average Delay at the Depo intersection was reduced by approximately 43.7 and 4.8 seconds, respectively. This suggests that turning a signalized crossroads into a roundabout intersection can assist reduce delays on approaches with less traffic. This is explained by the fact that in the event of a roundabout with low traffic volume, cars can pass the intersection without having to wait, and the number of vehicles in the 95th percentile queue decreased from 13.2 to 1.6.

Using SIDRA software, this article concludes with a thorough assessment of the signalized crossings in Bahir Dar City, Ethiopia. The results emphasize the potential advantages of optimization techniques and stress the significance of efficient intersection management in urban traffic planning. Increasing traffic enforcement, changing the geometry, and adjusting the timing of the signals are some suggestions for enhancing intersection performance. The use of intelligent transportation systems and adaptive signal control techniques may be investigated in future studies in an effort to improve Bahir Dar City's traffic efficiency and safety. The findings of this study offer valuable insights for traffic policy decision-making in Bahir Dar and other cities experiencing comparable congestion challenges. The analysis indicates that substituting signalized intersections with roundabouts significantly enhances traffic flow, thereby reducing delays, queue lengths, and overall congestion. Furthermore, optimizing signal phasing from four phases to two phases improves intersection performance, suggesting that similar modifications could be advantageous for other intersections.

These results can assist policymakers in prioritizing cost-effective infrastructure investments, enhancing traffic safety, and integrating sustainable urban transport strategies. The methodology employed in this study is also applicable to other Ethiopian cities, aimed at optimizing intersection performance and improving overall urban mobility.

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References

- [1] Akcelik, R. (1984). SIDRA-2 does it lane by lane. Paper presented at the Proc. 12th ARRB Conf.
- [2] Araghi, S., Khosravi, A., Johnstone, M., & Creighton, D. (2013). Intelligent traffic light control of isolated intersections using machine learning methods. Paper presented at the 2013 IEEE International Conference on Systems, Man, and Cybernetics.
- [3] Ashqer, M. I., Ashqar, H. I., Elhenawy, M., Almannaa, M., Aljamal, M. A., Rakha, H. A., & Bikdash, M. (2023). Evaluating a signalized intersection performance using unmanned aerial Data. *Transportation Letters*, 1-9.
- [4] Benhamza, K., & Seridi, H. (2015). Adaptive traffic signal control in multiple intersections network. *Journal of Intelligent & Fuzzy Systems*, 28(6), 2557-2567.
- [5] Cesme, B., Hayes, A., Wang, S., Warchol, S., Root, A., Bhagat, K., & Rouphail, N. (2023). Multimodal Intersection Signal Timing Considerations Framework, Performance Measures, and Case Study. *Transportation Research Record*, 03611981231159410.
- [6] De Schutter, B., & De Moor, B. (1998). Optimal traffic light control for a single intersection. *European Journal of Control*, 4(3), 260-276.
- [7] Dukiya, J., & Ajiboye, A. (2011). Performance analysis of urban road intersections and its environmental implication: a case study of the Lagos metropolitan area. *Urban Transport XVII*, 167.
- [8] Mohammed, A., Jony, H., Shakir, A., & Ambak, K. B. (2018). Simulation of traffic flow in unsignalization intersection using computer software SIDRA in Baghdad city. Paper presented at the MATEC Web of Conferences.
- [9] Nematichari, A., Pechlivanoglou, T., & Papagelis, M. (2022). Evaluating and forecasting the operational performance of road intersections. Paper presented at the Proceedings of the 30th International Conference on Advances in Geographic Information Systems.
- [10] Radjawane, L. E., & Lao, V. C. (2023). Evaluation of Type 322 Un-Signalized Intersection Performance. *International Journal of Science, Technology & Management*, 4(3), 568-574.
- [11] Ranjitkar, P., Shahin, A., & Shirwali, F. (2014). Evaluating operational performance of intersections using SIDRA. *The Open Transportation Journal*, 8(1).
- [12] Saldivar-Carranza, E., Li, H., Taylor, M., & Bullock, D. M. (2022). Continuous flow intersection performance measures using connected vehicle data. *Journal of Transportation Technologies*, 12(4), 861-875.
- [13] Schroeder, B., Rouphail, N., Salamati, K., Hunter, E., Phillips, B., Elefteriadou, L., . . . Mamidipalli, S. (2014). Empirically-based performance assessment & simulation of pedestrian behavior at unsignalized crossings. Retrieved from
- [14] Sisiopiku, V. P., & Oh, H.-U. (2001). Evaluation of roundabout performance using SIDRA. *Journal of transportation engineering*, 127(2), 143-150.
- [15] Son, S. (2017). Effect of Human Reactions at Signalized Intersections on Intersection Efficiency and Safety. Paper presented at the Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World®, Florida, USA.
- [16] Wang, B., Schultz, G. G., Macfarlane, G. S., & McCuen, S. (2022). Evaluating signal systems using automated traffic signal performance measures. *Future transportation*, 2(3), 659-674.
- [17] Yousef, K. M., Al-Karaki, M. N., & Shatnawi, A. M. (2010). Intelligent traffic light flow control system using wireless sensors networks. *J. Inf. Sci. Eng.*, 26(3), 753-768.
- [18] Zhong, Y., Liu, H., & Lv, M. (2022). Intelligent Algorithm Based Traffic Flow Automatic Control Method at Traffic Intersection. Paper presented at the 2022 6th Asian Conference on Artificial Intelligence Technology (ACAIT).