A Study on the Preemption Control Strategies Considering Minimum Green-time based on Real-time Vehicle Information

Sue-Kyoung, LEE  
Master Course  
Department of Civil and Environmental Engineering  
Seoul National University  
Daehak-dong, Gwanak-gu, Seoul  
Republic of Korea  
Fax: +82-2-873-2684  
E-mail: puretier@snu.ac.kr

Jung-Min, LEE  
Master Course  
Department of Civil and Environmental Engineering  
Seoul National University  
Daehak-dong, Gwanak-gu, Seoul  
Republic of Korea  
Fax: +82-2-873-2684  
E-mail: primeguy@naver.com

Dong-Sung, KIM  
Doctor Course  
Department of Civil and Environmental Engineering  
Seoul National University  
Daehak-dong, Gwanak-gu, Seoul  
Republic of Korea  
Fax: +82-2-873-2684  
E-mail: dskim716@gmail.com

Seong-Young, KHO  
Professor  
Department of Civil and Environmental Engineering  
Seoul National University  
Daehak-dong, Gwanak-gu, Seoul  
Republic of Korea  
Fax: +82-2-873-2684  
E-mail: sykho@snu.ac.kr

Abstract: In Korea, there are few preemption strategies for an emergency vehicle (EV). Moreover, there is no strategy to apply to real circumstances. Without preemption, EV’s drivers have to drive cars depending on only their own judgment. Also it causes danger of other vehicles on the street at the same time. Previous studies tried to overcome it but have progressed with shortage of useful traffic information. Therefore, we set up a preemption strategy based on real-time vehicle information. Especially, this strategy minimizes stops of EV caused by minimum greens for other phases controlling signal earlier. Proposed algorithm result in increasing speed of EV by 17.14~59.32% and increasing delay of total vehicle by 3.62~7.90%. Despite negative effect on other vehicles, it shows meaningful result which offers a new possibility to give more time for executing preemption strategy by eliminating limitations generated by minimum green time, queue and a way of point detection.

Key Words: preemption, emergency vehicle, signal strategy, minimum green

1. INTRODUCTION

In Korea, there are few preemption strategies for an emergency vehicle (EV) which has been studied. Moreover, there is no strategy to apply to real circumstances. Because of it, EV’s drivers have to drive a car depending on only their own judgments without safety and speed guarantees. Also it causes delay increase of other vehicles on the street at the same time. To prevent these problems, several studies related to EV have been conducted, but they have progressed with limit of traffic infrastructure which provides much useful information adaptable to strategies now. Therefore, in this paper, we set up a preemption strategy based on real-time vehicle information under the developed infrastructure. Especially, that strategy minimizes stops of EV caused by minimum greens for other phases. The strategy can not only improve existing environment of preemption but also makes it possible to do more efficient and practical preemption.
In next chapter, several previous studies are explained with their limitations. Then, proposed algorithm in this paper is suggested by making up for faults of previous studies. In chapter four, simulation is executed for proving effect of new algorithm, and it provides it results. In final chapter, we sum up the result and present future study.

2. LITERATURE REVIEW

Preemption is different from priority in aspect of providing green time for a special vehicle more flexibly. Preemption is free from keeping phase order and cycle, while priority provides green time keeping cycle and considering other factors. Preemption has a goal of making signal state green for EV, and it reduces delay and stops of EV. That is EV can pass intersections to destination without stops and it improve safety and speed of traffic flow. There are variety studies related to preemption. However, there are few researches have been conducted in field of preemption signal strategy. Most researches are about signal recovery method which affects to traffic flow at least and impact which represents cost and benefit in monetary unit. To investigate signal preemption strategies, we focus on papers which study mainly about preemption signal strategy.

2.1 Previous Studies of Preemption Signal Strategy

Kwon E. et al. (2003) suggested preemption strategy based on dynamic routing. In his study, a transportation center provided proper EV route considering congestion of each link. While detecting EV location in real time, the center decided when preemption would be conducted at each intersection and which flow movements would be provided for safety. Especially, he considered about pedestrian green which could not be ended suddenly. He suggested reasonable early end method of pedestrian green for pedestrians’ safety and speed of EV.

Y.H Yang (2008) tested a preemption strategy using a simulation tool, VISSIM, and he showed possibility of applying preemption to several case of traffic condition. Even though effect of preemption was not large by increasing traffic flow, every case of preemption results in improving speed of EV. Though he mentioned that detection was executed by wireless communication, his preemption method was based on point detection like using loop detectors. He assumed that minimum green time for each phase was 12 seconds. It means he absolutely did not consider about pedestrian crossing.

J.H Lee (2009) proposed new preemption algorithm which minimized delay of other traffic flow. This algorithm does not implement preemption immediately when EV entering the link is detected by a loop detector. It calculates time for clearing queue and time for EV merging the queue, then it estimates gap of these two kinds of times. This gap is time for executing preemption from now. This algorithm could provide more green time for other vehicles. As results showed, it reduced delay of other vehicles and worked as a normal preemption algorithm. However, its overall effect was not better compared normal preemption when EV ran through 200m links. Also, he supposed that minimum green time for each phase was 5 seconds without considering pedestrian green time.

S.B Kim (2010) studied about detour of EV using preemption strategy. Through his experiment using a simulation tool, VISSIM, he showed there was little difference between running times of EV which passed main streets and sub streets respectively. In his study, he
used preemption algorithm suggested by J.H Lee (2009).

2.2 Direction of Study

As other preemption studies shows, there is not much time to adapt variety preemption algorithms from detecting EV to executing preemption. Because most of algorithms are based on EV detection on a point of link, thus EV could be recognized when it entered the link connected to target intersection. Therefore, there is not much time to change signal before EV needs to get green time.

To overcome this problem, real-time data of EV and traffic state provided by developed infrastructure are used in this study. By using information of EV, it is possible to estimate arrival time of EV at each intersection ahead. It means that there is more time to change signal in advance before starting preemption. It makes preemption algorithm consider minimum green especially pedestrian green. Also, real-time traffic information is used to determine the required time of preemption.

In next chapter, new algorithm is proposed using real-time data, and it minimizes stops of EV occurred because of meeting green time of conflict phases.

3. PREEMPTION STRATEGY

In this study, preemption execution is consisted of seven steps. Under the assumption of knowing route of EV, the strategy focuses on pre-control of signal. Overall preemption control flow is below.

In the first step, EV starts after getting a call. At the same time, a center is given information of EV depart. Then, center secures whole path of EV from origin to destination. This is the second step. In the next two steps, it calculates arrival time of EV at the first arrival intersection and next arrival intersection. It is used when green time for EV provides properly. The fifth step decides final decision the time for providing green time for EV with considering minimum green time for other direction phases which would is encountered by EV. The fourth, fifth and sixth steps would be iterated until EV passes the last intersection. After EV passes the intersection which is working for preemption, it recovers signal pattern into original within three cycles. After ending green time for EV, the phase next to it would be provided. This flow could be confirmed by below figure 1.

Among these steps, fourth and fifth steps are mainly studied and set in this paper. Next two sub-chapters will explain about two steps more detail.
3.1 Calculation of arrival time at the second intersection from present location

To calculate arrival time at an intersection, preemption algorithm suggested by J.H Lee (2009) is partly applied. It is the algorithm that preemption time is defined by the gap between time for EV to meet with queue on a link and time for queue on a link to be cleared. The equation (4) represents this arrival time.

- Queue clearance time
  \[ G_{\text{queue}} = \frac{q_1}{6.3 \times (1900 - q)} + 2.0 \]  
  \( q_1 \): queue length (m)  
  \( q \): critical lane flow rate (vps)

- EV merging time
  \[ G_{\text{merge}} = \frac{L_{\text{link}} - L_{\text{queue}}}{60 \times 1000 / 3600} \]  
  \( L_{\text{link}} \): link length  
  \( L_{\text{queue}} \): queue length

Figure 1 Flow chart of preemption strategy
Proceedings of the Eastern Asia Society for Transportation Studies, Vol.8, 2011

- Preemption time considering only one intersection

\[
S_i = \begin{cases} 
0, & \text{if } G_{merge} \leq G_{queue} \\
G_{merge} - G_{queue}, & \text{if } G_{merge} > G_{queue}
\end{cases}
\]

\( S_i \) : preemption time considering only one intersection

Equation (3) is used only when the first intersection which EV passes. If other arrival time for EV at other intersection, this equation should be modified by adding time for EV to run through from present link to link connected to this intersection and delay time at present link due to minimum green or queue clearance time. Equation (4) represents EV arrival time at other intersection except the first one.

- Preemption time considering condition of before intersection

\[
T_i = S_i \\
T_{i+1} = D_i + T_r + S_{i+1} + 1
\]

\( T_{i+1} \) : final preemption time at \( i+1 \)-th intersection
\( D_i \) : EV delay in \( i \)-th intersection
\( T_r \) : EV run time from \( i \)-th to \( i+1 \)-th intersection (using EV speed under saturation condition)
\( S_{i+1} \) : preemption time considering only \( i+1 \)-th intersection condition

![Figure 2 Time of preemption at each intersection](image)

3.2 Setting preemption strategy considering minimum green time

Most of previous studies about preemption strategy do not consider pedestrian green so that they usually assume minimum green for each phase as 5 or 12 seconds. It is too impractical to apply to real traffic signal condition because most urban roads have a crosswalk which requires over 20-second green time for pedestrians. Under a case of having a crosswalk, preemption strategy might be not effective due to longer minimum time than other cases. If EV arrives at an intersection which starts to provide green time for pedestrians, EV has to wait until the green time is ended yet preemption is ready to execute.
To prevent this kind of EV delay, we decide preemption time of next intersection (i+1) in advance when EV is located at before intersection (i). By making more time to change signal, minimum green time is considered. The logic which judges final preemption time and strategy is following below.

\[
\begin{align*}
\text{If} & \quad i+1 \text{ link space length} < i \text{ link queue length} \\
\text{After providing min. green, phase end}
\end{align*}
\]

\[
\begin{align*}
\text{Else if} & \quad EV \text{ arrival time when min. green of a conflict phase (not EV phase) is provided} \\
\text{If} & \quad \text{required green time of previous phase} + \text{Min. G of a conflict phase} < \text{EV Arrival time} \\
\text{Previous phase decrease as required} \\
\text{Min. green of a conflict phase provide}
\end{align*}
\]

\[
\begin{align*}
\text{Else} & \quad A \text{ conflict phase skip}
\end{align*}
\]

\[
\begin{align*}
\text{Else} & \quad A \text{ conflict phase provide until preemption is executed}
\end{align*}
\]

\[
\begin{align*}
\text{Do preemption}
\end{align*}
\]

Figure 3 Preemption logic considering Min. Green

According to this logic, final preemption time and strategy are determined. It could reach the goal of minimizing stops of EV and providing signal circumstance which offers enough time to change signal phases.

4. SIMULATION

PARAMICS is decided to use for simulating traffic signal condition, because it can not only form preemption conditions for EV but also tests several scenarios of signal strategy for EV and gather data of these tests. T-7F is also selected to use for analysis of optimal signal phrases and phrase time in the test scenarios and traffic volume. And then these data is used for designing simulation traffic network. Network is consisted of five intersections for testing the proposed preemption which is considered to have larger impact when it executes on network consisted of long links. Others factors such as numbers of lane, turn rate and signal is decided under assumption of urban network. Direction of EV is the same as direction of offsets.

The result of preemption condition should be judged under stable traffic flow. Therefore, simulation time from 900s to 2700s is selected to analyze for preemption effect. EV enters network after simulation runs for 1800s.

| Geometric condition | major road : three-lane |
|                     | minor road : two-lane  |
|                     | left-turn available    |

<table>
<thead>
<tr>
<th>Signal condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>left-turn after straight</td>
</tr>
<tr>
<td>Pedestrian green time when straight phase is green (major road : 28 seconds, minor road : 22 seconds)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>right-turn : 5%</td>
</tr>
<tr>
<td>straight : 85%</td>
</tr>
<tr>
<td>left-turn : 10%</td>
</tr>
</tbody>
</table>

Table 1 Simulation condition
Table 2 Simulation - signal condition

<table>
<thead>
<tr>
<th>Intersection</th>
<th>V/C =1.0, 200m</th>
<th>V/C =1.0, 500m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1</td>
<td>Phase 2</td>
</tr>
<tr>
<td>1</td>
<td>67(3)</td>
<td>17(3)</td>
</tr>
<tr>
<td>2</td>
<td>67(3)</td>
<td>17(3)</td>
</tr>
<tr>
<td>3</td>
<td>67(3)</td>
<td>17(3)</td>
</tr>
<tr>
<td>4</td>
<td>67(3)</td>
<td>17(3)</td>
</tr>
<tr>
<td>5</td>
<td>67(3)</td>
<td>17(3)</td>
</tr>
<tr>
<td>min G</td>
<td>22</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 4 Simulation – network condition

Several cases of preemption control strategy are compared by their preemption algorithm. The condition of each scenario is described in Table 4. In case of 200m link length, existing and proposed algorithms are compared, because queue algorithm does not have more effective result than existing algorithm (J.H, Lee (2009)).

Table 3 Simulation - scenario

<table>
<thead>
<tr>
<th>Link length</th>
<th>Algorithm</th>
<th>V/c=0.6</th>
<th>V/c=0.8</th>
<th>V/c=1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td>Proposed</td>
<td>scenario 1</td>
<td>scenario 2</td>
<td>scenario 3</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>scenario 4</td>
<td>scenario 5</td>
<td>scenario 6</td>
</tr>
<tr>
<td>500m</td>
<td>Proposed</td>
<td>scenario 7</td>
<td>scenario 8</td>
<td>scenario 9</td>
</tr>
<tr>
<td></td>
<td>Queue</td>
<td>scenario 10</td>
<td>scenario 11</td>
<td>scenario 12</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
<td>scenario 13</td>
<td>scenario 14</td>
<td>scenario 15</td>
</tr>
</tbody>
</table>
5. RESULT

In this paper, the changing degree regarding delay of all vehicles and speed of the emergency vehicle is used as a measure of effectiveness (MOE). Speed of EV is calculated by division of travel distance by travel time of EV, and delay is sum of gap between travel time under free flow condition and travel time under each traffic flow case. The results are listed below.

Table 4 Travel speed change rate of EV compared with signal control without preemption (unit : %)

<table>
<thead>
<tr>
<th>v/c</th>
<th>Existing Preemption</th>
<th>Queue Preemption</th>
<th>Proposed Preemption</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>8.35</td>
<td>-</td>
<td>20.73</td>
</tr>
<tr>
<td>0.6★</td>
<td>14.37</td>
<td>-</td>
<td>37.85</td>
</tr>
<tr>
<td>0.8</td>
<td>3.19</td>
<td>-</td>
<td>17.14</td>
</tr>
<tr>
<td>0.8★</td>
<td>5.32</td>
<td>-</td>
<td>32.36</td>
</tr>
<tr>
<td>1.0</td>
<td>3.85</td>
<td>-</td>
<td>19.08</td>
</tr>
<tr>
<td>1.0★</td>
<td>4.45</td>
<td>-</td>
<td>23.44</td>
</tr>
<tr>
<td>500m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>20.40</td>
<td>13.98</td>
<td>23.65</td>
</tr>
<tr>
<td>0.6★</td>
<td>22.81</td>
<td>12.63</td>
<td>27.96</td>
</tr>
<tr>
<td>0.8</td>
<td>25.16</td>
<td>16.74</td>
<td>31.51</td>
</tr>
<tr>
<td>0.8★</td>
<td>39.46</td>
<td>25.85</td>
<td>44.19</td>
</tr>
<tr>
<td>1.0</td>
<td>30.07</td>
<td>16.95</td>
<td>39.75</td>
</tr>
<tr>
<td>1.0★</td>
<td>47.81</td>
<td>26.62</td>
<td>59.43</td>
</tr>
</tbody>
</table>

★ is a figure except in case EV starts when signal of its direction at first intersections is green

On all occasions, speed of EV increases considerably when applying the proposed preemption strategy. Especially, table 4 except for the cases EV starts when signal of its direction at first intersections is green shows even better speed improvement. If EV starts when the first intersection providing green time for direction of EV, it results in the effect as the offset effect. Furthermore the proposed preemption algorithm leads the result of higher speed improvement effect than the existing algorithm because this helps continuous driving of the emergency vehicle. Thus, the proposed preemption algorithm makes more advancement of the emergency vehicle flow regardless of both link length and v/c.

Table 5 Delay change rate of general vehicles compared with signal control without preemption (unit : %)

<table>
<thead>
<tr>
<th>v/c</th>
<th>Existing Preemption</th>
<th>Queue Preemption</th>
<th>Proposed Preemption</th>
</tr>
</thead>
<tbody>
<tr>
<td>200m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>1.77</td>
<td>-</td>
<td>3.84</td>
</tr>
<tr>
<td>0.8</td>
<td>0.20</td>
<td>-</td>
<td>3.62</td>
</tr>
<tr>
<td>1.0</td>
<td>-0.03</td>
<td>-</td>
<td>7.24</td>
</tr>
</tbody>
</table>
Nevertheless, delay of general vehicles compared with delay under normal signal control increases. It could be judged because there is lots of unstable traffic flow after preemption. Although major direction should have relatively large portion of green time due to method of recovering offset within recovery cycle, large portion green time of minor direction causes delay increase of major direction vehicles. Despite speed improvement of emergency vehicle, the new preemption algorithm introduced by this paper shows a little bit delay increase of the general vehicle than the origin preemption algorithm. Namely, the new preemption algorithm, which skips the phase in case of not keeping minimum green time in order to avoid a conflict between the emergency vehicle and the minimum green time, causes the delay increase of the general vehicle. In spite of delay increase of other vehicles, speed of EV rises when it increases v/c or lengthens link length. This result also is equal reason.

Therefore, the proposed preemption algorithm introduced by this paper has an effect on increasing travel speed of EV as much as it could expect far better speed improvement in case EV starts when signal of heading direction is not green. However, it is necessary to found a recovery cycle and a complementary algorithm for the delay decrease of the other vehicles.

6. CONCLUSION

The purpose of this study is to set up preemption strategy avoiding to encounter minimum green time with using real-time vehicle and traffic information. To achieve it, preemption time is calculated at an intersection before EV arrives the next intersection. Results show this goal is satisfied in aspect of improvement of EV speed. When proposed algorithm is executed, speed of EV becomes faster by 17.14~59.43%. It is more effectively under a case of having heavy traffic flow. However, total delay of individual other cars increases by 3.62~7.90% compared to origin algorithm.

Even though speed of EV is improved, the whole network has impact of increasing total delay. Therefore, more study about positive preemption algorithm should be conducted for reducing total delay. Moreover, other MOE index could be used to evaluate proposed algorithm such as number of EV stops and reliability of EV arrival time.

In addition to it, this algorithm could be upgraded and makes it possible to control whole intersections on the path of EV at the same time and to modify preemption time of rest intersection considering EV and traffic condition whenever EV passes a intersection. It gives more enough time to be ready for preemption. It could keep phase order and cycle, and this possibility leads to give less of impact to whole network. Through it, upgraded algorithm provides EV with faster speed and other vehicles with little increased delay.
ACKNOWLEDGEMENTS

This research is funded by Engineering Research Institute and BK21 Safe and Sustainable Infrastructure Research Group in Seoul National University.

REFERENCES