A Study on Determining the Minimum distance between a Near-side Bus Stop and Signalized Intersection in Considering Cut-in Lane Changing

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Abstract: Type and location of bus stops effect on the performance of signalized intersection. However, current guidelines on location of bus stop are insufficient. Especially at near-side bus stop, queue length of right-turn lane group is an important factor to decide the location of bus stop. Therefore, in this study, the effect of queue on right-turn lane group was considered in calculating the distance between near-side bus stop and signalized intersection. Also, effects of cut-in lane changing – one of mandatory lane changing – were considered. The distance between near-side bus stop and signalized intersection was calculated by using queuing theory. Then, the distance was adjusted by using macroscopic lane-changing model. However, the theoretical formula developed in this study has a limitation in assuming the relation between variables. To make up for this limitation, actual data collecting should be based on survey and perform research on driving behavior near the signalized intersection. This will reinforce the theory as a more rational guideline on the location of near-side bus stop.

Key Words: near-side bus stop, signalized intersection, queuing theory, cut-in lane changing

1. INTRODUCTION

1.1 Background and objectives
Existence, type and location of bus stops in urban intersections are main variables which influence the performance of signalized intersection. However, in Korean “Guidelines of highway structure and facility standard”, the location of bus stops should be a minimum weaving length apart from an intersection in each design speed. Therefore, there are some locations which do not satisfy enough distance between the bus stop and intersection. So, conflicts and delays on the intersection were caused frequently because of insufficient space
between the bus stop and intersection. Because Korean “Guideline of highway structure and facility standard” is designed to apply on an uninterrupted traffic flow according to only one variable, design speed, it does not consider both traffic attributes of signalized intersection and actual vehicle driving attributes near the intersection.

In early studies, the distance between a bus stop and intersection was calculated by using traffic capacity decrease caused by the location of a bus stop and rate of heavy vehicle mixture. In another research, queuing theory and gap acceptance were used to calculate the minimum distance.

Compared to other countries, there are a lot of turning vehicles in Korea. If lane changing within link section was not performed well, the driver would attempt to do mandatory lane changing near the intersection stop line. This kind of lane changing is called cut-in lane changing, which causes bad effects on the performance of the intersection. Therefore, the effects of cut-in lane changing must be considered in determining the minimum distance between a near-side bus stop and signalized intersection.

So, this study attempts to build the rational standard of location of near-side bus stop in considering actual conditions of intersection and limitations in earlier studies. Furthermore, this study aims to establish the new method of determining the minimum distance with the efficiency of analyzing and the simplicity of calculating instead of capacity analysis of intersection according as location of bus stop.

1.2 Scope

In this study, an analysis on a near-side bus stop at an intersection will be performed. And the cause of cut-in lane changing will be analyzed. Also, by using lane-changing probability of right-turn aiming vehicles, the distance between the near-side bus stop and signalized intersection will be calculated and adjusted.

The guideline on the location of bus stop will be examined and then the queue length at right-turn lane will be calculated and adapted to find the minimum distance between near-side bus stop and signalized intersection. The distance will be adjusted based on a macroscopic approach of lane changing model. Contents are presented as followed.

- Literature Review
- Type of bus stop / Attributes
- Type of Lane changing and lane changing model
- Calculating the minimum distance between near-side bus stop and signalized intersection
- Application and Validation
- Result and Further study

2. LITERATURE REVIEW

2.1 Korean “guideline of highway structure and facility standard”

When bus stop is located near the intersection in an urban area, minimum weaving length must be considered as presented in Table 1.

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1 Ministry of Construction and Transportation in Korea (2000) Guideline of highway structure and facility standard. 517
Table 1 Measurements of bus stop

<table>
<thead>
<tr>
<th>Design speed(km/hr)</th>
<th>Urban area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
</tr>
<tr>
<td>Deceleration lane length(m)</td>
<td>20</td>
</tr>
<tr>
<td>Bus stop lane length(m)</td>
<td>15</td>
</tr>
<tr>
<td>Acceleration lane length(m)</td>
<td>25</td>
</tr>
<tr>
<td>Bus bay Length (m)</td>
<td>60</td>
</tr>
<tr>
<td>Weaving length (m)</td>
<td>50</td>
</tr>
</tbody>
</table>

2.2 Location of bus stop considering traffic capacity of intersection
Rho(1990) studied how bus-stop influence the capacity and delay of intersection. Especially, capacity decrease of intersection according to the location of bus stop and rate of heavy vehicle mixture was calculated.

2.3 Location of bus stop considering queue length and gap acceptance
Ha(2002) calculated the minimum distance between a bus stop and intersection on a near-side bus stop and a far-side bus stop. In the case of the near-side bus stop, to calculate the minimum distance between the near-side bus stop and signalized intersection, queue length using queuing theory and gap acceptance according as the attempts for bus to weave left-turn lane were used. In the case of the far-side bus stop, to calculate the minimum distance between the far-side bus stop and signalized intersection, traffic flow volume from right-turn movement and gap acceptance of bus weaving from left-turn movement were considered.

Putting all the literature reviews together, the distance between a bus stop and intersection can be determined by the performance of the intersection or the left-turn characteristic of the bus. In Rho’s study, because capacity analysis of intersection must be accompanied, there is some insufficiency in regards to effectiveness to determine the location of bus stop. And there is a limit in Ha’s study because of the assumption that lane changing of other vehicles except the bus near intersection stop line was not accomplished. In reality, however, cut-in lane changing near intersections was frequently observed.

3. THEORETICAL REVIEW

3.1 Type of bus stop location
There are three types of bus stop locations: near-side, far-side, and mid-block. Figure 1 below illustrates each of the bus stop locations.
3.1.1 Far-side bus stop
A far-side bus stop is located immediately next to an intersection. Sight distance limitation is caused by obstacles in the intersection, Lack of capacity of the approaching lane, and existence of bus lane on the right roadside are the reasons for locating a far-side bus stop. One advantage of the far-side bus stop is that it can give more chances to turn right during the red time and more space for right-turn vehicles. There are fewer conflicts with other movements. So conflicts between a left-turn movement and a stopped bus can be decreased. However, in the peak hour, stopped buses interrupt vehicles going through the intersection, and the possibility of rear-end collision increases.

3.1.2 Near-side bus stop
A near-side bus stop is located immediately behind an intersection. This type of bus stop is appropriate when there is much volume from upstream, and allows pedestrians to cross in front of the bus. Also, transit users can aboard and alight on buses close to crosswalks and intersections, thereby minimizing walking distances to connect with transit service. However, traffic flow is interrupted by the stopped bus at bus-stop. Also, delay occurs in the peak hour by the stopped bus at bus-stop. However, if right-turn volume is more than 250veh/hr, other types of bus stop location might be considered instead of the near-side bus stop.

3.1.3 Mid-block bus stop
A mid-block bus stop is located between intersections. It is suitable when the length of block is long, because location of mid-block bus stop is generally less congested compared to that of other types of bus stops near intersection. Bus turnouts are most effectively located in a mid-block bus stop zone. The mid-block bus stop is applicable at locations generating a larger passenger volume. However, where street parking is allowed, great amount of no parking area is needed. Also, the connection to transit service and crosswalk is inconvenient. Generally, mid-block bus stop is located in industrial or business areas where there are many bus users.

3.2 Type of Lane Changing and cut-in lane changing
Type of Lane changing can be categorized as discretionary lane changing, mandatory lane changing, and anticipatory lane changing.

3.2.1 Discretionary lane changing
Drivers make a discretionary lane changing when they want to maintain their desired speed or driving condition. This type of lane changing is affected by the gap between vehicles, relative speed and driver's behavior such as aggressiveness, desire for free flow speed, and patience
3.2.2 Mandatory lane changing
Mandatory lane changing occurs at area where drivers must make lane changing; such as a merging area, diverging area, or lane reduction zone. If acquiring gap acceptance is not possible by the rear vehicle, a driver slows down to make gap and then changes the lane.

3.2.3 Anticipatory lane changing
In anticipatory lane changing, the driver’s intention is to change the lane in advance. Anticipatory lane changing is not done to acquire desired speed as in case of mandatory lane changing.

3.2.4 Cut-in lane changing.
Cut-in lane changing is one of mandatory lane changing. It is a progressive behavior of the driver who changes lane mandatorily even though the flank lane has insufficient gap. Because of this, conflicts between movements and delay are generated.

3.3 Lane Changing analysis methods
There are two types of approach in lane changing. One is microscopic approach and the other is macroscopic lane changing. The microscopic approach deals with individual merging or diverging of vehicle. On the other hand, the macroscopic approach deals with a group of vehicles and analyze by the lane changing ratio.

3.3.1 Microscopic Approach
Microscopic approach attempts to explain the actual situation as precisely as possible, considering a lot of variables such as distance, speed in each lane, gap acceptance and critical gap and so on. However, because it is focused on only one merging or diverging vehicle, it has a limitation. It cannot explain the variation of characteristics of traffic flow. For this reason, the probability of lane changing is assumed as that specific distribution is presumed, or empirical value is presented.

3.3.2 Macroscopic Approach
In General, the Markov process is used to apply a macroscopic approach to explain traffic flow. Because traffic condition in a certainly specific time can be obtained by this macroscopic approach, a more ideal description of merging or diverging behavior can be described. However, accurate probability of lane changing, \( p \), can be obtained only from the microscopic approach. Because this study deals with a macroscopic approach, the specific method to gain probability is not mentioned in the study.

4. CALCULATION OF THE DISTANCE BETWEEN NEAR-SIDE BUS STOP AND SIGNALIZED INTERSECTION
In the case of a near-side bus stop, bus-stop facility is located beside the right-turn lane. Therefore, the distance between near-side bus stop and signalized intersection is influenced directly by the queue length of the right-turn lane group. Also, if a lane changing of a right-turn aiming vehicle is performed unsuccessfully, the driver makes an attempt to do mandatory lane changing such as cut-in lane changing. Although there are not enough gaps to change the
lane, the driver noses into the right-turn lane to make a right turn. This causes the conflicts between movements, and also delays. And it is caused such as blocking the right lane and obstructing the traveling of buses at bus bay.

However, cut-in lane changing cannot be explained easily by microscopic approach, considering that cut-in lane changing is one of mandatory lane changing, which happens when there is not enough distance to make lane changing. And the variables used in microscopic approach, such as distance between vehicles, speed of lane group, gap acceptance and critical gap are hard to be aggregated and also the effectiveness of variables is not enough. Therefore, in this study, the macroscopic approach is adapted to find the relationship between cut-in lane changing and appropriate location of bus stop. Assumptions are presented below.

- Vehicles are all composed of passenger cars except buses.
- Rate of arrival vehicle volume is uniform and cannot exceed capacity of intersection.
- The length of vehicle and gap are fixed.

4.1 Methodology using the queuing theory

Every traffic flow in signalized intersection is controlled by traffic signal. Queue is generated by vehicles waiting for the green signal. Generation and disappearance of queue within a cycle is repeated periodically. Assumptions are presented below.

- $s$ of right-turn lane is uniform (a fixed constant).
- $q$ of right-turn lane is uniform (a fixed constant).
- RTOR (Right Turn On Red) is not considered.

![Figure 2 Queue length of signalized intersection](image)

Where,

$s$ : saturated flow rate or discharge rate
$q$ : arrival vehicle volume
$q_R$ : arrival rate of right-turn lane group
$s_R$ : queue discharge rate of right-turn lane group
$r_R$ : effective red time of right-turn lane group
$g_R$ : effective green time of right-turn lane group
$t_o$ : queue dissipation time
$l_c$ : vehicle length plus gap
$f_{LU,R}$: lane utilization factor of right-turn lane group

Analyzing the time zone can, it can be separated into time zone A and time zone B by the existence of queue.

At time zone A, a queue is generated from the beginning of the effective red time by approaching vehicles. This queue will increase in the end of the effective red signal. $t_0$ is the period when vehicles start to discharge from the intersection.

Time zone B is the effective green time excluding the queue dissipation time. Vehicles approaching to the right-turn lane are able to pass through the stop line as soon as they get into the intersection. Therefore, they can maintain the arrival distribution characteristics of the right-turn lane.

If queue length of right-turn lane is longer than the distance between bus stop and intersection, the bus at the bus bay will have a difficulty in changing lane into a right-turn lane. And a bus can change lanes into the right-turn lane after the queue length gets shorter than the distance between the bus stop and intersection. So, the queue length of right-turn lane can be the standard of minimum distance between a near-side bus stop and signalized intersection.

\[
L_{\text{queue}} = l_c \times q_R \times (r_R + t_0) \times \frac{1}{f_{LU,R}} \times \frac{1}{N_R} \quad (t_0 = \frac{q_R \cdot r_R}{s_R - q_R} \times \frac{1}{N_R})
\]

Lane utilization factor ($f_{LU}$) means that each lane volume in the lane group is, in actual, not identical.

4.2 Methodology using the macroscopic lane changing model

We can observe a lot of drivers who try to nose into other lanes in real life. Cut-in lane changing is one of mandatory lane changing which take place in a situation where there are not enough gaps to change the lane. Especially, cut-in lane changing into the right-turn lane leads to conflicts and delays between two lane groups: the through lane and right-turn lane. Also, it is caused such as blocking the right lane and obstructing the traveling of buses at bus bay.

Moreover, overall efficiency of intersection decreases because of generated delays. Therefore, the actual queue length of the right-turn lane increases, due to cut-in lane changing. And the discharge rate of vehicles in right-turn lane decreases.

Consequently, by cut-in lane changing, the length of queue increases and also makes an effect to the location of near-side bus stop.

![Figure 3 Relation between cut-in lane changing and right-turn lane group queue](image)

Failure of changing the lane into the right-turn lane causes cut-in lane changing. Therefore,
the smoothness of lane changing of right-turn aiming vehicles in a link section will be
analyzed by using the macroscopic lane changing model. In this study, Drew and Worrall’s
lane changing probabilities matrix method\(^2\) was used. Assumptions are presented below.

- Only one lane changing can be done in one chance.
- The probability of lane changing is only dependent on \( p \).
- Drivers change lanes up to the aimed lane.

\( p \) : average lane-changing probability of vehicle

\( p_{ij}(r) \) : lane-changing probability from \( i \) lane to \( j \) lane in section \( r \)

\( q_i \) : \( i \) th lane volume

\( R_i \) : \( i \) th right-turn aiming vehicle volume

\( L_i \) : \( i \) th left-turn aiming vehicle volume

\( T_i \) : \( i \) th through aiming vehicle volume

Intersection is partitioned by \( N \) sections whose length is \( L \). And \( p \) is the probability of
vehicle who succeeds to move from \( i \) lane to \( j \) lane in section \( r \). The lane changing
probabilities matrix is presented below.

\[
M(r) = \begin{bmatrix}
p_{11}(r) & p_{12}(r) & \cdots & p_{1m}(r) \\
p_{21}(r) & \ddots & \ddots & \ddots \\
\vdots & \ddots & \ddots & \ddots \\
p_{m1}(r) & p_{m2}(r) & \cdots & p_{mm}(r)
\end{bmatrix}
\]

The distribution of right-turn aiming vehicles from the upstream intersection is \( \alpha \) and the
distribution of right-turn aiming vehicle at the downstream intersection is \( \beta \). For example, If
the right-turn aiming vehicle volume from 1st lane to 4th lane at the link upstream are 200,
350, 350 and 100 respectively, \( \alpha \) is \([0.2,0.35,0.35,0.1]\). Then, After changing the lane in link,

the proportion the right-turn aiming vehicle volume at the link downstream is $\beta$.

- $\beta = \alpha \prod_{r=1}^{N} M(r)$

- $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_m]$ : ratio of right-turn aiming volume at the link upstream

- $\beta = [\beta_1, \beta_2, \ldots, \beta_m]$ : ratio of right-turn aiming volume at the link downstream

- $m$ : lane number

At the first section of the link, the driver who wants to change the lane on first lane has two choices. One is changing the lane into the second lane at the present section. And the other is not changing within the present section and making a lane change at other sections. The vehicle which succeeds in changing the lane attempts to make another lane change to AY direction in other section based on assumption that two lane-changing cannot be done simultaneously. If this method applies to Figure 4, lane changing probabilities matrix of each lane to AY direction is as follows.

$$M_{AY} = \begin{bmatrix}
1 - p & p & 0 & 0 \\
0 & 1 - p & p & 0 \\
0 & 0 & 1 - p & p \\
0 & 0 & 0 & 1
\end{bmatrix}$$

In the case of the lane changing of vehicles for the left-turn, or BY direction, because the near-side bus stop is located at the right roadside and cut-in lane changing of left-turn aiming vehicles does not affect near-side bus stop, this does not considered in the study. Also, right-turn aiming vehicles which already entered into the right-turn lane do not have to be considered. So, the probability is fixed to be ‘0’. The generalized formula can be presented as below.

- $\beta = \alpha \prod_{r=1}^{N} M_{AY}(r)$

- $M_{AY} = \prod_{i=1}^{N} M_{AY}(r) = \begin{bmatrix}
(1 - p)^N & Np(1 - p)^{N-1} & A_1 & A_2 \\
0 & (1 - p)^N & Np(1 - p)^{N-1} & A_3 \\
0 & 0 & (1 - p)^N & 1 - (1 - p)^N \\
0 & 0 & 0 & 1
\end{bmatrix}$

- $A_1 = \left[\frac{(N-1)N}{2}\right]p^2(1-p)^{N-2}$

- $A_2 = \left\{1 + (N-1)(1-p)^N - N(1-p)^N - \left[\frac{(N-1)N}{2}\right]p^2(1-p)^{N-2}\right\}$

- $A_3 = \left\{1 - (1-p)^N\right\} - Np(1-p)^{N-1}$
When right-turn aiming vehicles attempt to do lane changing to AY direction, success probability of lane changing is decided by the length between intersections, $D$, and lane changing probability, $p$.

While right-turn aiming vehicles pass through $N$ sections, ratio of right-turn aiming volume from upstream ($\alpha$), $[\alpha_1, \alpha_2, \alpha_3, 0]$ can be presented as $(\beta)$, $[\beta_1, \beta_2, \beta_3, \beta_4]$ by the lane changing model. That is, $\beta_4$ means ratio of accumulated right-turn aiming vehicles, which are changed the lane successfully.

If accumulated success probability of lane changing is too small at the minimum distance spot, vehicles will slow down and make an attempt to nose into the aimed lane, the right-turn lane, although there is not enough space in the right-turn lane.

Also, conflicts between the vehicles and right-turn movement will occur near the intersection. And delays on the right-turn lane and adjacent lane cause the decrease in the overall capacity of intersection. Simultaneously with the decrease of discharge rate of queue, additional arrival right-turn vehicles make the previous distance above inappropriate. Therefore, the minimum distance calculated above needs to be adjusted by the formula below.

$$\text{Minimum distance} = f_{cut} \times L_{queue}$$  \hspace{1cm} (4)

Where, $f_{cut}$ : adjustment coefficient of the distance considering cut-in lane changing (the following, cut-in lane changing coefficient)

The cut-in lane changing coefficient presented above is only a concept. So the coefficient needs to be formulated specifically.

4.3 Calculation of cut-in lane changing coefficient ($f_{cut}$)

If cut-in lane changing into the right-turn lane scarcely happens near the stop line ($S_R = S_{R,cut}$), the minimum distance which was calculated above does not have to be adjusted. So, the formula of optimal minimum distance between the near-side bus stop and signalized intersection can be presented as below.
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\[ L_{\text{min}} = L_{\text{queue}} = l_c \times q_R \times (r_R + t_0) \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} \]

(5)

However, if there is a large possibility that cut-in lane changing happens \((S_R > S_{R,\text{cut}})\), the optimal minimum distance between the near-side bus stop and signalized intersection would be presented as below.

\[ L_{\text{min}} = l_c \times q_R \times (r_R + t_{0,\text{cut}}) \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} \]

\[ = l_c \times q_R \times (r_R + t_0) \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} + l_c \times q_R \times t \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} \]

\[ = l_c \times q_R \times (r_R + t_0) \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} + l_c \times q_R \times (t_{0,\text{cut}} - t_0) \times \frac{1}{N_R} \times \frac{1}{f_{\text{LU},R}} \]

\[ = L_{\text{queue}} + \left( \frac{t_{0,\text{cut}} - t_0}{r_R + t_0} \right) \times L_{\text{queue}} \]

\[ = \left( \frac{r_R + t_{0,\text{cut}}}{r_R + t_0} \right) \times L_{\text{queue}} \]

\[ = f_{\text{cut}} \times L_{\text{queue}} \]

Where, \( t_{0,\text{cut}} = \frac{q_R \cdot r_R}{s_{R,\text{cut}} - q_R} \times \frac{1}{N_R} \)

\( s_{R,\text{cut}} \) : discharge rate of right-turn lane queue when cut-in lane changing happens

\( t_{0,\text{cut}} \) : queue dissipation time when cut-in lane changing happens

Cut-in lane changing coefficient can be formulated as below.

\[ f_{\text{cut}} = \frac{r_R + t_{0,\text{cut}}}{r_R + t_0} = f(t_{0,\text{cut}}) \text{ (where, } r_R, t_0 \text{ and } t_{0,\text{cut}} \text{ are constant)} \]  

\[ = (f \circ g)(s_{R,\text{cut}}), \quad (\because t_{0,\text{cut}} = \frac{q_R \cdot r_R}{s_{R,\text{cut}} - q_R} \times \frac{1}{N_R} = g(s_{R,\text{cut}}) \]

\[ = (f \circ g \circ h)(s_R, N_{\text{cut}}) \text{ (where, let } s_{R,\text{cut}} = h(s_R, N_{\text{cut}})) \]

Consequently, the distance between the bus stop and the intersection is the function of discharge rate of the right-turn lane queue when cut-in lane changing happens. And it must be adjusted considering the discharge rate of right-turn lane queue \((s_{R,\text{cut}})\), which is decreased due to cut-in lane changing.

4.5 Relation of possible generation amount of cut-in lane changing \((N_{\text{cut}})\) and discharge rate of right-turn lane group \((s_{R,\text{cut}})\)

Discharge rate of right-turn lane group \((s_R)\) is influenced by geometric characteristics of intersection, volume of conflicting flows, cycle, phase split, pedestrian signal, and effective
green time ratio and so on. In this study, by assuming that the relations between the possible
generation amount of cut-in lane changing and discharge rate of right-turn lane group is a
simple linear equation, the equation was formulated as below.

In case of other factors mentioned above, it is possible to internalize as external variable when
calibration of both the queue dissipation rate of right-turn lane group, \( s_R \) and the decreased
ratio of queue dissipation rate when cut-in lane changing happens, \( \alpha \) is performed. Also,
additional collecting of data and analysis are needed to obtain specific and accurate values.

\[
- s_{R,cut} = h(s_R, N_{cut}) \equiv s_R - a \times N_{cut} = s_R - a(C, g, r, k_{1,\ldots,n}) \times N_{cut} \quad (8)
\]

Where, \( a : \) decreased ratio of queue dissipation rate when cut-in lane changing happens

\[
N_{cut} = \left( \frac{C}{3600} \right) \left( 1 - p_{acc} \right) \times \left( \sum_{i=1}^{m-N_R} R_i \right) \quad (9)
\]

Where, \( p_{acc} : \) accumulated lane changing rate of right-turn aiming vehicle
\( C : \) cycle length
\( m : \) lane number

5. EXPERIMENTAL DESIGN

5.1 Input data
Input data is assumed as below and adapted to the formula developed in this study.

<table>
<thead>
<tr>
<th>Input data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane width, ( W )</td>
<td>3.5 m</td>
</tr>
<tr>
<td>Headway of queue, ( l_c )</td>
<td>5 m</td>
</tr>
<tr>
<td>Signal time, ( r ) and ( g )</td>
<td>( r = 90 ) sec, ( g = 30 ) sec</td>
</tr>
<tr>
<td>Discharge rate, ( s_R )</td>
<td>1,364(veh/hr/lane)</td>
</tr>
<tr>
<td>Lane utilization factor, ( f_{LU} )</td>
<td>1.00</td>
</tr>
<tr>
<td>Lane number</td>
<td>4</td>
</tr>
<tr>
<td>Number of right-turn lane</td>
<td>1</td>
</tr>
<tr>
<td>Distance between intersections</td>
<td>500 m</td>
</tr>
<tr>
<td>Section interval length, ( D )</td>
<td>20 m</td>
</tr>
<tr>
<td>Right-turn vehicle volume, ( q_R )</td>
<td>100, 200, 300, 400(veh/hr/lane)</td>
</tr>
<tr>
<td>Rate of right-turn aiming vehicle volume, ( \alpha ) ( (\alpha_1, \alpha_2, \alpha_3, \alpha_4) = (0.2, 0.4, 0.4, 0) )</td>
<td></td>
</tr>
<tr>
<td>Probability of lane changing, ( p )</td>
<td>0.10, 0.15, 0.20</td>
</tr>
</tbody>
</table>

5.2 Result

5.2.1 The minimum distance calculated by queuing theory.
Using the input values stated above, it is found that the distance between the near-side bus stop and signalized intersection increases considerably as volume increases.
Table 3 Location of bus stop as variation of right-turn volume

<table>
<thead>
<tr>
<th>Right turn volume (veh/hr/lane)</th>
<th>Distance between interchange and bus stop (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>13.5</td>
</tr>
<tr>
<td>200</td>
<td>29.3</td>
</tr>
<tr>
<td>300</td>
<td>48.1</td>
</tr>
<tr>
<td>400</td>
<td>70.7</td>
</tr>
</tbody>
</table>

5.2.2 The minimum distance re-calculated by macroscopic approach

Table 4 Minimum distance and cumulative lane-changing probability

<table>
<thead>
<tr>
<th>Right-turn Volume (veh/hr/lane)</th>
<th>Minimum Distance (m)</th>
<th>Accumulated lane changing probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>p = 0.10</td>
</tr>
<tr>
<td>100</td>
<td>13.5</td>
<td>0.744</td>
</tr>
<tr>
<td>200</td>
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When right-turn volume is 200veh/hr/lane, the minimum distance would be 29.3m. Simultaneously, if accumulated lane changing rate ($p$) is 0.15, the probability that lane changing would be failed is $1-0.888=0.112$. Therefore, 11.2% of right-turn aiming vehicles will make an attempt to do cut-in lane changing.

Due to cut-in lane changing, discharge of queue would be slower and during this time additional vehicles arriving at the right-turn lane would increases the length of queue practically. If discharge rate of queue is assumed to decrease by 40% and right-turn aiming volume was assumed to be 85% of right-turn volume in this example, the optimal minimum distance would be calculated as below.

- Optimal minimum distance ($L_{min}$)

$$ L_{cut} \times L_{queue} = \left( \frac{R_{R} + t_{0,cut}}{R_{R} + t_{0}} \right) \times L_{queue} = \left( \frac{90 + 21.48}{90 + 15.46} \right) \times 29.3 \simeq 31.0 \text{m} $$

- $s_{R,cut} = s_R - a \times N_{cut} = 1364 - 545.6 \times 0.635 \simeq 1038 \text{veh/hr}$
- \[ N_{cut} = \left( \frac{C}{3600} \right) \left\{ (1 - p_{acc}) \times \left( \sum_{i=1}^{m-N_2} R_i \right) \right\} = \frac{0.112 \times 170}{30} \approx 0.635 \text{ veh/cycle} \]

6. VALIDATION OF MODEL

Rho(1990) analyzed the delay of the intersection at Sadang subway station and presented the delay pattern according to the location of near-side bus stop. And it was divided to 4 sections such as Figure 8

![Figure 7](image1.png) Delay variation according to distance  
![Figure 8](image2.png) Delay pattern of the intersection

In section A, the delay of intersection was decreased rapidly when the location of near-side bus stop becomes apart to intersection. However, if location is more apart than a certain distance, section B and C, which hardly have a variation of the delay, are seen. In the last section, D, delay of intersection is increased again when location gets apart to intersection, but absolute value of increase rate of the delay is extremely small comparing with the section A.

Rho presented the reasonable distance between a near-side bus stop and intersection as 100m. Also, when identical data of the intersection was used, the westbound or northbound queue length are calculated as 51.6m, 76.1m respectively, which are not the same as the optimal distance presented by Rho.

![Figure 9](image3.png) Delay Variation of the westbound  
![Figure 10](image4.png) Delay Variation of the northbound

However, although other factors that influence the delay of intersection are not used, it is

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found that the delay on the location of bus stop calculated by queuing theory is approximately 1.1~1.3 degree of the minimum delay value in section B which was presented as proper distance range by Rho. And in terms of not considering other factors which influence the capacity of intersection, there is a chance to improve correctness of the model. Therefore, this model can have a validation. If additional survey and data collection of external variables internalized in this model are performed, the chance to improve on the aspect of validation may be high.

7. CONCLUSION

Existence, type and location of bus stop in urban intersections are main variables which influence the performance of signalized intersection. In the Korean “Guideline of highway structure and facility standard”, the location of bus stop should be apart as only the minimum weaving length from the intersection as to design speed. Therefore, there are some spots that do not have enough distance between the bus stop and intersection. Also, this causes conflicts and delays near intersection.

Because the Korean “Guideline of highway structure and facility standard” is designed to apply on uninterrupted flow according to only one variable, design speed, it is unsuitable to apply on an interrupted flow with signals. Also, it does not consider both traffic attributes in signalized intersection and real vehicle driving-behavior attributes near the intersection.

In early studies, the distance between the bus stop and intersection was calculated by using delay decrease caused by the location of bus stop and heavy vehicle mix rate. Also, queuing theory and gap acceptance were used to calculate the minimum distance.

Compared to other countries, there is a lot of turning volume in Korea. So, mandatory lane changing near the intersection stop line was frequently observed. If lane changing is not performed well in the link section between intersections, the driver attempts to do mandatory lane changing near the intersection stop line. This kind of lane changing is called cut-in lane changing, which causes bad effects on the performance of intersection. Also, it is caused such as blocking the right lane and obstructing the traveling of buses at bus bay. Therefore, cut-in lane changing must be considered when calculating the distance between bus stop and intersection.

In this study, the minimum distance between a near-side bus stop and signalized intersection was calculated considering the right-turn vehicle volume. Also, the cause of cut-in lane changing at signalized intersection in urban area was analyzed. To find the minimum distance, lane changing model of right-turn aiming vehicle volume was adapted. Finally, the appropriateness of calculated minimum distance was performed and the minimum distance was adjusted at the last step. And this study validated the new method of determining the minimum distance with the efficiency of analyzing and the simplicity of calculating instead of capacity analysis of intersection according as the location of bus stop.

Queuing theory was adapted as the basic approach method to calculate the minimum distance between a near-side bus stop and signalized intersection. And mandatory lane changing of right-turn aiming vehicle volume was considered to adjust the calculated minimum distance simultaneously.

When deciding the types of bus stops, only the right-turn volume had been considered in the Korean “Guideline of highway structure and facility standard”. If right-turn vehicle volume is more than 250veh/hr, far-side bus stop or mid-block bus stop can be recommended. In this study, probability of lane changing of right-turn aiming vehicle volume was adapted to decide the location of bus stop. Therefore, it could be a more objective and rational criterion. However, some limitations were found in this study. This methodology cannot be adapted
when volume exceeds capacity of intersection and the signalized intersection is interlocked. And the proper decision of section length, $D$ and assumption of lane changing probability, $p$, could be a problem. Also, research not only on the near-side but also on the far-side and mid-block bus stop locations should be complemented. In this study, analysis was limited to only the near-side bus stop. So in further studies, research on the far-side bus stop and the mid-block bus stop can be complemented. Also, if actual data collection based on survey and research of traffic flow characteristics near the signalized intersection are performed, they would contribute to developing the model to calculate the distance between the bus stop and intersection.

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