Effect of Left Turn Traffic on Control Delay and Guides to Permit or Protect it in Signalized Intersection

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Abstract: Left turn traffic affects the control delay and the chosen number of phases. Permitted and protected left turn traffic are usually decided as a function in left turn traffic volume and traffic volume of the opposite direction. This research studies the effect of two variables on the relation between left turn traffic and the control delay. These variables are the average lane volume and the percentage of difference in traffic volume between opposite directions. More than 160 model runs are done on Synchro software to record the relationships between these three variables. Three sets of curves are extracted from this analysis. The first set explains the effect of the value of the average lane volume on the relationship between control delay and the left turn traffic. This set is repeated for different values of difference between opposite traffic volume. The second set of curves explains the effect of the percentage of difference between opposite direction on the relationship between the control delay and the left turn traffic. This set is repeated for different values of traffic volume. The third set of curves summaries all variables that affect the relationship between left turn traffic and the control delay. The research concluded that the value of average lane traffic volume affects the relationship between the control delay and the percentage of left turn traffic. The same conclusion is acquired for the effect of percentage of difference between opposite traffic volume on the relationship between the control delay and the percentage of left turn. The research introduces guides for protecting and permitting left turn traffic.

Key words: Left turn traffic • Control delay • Signalized intersection

INTRODUCTION

The MUTCD gives rules for phasing system planning which depends on the complexity of the intersection. The left turn traffic affects in a great extent the phasing system. Permitted left turn traffic allows vehicles to turn after yielding to conflict with opposite traffic without any restriction. Protected left turn traffic assign the right of way for left turn traffic and prevent opposite traffic to conflicting it [1]. When all left turn traffic is permitted, the number of phases will be two. As the left turn traffic increase or the opposite traffic increase, it becomes not practical to leave the left turn traffic permitted. The control delay becomes high in a great extent. As traffic volumes increase at the intersection, the number of suitable gaps to permit left-turning vehicles to cross safely the intersection is limited. Traffic signal designers sometimes find some difficulties to decide either to permit or to protect left turn traffic. Permitted traffic minimizes the number of phases and the control delay accordingly. In some cases permitted traffic increase the overall signal delay. Ming-Heng Wang and Benekohal [2] stated that several researches estimated capacity for permitted left-turn traffic as a function of the left turn traffic and the traffic in the opposite direction [2]. Highway capacity manual, (2000) applies a constant correction factor to the left turn traffic in calculating the saturation flow [3]. Joseph and Chang [4] argued that this estimated value by highway capacity manual 2000 in underestimated [4]. HCM [5] estimated the saturation flow using equation that is a function in opposite traffic value [5]. Yi and Yu [6] stated that there are other methods to decide between permitted and protected volume in addition to volume criteria. These approaches include speeds, accident records and intersection geometry in designing the phasing system [6]. Navarro [7] stated also that the size of the intersection geometry affects permitting or protecting left turn traffic.
However, using the traffic volume is the most common method for choosing the phasing system. These methods include using the left turn traffic and opposite traffic volume and the cross product of both movements. Consequently, this research studied the process of deciding between permitted and protected left turn phases from a different perspective. The approach introduced in this paper is the study of the effect of shared through traffic with left turn traffic on the control delay. Three combined factors are considered that affect the control delay and then affect the decision of permitted or protected left turn traffic. These factors are the percentage of left turn traffic, the percentage of difference between traffic volumes on opposite directions and the average lane volume per lane. A graphical representation for the relationship between percentage of left turn and control delay is introduced in different cases. These cases include average lane volume and the values of difference between opposite directions. These relationships help designers to simply decide to choose between permitted and protected left turn traffic. Therefore, it gives some guides for designers to choose the suitable phasing system.

This research composed of three sections in addition to the introduction sections. Section two explained the methodology that is followed in this research. Section three introduces data analysis procedure. Section four presents the conclusion and recommendations.

**DATA AND METHODS**

Data is extracted using Synchro software version 8. A typical four leg intersection is used in the analysis. Each leg is a four lane divided street with lane width 3.65m. Three factors are considered in the analysis to estimate the control delay:

- Average lane volume (ALV) which is the total intersection volume per hour divided by number of approaches lanes.
- Percentage of left traffic (% LT) which is the percentage of left traffic from average lane volume.
- Percentage of volume difference (%VD) which is the percentage of volume difference between each two opposite approaches.

Table 1 shows analysis cases that are considered in the analysis of the intersection using Synchro 8 software. It is clear from Table 1 that about 160 model runs on the software is done. For each run the three above mentioned factors are recorded in addition to the control delay in each case. The extracted data are entered to Excel software for the purpose of analysis.

**Data Analysis:** In this stage, three sets of curves are introduced. The first set includes four curves. Each curve explains the relationship between control delay and the percentage of left turn traffic. This is introduced at different values of average lane volumes at a certain value of percentage of difference between volumes in the opposite directions. The second set is four curves. Each curve studies the effect of percentage of difference between traffic in opposite directions on the relationship between % LT and control delay at a certain value of average lane traffic volume. The third set is one curve that summaries the above relationships.

**Table 1: Analysis cases**

<table>
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<tr>
<th>Average traffic volume per lane (ALV)</th>
<th>275</th>
<th>330</th>
<th>396</th>
<th>475</th>
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<td>% of difference between opposite directions (%VD)</td>
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<td>Percentage of left turn (% LT)</td>
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As the average lane volume increase from 330 vehicles per hour to 396 vehicles per hour, the percentage of left traffic starts to tangibly affect the control delay. Control delay starts to increase with increasing % LT until a certain value and then decrease. The maximum control delay occurs at % LT of a value 35%. When the average lane volume becomes 475 vehicles per hour or more, the percentage of left traffic considerably affect the control delay. The rate of change of the value of the control delay becomes pronounced. The level of service changes from A to F, at the same average lane volume, as the % LT changes from 0 to 15%. The maximum value of the control delay can be obtained at 25% left turn value. The previous discussion leads to the conclusion that; when the average lane volume be less than 396 vehicles per hour, the effect of % of left turn traffic is not noticeable and two phasing signal will be suitable. As the average lane volume increases beyond 396 vehicles per hour and the percentage of left turn ranges between 15 and 85%, two phasing signal will not be suitable and left turn traffic should be protected. Fig. 2 shows the relationship between percentage of left traffic and control delay for various values of average lane volume in case of unequal opposite traffic (20% difference). It can be noticed from the Fig. 2 that the same previous conclusion may be proven. There is one difference in intersection behavior in term of control delay between zero difference and 20% difference. The rate of change of control delay with % LT after it gets maximum is less than the previous case especially in case of ALV 396 vehicles per hour or more. In this case protection of LT may be done when the percentage of it become more than 15% and two phasing traffic is not suitable in this case. Fig. 3 shows the relationship between percentage of left traffic and control delay for various values of average lane volume in case of unequal opposite traffic (40% difference). In this case, the situation becomes different. The value of control delay increases with increasing the percentage of left turn traffic for all values of average lane traffic volumes. The rate of change of control delay increases as the average lane volume increases. Two phasing signal is not suitable when the average lane volume 475 vehicles per hour or more and the percentage of left traffic more than 15%. In this case LT should be protected. For ALV between 396 and 475 vehicles per hour, two phasing signal is not suitable if the percentage left turn traffic more than 80%.

Fig. 1: Relationship between %LT and control delay (zero difference)

Fig. 2: Relationship between % LT and control delay (20% difference)
Fig. 3: Relationship between % LT and control delay (40% difference)

Fig. 4: Relationship between % LT and control delay (60% difference)

Fig. 4 shows the relationship between percentage of left traffic and control delay for various values of average lane volume in case of unequal opposite traffic (60% difference). In this case, control delay increases with increasing the value of left turn traffic for all values average lane volume. The rate of change of the control delay increase with increasing the value of average lane traffic volume. The rate of change of control delay with percentage left turn traffic in case of 60% difference between opposite directions is much more than the case of 40%. The two phasing system is not suitable in case of average lane traffic volume 475 vehicle per hour or more if the percentage of left turn is more than 15%. For average lane traffic volume 396 vehicles per hour or more, Left turn traffic should be protected if the percentage of left turn traffic is more than 80%. Fig. 5 shows the relationship between percentage of left traffic and control delay for various values of the percentage of difference between opposite direction at average lane volume 275 vehicle per hour. This Fig. 5 explains the effect of the percentage differences between opposite directions on the rate of change of the control delay with the change of the percentage of left turn traffic. It is clear from the Fig. 5 that at average lane volume 275 vehicle per hour, as the percentage of difference between opposite directions increase, the rate of change of control delay with change of percentage of left turn increase. The change is not tangible. Therefore, it can be concluded that the effect of changing the percentage of difference between opposite traffic is not clear at average lane volume 275 vehicles per hour or less.

Fig. 6 shows the relationship between percentage of left traffic and control delay for various values of the percentage of difference in traffic volume between opposite direction at average lane volume 330 vehicles per hour. It is clear from the Fig. 6 that as the percentage of difference between opposite direction traffic volume increase, the rate of change of the control delay increase with increasing the percentage of left turn traffic. Fig. 7 shows the relationship between the percentage of left traffic and control delay for various values of the percentage of difference in traffic volume between
Fig. 5: Relationship between % LT and control delay (ALV = 275 vehicles per hour)

Fig. 6: Relationship between % LT and control delay (ALV = 330 vehicles per hour)

Fig. 7: Relationship between % LT and control delay (ALV = 396 vehicles per hour)
Fig. 8: Relationship between % LT and control delay (ALV = 475 vehicles per hour)

Fig. 9: Relationship between % LT and control delay at various values of ALV and various values of differences between opposite traffic
opposite direction at average lane volume 396 vehicles per hour. It is clear from the Fig. 7 that there is no noticeable effect of change of parentage of difference between opposite traffic volume on control delay at percentage of left turn traffic value 35% or less. For values of the percentage of left turn traffic more than 35%, the effect of the percentage of difference between opposite traffic become obvious. Beyond 35% of left turn traffic, the control delay increase with increasing the value percentage of difference in traffic volume between opposite traffic volume.

Fig. 8 shows the relationship between the percentage of left traffic and control delay for various values of the percentage of difference in traffic volume between opposite direction at average lane volume 475 vehicles per hour. It is clear from the Fig. 8 that at average lane volume of 475 vehicles per hour or more, the effect of the percentage of difference between opposite traffic is not clear on the control delay for various values of left turn traffic. Fig. 9 summaries the relationship between % LT and control delay at various values of ALV and various values of differences between opposite traffic.

CONCLUSIONS AND RECOMMENDATIONS

Reference to the above analysis and discussion, the following may be concluded:

- When there is no difference between opposite traffic volume, ALV does not considerably affect the rate of change of control delay with the %LT for all values of ALV less than 396 per hour. In this case, As the average lane volume increases beyond 396 vehicles per hour and the percentage of left turn ranges between 15 and 85%, two phasing signal will not be suitable and left turn traffic should be protected. The same conclusion may be set if the difference between traffic in opposite directions becomes 20%.
- In case of 40% difference between traffic in opposite directions, for ALV between 396 and 475 vehicles per hour, two phasing signal is not suitable if the percentage left turn traffic more than 80%.
- In case of 60% difference between traffic in opposite directions, for average lane traffic volume 396 vehicles per hour and more, Left turn traffic should be protected if the percentage of left turn traffic is more than 80%.
- The effect of changing the percentage of difference between opposite traffic is not clear at average lane volume 275 vehicles per hour or less.
- For average lane volume between 330-396 vehicles per hour, the rate of change of the control delay increase with increasing the percentage of left turn traffic. The rate of change increase with increasing the percentage of difference between opposite direction.
- At average lane volume of 475 vehicles per hour or more, the effect of the percentage of difference between opposite traffic is not clear on the control delay for various values of left turn traffic.

It is recommended to be extended this study to include studies on three and four phasing systems. It should also be extended to include geometric characteristics especially the effect of opposite lane on the control delay.

REFERENCES