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Effect Of Cycle Time And Signal Phase On Average Time Delay, Congestion And Level Of Service: A Case Study At Hager Astedader Signalized Intersection in Addis Ababa

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Abstract: High urbanization rate and Economic development have caused many challenges to transportation systems. Among these, long time delay and high fuel consumption of vehicles at congestion places are a few to mention. Many literatures have revealed that road traffic congestions are caused by inadequate infrastructures, long signal cycle time and poor traffic management, such as incapable roads, inefficient public transit, and high travel demand. The research study was focused on the effect of traffic congestion on average time delay at selected signalized road intersection in Addis Ababa. The study area was Hager Astedadrerroad traffic signal intersection. The methodology that has been employed for the study was a quantitative descriptive research design method. The data needed were; road geometry data, signal data, traffic vehicles flow data including the pedestrian data were collected on peak hours (with 15minutes interval) from 7:30 - 9:30 AM and from 5:30 – 7:30 PM for the four consecutive working days. Data of traffic classes were extracted manually on a separate worksheet. The volume of each vehicle category was converted to the same vehicle category using passenger car unit (PCU) of each vehicle class. Data analysis and processing have been performed using SIDRA (Signalized and Unsignalized Intersection Design and Research Aid) intersection software in order to know the traffic flow condition at the intersection. The result of average time delay was used to know the corresponding level of service and operational performance of the intersection. The outcomes of the research work minimize average time delay by adopting different improving strategies that range from low-cost measures such as improvements to signal timing and phase numbers, to high-cost measures such as intersection reconstruction, which be applied in the study area after knowing the amount of average time delay as well as the types of the level of service within the intersection area.

Index Terms— Level of Service, Passenger Car Unit, Peak Period, SIDRA, Traffic Congestion, Time Delay, Traffic Management, Traffic Signal.

1 Introduction

In The cities and traffic have been developing parallel, because of human settlements. Though their magnitude or patterns are more complex today, cities still provide access to various social and economic activities, such as services, goods, markets, network, and these which determines the development of the urban areas [4].

Urban economic activities and movements have a direct relationship. An adequate transport system is needed to facilitate a greater choice of the peripheral areas if urban transport provided by the government. Because of most socioeconomic activities concentrated in the center of city, many urban mobility problems are created, such as increasing car usage and trips to the central business districts. This in turn leads to high demand for parking, urban environmental problem (pollution, noise), and inability to handle these problems results in congestion [5].

Fast growth in urban and industrializations demand the use of more vehicles group which leads to an imbalance between the infrastructures availability and mobility. In the third world, the roads are narrow or incapable to accommodate a heavy traffic that slow the traffic flow, accompanied by inadequate provision for parking and loading and boarding facilities, sidewalks along the street, and mixed land use [6].

Traffic Congestions become common characteristics in urban road transportation system of cities in developing countries which result in high operating cost, loss of users' productive time, and more fuel consumption among others [7].

Due to numerous factors, congestion is becoming a more serious problem in the Addis Ababa city from time to time, such as population growth- in addition to natural growth, pull factor that immigrate people from different part of the country to the city in searching for a livelihood. To sustain the city, it is clear that these added portions of the society also need transport service to sustain their day to day activities. However, the city is unable to cope up with the existing high transport services demand because of poor infrastructure, high population and the absence of well traffic management which are the major reasons why traffic congestion exist.

Understanding of the present situation of vehicle traffic congestion is a very important area of consideration in order to make the right decision to solve the issues [11].

2 Research Methodology

The quantitative descriptive research design used for the purpose of this study, which enable the research to interpret the finding adequately and accurately.

Consequently, the research work consisted the relevant data collection, intensive data analysis by some suitable tools and describe the effect of road traffic flow, the pedestrian data, road geometry data and signal characteristics with the relationship of average time delay and the Level-Of-Services by using the software at the signalized road intersection quantitatively. Below is the flow chart of the research work.

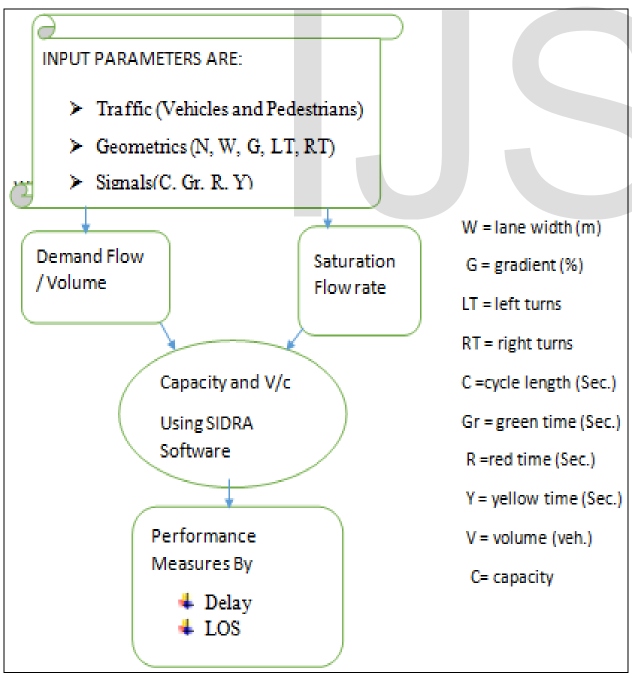

Figure 2.1: Flow Chart of Research Study

2.1 Study Area

Addis Ababa has five main roads that radiate from North-South and East-West directions linking to external Towns of the country. Among them, Addis Ababa - Akaki main road is the one which runs through Lafto sub-city and contributes the traffic congestions on the study area.

The study area is located at East of TikurAnbessa, North of Biheraw, South of Piazza, and Northwest of Filhuha (Posta Bet). The study intersection is comprised of two right turn and four approaches of which traffic flow enters/dissipates. The study area is located almost at the center of the city where high commercial/ business activities are highly experienced which result traffic congestion during the two activities are highly experienced which result traffic congestion during the two peak hours.

Figure 2.2: Location of the study area (Source: Google Map 2015)

At junction, or intersection, is the general area where two or more roads join. The study area is located on Churchill Avenue (street). The availability of nearby institutions such as Black Lion Hospital, Immigration Head Office, Ethiopian Telecommunication Head Office, Ethiopia Broadcast Corporation, Black Lion School, Ministry of Transportation and public bus stopping for those Office has an important effect on the intersection. Detail drawing of the intersection is as follows.

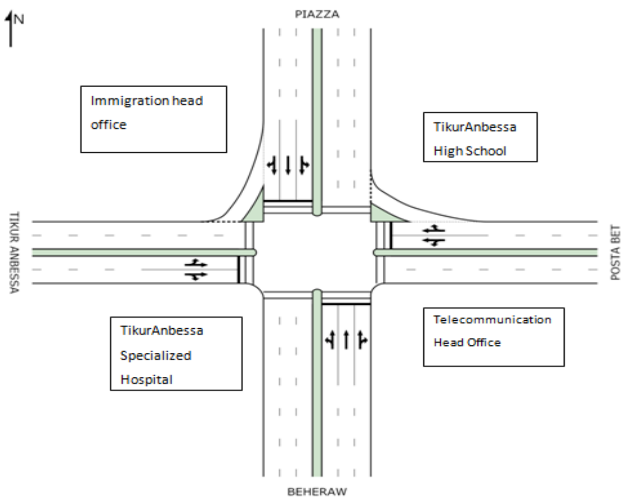

Figure 2.3: Sketch of study area with lane configuration

Where: PHF= peak-hour factor,
V= hourly volume (veh/h),
V_{15} = volume during the peak 15 min of the peak hour (Veh/15 min).
When the PHF is known, it can convert a peak-hour volume to a peak flow rate by Equation:

$$v = \frac{V}{PHF} \qquad (1)$$

Where:
v= flow rate from a peak 15-min period (veh/h),
V = peak-hour volume (veh/h), and
PHF= peak-hour factor

The flow rate than can be computed simply as 4 times the maximum 15-min count.

1.1.1 Saturation flow rate

The saturation flow rate is normally given in terms of straight-through passenger cars per hour of green. Most design manuals and textbooks provide tables that give common values for trucks and turning movements in terms of passenger car units (pica) [1].

Thus, the saturation flow rate was defined as the flow rate per lane at which vehicles can pass through a signalized intersection and can be computed by the following equation:

$$SFR = 990+ 288TL+8.5SL-26.8G \qquad (2)$$

Where:
SFR = Saturation flow rate, TL = Number of through lanes
SL = Speed limit,
G = Gradient in percent

1.1.2 Optimum Cycle Length

Optimum cycle time is the time at which relatively small vehicle delay recorded. This means, if the cycle is too long, delays will be lengthened, as vehicles wait for their turn to discharge through the intersection.

Table 3.1: Approach and exit grades Values (Study Area)

Name of approaches	Approaches grade values (%)	Exit grades values (%)
Piazza	-3.5	3.5
Posta Bet	2.3	-2.3
Beheraw	2.4	-2.4
Tikur Anbessa	-3.6	3.6

Webster's equation, which minimizes intersection delay, gives the optimum cycle length (C_O) as a function of the lost time and the critical flow ratios. Many design manuals use the Webster's equation as the basis for their design and only make minor adjustments to suit their purposes. Webster's equation is shown below:

$$Co = \frac{1.5L + 5}{1 - \sum (V/SFR)} \qquad (3)$$

L = (Starting loss + all-red) * number of phases.
= (2sec. + 2sec) * 4 = 16 Sec.

3 RESULTS AND DISCUSSION

During the field survey, road geometry, signal characteristics and traffic flow conditions like vehicle queues and travel patterns through the intersection were examined. These were identified and noted whether it would interfere with upstream intersections by not using SIDRA intersection software. Since there was no precise methodology during the design phases of any intersection, which usually guided by the geometry of the intersection, trial and error procedure usually adopted.

To summarize the research work; first the researcher has been tried to analyze the existing intersection using the collected data as it is (Do nothing) with the existing phase numbers and the cycle

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time. Then by improving those parameters (cycle time and phase numbers) the intersection was examined again. However, if the intersection did not show performance improvement after adjusting these parameters, the researcher had had to suggest an improvement of the intersection geometry.

Therefore, the output of the SIDRA Intersection Software Program was presented below based on Fixed Time Signal, parctical Cycle time of 160 seconds and four phasing system.

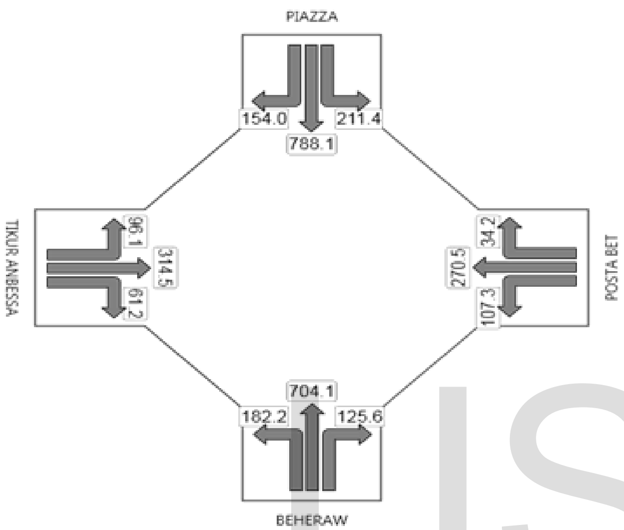


Figure 4.1: Capacity of the existing Hager Astedader signalized intersection

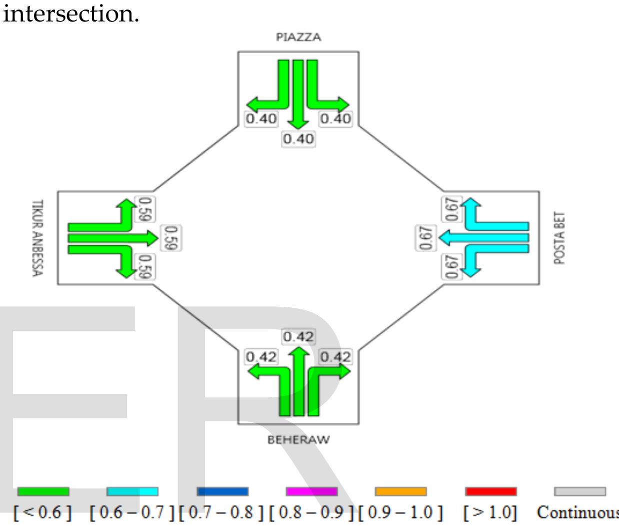
The above figure 4.1 shows the maximum sustainable flow rate at which vehicles were traversed at the study area intersection during a specified time period. The maximum capacity of the study area intersection was determined by the maximum capacity of each leg or each lane group which is summarized in the following table 4.1. The maximum numerical value in any lane group represents the capacity of the intersection.

3.2 Degrees of saturation (V/C) for "do nothing"

Figure 5 below referred to as the ratio of demand volume to capacity of each lane group. The volume to capacity ratio of the software output for Hager Astedader intersection was less than one as shown in the below figure5 which represents the current traffic operation in the study area is moderately congested flow condition.

Based on Highway Capacity Manual, when v/c ratios are less than 1.0, the intersection is serving under capacity. Even if the v/c ratio is less than 1.0, there may be considerable delay by looking at its level of service. For an individual lane group or for the overall intersection, departure volumes may not equal to arrival volumes due to the existing signal or phase allocations. If so, changes or modification in either or both should be considered especially in cycle length.

The degree of saturation for each lane group can determine the degree of saturation for the signalized intersection. This means that the maximum degree of saturation of any lane group from all approaches represents the degree of saturation of the intersection.



Color code based on Degree of Saturation

Figure 4.2: Demand Volume to Capacity (v/c) ratio at Hager Astedader Signalized Intersection.

In the study area signalized intersection, demand volume to capacity ratio was higher in the Eastern leg than the others. In fact, all approaches were near stable flow results in a wide range of delay even if the capacity exceeds the available demand of the intersection, which brings excessive delays as per volume to capacity ratio threshold.

Table 3.2: Volume-to-Capacity Ratio threshold at Signalized Intersection.

V/C ratio	Assessment
<0.5	Intersection is operating under capacity. Excessive delays are not experienced
0.5 to 0.74	Intersection is operating near its capacity. Higher delays may be expected, but

	continuously increasing queues should not occur, Moderate congestion can be occurred. Signal improvement will be required to reduce delay.
0.75 to 1.00	Unstable flow results in a wide range of delay. Intersection improvements will be required soon to avoid excessive delays.
>1.00	The demand exceeds the available capacity of the intersection. Excessive delays and queuing are anticipated.

Source: Victoria Transport Policy Institute

3.3 Movement Timing

Table 3.3: Phase time determined by the SIDRA Program

Phase	**A**	**B**	**C**	**D**
Green Time (Sec)	40	40	30	30
Yellow Time (Sec)	3	3	3	3
All-Red Time (Sec)	2	2	2	2
Parse Time (Sec)	45	45	35	35
Phase Split	28 %	28 %	22 %	22 %

Sequence: Four Phasing
Input Sequence: A, B, C, D
Output Sequence: A, B, C, D

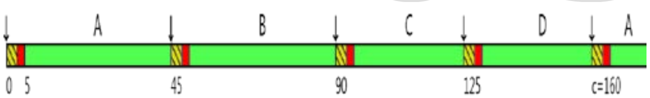


Figure 4.3: Diagram of signal phasing of the existing intersection

The number shows the timing of the actual existing signals for each four phases, for example;
45 seconds = yellow time for phase A + all-red time for phase A + green time of phase A

Re-analyzed intersection after adjusting the cycle time and phase number.

Table 3.5: Adjusted cycle time of the study intersection with two phasing

Signals	Phase A (From North)	Phase B (From south)	Phase C (West-East)
Green	24	24	33
Yellow	3	3	3
All-Red	2	2	2
Cycle time	96 seconds		

3.4 Movement Timing

Phase times determined by the program
Sequence:
3- Phasing
Input Sequence: A, B, C
Output Sequence: A, B, C

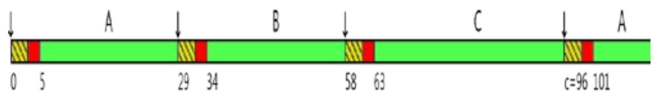


Figure 4.4: Diagram of adjusted signal timing of the existing intersection

The number represents the sum of the given signal timing and finally gives cycle time (C= 96 Sec.). The reason for allocating larger green time for phase C, it comprised the number of traffic volume comes from two directions (West-East direction).

3.5 Revised Capacity

Table 3.4: Adjusted capacity of the existing intersection and approaches

Entering	South	East	North	West	Intersection
Capacity (Pcu/h)	717	422.4	806.5	475.8	806.5

This implies that as the number of vehicles passing the intersection become increase, the average delay at the intersection will decreases based on their green signal time. Not only the capacity of the intersection increased, but also capacity of each lane group was increased.

3.6 Revised Degree of Saturation

Table 3.6: Revised degree of saturation of the existing intersection and approaches

Entering	South	East	North	West	Intersection
Degree of Saturation	0.41	0.43	0.39	0.39	0.43

As observed in the above table 5, degree of saturation for the intersection implies in the range of stable traffic conditions, low or no congestion as per Victoria Transport Policy Institute (VTPI) specified bellow.
V/C Ratio greater than 1.0 = Severe Congestion, V/C Ratio of 0.75 to 1.0 = Heavy Congestion
V/C Ratio of 0.5 to 0.74 = Moderate Congestion, V/C Ratio of less than 0.5 = Low or No Congestion/ less delay

3.7 Revised Level of Service

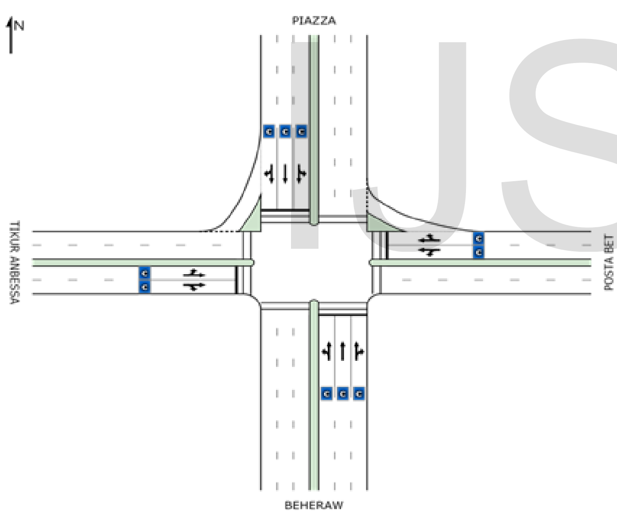


Figure 4.5: Revised Level of service of Hager Astedader signalized intersection

The level of service of the intersection in "do nothing" was E for vehicles, but after adjusting the cycle time and phase number the level of service of the intersection became C as shown in the above figure 9.

4 CONCLUSION

Any intersection has to be designed to provide good quality of service as perceived by the users and to avoid conflicting traffic flow movements. The "do nothing" or the actual traffic movements of the existing signalized traffic intersection were noted to have long average time delay of 58.7 seconds per vehicles while after adjustment of cycle time and phase number was made, the average time delay of the intersection became reduced to (30.1 seconds per vehicles). The delay in this research work was not due to the intersection geometric problem rather due to long cycle time. The level of service of the intersection in the "do nothing" was found to have LOS E which means, the intersection has been serving near its capacity with low speed, but for the revised it became LOS C which implies relatively stable flow condition at the intersection.
The traffic flow conditions of the intersection in the "do nothing" was moderately congested with a V/C ratio of 0.67 while in the "Revised" it became low or no congestion because of the degree of saturation (V/C ratio) of the intersection in the "Revised" became less than 0.5, which indicates that arrival and departure volumes are the same. Delay and level of service are an indication of the potential capacity and performance measure of an intersection. Based on this research work, the main contributory factors for moderate traffic congestion in the study area, was the allocation of long cycle time and four phase numbers at the intersection. Finally, the possible measures would be undertaken in reducing average time delay at the study area by checking the allocation of signal cycle time and phase numbers by concerning the bodies.

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