Intersection Traffic Control Through Coordination of Approach Speed

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• VARIATION of approach speed promises considerable improvement in traffic control at signalized intersections. It can be accomplished by means ranging from complex speed control signal systems to simple roadside signs. The aim of these controls is to improve the smoothness and efficiency of intersection operation and, even more importantly, to move the driver through the intersection with ease.

The need for improving the flow of traffic at signalized intersections is as old as the traffic signal itself. The arbitrary alternation of complete blockage and free flow at the intersection brings with it two severe driver objections. One grows out of the uncertainty and anxiety of the approaching driver towards the end of the green phase, when he worries whether the light will change on him and require sudden stopping. The other is a combination of irritation at being stopped and impatience at the length of the stop.

Approach speed control can keep the traffic moving at all times. If properly designed, it can replace the stop-and-go alternations along the highway with fluctuations in the speed of flow. This creates flow concentrations, which mesh with similar flow concentrations on the cross-route, thus alternating the use of the intersection by the crossing routes without stopping the flow. This system eliminates stopping at the intersection on the highway and so obviates the anxiety about a sudden light change.

A discussion of the principles and theories of controlling approach speed and a description of a low-cost application, together with a discussion of the fundamentals of the well-known traffic pacer, outline the possibilities of this type of control.

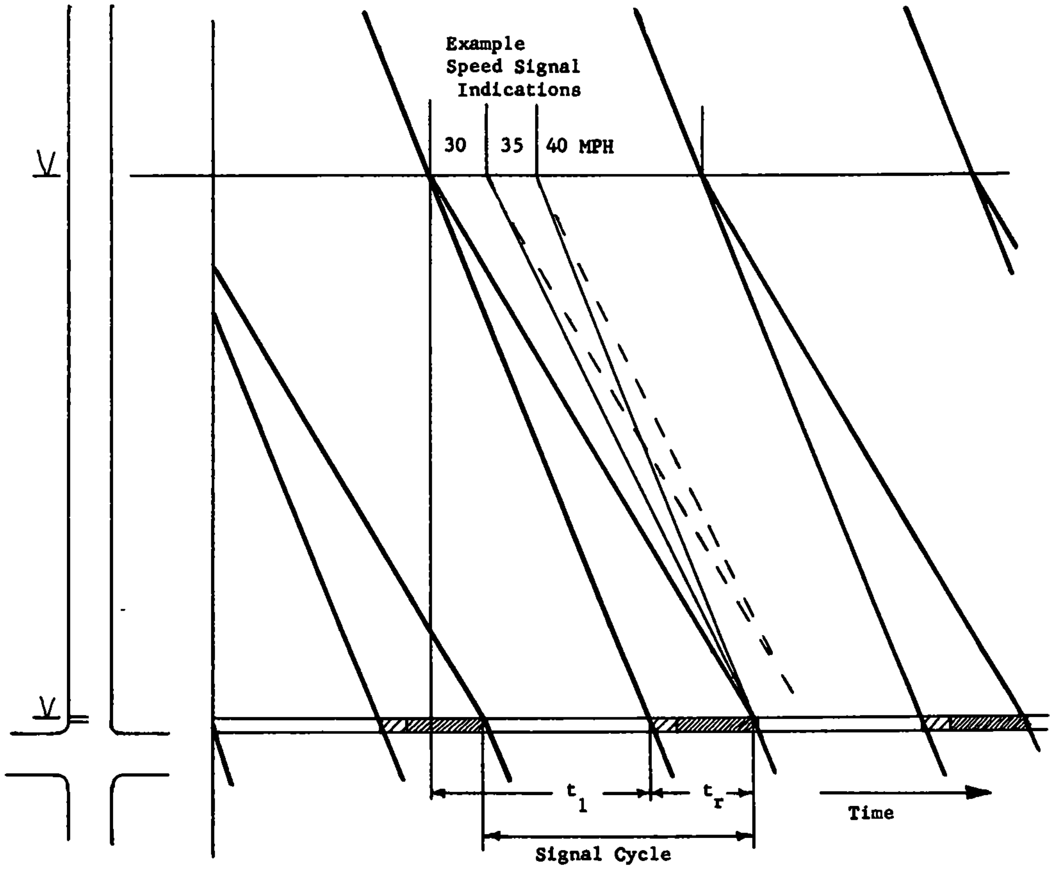
TRAFFIC FUNNEL THROUGH APPROACH SPEED CONTROL

A funnel is a cone used for pouring things into narrow-mouthed containers. A traffic funnel "pours" vehicles, originally spaced at random along a highway, into the narrow time period of the green phase at an intersection.

Operation of the Traffic Funnel

Figure 1 shows the principle of a traffic funnel on a time-distance graph, familiar to everyone who has worked on signal timing. The "funneling" of the traffic approaching the intersection is accomplished by reducing the speed of a group of vehicles passing a given point on the highway ahead of the intersection during a given time period, while the speed of the succeeding group is reduced somewhat less, and so forth, until the last group passing the given point maintains its free speed. While moving through the funnel, a platoon is gradually built up behind the vehicles that have been slowed, until all vehicles are closely spaced so that they all reach the intersection during the green phase. None need be stopped.

The motorist approaching the intersection encounters at a considerable distance (in the order of several thousand feet) ahead of the intersection a speed signal that indicates at what speed he should proceed. If he follows the recommended speed he will be funneled to reach the intersection while the signal is green. The recommended speed at the approach signal varies between the free-flow speed of the traffic (or the speed limit of that roadway) and a reduced speed of about ¾ to ⅔ of the free flow speed, so that a comparatively minor modification will guarantee arrival at the intersection during the green phase.



t_r = Amber + Red Phase Time

t_1 = Approach Time at Free Speed

Figure 1. Components of approach speed control.

Advantages of the Traffic Funnel

In its ideal form approach speed control not only minimizes interference with the free passage of the individual automobile driver, but also increases the capacity of the intersection through compression of the vehicle platoon in the funnel and through the reduction of acceleration losses at the beginning of the green phase. A better safety record may also be expected through elimination of the unexpected change of light. Savings in time, gasoline, mechanical wear, accident damage and drivers' emotional energy are all possible with a well-designed system of approach speed control.

COMPARISON WITH OTHER CONCEPTS OF INTERSECTION CONTROL

A review of other methods of controlling traffic at intersections and of their characteristics in use will demonstrate the conceptual difference that underlies the principle of controlling approach speed.

The Intersection

An intersection is a piece of real estate belonging simultaneously to two or more crossing routes. In this definition "simultaneously" obviously presents the aspect that creates a problem. Any attempt by the users of two intersecting routes to use the intersection simultaneously leads to undesirable results. Consequently, controls or design changes have been developed to eliminate the simultaneous use of the intersection roadway by two or more routes.

The most obvious solution, but usually a prohibitively expensive one, is to remove the intersection by providing roadway surfaces above or below each other on the same piece of real estate. This provides uninterrupted right-of-way to each route.

Basic Right-of-Way Rule

The basic rule, on any intersection not otherwise controlled, provides a right-of-way preference only in the case of conflict, but then arbitrarily assigns it to the vehicle on the right. This rule works well only for light traffic on intersecting routes of the same type.

Stop or Yield Control

This type of control gives preference at all times to one route over others and permits the use of the intersection roadway by the secondary routes only when there is no possible conflict with users on the primary route. It works well until the traffic on the major route approaches continuous flow or the volume on the secondary routes increases sufficiently that delays become excessive.

Signal Control

The traffic signal assigns the right-of-way on the intersection to the intersecting streets alternatively or in rotation. The use of the intersection is always given completely to one road and denied completely to the other routes. Consequently, traffic on the intersecting streets either is completely stopped or is allowed to flow completely unimpeded (although the later drivers must worry about the possible change of the signal light indication).

This method of control always delays about one-half of the traffic using the intersection and therefore should be used only when the other methods of control are sure not to work.

Approach Speed Control

This control is applied at the approaches to an intersection by funneling the traffic flow on each route into the green phase, and thereby clearing each route of any traffic at the intersection during its red phase, while cross-route traffic is being accommodated. Thus approach speed control works by concentrating and intermeshing the crossing traffic streams.

This type of control is a modification of the method of assigning the use of the intersection exclusively to one of the intersecting streets in turn. But complete and abrupt blockage never occurs and therefore this control system does not interfere severely with the traffic flow.

This system would seem to be applicable to every traffic signal to which it can be fitted. Moreover, because it does not generate the same objections as a traffic signal, it might find application in many locations where traffic signals alone have not been considered desirable before.

COMPUTATION OF TRAFFIC FUNNEL

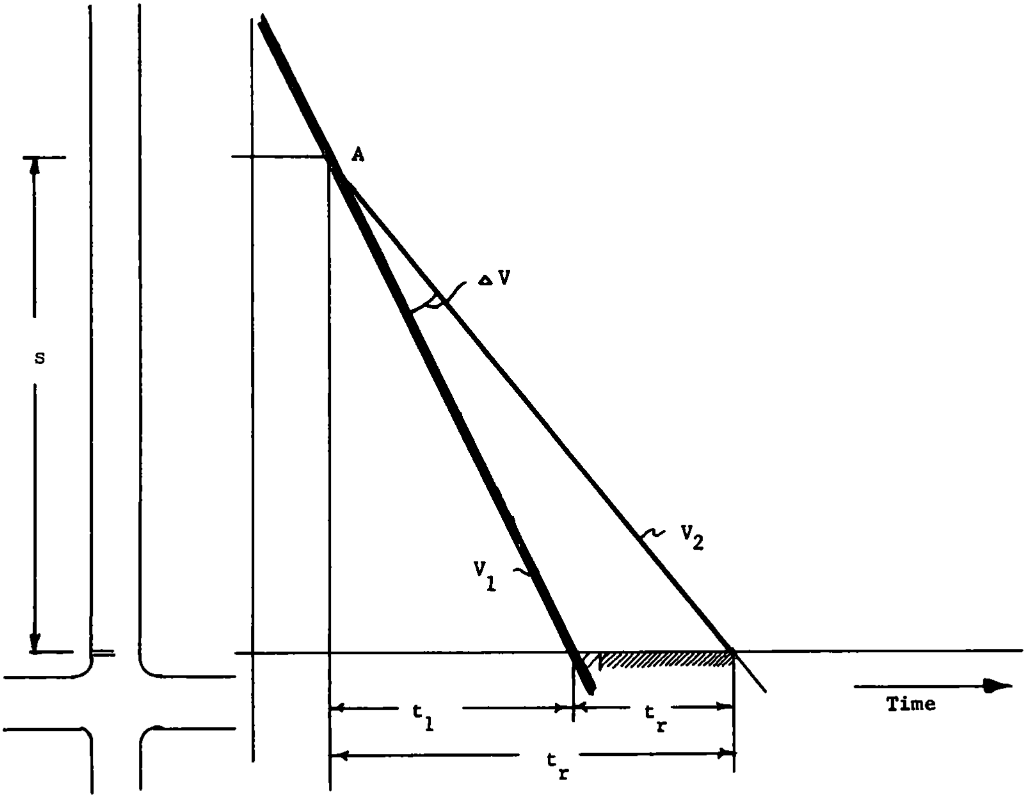
For simplicity, an intersection of only two routes is used in this discussion.

Time Gap

Because the funneling process at a signalized intersection must be repeated for every signal cycle, it is somewhat easier for computation to consider the time gap that is created between the last car of the first funnel and the first car of the following funnel. This time gap increases towards the intersection and at the intersection must be as long as the red phase of the signal. Figure 2 shows how a "time gap triangle" is formed on the time-distance diagram between the last potential vehicle traveling at free flow speed V_1, the first potential vehicle at the slow speed V_2, and the time of red and amber phase t_r.

Definitions

V_1 = free flow speed,
V_2 = slow approach speed,



$$s = 1.47\, t_r V_1 \left[\frac{V_1}{\Delta V} - 1 \right]$$

$$t_1 = \frac{s}{V_1} = 1.47\, t_r \left[\frac{V_1}{\Delta V} - 1 \right]$$

Figure 2. Development of traffic funnel.

ΔV = $V_1 - V_2$; approach speed difference,
s = approach distance, or length of traffic funnel,
t_1 = approach time, or travel time through funnel at free flow speed,
t_2 = approach time at slow approach speed, and
t_r = red phase at signal (including amber).

Computation

With these components the characteristics of and the interrelationships within the funnel can now be computed. It may be assumed that normally the free flow speed of traffic V_1, the duration of the green phase at the intersection t_r, and one of the remaining three variables are known. If the speed difference is given or assumed, approach distance, s, and approach time t_1 can be computed to define point A, which determines both the distance ahead of the intersection where the speed control signal must be installed, and the timing of that signal in relation to the timing of the intersection signal.

From the basic speed equations,

$$V_1 = \frac{s}{t_1} \text{(fps) and } V_2 = \frac{s}{t_1 + t_2} \text{ (fps)} \qquad (1)$$

$$V_1 = \frac{s}{1.47\, t_1} \text{ (mph)} \qquad V_2 = \frac{s}{1.47\,(t_1 + t_r)} \text{ (mph)} \qquad (2)$$

Solving for t_r,

$$t_r = \frac{s}{1.47\, V_2} - \frac{s}{1.47\, V_1} = \frac{s\,(V_1 - V_2)}{1.47\, V_1\, V_2} \qquad (3)$$

and substituting $\Delta V = V_1 - V_2$,

$$t_r = \frac{s}{1.47} \; \frac{\Delta V}{V_1\,(V_1 - \Delta V)}$$

Solving for s,

$$s = 1.47\, t_r\, V_1 \left(\frac{V_1}{\Delta V} - 1\right) \qquad (4)$$

$$\frac{s}{t_r} = 1.47\, V_1 \left(\frac{V_1}{\Delta V} - 1\right) \qquad (5)$$

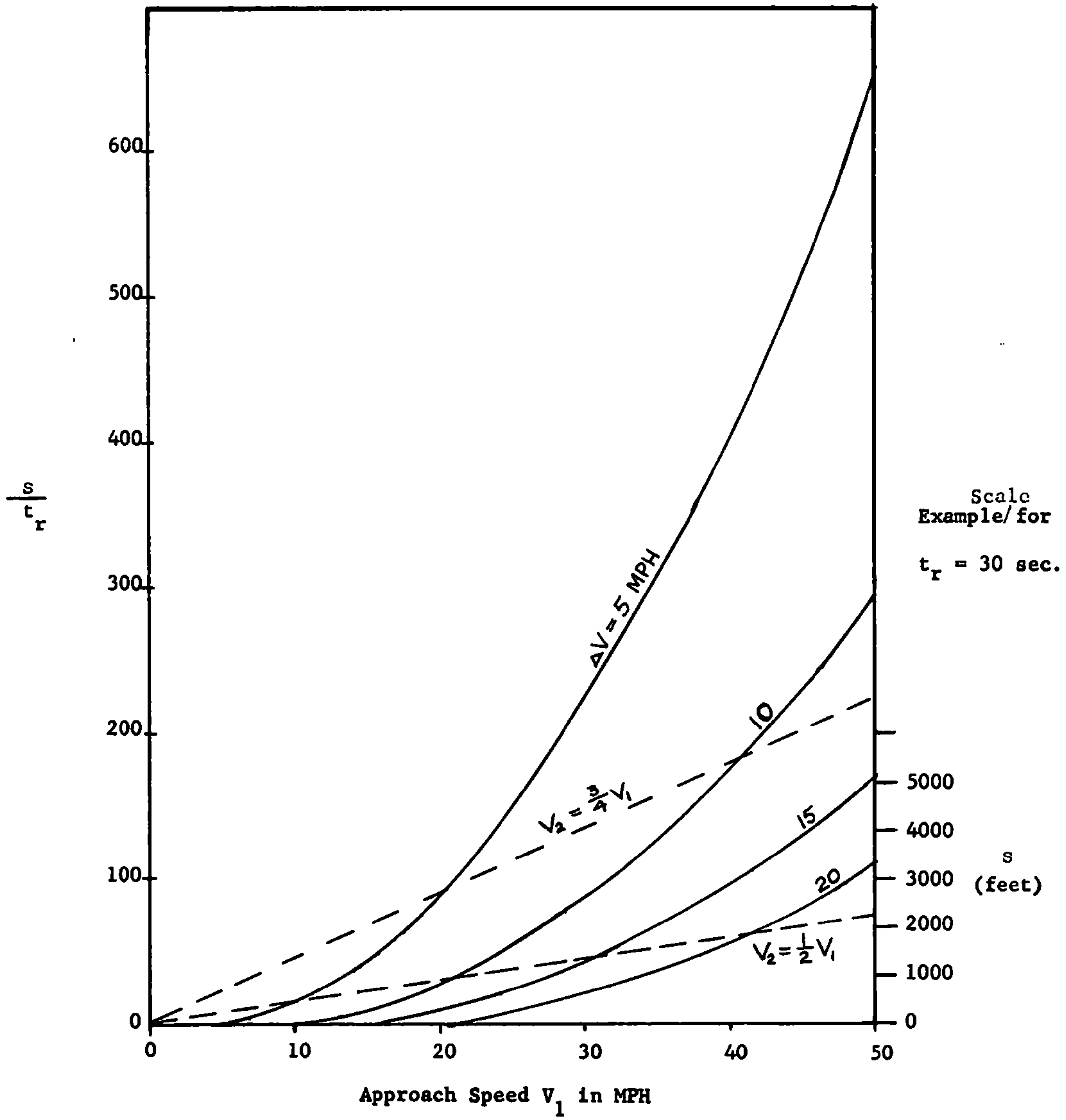
and for t_1,

$$t_1 = \frac{s}{V_1} = 1.47\, t_r \left(\frac{V_1}{\Delta V} - 1\right) \qquad (6)$$

Eq. 4 shows that the approach distance increases with the square of the free flow speed. It also increases linearly with the duration of the red phase and decreases with an increase in speed difference. As a consequence, rather long approach distances are necessary for high-speed intersections.

A chart showing the range of s as a function of free flow speed and speed difference is given in Figure 3. The vertical scale is s/t_r, which might be considered the "unit approach length." It is the length in feet required for each second of red phase duration. The use of this scale makes the data in this chart almost universally applicable. As an example of actual approach length requirements, the distance for 30-sec red phase duration is also given.

The chart shows plainly the excessive approach lengths required for high free flow speed and low speed differences. This will require careful compromising in selecting the most advantageous values for actual applications.



$\frac{s}{t_r}$ = Unit Approach Length per Second of Red Phase

s = Approach Length in Feet

Figure 3. Approach length chart.

Introduction of the speed difference as a fixed fraction (1/n) of the free flow speed would yield an equation linear in V_1. From Eq. 4 and $\Delta V = \frac{1}{n} V_1$,

$$s = 1.47\, t_r\, V_1 (n - 1) \tag{7}$$

or

$$\frac{s}{t_r} = 1.47\, V_1 (n - 1) \tag{8}$$

which is a straight line from the origin. For example, the required distance for speed reductions by one-quarter and one-half are shown dashed in the graph. Eq. 7 or 8 will not be used here, because each expresses a relative speed reduction by a given fraction and not the absolute speed reduction, which governs the action of the motorist. A speed reduction of 10 mph requires almost as much action from the motorist and takes almost as long at 50 mph as at 25 mph.

Accuracy

There are three sources of difference when these theoretical computations are compared with data from actual field installations: (a) variability of point where driver responds to the speed signal, (b) variation in pattern of actual speed change, and (c) inaccuracy of speed indication on automobile speedometers.

Location of Driver Reaction

The performance of approach speed control depends first of all, but probably not mostly, on the time and place where the driver will react to the message given him by the approach speed control signal. It will vary widely between the driver encountering this control for the first time and traveling past the signal before comprehending and reacting to its message, and the driver traveling this route slowly and responding to each sign whenever he can first read its message.

Most installations will probably be used primarily by repeating drivers using the intersection frequently. Driver familiarity with the system should therefore be assumed when trying to determine where he will react to a speed signal. Probably he will react to an unchanging speed instruction some distance before reaching the signal itself, but will react to any change in the speed signal whenever that change occurs while the signal is visible to him.

Visibility thus also is a factor. In this case, good visibility may be a disadvantage, because it spreads out the length over which drivers will see and react to the speed message given, especially when it is changing.

Further clarification of this point (as well as of those following) will have to be found by experimentation in the field.

Actual Speed Change Pattern

Speed changes are primarily reductions from free flow speed, requiring some deceleration to the suggested approach speed. Although the computations in this paper assume instantaneous speed change, the actual deceleration rates will likely be those of coasting at about 1 mph per sec. For small speed changes of 10 mph or less the effect of the gradual speed change is negligible, especially because most drivers will probably begin the speed change ahead of the signal. But for larger speed changes the effect should be considered for each application. It will require larger speed differences because the gradual change delays the attainment of the new speed.

Speedometer Accuracy

Most automobile speedometers give speed indications 5 to 10 percent higher than the actual speed. This factor should be considered in designing a traffic funnel application. One way is to set the speed indications at the entrances to the traffic funnels 5 to 10 percent higher than actually desired. Particularly the last vehicle approaching at free flow speed would (if its speedometer indicated too high a speed) travel too slow to reach the intersection during green time. For these last vehicles an overcorrection might even be necessary.

It will be necessary to check field applications for possible variations from the theoretical computations and to make any adjustments that might become necessary. Motorists too will adjust their driving habits to fit properly into the traffic funnel, although this correction will never be as efficient as the appropriate correction in the system design.

GENERAL APPLICATIONS

There are essentially two applications of the principle of controlling the speed of approach to intersection traffic control: (a) the complete traffic funnel, and (b) the partial traffic funnel.

The complete traffic funnel can be used on isolated intersections where the rather long approach distances can be accommodated. It can also be used on entrances into arterial roads with progressive signal systems.

The partial traffic funnel is used in the form of a "traffic pacer" to give speed recommendations on comparatively short roadway sections between signalized intersections. It can be used to guide the motorist through any progressive signal system, but is especially necessary in systems in which the speed of progression changes. It can also be used to redistribute the traffic flow bands between signal systems of varying cycle length.

APPLICATION OF APPROACH SPEED SIGN

An extremely inexpensive application of the principle of controlling the speed of approach by signs can be used on many intersections where the conditions are favorable.

Description of the Device

Figure 4 shows that the recommended approach speed is different for different phases of the signal indication and any given instruction for approach speed must be matched to the duration of the phase on the signal ahead. Furthermore, it is necessary that the approaching driver sees the signal and its light indication from the location of the

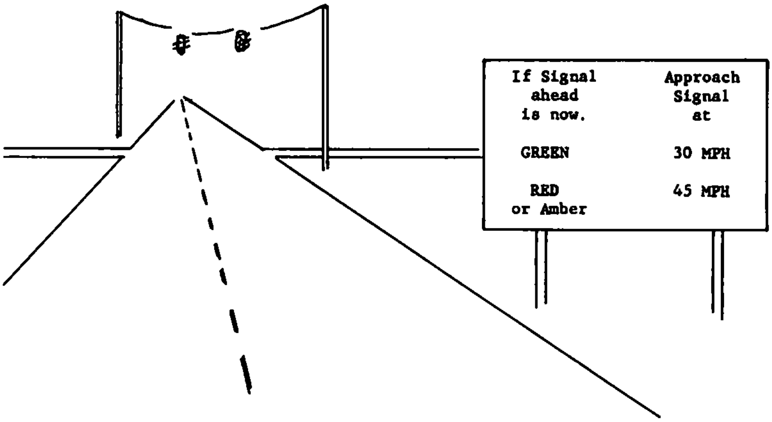


Figure 4. Principle of approach speed sign.

approach speed sign. The device will work on fixed-time signals, with the green phase either longer or not much shorter than the red phase. It is, of course, not necessary to apply approach speed control to all approaches of an intersection.

Evaluation of the Control of Speed of Approach with Signs

The primary advantage of controlling speed of approach with signs only is the very low cost. Controlling approach speed by speed signals costs as much as or more than the original signal installation. In these circumstances, exploring the possibility of using a sign to control speed of approach is certainly justified.

Because controlling the speed of approach never increases the free approach speed nor overrides the signal indication, the use of an approach speed sign should not create a worse situation than exists at the signal without such a sign. Many drivers already attempt to adjust their speed when approaching a signal, but are often thwarted by lack of clues. A sign indicating speed of approach could be a boon. Any such operational advantage will justify the small expenditure for a sign advising speed of approach.

If some drivers do not comprehend the message at first passage, no harm is done. But those who pass through that intersection repeatedly will quickly adapt to the system and even make their own adjustments for speedometer inaccuracy or other individual peculiarities.

Approach speed control signs can be used with considerable savings at those approaches to an intersection, which have the required visibility. At other approaches, speed signal systems can be used for controlling speed of approach. If visibility of the signal indication is not always assured, the period of effectiveness of the sign will be reduced, but no harm will be done, and the gains will still be high during the time when the sign is useful.

Computation for Approach Speed Signs

The basic relationships discussed in connection with Figure 2 hold here with the following modifications. Because the timing of the approach speed indication must be identical with the signal cycle timing, the approach time t_1 becomes equal to the duration of the green phase t_g (or the entire cycle duration t_c). The given values in this case are the times of the signal phases and the free approach speed. The needed values are s (the approach distance), indicating how far in advance of the intersection the approach speed sign must be located, and V_2 (the slow approach speed).

Similar to the previous computations,

$$V_1 = \frac{s}{1.47\, t_g} \qquad V_2 = \frac{s}{1.47\,(t_g + t_r)} = \frac{s}{1.47\, t_c} \tag{9}$$

giving

$$V_2 = \frac{t_g}{t_c}\, V_1 \sim \tfrac{1}{2}\, V_1 \tag{10}$$

and

$$s = 1.47\, V_1\, t_g \tag{11}$$

A time-gap triangle for this type of control of the speed of approach is shown in Figure 5. The slow approach speed is related to the free approach speed as the green phase is related to the cycle length. This ratio would in the average be about one-half, thus requiring a speed reduction for the slow approach speed to one-half the free approach speed. This is a rather drastic speed reduction. Longer approach distances, with an approach time equal to an entire cycle length (as shown in Fig. 6), will permit less marked reductions. Eqs. 10 and 11 will then be written:

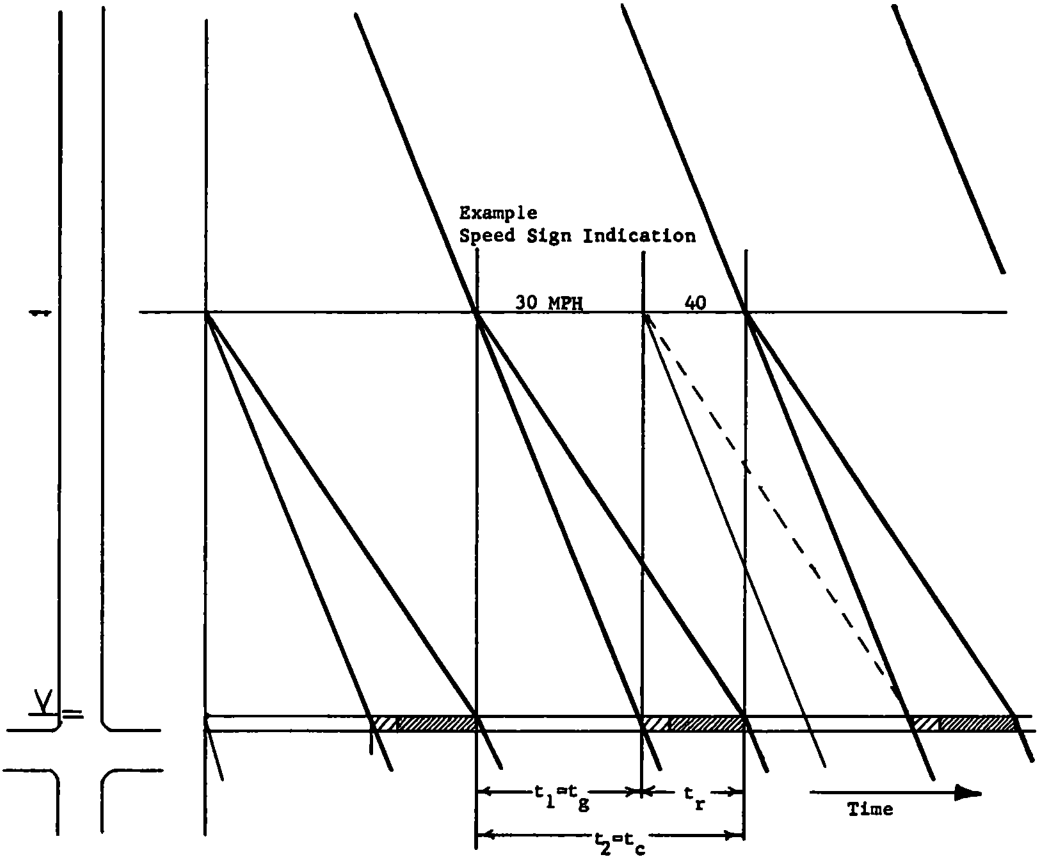
$$V_1 = \frac{s}{1.47\,t_c} \qquad V_2 = \frac{s}{1.47\,(t_c + t_r)} \tag{12}$$

and

$$V_2 = \frac{t_c}{t_c + t_r}\,V_1 \sim {}^2\!/_3\,V_1 \tag{13}$$

$$s = 1.47\,V_1\,t_c \tag{14}$$

Although the approach distance now is about twice as long as in the previous case, in some cases a second sign controlling the speed of approach can be installed closer

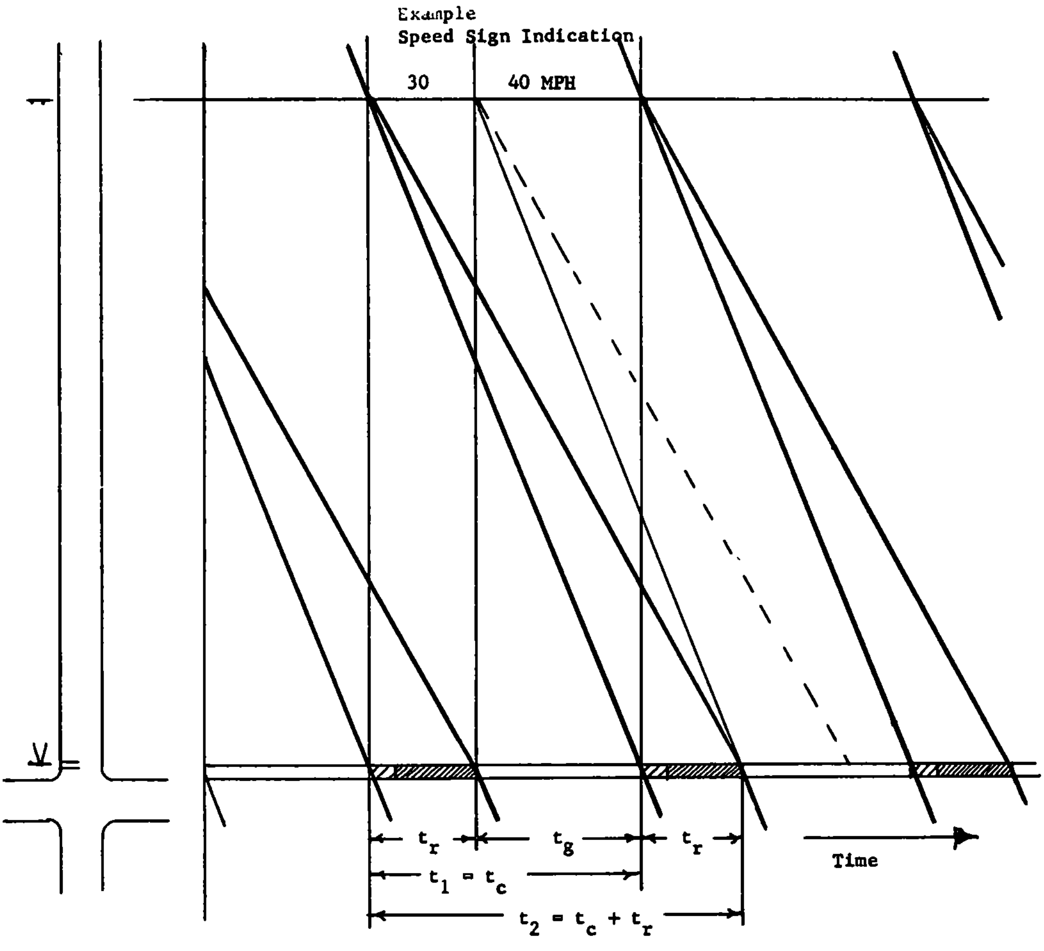


$t_1 = t_g$ = Green Signal Phase

$t_2 = t_c$ = Signal Cycle Time

$V_2 = \frac{t_g}{t_c}\,V_1$

Figure 5. Approach speed sign with one-phase advance.



$t_1 = t_c$ = Signal Cycle Time

$t_2 = t_c + t_r$

$$V_2 = \frac{t_c}{t_c + t_r} V_1$$

Figure 6. Approach speed sign with one-cycle advance.

to the intersection, superimposing a funnel based on the one-phase advance. Superposition of those two funnels might improve approach speed control and assure better performance on these long approaches.

For instance, a free approach speed of 50 mph and a green phase of 30 sec in a cycle of 60 sec would require that the approach distance in the first case be 2,200 ft, with a required speed reduction for the slow approach speed to ½ of the free approach speed. In the second case, the approach distance would be 4,400 ft and the slow approach speed equal to ⅔ of the free approach speed. Of course, this example is given for rather high-speed intersections, where good approach visibility is often available.

Approach Speed Sign Application

The three causes for discrepancy between theoretical computations and the facts in actual applications of signals controlling speed of approach hold equally for the approach speed sign. The rather large speed reduction required with the use of a sign increases the difference between an assumed instantaneous speed change and the actual gradual deceleration on the highway, thus increasing this source of inaccuracy.

CONCLUSION

For the motorist, great potential benefits can be gained by controlling the speed of approach at intersections. The principles and theories outlined here will help in determining the best application of this control method for each practical case.

The low cost of signs for controlling speed of approach should encourage experimentation with this method.