CAPACITY ANALYSIS OF SELECTED MAJOR INTERSECTIONS ON THE ROUTE AUTOBUS TERA - KALITY BUS STATIONS AND MITIGATION MEASURES

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ABSTRACT

Engineering mitigation measures were proposed in order to improve the existing levels of service for major intersections. The adjustment to the existing cycle time, delineation of movements on existing lane configuration and geometric modifications to observe the improvements on the respective levels of service were among the proposed mitigation measures. It was hypothetically believed that there exist short comings on the route Autobus Tera - Kality bus stations from congestion and level of service points of view. Subsequently, four signalized intersections were selected based on statistical outputs of mixed type of questionnaire. They were then analyzed by using software tool (SIDRA) so that the outcome could be used as a source of information and data for transport sector organizations and academic reference. Accordingly, the level of service of Eliana hotel site improved from level F to D & the average delay from 167.3 seconds to 54.7 seconds and level of service of Immigration site improved from level F to E & the average delay from 435.5 seconds to 68.7 seconds. Moreover, level of service for both Harambae and Saris Adey Ababa sites improved from F to D & the average delay from 642.6 seconds to 54.2 seconds and from 865.1 seconds and 49.13 seconds, respectively.

Key words: level of service, delay, major intersections, SIDRA

1. INTRODUCTION

The Addis Ababa city transport policy has the general objectives of providing safe, efficient, comfortable, affordable, reliable and accessible transport service for the urban dwellers, enabling the sector to provide socio-economic development, good governance, improve the livelihood of the society and adopt environmental protection of the city and enhancing the status of the city as international seat, by introducing seamless traffic flow through modern traffic management system [1]. In order for the above policy objectives to be achieved, continuous assessment of performance at transport infrastructures must be carried out. The route considered for this research runs from north to south of the city and crosses 5 sub cities namely Addis Ketema, Arada, Kirkos, Nifas Silk Lafto and Akaki Kality sub cities. The three measures of effectiveness commonly used to evaluate signalized intersection operations are, capacity and volume-to-capacity ratio, delay and queue [3]. Level of Service (LOS) is considered as a performance measure. It is computed for the automobile, pedestrian, and bicycle travel modes. It is useful for describing intersection performance to elected officials, policy makers, administrators, and the public. Capacity is defined as the maximum rate at which vehicles can pass through a given point in an hour under prevailing conditions. Delay is defined as the additional travel time experienced by a driver, passenger, or pedestrian. Control delay is used as the basis for determining

LOS. Intersection control delay is generally computed as a weighted average of the average control delay for all lane groups based on the amount of volume within each lane group [4]. The signal timing of an intersection plays an important role in its operational performance. Key factors include effective green time, clearance interval, loss time, cycle length and progression [5].

Many of the intersections especially in the capital city, Addis Ababa were found to be operating in low LOS with higher delays [6 – 9]. Similarly, various capacity analysis and study of traffic intersections had been made in major cities of countries in the world and found out that many of the intersections were with level of service F. The researches also pointed out engineering mitigations such as geometric modifications, cycle time optimization and dedication of lanes for traffic movements which could possibly improve the site levels of service [10–12].

Researches had been conducted in analysis of intersections located in major cities of Ethiopia. The researchers analyzed the level of services, delay and environmental problems of major intersections. However, only few researches showed the comparison of suggested mitigation measures with the existing conditions [6].

The present work has analyzed the existing conditions at the major intersections and unlike the previous researches conducted, it proposed three engineering mitigation measures (cycle time optimization, delineation of movements and geometric modifications) for all the four major intersections there by comparing and contrasting the level of improvements with the existing conditions and to each proposed mitigations so that the most applicable and economic approach in view of short term and long term plan can be inferred and applied to solve the engineering problems prevailing at the major intersections.

2. MATERIALS AND METHODS

Primary sources of data like questionnaire and field data recording were used for analysis based on statistical estimations of sample size required. The data were then analyzed using the software tool Signalized & Unsignalized Intersection Design and Research Aid (SIDRA) [2].

2.1 Study Area

The study areas for this research were located in Addis Ababa, specifically, the major signalized intersections on the route from *Autobus Tera* to *Kality* Bus stations namely *Eliana Hotel/ Banco Di Roma*, *Immigration*, Ethiopia hotel/ *Harambae* and *Saris Adey Ababa* signalized intersections. Figures 1 and 2 show two of the signalized intersections.

Figure 1 Study area of Eliana Hotel signalized intersection

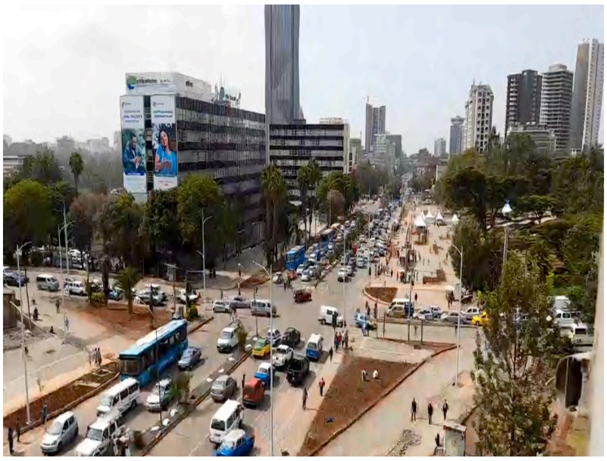

Figure 2 *Immigration* signalized intersection

2.2 Data Gathering

2.2.1 Questionnaire

In developing the questionnaire, the respondent's status including gender distribution, age, driving license level and experience in years was used because these data provide an oversight to the driver's capability to understand situations related to driving.

The statistical calculation of sample size for questionnaire distribution was determined from Cochran's formula (Eq. 1) with infinite population size and found to be 70 with 90% confidence interval and no previous data is available [p=q=0.5].

$$N = (Z^2 * pq)/e^2 \qquad (1)$$

where N = sample size

P= is the estimated proportion of an attribute that is present in the population (0.5 if no previous data is available)

q = 1-p

e= margin of error

Z= Z score

The road users who participated were public transport and private vehicles drivers who have used the route most frequently. The road users selected were drivers because these test samples experience the urge to attain the travel reliability and were exposed to performance measurements like delay and queue at intersections along the route.

A pilot survey was conducted before making the main questionnaire distribution and it was found out that the English version of the questionnaire needed to be changed to Amharic (local language) due to communication barrier with the respondents. Moreover, responses which had faulty responses such as unspecified experience year, driving license level and unmarked intersection were discarded.

2.2.2 Video Rrecording

Video recording was used for the research in order to gather reliable primary source of traffic volume data for the vehicles and pedestrians.

2.3 Data Analysis

2.3.1 Software Tools

SIDRA Intersection 8 plus was used for performance analysis of selected major intersections due to its versatility and non-complexity. Unlike other software packages, the HCM Setup in SIDRA intersection offers various extensions on the capabilities HCM offers. The Parameter settings option in the software provides the capability to use HCM 2010 delay & v/c method of analysis for site and pedestrian level of service analysis and selection of specific performance measures like capacity, delay, queue, degree of saturation, etc.

2.3.2 Intersection and Movement Definitions

The standard right option was selected under the software setup menu to meet the driving rule in the country. The intersection type was selected as at-grade intersection from signals option under site tab. The standard classes included for the analysis procedure were light vehicles and heavy vehicles with ids LV and HV, respectively

2.3.3 Lane Geometry and Grade

The lane geometry and editor option were used to input number, arrangement and geometric properties for the approach lanes, exit lanes and strip islands. The other lane property is the grade for lanes and it was calculated based on the elevation difference of approach and exit lanes of the intersection.

2.3.4 Lane Length and Lane Movements

In the lane length option, the approach distance was taken as the mid-block distance between two intersections in the approach travel direction on an intersection leg while exit distance was taken as the mid-block distance between two intersections in the exit travel direction on an intersection leg.

The lane movements' option specifies the proportion of flow for the flow directions on the approach lanes. The movements were setup based on the lane discipline for the respective approach legs.

2.3.5 Vehicular Volumes, Vehicle Movement and Vvolume Data

The volumes option was used to input the vehicles volume for the respective approaches of the signalized intersection considered. There are three options to feed the volume data namely;

Separate - where the volume of light vehicles and heavy vehicles were fed and total volume were calculated and displayed.

Total and %:- where total volume and percentage of vehicle class is fed and the remaining class percentage were calculated and displayed.

Total and vehicles - Total volume and volumes for Movement Classes other than Light Vehicles are specified.

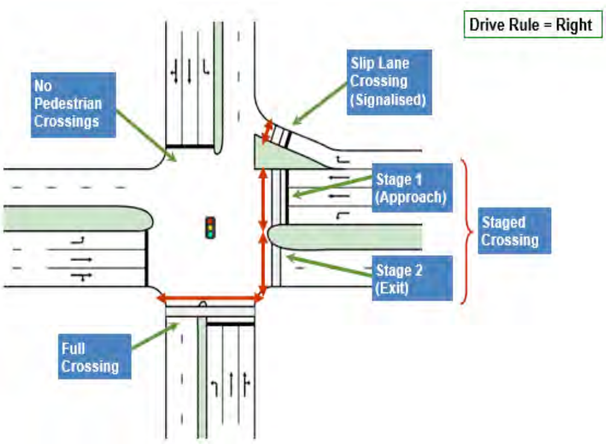

Figure 3 Pedestrian movement definitions and description

2.3.6 Parameter Ssettings

This setting contained the general options, model parameters, cost and fuel & emissions inputs. The general option tab was used to specify the site level of service method, target and pedestrian level of service target and performance measure.

2.3.7 Phasing and Timing

This setting included the sequence selector, sequence editor, phase and sequence data and timing options. The sequence option provided a choice between variable phasing, two phase, split phasing or leading left turn phasing while the timing option provided choices between practical cycle time, optimum cycle time user given cycle time and user given phase times.

2.3.8 Stochastic Analyses of Queues

Using a stochastic approach to analyze queues considers the fact that certain traffic characteristics such as arrival rates are not always deterministic. Arrivals at an intersection are deterministic or regular only when approach volumes are high. Arrival rates tend to be random for light to medium traffic. Thus, the stochastic approach was used to determine the probability that an arrival would be delayed, the expected waiting time for all arrivals, the expected waiting time of an arrival that waits, and so forth.

This method was applied at the *Saris Adey Ababa intersection* since it is composed of vehicular traffic movement and Light Rail Transit (LRT).

Regarding the queue performance, it was considered with random arrival and random service with single channel for the left turns of each approach and through movements of the East–West approach since there exists only 1 entry and exit lane for the movements. Hence the que performance was taken as M/M/1 (∞, FIFO). Based on the above conditions the average delay was calculated from:

$$D = \frac{1}{\mu - \lambda} \quad (2)$$

where D is average delay and μ & λ are service rate and arrival rate respectively.

3. RESULTS AND DISCUSSIONS

3.1 Questionnaire Results

Based on the distributed questionnaire the following four out of the nine major intersections were ranked with higher congestion as shown in Table 1. The respective percentages of replies are also indicated.

Table 1 Selected Intersections for analysis based on questionnaire response

No	Major Intersection	Percentage
1	Saris Adey Ababa	95.70%
2	Immigration	72.90%
3	Ethiopia hotel/ Harambae	67.10%
4	Eliana Hotel/ Bancodiroma	61.40%

3.2 Existing Levels of Service

3.2.1 Eliana Hotel/Bancodiroma site

The hourly vehicle's volume distribution with the peak hours being 11:45-12:45 am and 4:15-5:15 pm was 3676 and 3907 vehicles, respectively and the movements gradually decrease onwards. The right turns at each leg of the intersection were with level of service A because all the signal phases were not right protected and allowed turn on red on each approach leg.

Moreover, the level of service of the intersection was F. This was mainly because of the capacity difference at which the intersection could operate and the arrival volume during the peak hour volumes. Majority of the approaches were with degree of saturation greater than one and closer to one. Especially, *Betemengist* approach had the maximum degree of saturation. In addition to this, the average delay for the East – West direction had higher delay values which indicated poor performance of the intersection. The *Churchill* through movements were with level of service C with the average delay of 25.9 seconds. The left turn of *Piassa* approach was level of service E with average delay of 73.4 seconds. The remaining movements except the right turns were with level of service F with average delay of greater than 80 seconds. The average delays in the four directions for pedestrians were greater than 60 seconds which exceeded tolerance level and hence there was high likelihood of pedestrian risk-taking to make crossings.

3.2.2 Immigration Site

The hourly vehicular volume distribution of the site was with multiple peak hours. The highest vehicular volume was recorded between 11:30 am and 12:30 pm with 4283 vehicles which slightly differed from an hour before, 10:45-11:45 am with volume of 4209 vehicles.

The average delay, especially for the *Bherawi* approach and the *Tikur Anbessa* approach were higher. Hence, the intersection's performance was with level of service F and average delay of 435.6 seconds. The left turns of south-north direction were with level of service E with average delays of 71.7 and 60.1 seconds, respectively. The average delays in the four directions for Pedestrians were greater than 60 seconds which exceeded the tolerance level and hence there was high likelihood of pedestrian risk-taking to make crossings.

3.2.3 Ethiopia Hotel/ Harambae Site

The hourly vehicular volume distribution had multiple peak hours. The highest vehicular volume was recorded between 02:45pm and 03:45 pm with 3702 vehicles. The next highest volumes were recorded between 9:00-10:00 am, 8:15-9:15 am and 10:45-11:45 am with the respective volumes of 3402, 3381 and 3376 vehicles. The characteristic of the vehicular movement drastically changed in the afternoon after attaining its peak of the day. The right turns at each leg of the intersection were with level of service B because even though the intersection signal was not right protected and allows turn on red on each leg, the average delays exceeded 10 seconds. The left turns of all the approaches were with level of service E due to the average delay which lied between 55 and 80 seconds. The intersection level of service was F with average delay of 642.6 seconds. The pedestrian level of service of the intersection was also F because of the average delay the pedestrian experience. The average delays in the four directions namely P1 up to P4 were greater than 60, around 80 seconds, which exceeded the tolerance level and hence there was high likelihood of pedestrian risk-taking to make crossings.

3.2.4 Saris Adey Ababa Site

Saris Adey Ababa signalized intersection was different from the above discussed intersections in that the intersection had LRT route along the South – North direction of the intersection. The clearance time was calculated from the difference between the train arrival detection time (Arrival time) and the time the train fully clears the intersection (Departure time). The arrival difference was obtained by taking the difference between the time a train is detected/arrived at the intersection and the time the next train arrives/detected at the intersection from either of the South –North approach. Based on these it was seen that the average time for a train to clear the intersection was 29 seconds, while the average time for arrival interval was 6minutes and 30 seconds.

Table 2 Frequency of trains' arrival time

Designation	**Arrival Time interval**	**Freq**
A	00:00:06 < t =< 00:05:00	42
B	00:05:00 < t =< 00:10:00	45
C	00:10:00 < t =< 00:15:00	17
D	t > 00:15:00	3
	Total	107

The distribution of hourly volumes for *Saris Adey Ababa* site are shown in Figure 7, where it can be seen that the hourly volume was more or less uniform after it peaked between the time 8:30 am and 9:30 am and then decreased starting from 4:00 and 5:00.

Table 3 Time occupied by the LRT

Description	**Time/no**
Average train Clearance time [A]	00:29
Average Train Arrival time [B]	06:30
Number of Arrivals in 1hr. [C]=60sec /[B]	9.23 ≈ 10
Time occupied by the LRT 1 hr. [D]=[A]*[C]	04:46

The time occupied by the train in an hour was found to be 4 minutes and 24 seconds during its arrival and departure in peak hour. The average train clearance time was determined by averaging the clearance times recorded in the field data.

Table 4 Average delay from the LRT clearance time

Direction	**Average Delay due to Light Rail transit (LRT)**					
	Arrival Rates (Veh/hr)			**Average Delay (sec)**		
South Approach	Left	Through	Right	Left	Through	Right
	230	405	54	16	0	0
North Approach	Left	Through	Right			
	190	400	86	19	0	0
West Approach	Left	Through	Right			
	248	67	26	15	54	0
East Approach	Left	Through	Right			
	98	134	121	37	27	0
			Total	166	≡ 2 min 46 sec	

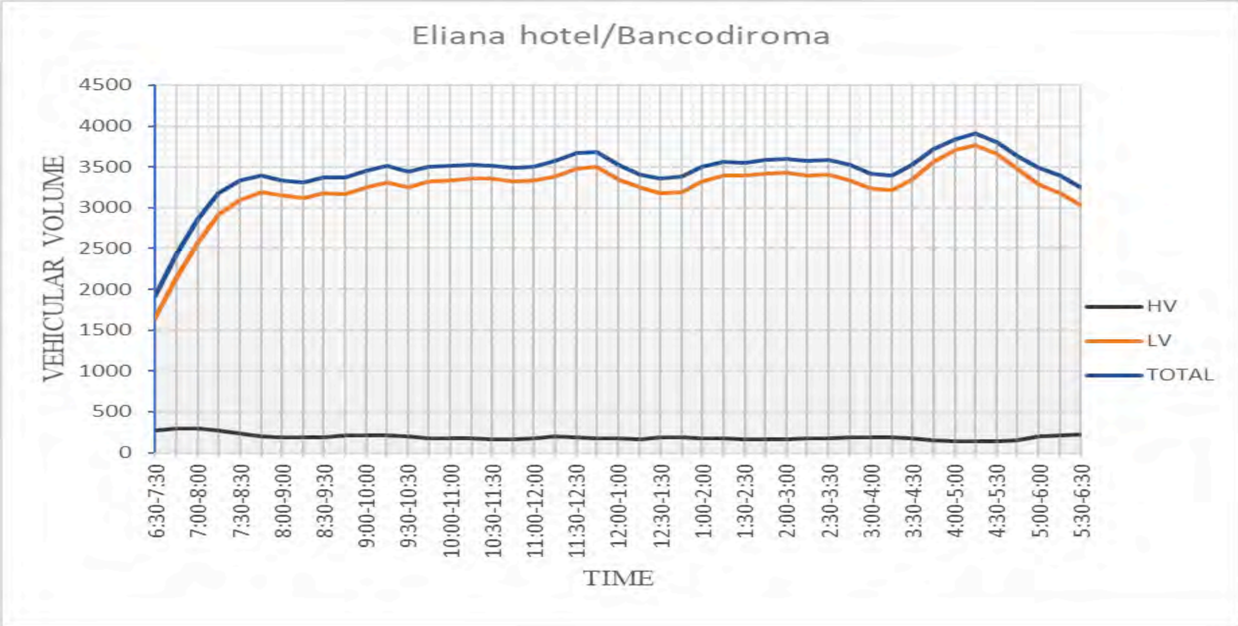

Figure 4 Eliana Hotel site hourly Volume distributions

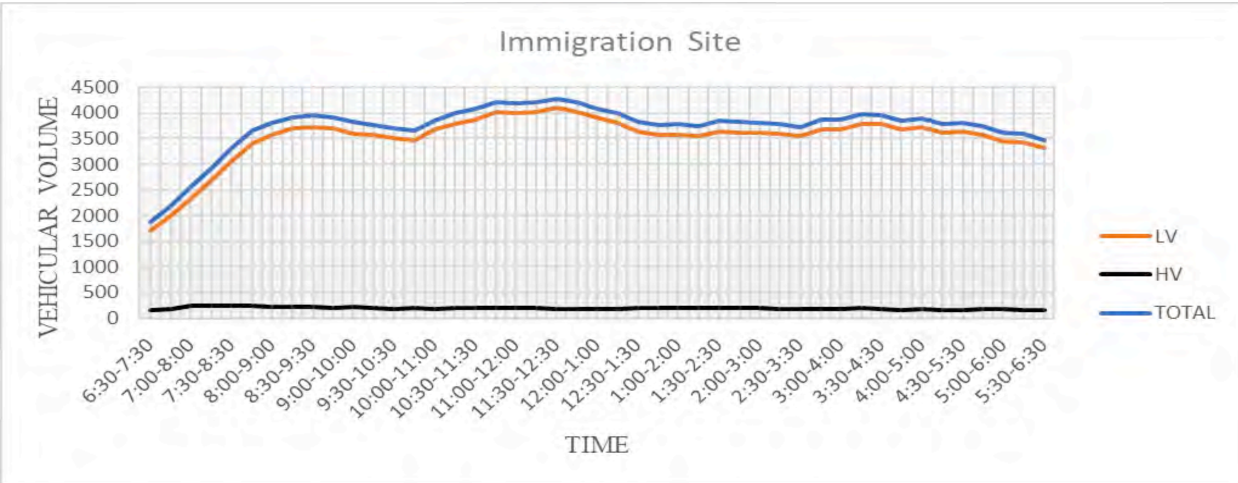

Figure 5 Immigration site hourly Volume distributions

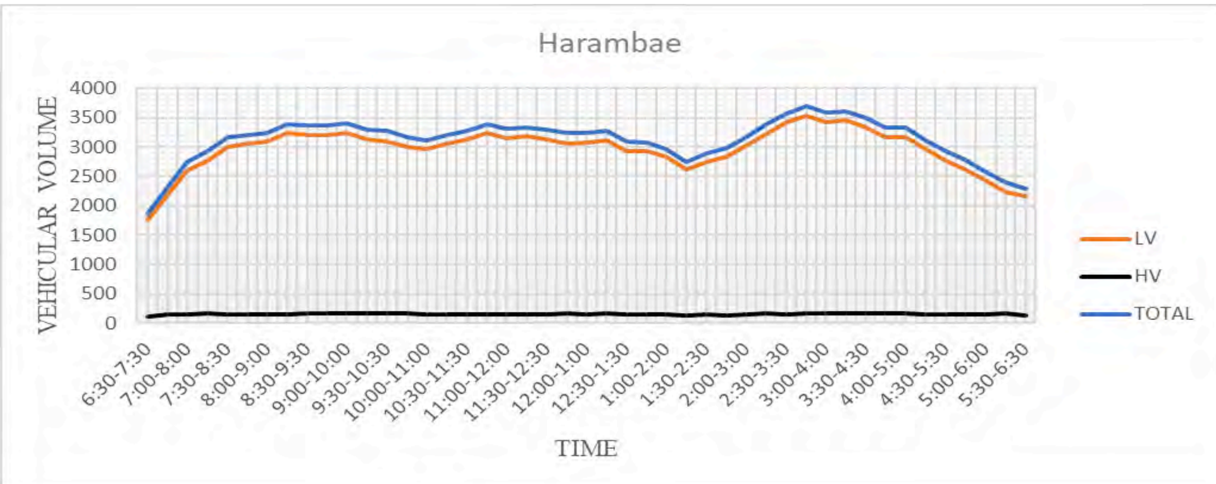

Figure 6 *Harambae* site hourly Volume distributions

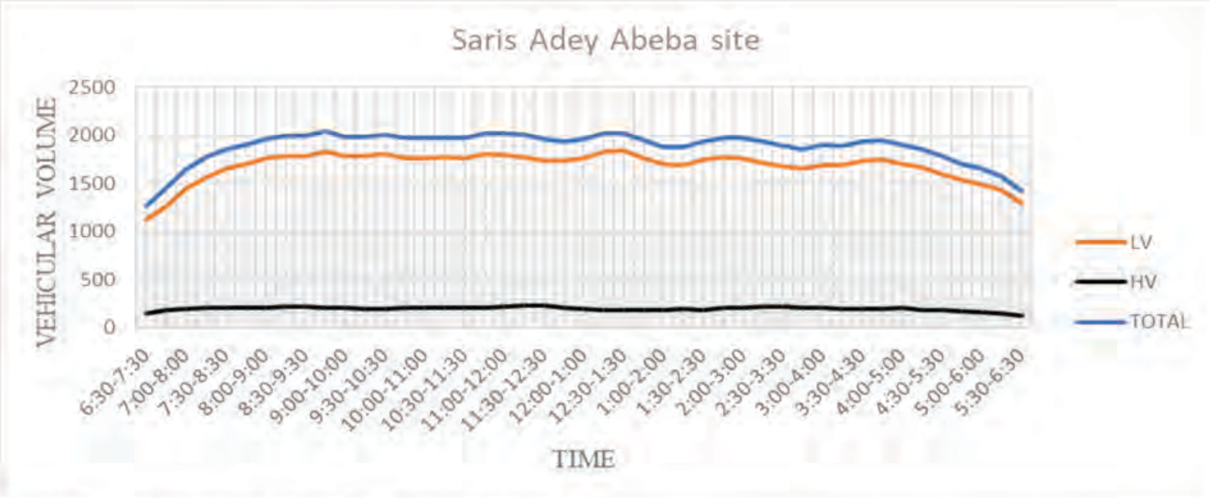

Figure 7 *Saris Adey Ababa* hourly Volume distributions

The Saris Adey Ababa signalized intersection was with level of service F with an average delay of 756 seconds.

Delay incurred by the LRT during its clearance of the intersection was determined by the stochastic queue analysis and is shown in Table 4.

3.3 Engineering mitigations

The proposed engineering mitigations for the signalized major intersections were cycle time adjustment with updated volume, delineation of movements and geometric modification of the approaches and site.

3.3.1 Eliana Hotel/Bancodiroma site

With varied cycle times in order to improve the intersection, there was no significant improvement obtained at the site during the peak hour due to the higher volume of traffic at the intersection. With an increase in cycle time the *Piassa* approach tended to improve yet the intersection level of intersection remained F.

Table 5 Improvement for cycle time and delineation adjustments for Eliana hotel intersection

Adjustment	Intersection LOS	Avg. Delay
None (Existing)	F	167.3 sec
Cycle time (157sec)	F	262.3 sec
Cycle time + Delineation	E	58.8 sec

At complex intersections where the correct path through the intersection may not be immediately evident to drivers, pavement markings may be needed to provide additional guidance. In this case, assigning through movements to the right turns of each approach has a significant improvement on the level of service of individual lanes as well as the intersection. The movement performance measure, average delay was also improved significantly for *Betemengist* and *Somalitera* approaches with 986 to 74 seconds and 645 to 76 seconds on average respectively.

The geometric improvement made for analysis at the Eliana Hotel site was the addition of a single lane along the East – West direction approaches and exits. The geometric improvement was then coupled with delineation of through movements to the right turn movement in the South–North (SN) direction and assigning through movements to both the right and left turn movement in the East–West (EW) approaches. The reason for doing so was the variation on the degree of saturation and delay between the SN and EW directions when using the conventional movement assignments.

Table 6 Improvement for adjustments for Eliana hotel intersection

Adjustment	Intersection LOS	Avg Delay
None (Existing)	F	167.3 sec
Cycle time (157 sec) + Delineation	E	58.8 sec
Geometric + Delineation (150 sec)	D	54.7 sec

3.3.2 Immigration site

The cycle time optimization for this site was preceded as analyzing incremental cycle times with a difference of 10 seconds. This was made because the site exhibits a very low performance and hence even the optimization was incapable of improving the level of service of each approach as well as the intersection as whole whenever the cycle time is increased excessively. The level of service for the South –North direction increases while down pressing heavily the other direction, East – West. Likewise, the reverse happens when the cycle time was reduced below the existing cycle time.

The statistical approach used was the application of regression using the practical spare capacity for graphical plot simplicity because of its integer number format rather than using fraction as in the degree of saturation. The purpose was to obtain balanced spare capacity from the left and through movements of all the approaches and obtain the corresponding cycle time from best fitting curve by regression.

Figure 8 shows four of the movements named *Bherawi* left turn, *Churchill* left turn, *Tikur Anbessa* and *Post office* both movements exhibited a decrease in spare capacity hence increase in degree of saturation while the Churchill through and *Bherawi* through movements increase in spare capacity hence reduced degree of saturation.

Based on the above analysis tool, the optimum cycle time was found to be 138 seconds which corresponds to the total average practical spare capacity of 43 vehicles. The statistical parameters of the data analysis are R squared value is 0.97 with confidence level of 95%. The p value was $6.85x10^{-06}$ which is less than 0.05 which showed the test is statistically significant. From these values the cycle time could be adjusted to 138 seconds though the level of service remains very poor. This adjustment added only 3 second to the existing condition.

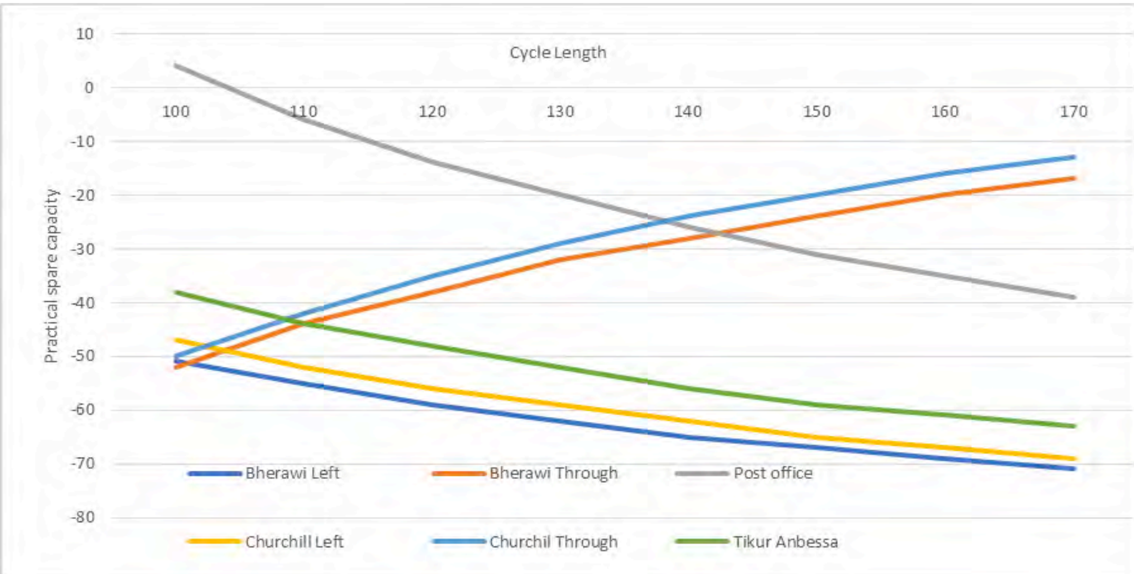

Figure 8 Plot for practical spare capacity vs Cycle time for immigration site

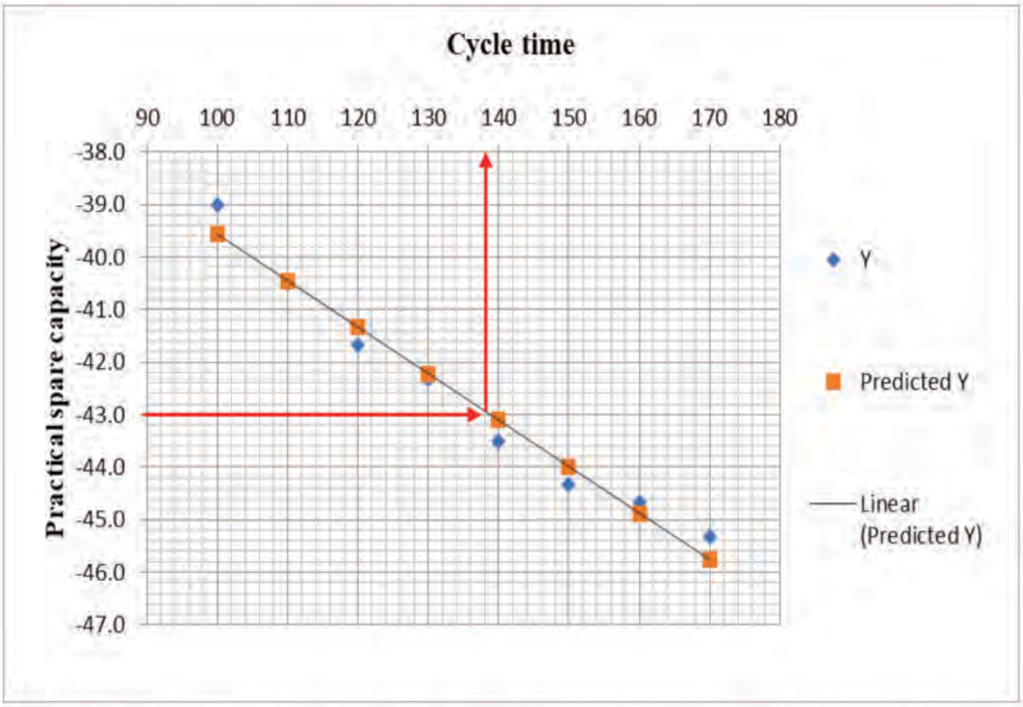

Figure 9 Curve fitting plot for cycle time (sec) and average practical spare capacity (vehicle)

The delineation of movements on the Immigration site was made by assigning the through movements of all the approaches onto the right turns. The right turns were with level of service A due to the reason of turn on red. Hence delineating the through movements will share some proportion of the through movement volumes and increased the level of service. The degree of saturation for through movements of all the approaches was improved. For instance, the *Bherawi* approach decreased from 1.63 to 0.833% and Churchill approach from 1.43 to 0.9%. Likewise, the post office and *Tikur Anbessa* approaches improved from 1.37 to 0.83 and 1.87 to 1%, respectively. The average delays for all the approaches were improved; the delay on *Bherawi* approach decreased from 1189 to 41 seconds and from 1612 to 146 seconds on the *Tikur Anbessa* approaches along the through movements. The left turns' delays were increased as the degree of saturation for the South -North directions decreasing the level of service.

The addition of a single lane on the East–West direction only alongside the delineation of movements and the adjusted cycle time improved the level of service for all approaches except the left turns of the South–North direction. The degree of saturation for the *Bherawi* and Churchill approaches decreased from 1.6 to 0.8% and 1.43 to 0.9% respectively while the average delay decreased significantly from 1189 to 43 seconds and 830 to 47 seconds respectively. Likewise, the degree of saturation for Post office and *Tikur Anbessa* approaches decreased from 1.37 to 0.5% and 1.9 to 0.5% respectively. The average delay decreased from 728 to 55 seconds and 1612 to 60 seconds.

Table 7 LOS comparisons and Geometric improvement phase times' description for Immigration site

Adjustments	Intersection LOS	Avg Delay
None (Existing)	F	435.5 sec
Cycle time only	F	838.9 sec
Cycle time + Delineation	E	78.3 sec
Geometric + Delineation	E	68.7 sec

3.3.3 Ethiopia Hotel/Harambae site

The optimization of existing cycle time for *Harambae* site was done through iteration. Analyzing the intersection by changing the existing phasing sequence the optimum cycle time would be 160 seconds. Increasing of the cycle time after 160 seconds would make the right turns of the approaches with level of service A and the west approaches to Level of service of E whereas the remaining approaches and overall level of service of the intersection remain F.

The degree of saturation for the lanes on each approach did not show significant difference from the existing condition, while the degree of saturation for pedestrian movements significantly decreased.

We can see that the pedestrian movement along the Stadium approach (P3) improved from 0.507 to 0.463 and the delay from 81.8 seconds to 74.8 seconds. The average delay was decreased from the existing level for the through and right turns. The average delay in seconds of Stadium approach for through and right turn were 1818.9 and 10 seconds in the existing condition while reduced to 623 and 3.5 seconds, respectively after the cycle time was optimized.

When delineating the through movements on the respective right turn movement lanes, the overall level of service improved to level D from existing level F. The optimum cycle time also decreased to 120 seconds from the optimization and decreased from the existing cycle time of 174 seconds. The degree of saturation for all the approaches decreased like in Stadium and *Bherawi* approaches from 2 to 0.8. Likewise, the delay in pedestrian movements decreased from 82 to 54 seconds which was Level of service E and the delay approaches tolerance level, risk-taking behavior was likely.

Table 8 LOS for Delineation of movements for *Harambae* site

Adjustments	**Intersection LOS**	**Avg. Delay**
None (Existing)	F	642.6 sec
Cycle time (160)	F	193.3 sec
Cycle time (120) + Delineation	D	54.2 sec

The land use of *Harambae* area was majorly business area surrounded by large newly constructed buildings such as Commercial bank of Ethiopia and another nearby newly planned construction site.

Moreover, the geometric improvements (addition of lanes) shall consider the impact of the intersection on the neighboring intersection such as *Bherawi* signalized intersection, *Post office* signalized intersection, *Immigration* signalized intersection, *Legehar* signalized intersection and *Filwha* T-section unsignalized intersections detailed network model analysis should be done prior to effecting the geometric improvements.

3.3.4 Saris Adey Ababa site

The traffic types in Saris Adey Ababa intersection included vehicular movements from the four approaches, LRT along the South – North direction and pedestrian movements.

Figure 10 Traffic type demonstrations in *Saris Adey Ababa* intersection

Since the Saris Adey Ababa intersection constitutes the LRT it was proposed for semi actuated signal for the operation in order to control the vehicular movements with respect to the arrival of the train.

Table 9 LOS comparisons and phase times' description for actuated signal at Saris Adey Ababa site

Adjustment	Intersection LOS	Avg. Delay
None (Existing)	F	756 sec
Actuated signal design	D	48.5sec

In addition to designing and optimizing the existing nonoperational traffic signal, another mitigation measure could also be applied which avoids the traffic conflicts with the rail transit. Based on the engineering remedies taken in other parts of the city like *CMC Michael* overpass (over LRT), *Global Lancha* overpass (over LRT) and *Gerji* overpass (Over highway) the engineering mitigation proposed for this intersection was similarly to construct an overpass in the direction of East–West approaches.

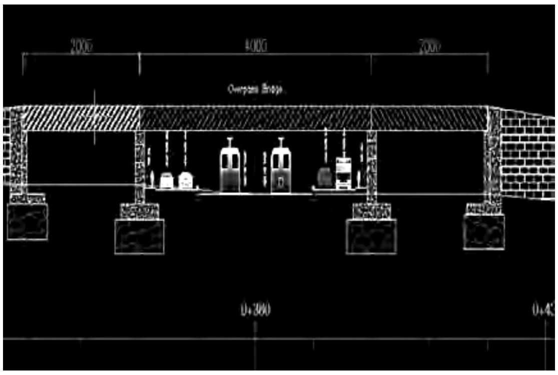

Figure 11 Traffic movement types after construction of Overpass Bridge

The proposed over pass design will modify the total number of lanes in both directions of the East – West approach from 4 lanes to 6 lanes keeping the number of lanes in the South – North direction to 4. Moreover, this proposed overpass is with a width of 12 meters where 9 meters of turning lanes are provided at each side of the bridge totaling to 30 meters of clear span on the East – West direction of the approach. The number of lanes for the right turners from the South – North approaches will be 2 in order to accommodate the left turn movements of these approaches as they shall use the overpass bridge to turn without a conflict with the rail transit.

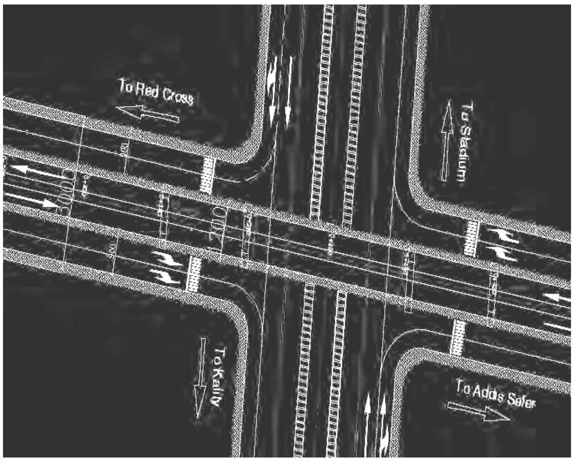

Figure 12 Plan view and dimensions of Overpass Bridge

4. CONCLUSIONS

Based on the above outcomes in the results and discussions sections and the proposed engineering mitigations for existing problems the following conclusions are made.

Regarding the Eliana Hotel/ *Bancodiroma* site while most of the approach lanes remained in poor level of service according to the existing condition analysis. The delineation of movements with optimization of the cycle time and geometric modification of the site can improve the site level of service.

When Immigration signalized intersection was considered, the vehicular volume along the major approaches (*Churchill-Bherawi*) was significantly higher than that of the minor approach (*Tikur Anbessa-Post office*). This caused an inverse relation to the adjustment of the cycle time in regard to the major and minor approaches. The provision of additional lane along the minor road can improve the intersection level of service.

The existing condition at *Ethiopian hotel/Harambae* signalized intersection is better than that of the above two. Yet this intersection is in a condition where major improvements regarding geometry were almost incapable of due to the location of the intersection. But with proposed engineering mitigations such as cycle time adjustment and delineation of movements in addition to changing the signal phase adjustments, level of service and delay could be improved.

Lastly, the *Saris Adey Ababa* site was completely different from the rest of the three intersections as the intersection has LRT that passes through it in the South – North direction. The arrival time of the trains has been significantly variable which necessitates designing and optimizing of signal controls on the intersection. Moreover, constructing Overpass Bridge over the intersection can improve the level of service and delay.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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