Timing of Intergreen Periods at Signalized Intersections: The German Method

by Hans-Georg Retzko and Manfred Boltze

Recently several reports on timing of intergreen periods at signalized intersections have appeared in American magazines. We assume this problem is intensively being discussed in the United States. The article "Effect of Clearance Interval Timing on Traffic Flow and Crashes at Signalized Intersections" by Zador, et al., reports a strong correlation between the "clearance interval duration" and the accident density at a signalized intersection. The final remark that a suitable procedure for calculating clearance interval timing should be applied for guaranteeing sufficient safety seems to be the correct approach because of being goal oriented. The "trial-and-error" method for finding the best solution must be rejected, because the "errors" are accidents.

An article by Susan Jourdain in *Traffic Engineering and Control* gave recommendations for amber and all-red timings from British and American points of view. Howard Stein then published a review in *Transportation Quarterly* on today's policies and practices of intergreen timing in the United States.

We intend to contribute to these discussions by introducing an algorithm that is part of the official signal timing standards (RiLSA) in the Federal Republic of Germany and that is in widespread use there. In addition, we will report about a new approach of timing intergreen periods. (The not rounded numbers in this article result from the transformation of metric units into American ones.)

Timing of Intergreen Periods According to German Standards

The definition reflects the philosophy of the procedure: the intergreen time is the time between the end of the green time of a traffic flow and the beginning of the green time of another (conflicting) flow, which will cross or merge the first one. During the intergreen time different operations occur—overrunning, clearing, and entering.

Overrun time, t_o, is understood to be the time between the end of the green time and the point of time at which the last vehicle of the ending green time passes the stop line. Clearance time, t_c, is the time necessary for the last vehicle of the ending green time to drive the clearance distance (distance from the stop line until having cleared the conflict area). Entrance time, t_e, is the time necessary for the first vehicle of the beginning green time to pass the entrance distance, that is the distance from the stop line until arriving at the conflict area. The last vehicle of the ending green time must have cleared the conflict area when the first vehicle of the beginning green time arrives at the conflict area (Figure 1). Intergreen time (t_i) is equal to overrun time plus clearance time minus entrance time:

$$t_i = t_o + t_c - t_e \qquad (1)$$

To determine intergreen times in a way that conflicts will not occur is impossible. Assumptions are necessary for describing the operations during signal stage change. Some patterns of "normal" behavior can be presumed. According to empirical data the parameters can be chosen to such an extent that even the most critical combination of these parameters is considered within certain limits.

Overrun Time

We assume that a driver will stop at the beginning of the amber interval if he can do this without danger. (This assumption is in accordance to the legal traffic regulations in the Federal Republic of Germany.) Stopping is possible when there is a definite distance d_s up to the stopping line at the moment of the

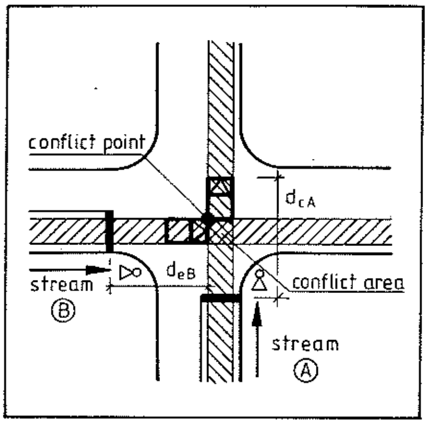


Figure 1. Clearance distance and entrance distance for the timing of intergreen periods. d_{cA} = clearance distance for the last vehicle of stream *A*. d_{eB} = entrance distance for the first vehicle of stream *B*.

decision to stop. This moment is the end of green time, and, the beginning of the amber interval. That means

$$d_s = v \cdot t_{re} + \frac{v^2}{2 \cdot b} \qquad (2)$$

Where
- d_s = distance up to the stopping line,
- v = approach speed at the moment of the end of green time/the beginning of amber interval,
- t_{re} = reaction time, and
- b = deceleration rate.

The approach speed can be assumed to equal the speed limit. Reaction time can be assumed as 1 sec, and the deceleration rate may be 11.5 ft/sec^2.

Assuming that the speed of the last vehicle of the ending green time does not change in the intersection area, the overrun time is

$$t_o = \frac{d(t^*)}{v} \qquad (3)$$

Where
- $d(t^*)$ = distance up to the stop line at the moment of the end of green time and
- v = speed.

Driving is allowed if

$$d(t^*) \leq d_s \qquad (4)$$

Therefore the maximum overrun time is

$$\max t_o = \frac{d_s}{v} = t_{re} + \frac{v}{2 \cdot b} \qquad (5)$$

This means that the maximum overrun time that considers behavior according to the traffic situation depends on the reaction time t_{re}, the approach speed v, and the deceleration rate b.

To avoid overrunning a red signal the duration of the amber interval should be equal to the maximum overrun time.

Clearance Time

The clearance time is

$$t_c = \frac{d_c}{v_c} \qquad (6)$$

Where
- d_c = clearance distance and
- v_c = clearing speed.

Conflicts do not happen if it is assumed when determining intergreen time that clearing ends at the earliest when the last clearing vehicle has passed the conflict area (see Figure 1). So the clearing distance d_c is the distance between the stop line and the end of the conflict area plus the length L of the clearing vehicle (see Figure 1—d_{cA}). The length of the clearing vehicle may be L = 20 ft on the average.

The clearing speed v_c is that speed with which the last clearing vehicle drives over the clearance distance d_c. The maximum value is equal to the speed limit at the intersection. The minimum value considers vehicles with low speed (v_c = 23 ft/sec). Only for vehicles that have to pass small curves, v_c may be assumed to be lower, for example 16.4 ft/sec for R < 49.2 ft.

If we assume lower clearing speeds than the existing speed limit, we are allowed to use a smaller overrun time, because slowly driving vehicles are better able to react on green time ending ($v_c \leq$ 23 ft/sec $\rightarrow t_o$ = 2 sec).

If there are clearings with different clearing speeds v_c, then that case of clearing is relevant for which the highest sum of clearance time and overrun time is calculated.

Entry Time

We distinguish between two cases in the behavior—start from stopping and "flying" start. In both cases the entry time depends on the speed v_e when crossing the stop line, the acceleration rate b, the entering distance d_e and the moment of crossing the stop line in relation to the beginning of the green time.

The entering distance is the distance between the stop line and the beginning of the conflict area (see Figure 1—d_{eB}). It depends only on the geometry of the intersection.

According to German standards we calculate t_e for the case "start from stopping" as

$$t_e = \sqrt{\frac{2(d_e + d_o)}{b}} - t_{RY} \qquad (7)$$

Where

t_e = entry time,
d_e = entering distance,
d_o = start position at the stop line (4.9 ft),
b = acceleration rate (11.5 ft/sec^2), and
t_{RY} = red and yellow interval (1 sec).

For the "flying" start we consider the entering speed to be 24.9 mph (36.5 ft/sec). (Please consider the influence of the red and yellow signal if using these values in the United States.)

So

$$t_e = \frac{d_e}{v_e} \qquad (8)$$

There are specific assumptions being made for pedestrians and cyclists. They shall not be mentioned here.

Intergreen Time Diagram

The intergreen time diagram used in the Federal Republic of Germany considers the red and yellow interval of 1 sec. It is shown in Figure 2.

Procedure

First we have to determine which traffic flows have conflicts with each other when the stages change. For all possible cases the intergreen times must be calculated. They are brought up to round figures. The results can be shown by a matrix (see Figure 3).

If several streams have a common signalization, the longest intergreen time is chosen. The final signal program must contain all intergreen times.

A New Approach to Timing Intergreen Periods

The preceding procedure of calculating intergreen times may be criticized. It may be said that traffic flow during the changes of the stages is a stochastic process. Or it may be asked why such a sophisticated procedure must be done if in this procedure many assumptions have to be made. Therefore, Jakob developed at our institute a new approach that depends on a probabilistic treatment. All cases of conflicts are classified to typical cases. For every type of conflict a specific intergreen time is determined wherein the traffic streams that form a conflict can be alternatively treated as "clearing" or "entering" (see Figure 4). The intergreen time values

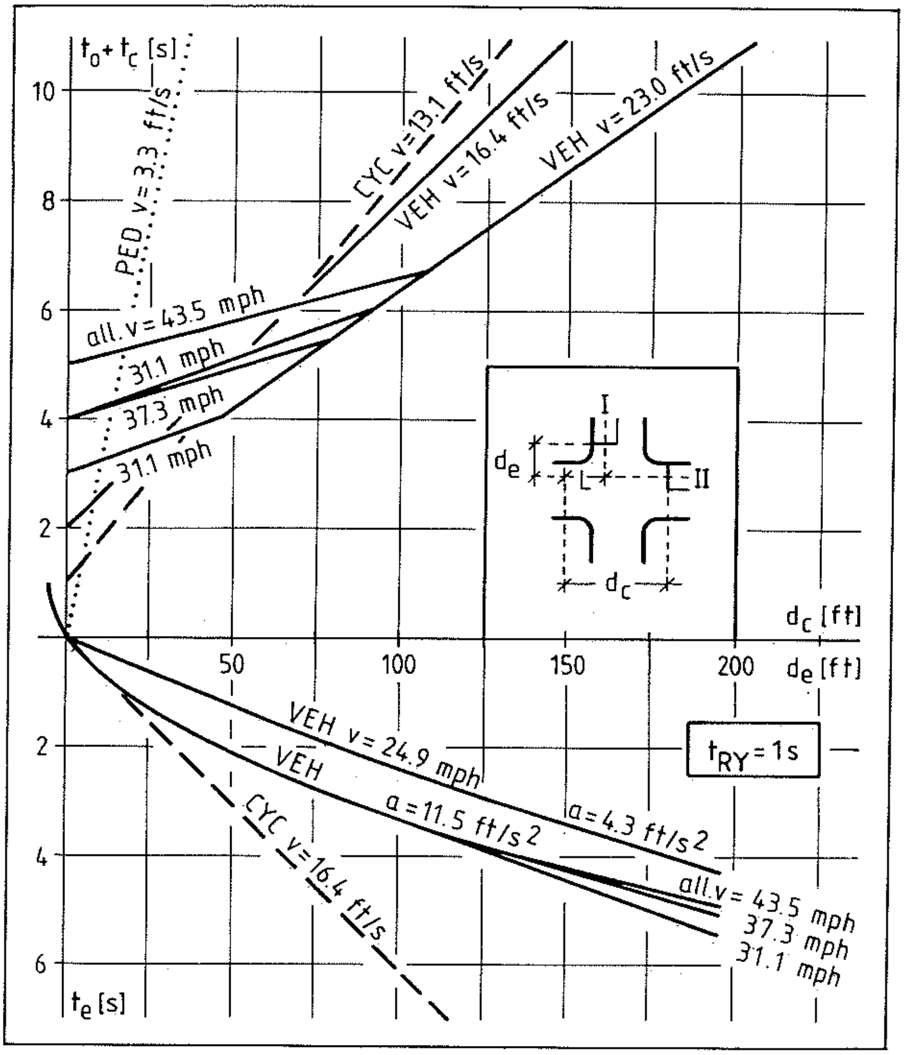


Figure 2. Diagram for the timing of intergreen periods.

clearing stream \ entering stream	1	2	4	5	6	7	8	9	10	11	12	14	15
1	X	X	X	2	X	X	X	2	X	X	X	X	X
2	X	X	X	3	3	X	X	5	5	5	4	6	X
4	X	X	X	X	X	X	2	X	X	X	3	X	3
5	5	5	X	X	X	X	3	4	X	X	6	X	3
6	X	4	X	X	X	X	4	5	5	5	X	6	3
7	X	X	X	X	X	X	X	X	X	2	X	3	5
8	X	X	5	5	5	X	X	X	X	3	4	3	X
9	5	5	X	4	4	X	X	X	X	4	6	3	X
10	X	2	X	X	2	X	X	X	X	X	X	5	X
11	X	3	X	X	4	5	5	4	X	X	X	X	6
12	X	4	5	5	X	X	4	4	X	X	X	X	X
14	X	12	X	X	11	13	13	13	13	X	X	X	X
15	X	X	6	6	6	5	X	X	X	4	X	X	X

[s]

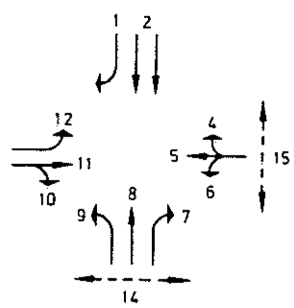


Figure 3. Example of an intergreen time matrix.

have to be increased if there are triangular islands and/or divisional islands. Only car traffic is considered, in so far as the new approach has disadvantages. The new approach of intergreen timing can be applied to intersections with "normal" character. If cyclists are signalized together with car traffic at large intersections one must add a value according Figure 5.

It could be proved that the new approach of intergreen time determination works much quicker than the "classic" procedure and also guarantees safe traffic operation at signalized street intersections. The new approach is not yet allowed to be used in Germany because of juridical considerations.

Final Remark

Calculations of intergreen times for signal programs are of the greatest importance. Correct intergreen timing guarantees safe traffic operations during changes of stages. Intergreen timing cannot be determined by trial-and-error methods. The German method is described in this article. We ask U.S. traffic engineers to test our procedure.

Bibliography

Richtlinien für Lichtsignalanlagen, Ausgabe 1981. Hrsg.: Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln.

Aktuelle Themen der Lichtsignalsteuerung, Ausgabe 1985. Hrsg.: Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV), Köln.

Frantzeskakis, John M. "Signal Change Intervals and Intersection Geometry." *Transportation Quarterly*, Vol. 38, No. 1, January 1984, pp. 47-58.

Jakob, G. Wahrscheinlichkeitstheoretische Untersuchungen zur Bemessung von Zwischenzeiten in Signalprogrammen. Technische Hochschule Darmstadt, 1980.

Jourdain, S. "Intergreen Timings." *Traffic Engineering and Control*, April 1986, pp. 179-182.

Stein, Howard S. "Traffic Signal Change Intervals: Policies, Practices, and Safety." *Transportation Quarterly*, Vol. 40, No. 3, July 1986, pp. 433-445.

Zador, P.; Stein, H.; Shapiro, S.; et al. "Effect of Clearance Interval Timing on Traffic Flow and Crashes at Signalized Intersections." *ITE Journal*, Vol. 55, No. 11, November 1985, pp. 36-39.

Hans-Georg Retzko received his doctor degree in engineering from the Technical University Hannover (1961). Since 1966 Retzko has been professor for traffic and transport engineering at the technical University Darmstadt. He serves as consultant for federal and state departments, regional authorities, and other public or private institutions.

Manfred Boltze received his Diplom of Civil Engineering in 1984 at the Technical University Darmstadt. He is now research assistant at the Fachgebiet Verkehrs planung und Verkehrstechnik (Traffic Department) at the Technical University Darmstadt and specializes in traffic control technique research.

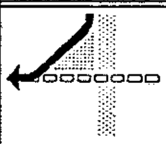
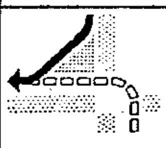
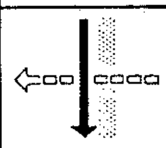
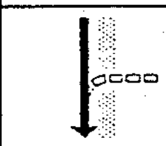
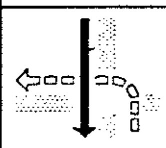
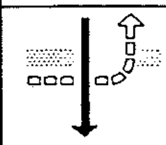
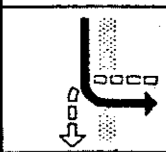
▭▭▭▭ clearing, ▬ entering				case of conflict	▬ clearing, ▭▭▭▭ entering		
standard form	increase: triangular island	increase: central island (width) 20...40[ft]	increase: central island (width) > 40 [ft]		standard form	increase: central island (width) 20...40[ft]	increase: central island (width) > 40 [ft]
7	+2	+1	+2		4	-	-
7	+2	+1	+2		4	-	-
6	-	+1	+2		5	-	-
6	-	+1	+2		6	-	-
5	-	+1	+2		5	-	-
5	-	-	-		5	+1	+2
4	-	+1	+2		6	-	-

Figure 4. Timing of intergreen periods according to Jakob.

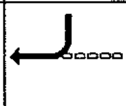
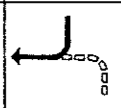
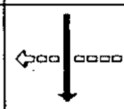
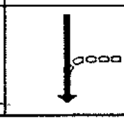
increase for cyclists		
▭▭▭ clearing, ▬ entering	case of conflict	▬ clearing, ▭▭▭ entering
+1		-
+1		-
+1		-
+1		+1

Figure 5. Timing of intergreen periods according to Jakob—increase for cyclists.