Design of Traffic Signals at Closely Spaced Intersections in Ilorin, Kwara State, Nigeria

Clarkson Uka CHIKEZIE

ABSTRACT [ENGLISH/ANGLAIS]
The unprecedented increase in road user's costs in terms of excessive delay at Unity/Taiwo and Old Yidi/Taiwo intersections in Ilorin demanded a traffic control scheme. Hence, a thorough study of traffic, roadway conditions and the type of controls designed were based on the results of the study for the closely-spaced intersections. Closely spaced intersections by definitions are very near to each other such that the traffic flow at one intersection is influenced by the closeness of the other. In the course of the study, the level of service of the two traffic warden-controlled intersections were analysed. Achievement of the study and design include: establishing the delay, analysis of the traffic and physical characteristics; improving the level of service from D to A (848 pcu/hr) and B (1094 pcu/hr) for Unity/Taiwo and Old Yidi/Taiwo intersections respectively; design of geometric characteristic: design of co-ordinated traffic signals to minimize accident rates and excessive delay.

Keywords: Intersections, excessive delay, traffic signals, point of conflicts, warrants

INTRODUCTION
Intersections are critical areas in the effective use of streets and highways. In-depth studies show that they are focal point of conflicts and congestion at road crossings. By definition, an intersection is the place where two or more highways meet and provides an area for the cross movement of vehicle traffic [1, 5]. The efficiency, speed, cost of operation and capacity of an intersection are dependent upon its design. The primary operational function of an intersection is to permit a change in travel route. Hence, it becomes a point of decision for motorist. Highway designers must recognize the problems of a driver passing through an intersection and make driving as simple as possible by the use of good control scheme and geometric design [2, 6]. The essential elements of an intersection are resolving conflicts, providing manoeuvre areas, channeling and controlling traffic into clear paths and permitting entry and exit to and from stream safety at correct speeds and angles. As the frequency and severity of conflicts increase, regulation and control become more necessary. To a considerable extent the design of a control scheme for an intersection is covered by traffic demands, physical factors, land use, economic and environmental consideration. The proper compromise is a decision to be made by the designer.
STUDY AREA
For the purpose of this study the two intersections of study are Unity/Taiwo and Old Yidi/Taiwo roads. They are about 100 m apart. The Taiwo and Unity roads are dual carriageway while this is about in the Old Yidi and Adamu roads. The two intersections are controlled by traffic wardens. Commercial buildings are found very close to the intersections. Also available are drainage systems. These intersections are about 3 km from the General Hospital in Ilorin. The map of the study area is shown in figure 1[3].

**Figure 1:** This figure shows the Map of the Study Area [3]

![Map of the Study Area](image)

The compound nature of the two intersections i.e. Unity/Taiwo and Old Yidi/Taiwo could be seen in the high level of traffic density, traffic conflicts which include merging, diverging and crossing. All these inhibit free movement and thereby reducing the level of service of the intersections. The importance of delay could be looked at in terms of the road users' costs. These costs in the two intersections are in the form of time wasted by the road users, car occupants, pedestrians and others, additional fuel consumed by motor vehicles slowing down and/or stopping and accelerating again, grades which are steeper, additional motor vehicles running cost and traffic accident costs. These have cumulative adverse effect on individual and the government. The government wastes its resources in terms of money spent as salaries on manual control through the traffic wardens (i.e. the amount spent on one traffic warden per month on an intersection could be used to operate traffic signals in four intersections per month) and excessive delays in Unity/Taiwo and Old Yidi/Taiwo intersections which are controlled by unco-ordinated traffic wardens. Conflicts between opposing flows of traffic streams cause a major delay. The delay at the two intersections cannot be completely eliminated but can be improved upon [3]. Thus, a designed traffic signal is to be established to minimize the delays for the critical conditions (a-4 leg and a T – Junction) at Old Yidi/Taiwo and Unity/Taiwo intersections respectively, introduction of raised medians and channelization at the intersections.

MATERIALS AND METHODS
People were employed for the purpose of data collection. Each person was stationed at each arm of the two intersections. The following data were collected for the two intersections:

i. The number of vehicles entering the intersections every hour, from each approach, for a period of 12 hours

ii. The number of vehicle entering the intersections every 5 minutes, from each approach, for the peak period in the morning and in the afternoon and the average thus found
iii. Vehicle volumes for each traffic movement from each approach, classified by vehicle type i.e. motorcycles, light trucks, medium trucks and heavy trucks – during traffic entering the intersections is highest iv. A condition diagram showing the physical layout, including such features as intersectional geometries, channelization, pavement making and adjacent land use

**Analysis**

The data collected and analysed at each intersection are shoulder, median, channel widths and number of lanes. A sketch of the intersections is shown in figure 2.

**Figure 2:** This figure shows the layout of the existing geometry

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**Traffic Volume Data Analysis**

The hourly count from 7.00am to 7.00pm was collected and analysed. The analysis is shown in figures 3(a) and (b).

**Figure 3a:** This figure shows 12-hour traffic volume at Unity/Taiwo intersection

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**Figure 3b:** This figure shows 12-hour traffic volume at Old Yidi/Taiwo intersection

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**Average Daily Traffic (ADT) of the intersections**

The average daily traffic is the number of vehicles that pass a particular point on a roadway during a period of 24 hours consecutive hours averaged over a period of 365
days. The volume collected for 12 hours ($V_{12}$) in passenger car unit pcu is made use as shown in table 1.

**Table 1:** This table shows the average Daily Traffic (ADT) of the intersection

<table>
<thead>
<tr>
<th>Intersection</th>
<th>For Unity/Taiwo</th>
<th>For Old Yidi/Taiwo</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{12}$</td>
<td>29,545</td>
<td>30,943</td>
</tr>
<tr>
<td>But $V_{12} = 80%$ ADT</td>
<td></td>
<td>But $V_{12} = 80%$ ADT</td>
</tr>
<tr>
<td>The average volume for 24 hours is thus</td>
<td></td>
<td>The average volume for 24 hours is thus</td>
</tr>
<tr>
<td>$V_{24} = ADT = V_{12}/0.8$</td>
<td>$V_{24} = ADT = V_{12}/0.8$</td>
<td></td>
</tr>
<tr>
<td>29,545/0.8</td>
<td>30,943/0.8</td>
<td></td>
</tr>
<tr>
<td>ADT = 36,931 vehicles/day</td>
<td>ADT = 38,678 vehicles/day</td>
<td></td>
</tr>
</tbody>
</table>

**Warrant Evaluation**

Phase of process, volume data and the accident history of the locations are the basic information required at most of the standard warrant prescribed in Equivalent State Manuals. It lists eight minimum warrants. The requirements of one or more of these warrants should be satisfied before a signal is installed [4, 7]. Therefore, only the minimum vehicle volume was used since it met the prescribed requirement.

**Table 2:** This table shows the Warrant Volume

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Major street volume (pcu)</th>
<th>Minor street volume (pcu)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unity/Taiwo</td>
<td>1647 (600)</td>
<td>774 (200)</td>
<td>Warranted</td>
</tr>
<tr>
<td>Old Yidi/Taiwo</td>
<td>2078 (600)</td>
<td>352 (150)</td>
<td>Warranted</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

From the analysis, it was evident that the two intersections operate at a low level of performance. Hence, the intersections warrant some forms of control scheme for better operation.

The peak hour traffic flow was analysed. The graphic summary of the peak hour traffic flow band at both intersections are shown in figure 5.
**Figure 5:** This figure shows a graphical summary of flow band for 12 hours volume

![Figure 5](image1)

**Old Yidi/Taiwo Signal Phasing Scheme**

**Figure 6:** This figure is a schematic diagram of the existing traffic flow

![Figure 6](image2)

2 – Phase Scheme was not suitable after trying it. Hence 3 – Phase Scheme

Case 1 3– phase operation

Since the volume on approaches B and D are very high it is better to create a separate left turning to minimize delay, hence 3– phase scheme is to be tried.

CL1 = 60 + 142 = 202
CL2 = 132 = 132
CL3 = 760 = 760

\[ TCL = \sum_{i=1}^{3} CL_i = 202 + 132 + 760 \]
\[ = 1094 < 1200 \]

Level of Service B

Rule I is satisfied

\[ \left( \sum_{i=1}^{N} CL_i \leq 1200 \right) \]

Checking for Left Turn

\[ WL1 \leq 1200 \left( \frac{CL1}{TCL} \right) = 1200 \times \frac{202}{1094} = 221 \]
Rule III Headway – Check

\[ \sum_{i=1}^{3} H_i = 686 + 277 + 1596 = 2559 < 3600 \]

Rule III is satisfied \( \left( \text{of} \sum_{i=1}^{n} H_i \leq 3600 \right) \)

Maximum Ratio of Flow to Saturation Flow

\[ y = \frac{y_1}{s} = \frac{CL1}{S} = \frac{202}{1700} = 0.119 \]

\[ y_2 = \frac{132}{1700} = 0.078 \]

\[ y_3 = \frac{760}{1700} = 0.447 \]

\[ y = \frac{y_1 + y_2 + y_3}{3} = \frac{0.119 + 0.078 + 0.447}{3} = 0.644 \]

Lost time for \( \varnothing_v \), \( \varnothing_2 \) and \( \varnothing_3 \)

\[ L = nl + R = 3 \times 3.7 + 1 = 12.1 \]

Checking for Minimum Delay Requirement

\[ C_o = \frac{1.5 \times 12.1 + 5}{1 - 0.644} = 65 \text{ seconds} \]

Checking for the governing rule \( 0.5C_o < C < 1.5C_o \)

\[ 0.5 \times 65 < C < 1.5 \times 65 \]

\[ 32.5 < C < 97.5 \]

But the cycle length of 65 seconds was inadequate when used for calculation of the green time. Hence cycle length of 75 seconds is thereby recommended.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Design volume</th>
<th>Saturation flow</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>202</td>
<td>1700</td>
<td>0.119</td>
</tr>
<tr>
<td>2</td>
<td>132</td>
<td>1700</td>
<td>0.078</td>
</tr>
<tr>
<td>3</td>
<td>760</td>
<td>1700</td>
<td>0.447</td>
</tr>
</tbody>
</table>

Total Effective Green Time

\[ G = C - L = 75 - 12.1 = 62.9 \]

\[ g_1 = \frac{21.1}{x} \times 62.9 = 11.5 \]

\[ g_2 = \frac{0.78}{0.644} \times 62.9 = 7.6s \]

\[ g_3 = \frac{4.47}{0.444} \times 62.9 = 43.7s \]

Adjusted Green Time

\[ G_i = g_i + L \]

Old Yidi Road

\[ G_1 = 11.6 + 3.7 = 15.3 = 21s \]

\[ G_2 = 7.6 + 3.7 = 11.3 = 12s \]

\[ G_3 = 43.7 + 3.7 = 47.4 \]

Checking for pedestrian requirements

\[ GP_t = 7 + \frac{17}{1.2} = 21s \]

Where

\[ W_i = \text{width of approach to be crossed in metres} \]

\[ V_p = \text{Pedestrian walking speed in m/s} \]

Vehicle clearance interval (Yellow time)

i. Through Traffic

\[ t = 1s, \quad v = 45km/hr = 12.5m/s, \quad L = 6m \]

\[ a = 4m/s^2, \quad W = 17m \]

\[ \frac{t}{2} + \frac{v}{\sqrt{2a}} + \frac{L + W}{v} \]

\[ Y = 5s \]

ii. Left Turn Traffic

\[ W = \frac{\pi v^2}{4} + 5 \]

\[ = 23.3m \]

\[ V = 35km/hr = 9.7m/s \]

\[ Y = 5s \]

b. Taiwo Oke

i. Through Traffic

\[ V = 60km/hr = 16.67 \]

\[ Y = 1 + \frac{10.67 	imes 24}{2 	imes 4} = 4.9 \]

\[ = 5s \]
New Green Time

<table>
<thead>
<tr>
<th>G+Y</th>
<th>Y</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>47/80</td>
<td>5</td>
<td>42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>g₁</th>
<th>g₂</th>
<th>g₃</th>
<th>y₁</th>
<th>y₂</th>
<th>y₃</th>
<th>R₁</th>
<th>R₂</th>
<th>R₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>16</td>
<td>7</td>
<td>42</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>59</td>
<td>68</td>
<td>33</td>
</tr>
</tbody>
</table>

Figure 7: This figure is the interval chart for old Yidi/Taiwo Junction

<table>
<thead>
<tr>
<th>Interval</th>
<th>Through Pedest.</th>
<th>Left Turn Vehicle</th>
<th>Through Vehicle</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>G16</td>
<td>W10</td>
<td>R21</td>
<td>.125</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>DW10</td>
<td>R33</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>G7</td>
<td>6.3</td>
</tr>
<tr>
<td>7</td>
<td>R59</td>
<td></td>
<td>G42</td>
<td>4.6</td>
</tr>
<tr>
<td>8</td>
<td>DW59</td>
<td></td>
<td>W34</td>
<td>42.5</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>DW12</td>
<td>6.3</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unity/Taiwo Signal Phasing Scheme

Figure 8: This figure is a schematic diagram of the existing traffic flow lanes

2 - Phase Scheme was tried but was not suitable hence 3 phase Scheme

Case 1 - 3 - phase operation

\[ TCL = \sum_{i=1}^{n} CL_i = 400 + 154 + 294 = 848 \]

848 < 1200
Level of service is A.
Rule III headway check

\[ H_1 = 400 \times 2.1 = 840 \]
\[ H_2 = 152 \times 2.1 = 319 \]
\[ H_3 = 294 \times 2.1 = 617 \]
\[ \sum_{i=1}^{n} H_i = \sum_{i=1}^{3} H_i = 840 + 319 + 617 = 1776 \]

\[ 1776 < 3600 \]

Rule III is O.K.

CL1 = 400 P.C.U.
CL2 = 154 P.C.U.
CL3 = 294 P.C.U.

\[ \sum_{i=1}^{n} CL_i = 400 + 154 + 294 = 848 \text{ P.C.U.} \]

\[ n = 3, \quad R = 1 \text{ s} \]
\[ s = 1700, \quad l = 3.7 \text{ (lost time by the first 5 vehicle)} \]

Where

\[ n = \text{number of phases} \]
\[ s = \text{saturation flow} \]
\[ R = \text{Time when all signals turn red simultaneously} \]
\[ l = \text{lost time per phase} \]

Maximum Ratio of Flow to Saturation Flow

\[ y_1 = \frac{CL_1}{s} = \frac{400}{1700} = 0.235 \]
\[ y_2 = \frac{154}{1700} = 0.091 \]
\[ y_3 = \frac{294}{1700} = 0.173 \]
\[ Y = \sum_{i=1}^{n} y_i = y_1 + y_2 + y_3 \]
\[ = 0.235 + 0.091 + 0.173 = 0.499 \]

Lost time for \( \varnothing_1, \varnothing_2, \varnothing_3 (L = nL + R) \)
\[ L = 3 \times 7 + 1 = 12.1 \text{ s} \]

Checking for Pedestrian Requirements

\[ G_{p2} = 7 + \frac{17}{1.2} = 21.5 \]
\[ G_{p2} = G_{p2} = 7 + \frac{17}{1.2} = 21.5 \]

Where 1, 2, 3 are the phase numbers

Vehicle Clearance Internal (Yellow Time)

a. Unity

i. Through Traffic

\[ t = 1 \text{ s}, \quad v = 50 \text{ km/h} = 13.89 \text{ m/s} \]
\[ l = 6 \text{ m}, \quad a = 4 \text{ m/s}, \quad w = 21 \text{ m} \]

\[ Y = t + \frac{v}{2a} + 6 + 21 = \frac{1.74 + 1.94}{13.89} = 1.74 + 1.94 = 4.7 \]

\[ Y = 5 \text{ s} \]

b. Taiwo Isale

i. Through Traffic

\[ V = 60 \text{ km/hr} = 16.67 \text{ m/s} \]

\[ Y = 1 + \frac{13.89}{2 \times 4} + \frac{6 + 21}{13.89} = 1 + 1.74 + 1.94 = 4.7 \]

\[ Y = 5 \text{ s} \]

ii. Left Turn Traffics

\[ w = 8 + \frac{\pi v}{2} \]

\[ = 8 + \frac{3.142 \times 12}{2} = 26 \]

\[ Y = 1 + \frac{11.11}{2 \times 4} + \frac{6 + 26}{11.11} = 5.26 \text{ s} \]

\[ Y = 5 \text{ s} \]

New Green time

\[ G + Y \quad Y \quad G \]

\[ \varnothing_1 \quad 35 \quad 5 \quad 30 \]
\[ \varnothing_2 \quad 17 \quad 5 \quad 12 \]
\[ \varnothing_3 \quad 28 \quad 5 \quad 23 \]

80

<table>
<thead>
<tr>
<th>C</th>
<th>g_1</th>
<th>g_2</th>
<th>g_3</th>
<th>y_1</th>
<th>y_2</th>
<th>y_3</th>
<th>R_1</th>
<th>R_2</th>
<th>R_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>30</td>
<td>12</td>
<td>23</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>45</td>
<td>63</td>
<td>52</td>
</tr>
</tbody>
</table>
Figure 9: This figure shows interval chart for Unity/Taiwo Junction

Average Delay per Approach

a. Unity/Taiwo Intersection

<table>
<thead>
<tr>
<th>Phase</th>
<th>Approach</th>
<th>C (sec)</th>
<th>Veh/hr</th>
<th>G (sec)</th>
<th>λ</th>
<th>q</th>
<th>x</th>
<th>D (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unity road</td>
<td>80</td>
<td>1700</td>
<td>30</td>
<td>0.37</td>
<td>400</td>
<td>0.64</td>
<td>20.7</td>
</tr>
<tr>
<td>2</td>
<td>Taiwo Isale</td>
<td>80</td>
<td>1700</td>
<td>12</td>
<td>0.15</td>
<td>154</td>
<td>0.60</td>
<td>31.8</td>
</tr>
<tr>
<td>3</td>
<td>Taiwo Oke</td>
<td>80</td>
<td>1700</td>
<td>22</td>
<td>0.275</td>
<td>294</td>
<td>0.629</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>Average delay per approach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25.9</td>
</tr>
</tbody>
</table>

b. Old Yidi/Taiwo Intersection

<table>
<thead>
<tr>
<th>Phase</th>
<th>Approach</th>
<th>C (sec)</th>
<th>Veh/hr</th>
<th>G (sec)</th>
<th>λ</th>
<th>q</th>
<th>x</th>
<th>D (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Old Yidi, Adamu Bound</td>
<td>80</td>
<td>1700</td>
<td>12</td>
<td>0.15</td>
<td>202</td>
<td>0.79</td>
<td>32.7</td>
</tr>
<tr>
<td>2</td>
<td>Taiwo Oke, Taiwo Isale road</td>
<td>80</td>
<td>1700</td>
<td>18</td>
<td>0.1</td>
<td>132</td>
<td>0.776</td>
<td>35.08</td>
</tr>
<tr>
<td>3</td>
<td>Taiwo Oke, Taiwo Isale Bound</td>
<td>80</td>
<td>1700</td>
<td>43</td>
<td>0.538</td>
<td>760</td>
<td>0.831</td>
<td>15.43</td>
</tr>
<tr>
<td></td>
<td>Average delay per approach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27.7</td>
</tr>
</tbody>
</table>

CONCLUSION

Based on empirical studies carried out on traffic delay for the two intersections controlled manually as much as 58 vehicles-hour and 63 vehicles-hour per day were calculated at Unity/Taiwo and Old Yidi/Taiwo intersections respectively. This shows invariably that both intersections are currently operating at a low level of service.

Preliminary studies show level of service D (1234 vehicles/hour) at Unity/Taiwo intersection and level of service D (1315 vehicles/hour) at Old Yidi/Taiwo intersection. The causes of low level of service from the...
number of lanes were inadequate. There are only two lanes from Taiwo Isale, (from general Hospital roads) where there is dual carriageway. Also, only one lane is existing from Old Yidi and Adamu Roads. To worsen the condition, it is clearly discernible that the approaches from General Hospital, Old Yidi road, Adamu road and Taiwo road have no separate left turn lanes. The field study conducted shows that left turning movement consumes more time than the through movement resulting in unwanted delay to the through movement vehicles and thus reducing the level of performance of the intersections.

Figure 10: This figure shows the geometric design of the two proposed intersections and the traffic signal

In addition, inadequate control by the traffic wardens contributed to the delay because when the traffic warden is exhausted before he is relieved by another traffic warden, it becomes difficult for him to concentrate and process traffic stream approach at the right time. Because of the above causes of unnecessary delays at the two intersections, phasing schemes were carried out at the two intersections. The existing dual carriageway in Taiwo road was improved by introducing separate left turn lanes and traffic islands which will serve as refuge to the pedestrians. A design cycle length of 80 seconds was used for coordinating the signal timing based on the current traffic volume.

Control scheme of signalization was designed for the two intersections because of the findings. The signal control scheme was however, found to be most acceptable in stepping up the level service of Unity/Taiwo and Old Yidi/Taiwo intersections. The phasing scheme yielded a level of service A (848 Vehicles/hour) and level of service B (1094 vehicles/hour) at Unity/Taiwo intersection respectively. To this end traffic signals have improved the level of service of the two intersections.

REFERENCES


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CONFLICT OF INTEREST
No conflict of interest was declared by authors.