All-Red Time Design accounting for the Interaction between the Clearing Vehicle and the Entering Vehicle

Yukiko OTASHIRO, M.-Eng.
Department of Human-Social Information Sciences
Graduate School of Information Sciences
Tohoku University
Aramaki 6-6-06, Aoba-ku, Sendai, Miyagi 980-8579 Japan
Fax: +81-22-795-7494
E-mail: ootashiro@plan.civil.tohoku.ac.jp

Masao KUWAHARA, Ph.D.
Professor
Department of Human-Social Information Sciences
Graduate School of Information Sciences
Tohoku University
Aramaki 6-6-06, Aoba-ku, Sendai, Miyagi 980-8579 Japan
Fax: +81-22-795-7494
E-mail: kuwahara@plan.civil.tohoku.ac.jp

Keshuang TANG, Dr.-Eng.
Associate Professor
Department of Traffic Engineering
School of Transportation Engineering
Tongji University
No. 4800, Cao'an Road, Shanghai 201804 China
FAX: +86-21-3362-6308
E-mail: tang@tongji.edu.cn

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In Japan, over 40.0% of the total accidents occurred at or near intersections, and approximately 16.2% of the total fatal accidents took place inside signalized intersections in the year of 2009. A significant portion of the fatalities were due to the violation of traffic signals, e.g., red-light-running and hurry start. Those indiscipline or law-violating behaviour at the change of phases is closely associated with the all-red clearance interval.

In Japan, the all-red time is determined by Eq. (1), according to the current manual (JSTE, 2006). It is often set longer than sufficient because of the current intersection planning and design philosophy. Unnecessarily long all-red time not only induces the aforementioned risky behaviour of drivers being aware of its abundant length, but also results in larger lost time, cycle length, and thus control delay.

$$AR = \frac{W}{V} \quad (1)$$

Where, W=intersection width, m; V=clearing speed, km/h.

On the other hand, a shorter all-red time can be produced by the German method, given by Eq. (2) (FGSV, 2003). In this type of methods, the first entering vehicle will almost collide with the last clearing vehicle. However, entering drivers rarely accept that degree of risk in reality, and thus may have to take evasive actions and wait for crossing after the clearing vehicle is far enough from the conflict point. Consequently, extra start-up lost time occurs and meanwhile risk exposure to the following vehicle increases due to the evasive actions.

$$AR = t_c - t_e \quad (2)$$

Where, t_c=clearing time, s; t_e=entering time, s.

Therefore, the optimum all-red clearance interval, i.e., enabling to avoid the evasive actions and eliminate the extra clearance lost time, can be determined if the interaction time of the entering vehicle and the clearing vehicle is known. This study is intended to propose a new calculation method for the all-red time that is able to account for the interaction of the entering vehicle and the clearing vehicle.

Figure 1 shows example trajectories of the clearing right-turn vehicle and the entering through vehicle at the change of phases. In the conventional signal phasing plans at signalized intersection in Japan, this type of conflicts are vitally importantly in terms of its high occurrence frequency and important effects on operational efficiency because of its comparably long all red clearance intervals.

Figure 2 further illustrates the interaction between the last clearing vehicle and the first entering vehicle. Where, it is assumed that the last clearing vehicle crosses the stop-line exactly at the beginning of all-red clearance interval at a constant speed, and the first entering vehicle makes a usual start at a stable acceleration rate. Insufficient all-red was considered to be the value based on the German method, i.e., $AR=t_c-t_e$.

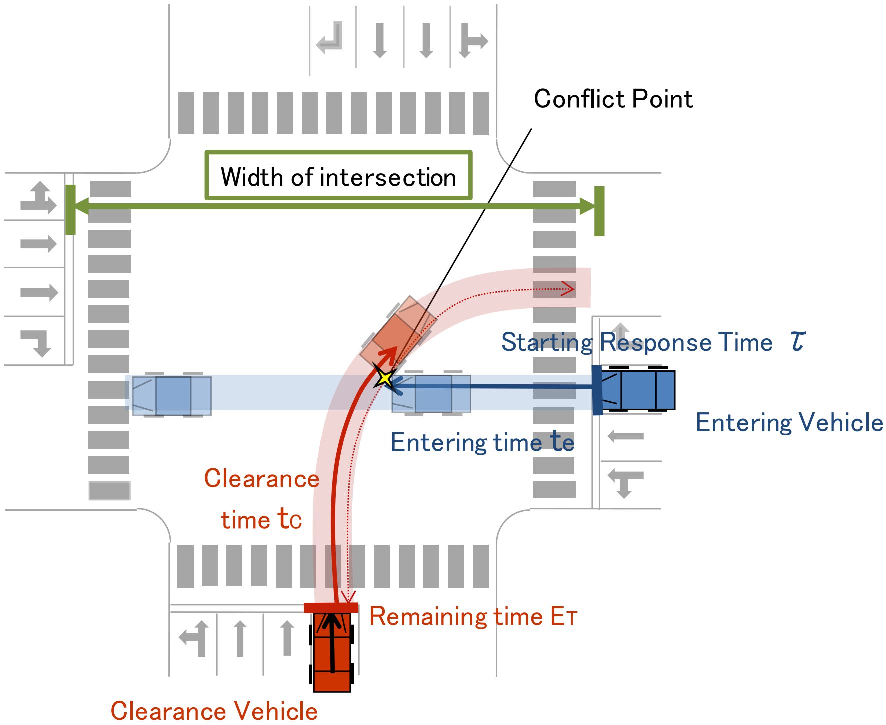
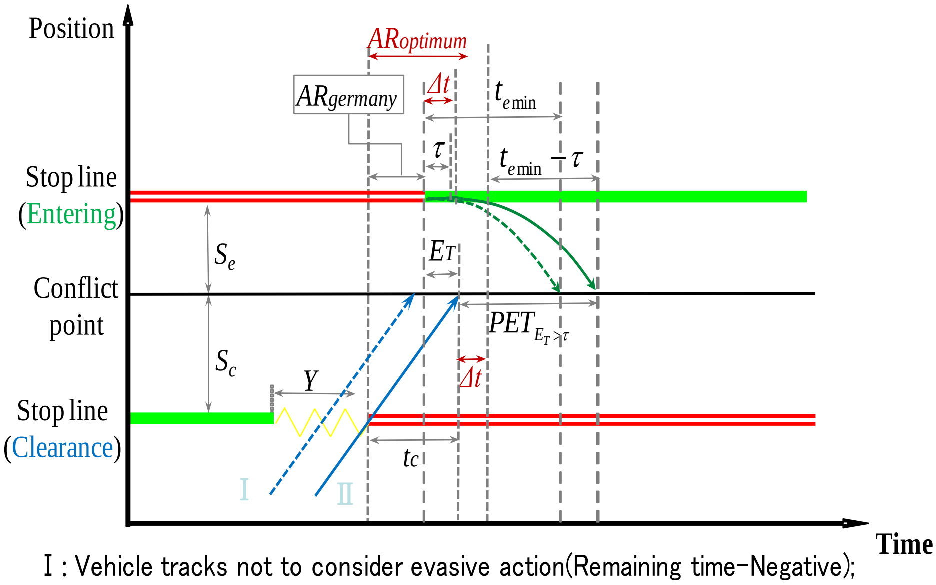


Figure 1 Trajectories of the clearing vehicle and the entering vehicle at the change of signal phases

In this study, a time-based surrogate measure (Post-Encroachment Time, PET) was applied to evaluate such type of traffic conflicts. PET is uniquely defined for a conflict point and refers to the time between the departure of the encroaching vehicle from the conflict point and the arrival of the vehicle with the right-of-way at the conflict point.

A concept of Exit Time (E_T) is defined to quantify how late the clearing vehicle exits from the conflict point. It represents the elapsed time from when the all-red time ends up to when the clearing vehicle completely leaves the conflict point. A positive value translates that the clearing vehicle fails to clear from the conflict point before the start of green for traffic movements on the crossing road, i.e., a late exit. For a late exit, drivers may have either entered the intersection at the end of the yellow change interval or during the red signal. E_T is opposite when the clearing vehicle passed the conflict point before the end of all-red time, as shown in trajectory I. While, it is positive when the clearing vehicle rushed into the intersection after the start of the all-red time, represented by Trajectory II.



Ⅰ: Vehicle tracks not to consider evasive action(Remaining time-Negative);
Ⅱ: Vehicle tracks to consider evasive action(Remaining time-Positive).

Figure 2 The interaction between the clearing vehicle and the entering vehicle

According to Figure 2, the optimum all-red time ($AR_{optimum}$) should be calculated as follows.

$$AR_{optimum} = t_c - t_e + \Delta t \tag{3}$$

Where, Δt =interaction time of the entering vehicle and the clearing vehicle, calculated by Eq. (4).

$$\Delta t = PET_{ET>\tau} - (t_{e\min} - \tau) \tag{4}$$

Where, $PET_{ET>\tau}$ =post-encroachment time when E_T is greater than τ, s; t_{emin}=the minimum entering time, s; τ=perception-and-reaction time, s.

To validate this method, empirical data was collected at 3 intersections located in three different cities, one in Tokyo, one in Sendai, and another in Berkeley, by the use of video cameras. With the aid of an image-processing software, necessary traffic operation and driver behaviour parameters were extracted from the video data. Based on the obtained data, distributions of the clearing time (t_c), the entering time (t_e), the exit time (E_T), and the perception-and-reaction time (τ) as well as their relationships were investigated in order to estimate the distribution of the interaction time (Δt). The estimated distribution of Δt was then used for the calculation of the optimum all-red time ($AR_{optimum}$) through Eq. (3) and (4).

The results are presented in Figure 3. It was found that the calculated $AR_{optimum}$ based on the proposed method is the same as the currently used value at the intersection in Berkeley, but 1.5s and 0.5s shorter than the current values at the intersections in Sendai and Tokyo respectively. It implies that the proposed method could be helpful in improving operational efficiency at the intersections in Japan.

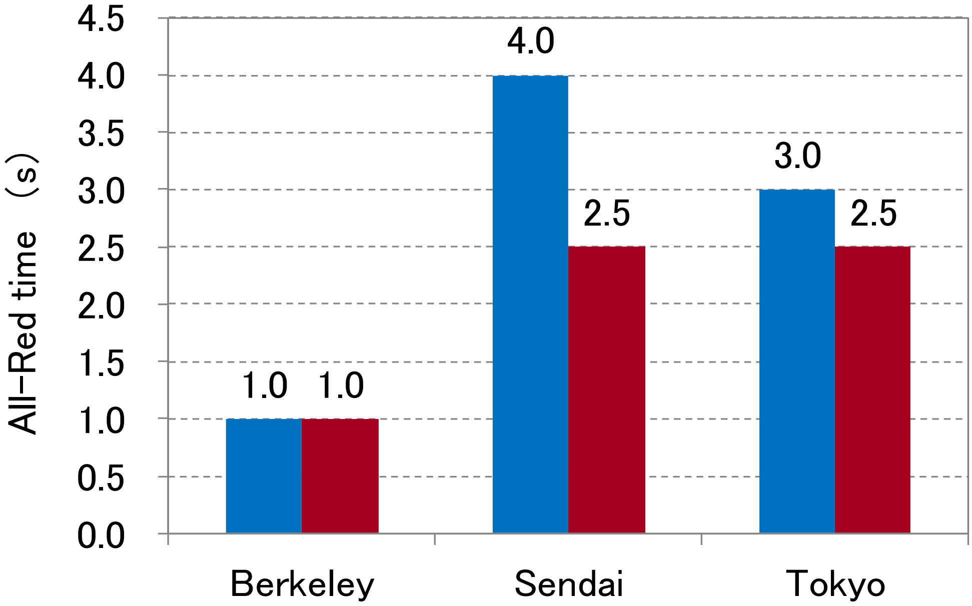


Figure 3 Comparison of the optimum all-red time and the current all-red times