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A Macroscopic Performance Evaluation of Unsignalized Intersections in Mixed Traffic: A Case Study of Adama City, Ethiopia

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ABSTRACT

This study evaluated three unsignalized intersections in Adama City, Ethiopia, which were identified as critical congestion points. Performance analysis confirmed all were operating under Level of Service F, characterized by extreme control delays (51-210 seconds/vehicle) and unsustainable saturation levels (v/c ratios of 2.38-6.15). In response, targeted mitigation strategies such as road widening and signalization were developed and modeled. The results demonstrated the high effectiveness of these interventions, showing a dramatic reduction in delays and an improvement in the Level of Service to B, C, or D. These findings offer a validated, actionable strategy to significantly increase capacity, restore operational efficiency, and enhance safety.

1. Introduction

Intersections are crucial components of any road network, functioning as nodes where traffic streams from various directions converge and interact. Their efficient operation is paramount for ensuring mobility, safety, and overall network performance. An Unsignalized intersection, lacking traffic signals for control, relies on driver judgment, priority rules, and gap acceptance, making it particularly complex under mixed traffic conditions characterized by diverse vehicle types (Wang et al., 2017).

In developing countries like Ethiopia, the traffic stream is highly heterogeneous, comprising a mix of motorized and non-motorized vehicles sharing the same right-of-way without lane discipline. This leads to unique challenges such as reduced capacity, increased delays, and heightened accident risks (Dagimwork, 2019). Adama City, one of Ethiopia's rapidly growing urban centers, experiences severe traffic congestion at its Unsignalized intersections, resulting in significant economic losses due to increased travel time, fuel consumption, and operational costs (Tadesse, 2011; & Fasika Mekonnen, 2015).

Previous studies have highlighted the poor performance of intersections in Ethiopian cities. For instance, Hassan & Nurhussien (2015) found low levels of service and high degrees of saturation in Bahir Dar City. Similarly, (Wondwossen (2011) reported LOS F conditions at major corridors in Addis Ababa. While these studies identify the problem, there is a gap in applying advanced simulation software like SIDRA and SYNCHRO to propose and evaluate specific, calibrated improvement measures for unsignalized intersections in the Ethiopian context. This study aims to fill this gap by conducting a detailed performance evaluation of three critical unsignalized intersections in Adama City. The specific objectives are:

1. To measure traffic volume, speed, and travel time at selected intersections.
2. To evaluate the existing capacity, delay, and Level of Service (LOS).
3. To identify parameters affecting intersection performance.
4. To propose and evaluate improvement measures using SIDRA and SYNCHRO software.

1.1. Statement of the Problem

The characteristics of heterogeneous traffic flow are extremely typical of Adama City. Both motorized and non-motorized vehicles simultaneously use the road network, which creates mixed traffic conditions and causes many problems. Such as low level of service, increase in the time of travel, high congestion, low speed, and increased accidents, especially throughout the morning and evening rush hours, and mismanagement of the transport networks, which is due to the absence of lane-based traffic systems; he1nce, some special attention is needed for such types of traffic and transport problems.

1.2. General Objective

To comprehensively evaluate the operational performance and identify key deficiency patterns of unsignalized intersections in Adama City, Ethiopia, using a macroscopic approach under prevailing mixed traffic conditions.

1.3. Specific Objectives

- To quantify the operational performance of selected unsignalized intersections by measuring key traffic parameters, including approach speed, traffic volume, and vehicle travel time.
- To identify and analyze the critical factors influencing the capacity of unsignalized intersections in Adama City, with a focus on the impact of mixed traffic composition, gap-acceptance behavior, and geometric layout.
- To evaluate the quality of service at the selected intersections by analyzing control delay and determining the corresponding Level of Service (LOS).

2. Literature Review

The performance of intersections is typically evaluated using Measures of Effectiveness (MOEs) such as control delay, degree of saturation (volume-to-capacity ratio), queue length, and Level of Service (LOS). The Highway Capacity Manual (HCM) is a widely accepted standard for this purpose (HCM, 2010).

2.1. Level of Service (LOS) for Unsignalized Intersections

LOS is a qualitative measure that categorizes operational conditions from A (best) to F (worst). For unsignalized intersections, LOS is primarily based on control delay (HCM, 2010), as shown in Table 1.

Table 1: LOS Criteria for Unsignalized Intersections (HCM, 2010)

LOS	Control Delay (sec/veh)	Description
A	≤ 10	Free flow
B	>10 - 15	Stable flow, slight delays
C	>15 - 25	Stable flow, acceptable delays
D	>25 - 35	Approaching unstable flow
E	>35 - 50	Unstable flow, intolerable delays
F	>50	Forced flow, intersection failure

2.2. Capacity and Delay

The capacity of an intersection is the maximum sustainable flow rate it can accommodate. The degree of saturation (v/c ratio) indicates the utilization of this capacity. A v/c ratio exceeding 1.0 signifies demand exceeding capacity, leading to excessive delays and queue formation (FHWA, 2000). Delay, the extra time spent by a vehicle traversing an intersection, is the primary MOE for determining LOS.

2.3. Application of Traffic Software

Software tools like SIDRA INTERSECTION and SYNCHRO are indispensable for modern traffic analysis. SIDRA uses lane-based micro-analytical models to estimate capacity and performance for signalized and unsignalized intersections (Akçelik, 2011). SYNCHRO is widely used for signal optimization and network modeling. Several studies, including Prakash Ranjitkar (2014) and Tsedey (2020), have successfully used SIDRA to evaluate intersection performance and propose improvements.

The three fundamental types of intersections are the three-leg or T-intersection (with variations in approach angle), the four-leg junction, and the multi-leg intersection. Any road's traffic junctions are difficult to navigate. This is the result of vehicles trying to share a space while going in different directions. In addition, drivers must make split-second decisions at crossroads while taking into account their path, the layout of the intersection, the speed and direction of oncoming traffic, etc. (J. Li et al., 2004).

3. Material and Methodology

3.1. Study Area

Adama City is located in the central region of Ethiopia, approximately 99 kilometers southeast of Addis Ababa. Ethiopia's central Oromia Region contains the city of Adama. It is situated between latitude 8.54°N and longitude 39.27°E at an elevation of 1712 meters.

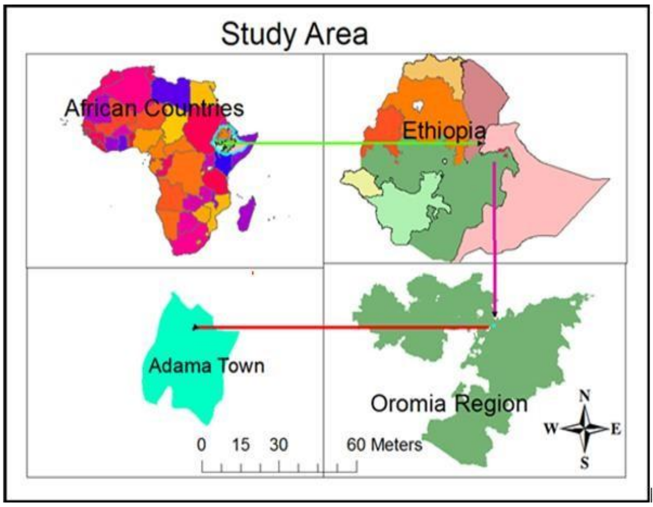

Figure 1. Study area map

After deciding on the study's goals, it was decided to perform a preliminary survey throughout the entire city of Adama. Based on the preliminary survey data, there are more than 18 important intersections in the city. However, due to time and resource limitations, the researcher selected three of the eighteen (18) intersections to further analyze, namely Mebrathaile, Sartrea, and National.

Table 3. Total Approach Traffic Volume for all Intersections

MEBRAT HAILE INTERSECTIONS				
	Posta bet Approach	Mariam Approach	Sartera Approach	Medhanialem Approach
Tuesday (10/02/2015)	14009	9072	15163	14998
Wednesday (11/02/2015)	10472	7072	13329	12581
SARTERA INTERSECTION				
	Kera Approach	Mebrathaile Approach	Atanatera Approach	Ginb Approach
Tuesday (17/02/2015)	10960	11868	11422	12495
Wednesday (18/02/2015)	11820	14964	18758	21388
NATIONAL INTERSECTION				
	Ginb Approach	Francho Approach	Posta Approach	Sartera Approach
Tuesday (23/02/2015)	14033	8802	12659	13653
Wednesday (24/02/2015)	13771	8111	11281	13838

3.3. Data Analysis

Traffic volumes were converted to Passenger Car Units (PCU) using HCM (2000) equivalent factors. The Peak Hour Factor (PHF) was calculated for each approach. The processed data (volumes, geometry, PHF, PCU values) were input into SIDRA INTERSECTION software to determine the existing MOEs: capacity, control delay, degree of saturation, and LOS.

3.4. Improvement Strategies

Based on the analysis, improvement scenarios were developed:

- Scenario 1 (Mebrathaile): Restriction of Bajaj and heavy vehicles, and implementation of traffic signals.
- Scenario 2 (Sartera): Road widening (adding lanes to one-way approaches) and signalization.
- Scenario 3 (National): Road widening and construction of a flyover on the Sartera-Franco corridor.

These scenarios were modeled and evaluated using SIDRA and SYNCHRO software to quantify there.

3.5. Geometry Data

Geometric data are crucial elements for the analysis and model calibration process of intersection performance for smooth flow of transportation systems.

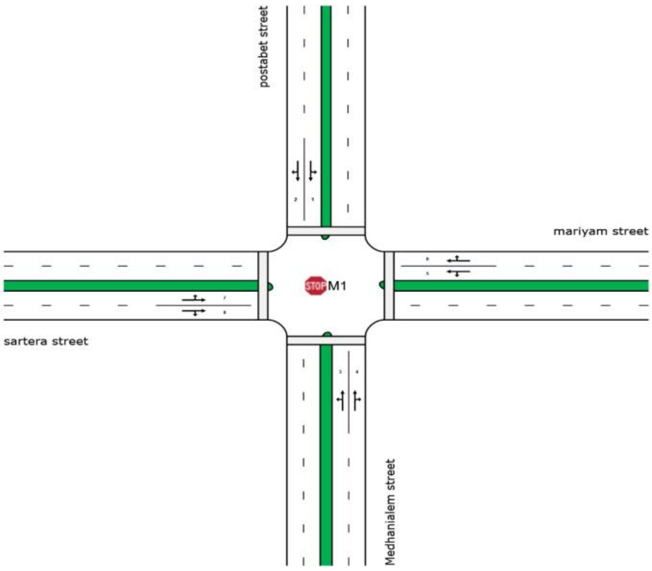

Figure 2. Mebrathaile intersection's geometric layout

3.6. Analysis Method

Using SIDRA intersection software and actual site data, the performance analysis of the study's selected unsignalized intersections has been carried out as follows steps:

Steps follow for Sidra Intersection Input Data

The software allows the input of many variables that account for the variable conditions, including minimum-required geometric, pedestrian, and vehicular features, for each intersection.

- Site name (name of the intersection)
- Intersection identification number
- Site title (two-way, one-way, three-way) Approach geometry.

Approach geometry

- Approach name
- Approach leg geometry (one-way, two-way, one-way exits, one-way entries, etc.)
- Approach distance and exit distance : distance from other intersection.

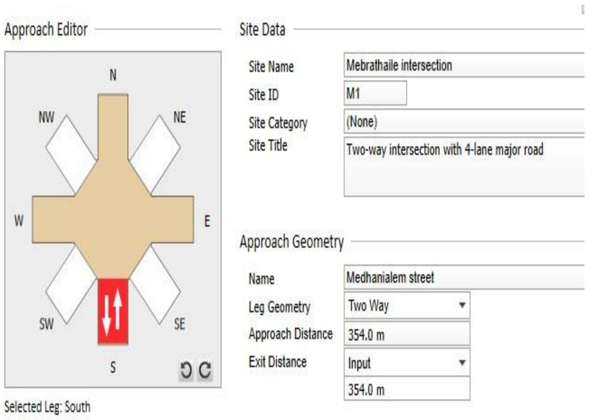

Figure 3. Intersections dialogue box source (screen shoot from sidra software)

Step 2. Movement definition dialogue
Write the names of vehicles and allocate vehicles for movement classes based on the filed study, and allocate the origin destination turning movements (right turn, left turn as well as through movement) as shown below.

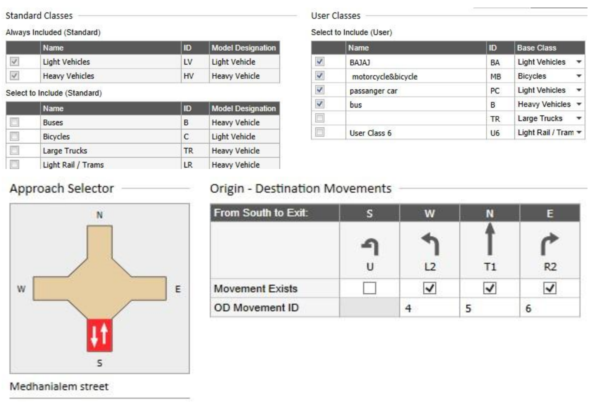

Figure 4. Movement definition dialogue (screen shoot sample from sidra software)

Step3- lane geometry dialogue Lane configuration data

- Lane type (normal, slip/bypass high angle, and slip/bypass low angle).
- Lane length, Lane width, Median width.
- Lane configuration (full-length lane, shot-length lane, short lane with parking, etc.) .

Lane discipline data and

- Allocate the vehicle's turning movements (LT, RT, and TH).
- And enter lane data, saturation flow rate.

Step4 -pedestrian dialogue box

- Volume of pedestrians (per 60 m),
- Peak flow factor,
- Flow scale (constant),
- Growth factor.

4. Results and Discussion

4.1. Existing Traffic Conditions

The analysis revealed extremely high traffic volumes during morning (7:45-8:45 AM) and afternoon (4:30-5:30 PM) peak hours. The vehicle composition was dominated by Bajaj (34-37%) and passenger cars (23-33%), contributing to the heterogeneous traffic flow.

4.2. Mebrat haile intersection traffic volume analysis

The main center of business activity in Adama City is the Mebrat Haile intersection. The primary commercial district around the intersection is Arada and other features markets, shopping centers, offices, schools, colleges, restaurants, and more on every side of this intersection.

4.3. Travel time and speed

4.3.1. Travel time

The graph below displays an average travel time at a 15-minute interval for the selected intersection.

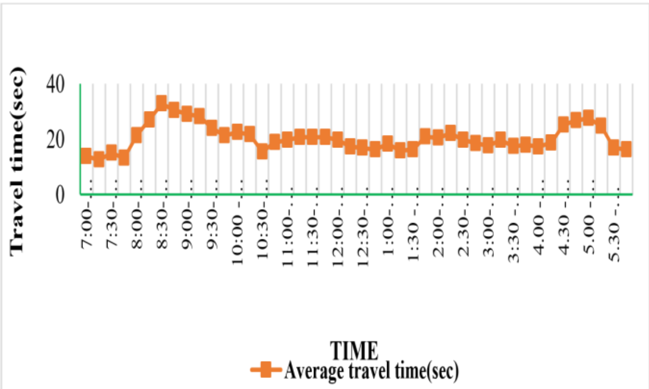

Figure 5. Average Travel Time at mebrat haile intersection

4.3.2. Average travel and Average speed

The following were the Posta bet approach's 15-minute average travel times and speeds to the Mebrat Haile intersection:

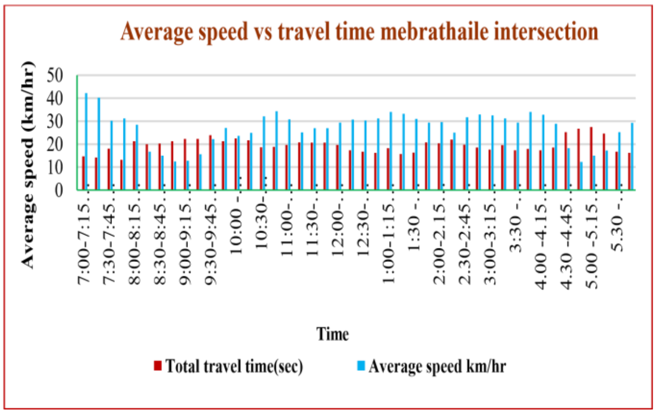

Figure 6. Travel time and Average speed mebrathaile intersection

4.4. Intersection performance analysis

4.4.1. Delay of Mebrathaile intersection

Delay and level of service evaluations were conducted using the information collected. The Highway Capacity Manual 2010 metric edition was used in order to achieve the right outcome and make it consistent with Ethiopian driving regulations. The level of service maintained at LOS F represents jammed and unstable traffic flow conditions.

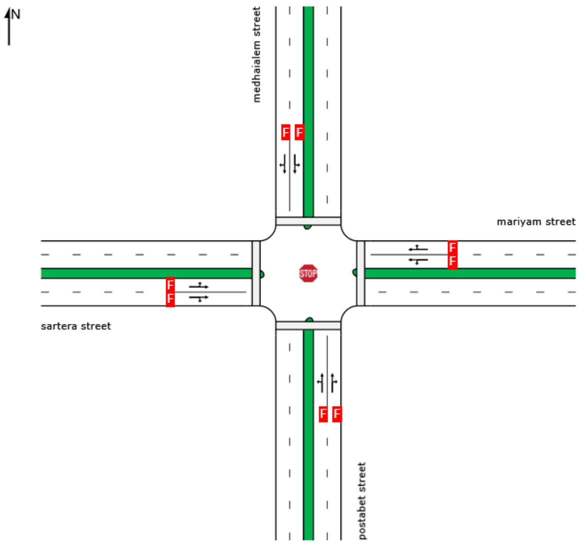

Figure 7. Lane LOS of Mebrathaile Intersection

4.4.2 Delay of Satera Intersection

In this intersection the two approach of the road is one way road from atanatera and national streets, this leads to a very high delay and long queues of vehicles comes from this two approach. The level of service at this intersection remained at LOS F, which indicates poor capacity and congested traffic flow conditions occurred.

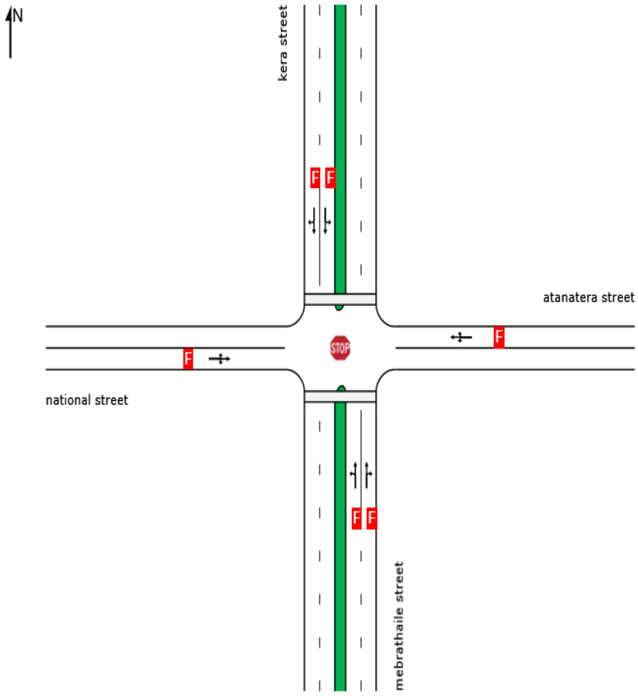

Figure 8. Lane LOS of Sartera Intersection

4.4.3. Delay of National Intersection

The primary indicator of effectiveness used to assess the intersection's operational performance is the intersection delay. The analysis result for the National intersection indicates high values for the degree of saturation, delay and queue length and low values for capacity for the intersection's four approaches, resulting in a level of service rating of F for all approaches.

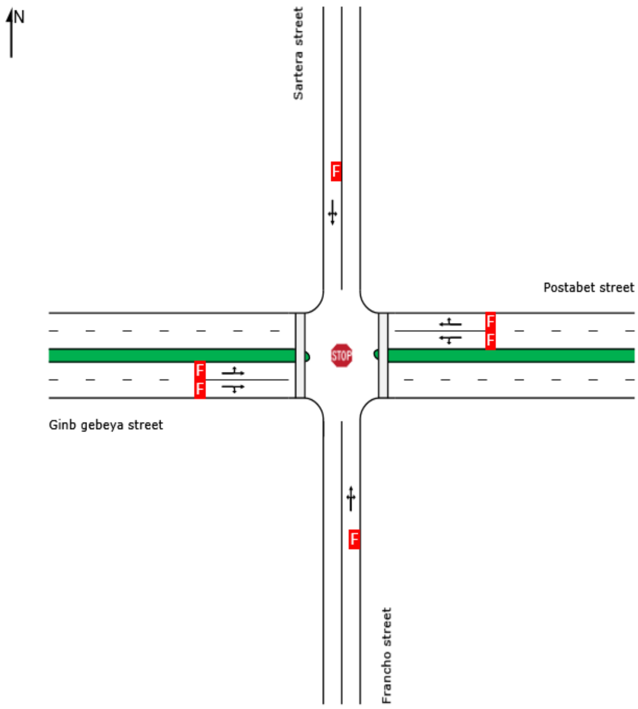

Figure 9. Lane LOS of national Intersection

5. Conclusion and Recommendation

This study evaluated the performance of three unsignalized intersections in Adama City under mixed traffic conditions. The analysis conclusively determined that all selected intersections are operating at Level of Service F, characterized by excessive delays, severe congestion, and volume-to-capacity ratios far exceeding 1.0. The heterogeneous traffic, high demand during peak hours, and inadequate geometric design are the primary contributors to this poor performance.
The research successfully demonstrated that targeted engineering interventions, such as road widening, movement restrictions, and traffic signalization, can significantly improve intersection performance. The simulation results from SIDRA and SYNCHRO confirmed that these measures can reduce delays by over 80% and improve LOS from F to B/C/D, thereby enhancing capacity, safety, and overall traffic flow efficiency.

Based on the following recommendations are proposed for Adama City:

1. Immediate Implementation: The proposed improvement measures (signalization at Mebrathaile and Sartera, lane addition at Sartera and National) should be prioritized for implementation by the city administration.
2. Long-Term Infrastructure Planning: For the National intersection, the construction of a flyover should be considered as a long-term solution to segregate through traffic.
3. Traffic Management: Enforce traffic regulations, particularly regarding restricted vehicle movements, to maintain the benefits of the improvements.
4. Future Research: Further studies should investigate the impact of driver behavior, pedestrian crossing patterns, and the economic and environmental benefits of these improvements (e.g., reduced fuel consumption and emissions).

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