Effects of Actuated Signal Settings and Detector Placement on Vehicle Delay

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In this paper, the EVIPAS simulation and optimization model was used to analyze vehicle-actuated traffic signals. The variables studied were detector type and placement and the settings were for minimum green and vehicle extension. The evaluation criterion was minimum average vehicle delay. The study shows that the optimum design of a vehicle-actuated signal is specific for some variables but is relatively unaffected by others. The design is critical only for high traffic volumes. At low volumes, vehicle delay is relatively unaffected by the design parameters studied in this paper. The most critical variable is vehicle extension, particularly for passage detectors, where it should be at least 4.0 seconds regardless of detector placement and approach speed. For a presence detector, a short vehicle extension is recommended provided the detector is at least 60 ft in length. A length of 80 ft is preferred. For minimum green, the conventional design practice gives the best delay outputs.

It is generally accepted that a fully actuated traffic signal is almost always the most efficient form of signal control for an isolated intersection. The successful design of an actuated signal requires the specification of several critical parameters, including the type and placement of the detectors and the settings for the timing variables. Primarily, these factors are derived from considerations of driver behavior, vehicle characteristics, and safety. Within these constraints, however, there may be sufficient flexibility to allow traffic delay and associated vehicle operating costs to be considered.

This paper analyzes traffic delay at a fully actuated traffic signal as it relates to detector type and placement, and the settings for minimum green and vehicle extension. The analyses use the recently developed EVIPAS (*1*,*2*) simulation and optimization model for a vehicle-actuated traffic signal.

BACKGROUND

The design parameters for vehicle-actuated traffic signals have been extensively documented in many reports and publications. Summaries of these are available in the *Traffic Control Systems Handbook* (*3*), *NCHRP Report 233* (*4*), and the *Manual of Traffic Signal Design* (*5*).

The most commonly used detection arrangements are single passage and presence detectors. More sophisticated multiple detector arrangements for high-speed approaches are not the focus of this paper.

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Presence detectors usually range from 40 to 120 ft in length and are generally restricted to approach speeds of less than 30 mph. The minimum green is set from 0.0 to 4.0 seconds, and the vehicle extension is set from 0.0 to 3.0 seconds. Some literature provides a particular recommended minimum vehicle extension of 1.5 seconds, which ensures that drivers do not face an unexpected yellow when discharging.

Passage detector location is a function of the approach speed and the boundaries of the dilemma zone. Recommended distances range from 75 ft upward. The realized minimum green is set for the time required to evacuate the waiting vehicles within the detector distance. Generally this time is in the range of 12 to 14 seconds. The vehicle extension is the time for the vehicle to travel the distance from detector through the intersection. It can be a function of detector placement or can be set at a fixed value with detector placement being adjusted accordingly. A value of 3.5 seconds is frequently recommended.

The impact of these design values on signal performance and vehicle delay has been summarized in NCHRP 233 (*4*). Many of these results are based on somewhat simplified simulations and analytical procedures. Analyses of presence detectors show that a 60-ft length gives minimum delay, whereas for passage detectors a setback of 150 ft gives minimum delay.

The major timing variable related to vehicle delay is vehicle extension. For passage detectors, vehicle delay is shown to increase for very short or very long vehicle extensions. Generally, it is recommended that vehicle extensions should be kept as short as possible to give "snappy" signal operation and this recommendation is repeated in other literature. NCHRP 233 (*4*) point outs, however, the potential difficulty with early green termination because of variable queue discharge headways, the effects of which were not analyzed in that publication.

STUDY METHODOLOGY

The EVIPAS vehicle-actuated traffic signal model provides a mechanism for analyzing all of the factors described above in some detail. The effect on vehicle delay of variations in these parameters was studied for a variety of situations.

The EVIPAS model was field tested at ten vehicle-actuated traffic signals ranging from two to eight phases. Comparisons of stopped delay by approach lane were within 15 percent, which is within the statistical variation shown by traffic flow. The computer model also reproduced within 5 percent, the field observations of average cycle length and average phase length.

To keep the analyses fairly simple, only two phase signals on intersections with one- or two-lane approaches were studied. With one exception, only single detectors were considered.

Traffic volumes were varied from 350 vehicles per lane per approach per hour to 750 vehicles per lane per approach per hour. Passage detectors were located from 50 to 250 ft, and presence detectors of 40 to 120 ft in length were used. Approach speeds of the traffic ranged from 25 to 55 mph.

The minimum green values ranged from 0.0 to 5.0 seconds for presence detectors and from 5.0 to 20.0 seconds for passage detectors. The vehicle extensions ranged from 0.0 to 5.0 seconds for presence detectors and from 1.5 to 9.0 seconds for passage detectors. To minimize random variations, each simulation run simulated 4 hours of real time.

Whenever minimum green is discussed, it is the realized minimum green, i.e., the set value plus one vehicle extension for those controllers that operate in this mode.

STUDY RESULTS

Traffic Volume

The simulation results consistently showed that the design parameters are much more important at high volumes than at medium to low volumes. These results indicate that a signal designed to handle the peak period will be satisfactory for the off-peak periods. High volumes were considered to be 750 vehicles per hour per lane per phase, whereas low volumes were 350 vehicles per hour per lane per phase.

These characteristics regarding volume, which are detailed further below, indicate that as an intersection approaches capacity, the design of the actuated signal is critical. Slight design errors can lead to significant increases in delay and operating cost. At medium to low volumes, however, a considerable design variation can be tolerated and even a poorly designed signal can operate well.

Presence Detector Length

Provided that the timing variables were set correctly, the length of a presence detector can vary from 60 to 100 ft with little effect on delay at high volumes and low to moderate approach speeds. Figure 1 is an example of the variation of delay with detector length. At lengths below 60 ft, delay starts to increase significantly. This result is similar to that in NCHRP 233 (*4*) except that it specifically shows 60 ft to be the most efficient, whereas in this study 80 ft was found to be slightly more effective.

Passage Detector Location

Figure 2 shows the variation of delay with detector location. In the range of 100 to 200 ft, there is little effect on delay,

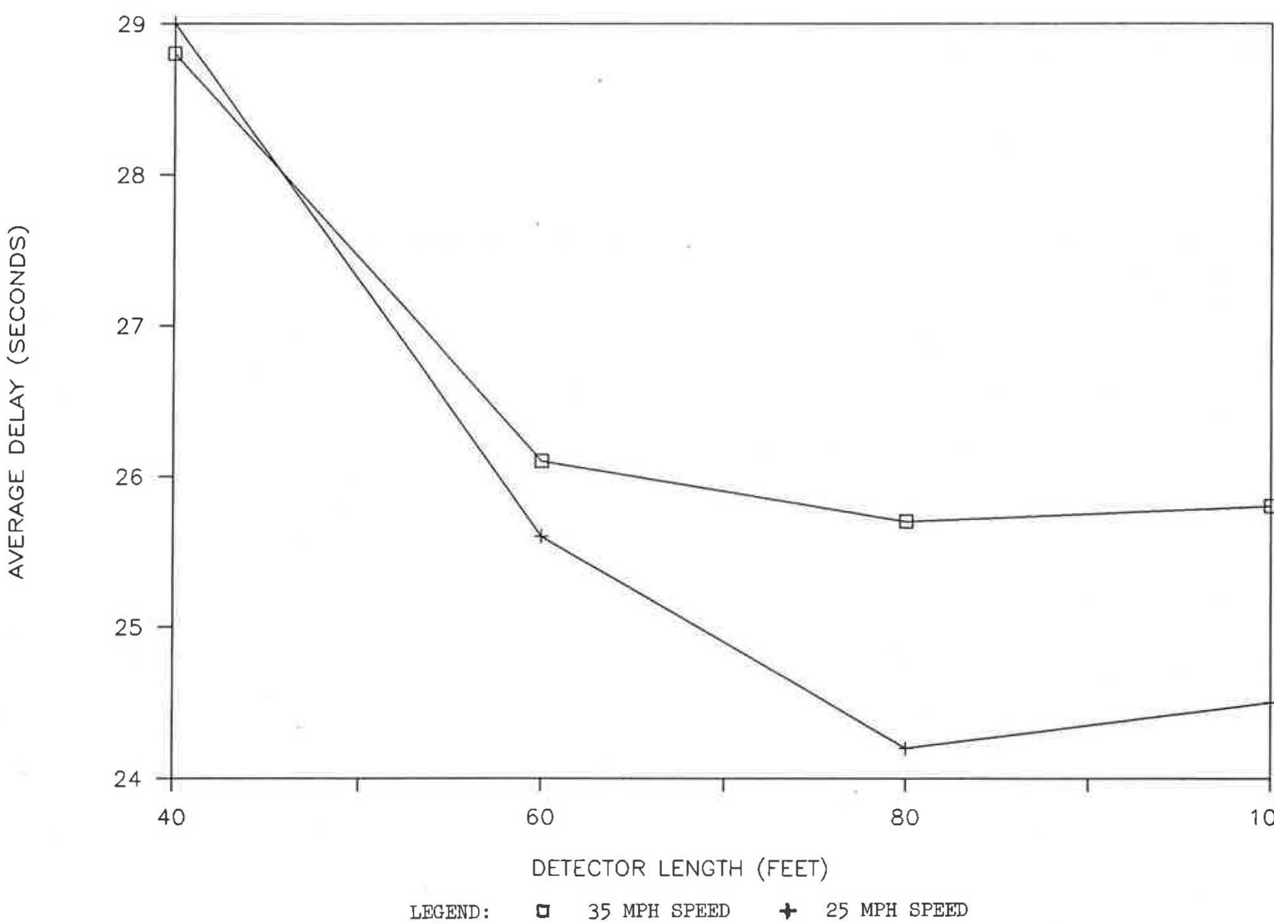

FIGURE 1 Presence detector length.

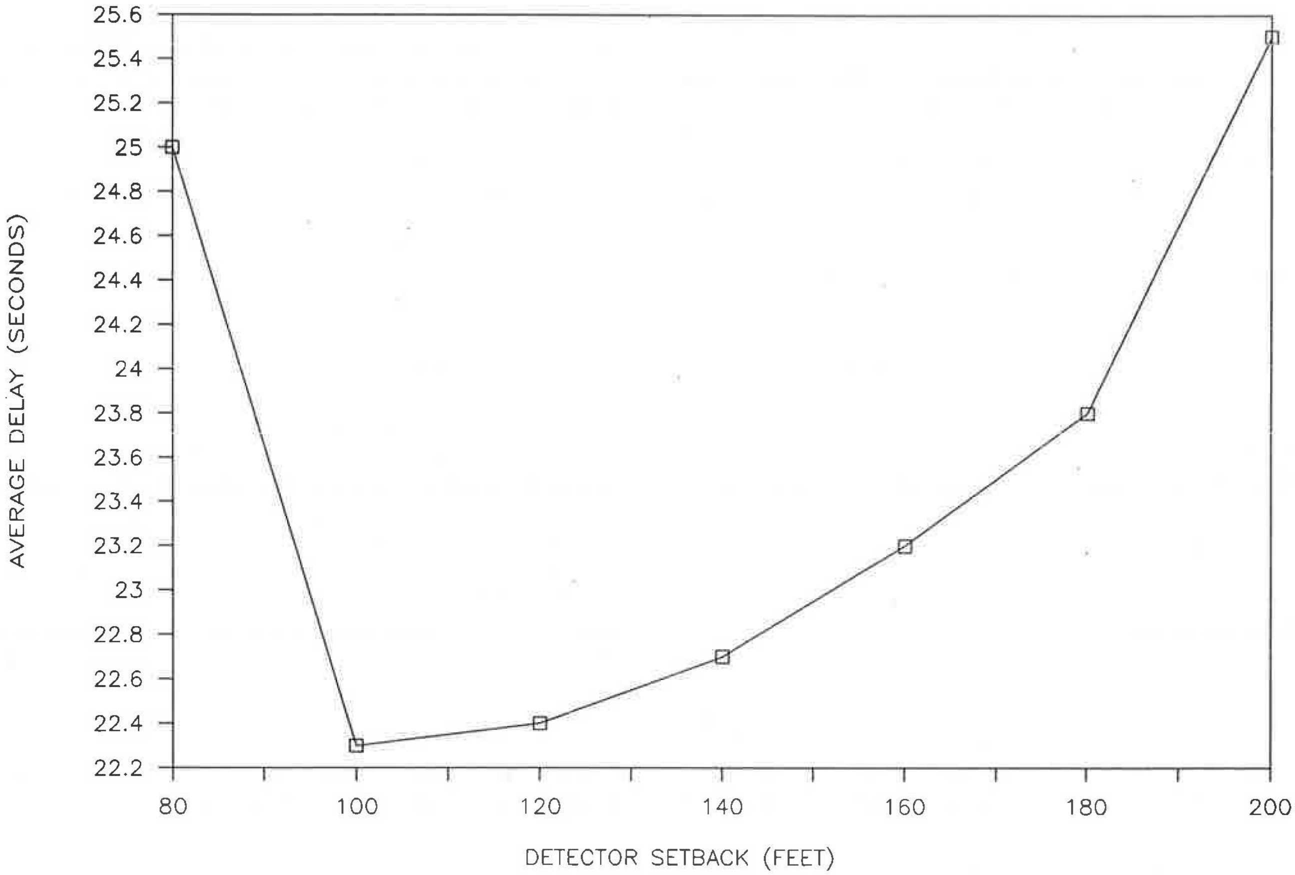

FIGURE 2 Passage detector setback.

provided the timing settings are optimized. Above 200 ft, the delay increases partly because the required minimum greens become large. Below 100 ft, the delay also starts to increase more rapidly. These results are somewhat more flexible than those from NCHRP 233 (*4*), in which a setback of 150 ft is specifically recommended for greatest efficiency.

The analysis of approach speed showed that detector location is not affected by this parameter. This conclusion, however, applies only to the minimum delay criteria and does not include driver behavior or safety.

Vehicle Extension: Presence Detectors

The study clearly shows that vehicle extension is the most critical variable for minimizing delay. For detectors greater than 60 ft in length, a vehicle extension of 0.0 seconds gives minimum delay, provided the minimum green is set correctly. Figure 3 shows the variation in delay with vehicle extension. For a 40-ft detector, which is not recommended, a vehicle extension of 1.5 to 2.0 seconds is required. Trucks in the traffic stream will modify these results by increasing the required vehicle extension.

Studies of delay for moderate and low traffic volumes indicated that efficiency is relatively insensitive to vehicle extension.

Vehicle Extension: Passage Detectors

The results of these studies of vehicle extension contradict to some extent the desires expressed in the literature for short snappy signal phases through short vehicle extensions. This difference is because the EVIPAS program has variable queue discharge headways and therefore models the penalty associated with the early green cutoff within a discharging queue.

The general relationship is illustrated in Figure 4. This figure shows delay as a function of vehicle extension for various volumes of passenger cars only. The pattern shows an optimum vehicle extension of 4.0 seconds. As the vehicle extensions increase, the increase in delay is moderate and the penalty for higher vehicle extensions is not severe even for high volumes. Below the optimum value, however, the increase in delay is sharp and rapidly becomes infinite. The penalty for a short vehicle extension is severe. Thus, the vehicle extension should always be a little on the high side rather than a little on the low side. This pattern of a delay curve that decreases rapidly and then increases slowly is typical of the relationship regardless of detector location, vehicle approach speed, or minimum green.

Figure 5 indicates an analysis in which two passage detectors are located in the lane at 75 and 150 ft. Although this arrangement should indicate a vehicle extension only half that of the

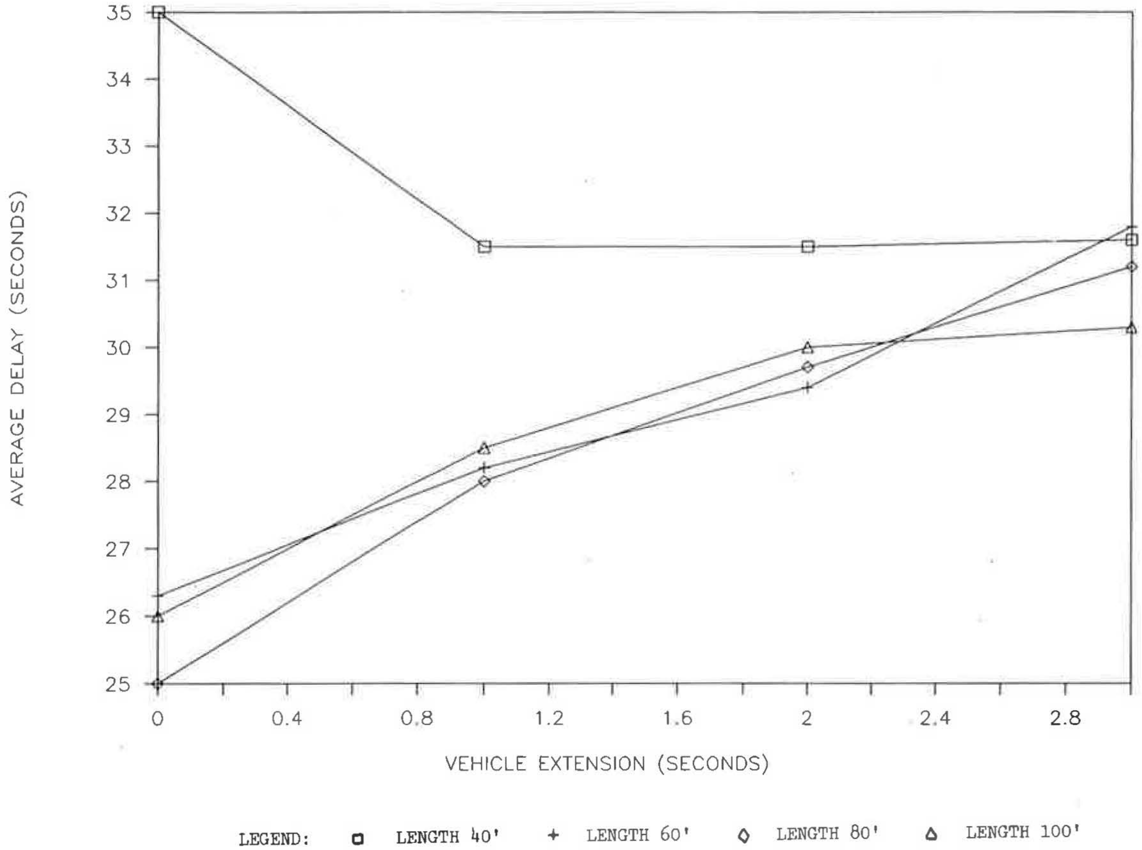

FIGURE 3 Presence detector extension.

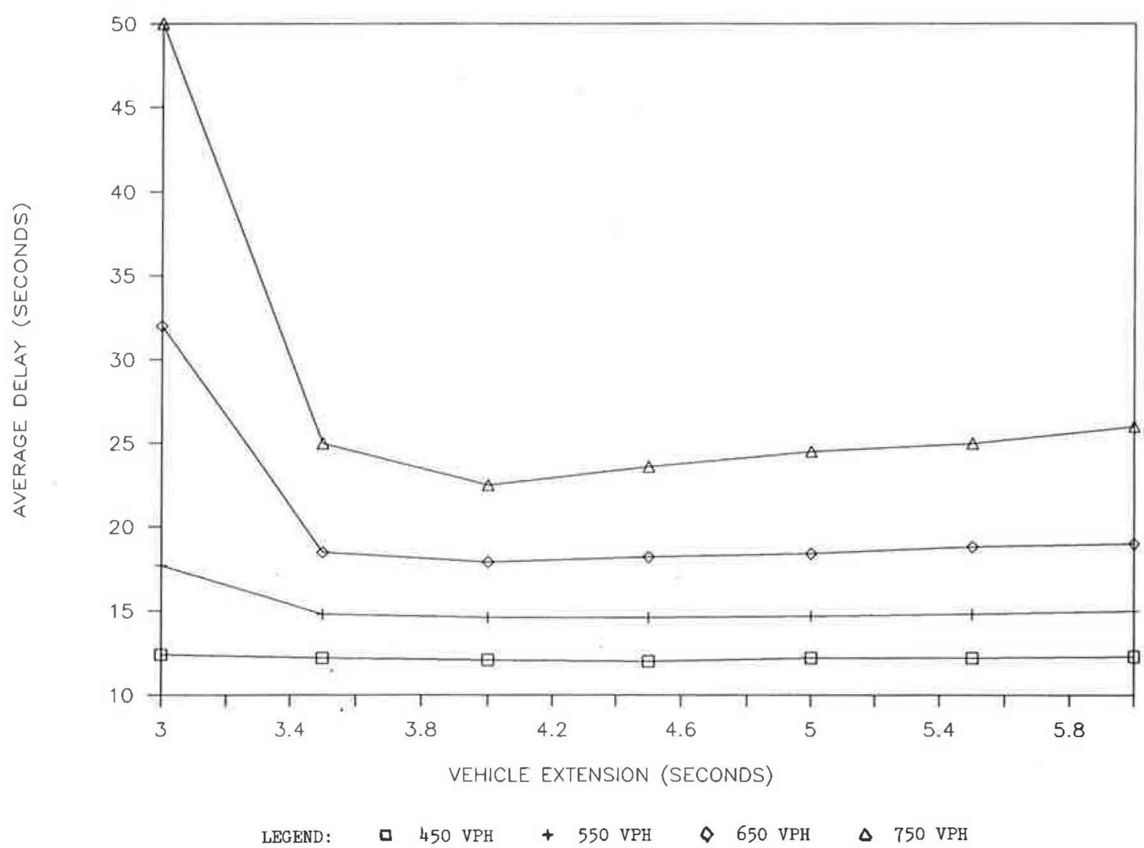

FIGURE 4 Vehicle extension and volume.

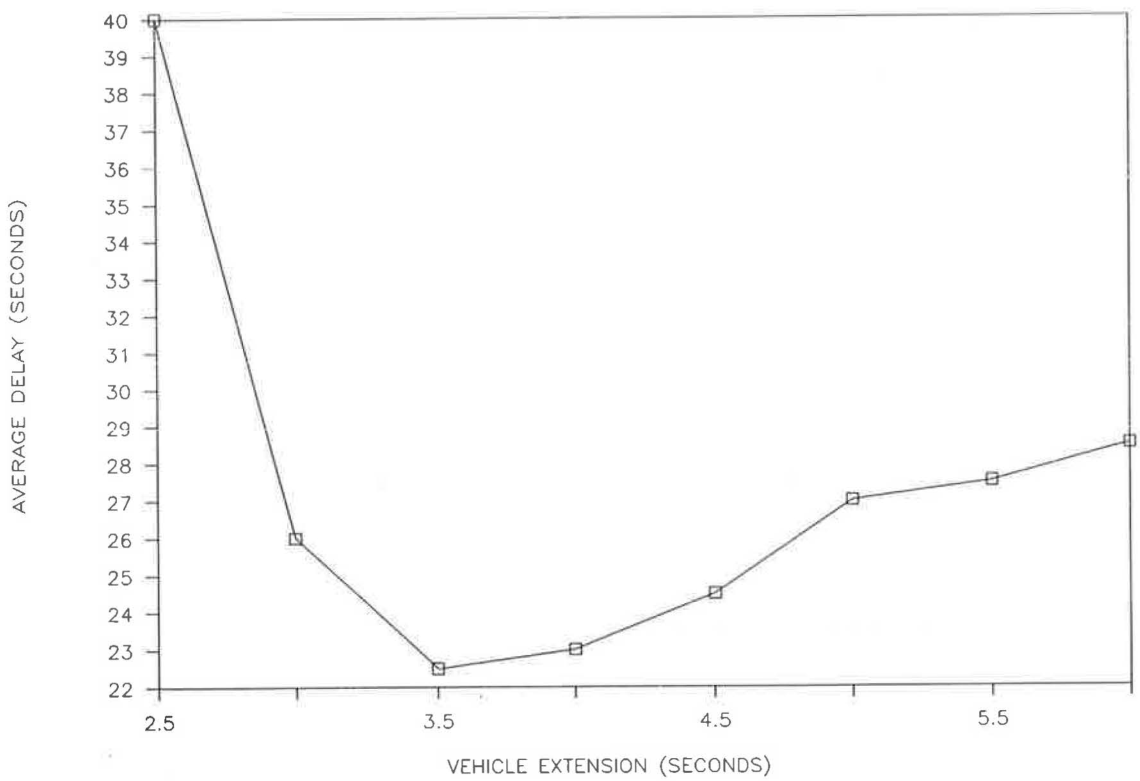

FIGURE 5 Two passage detectors.

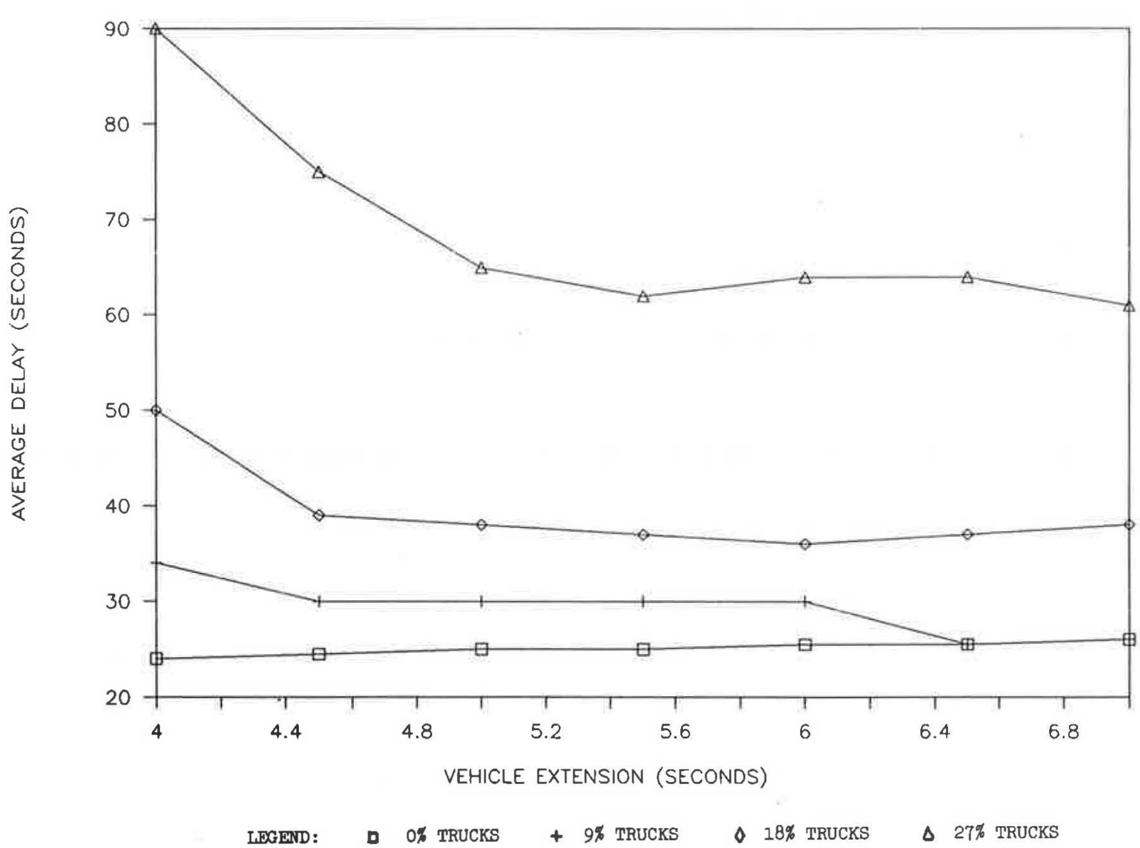

FIGURE 6 Effects of trucks.

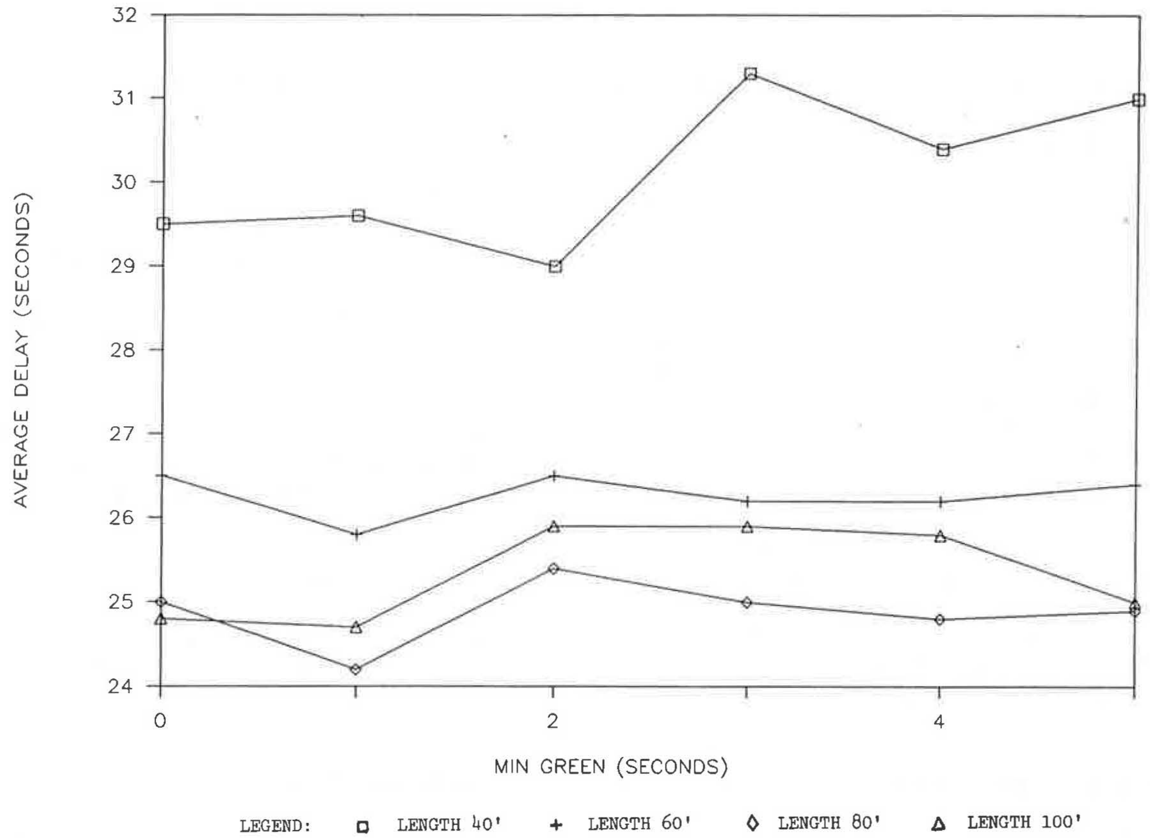

FIGURE 7 Presence detector, minimum green.

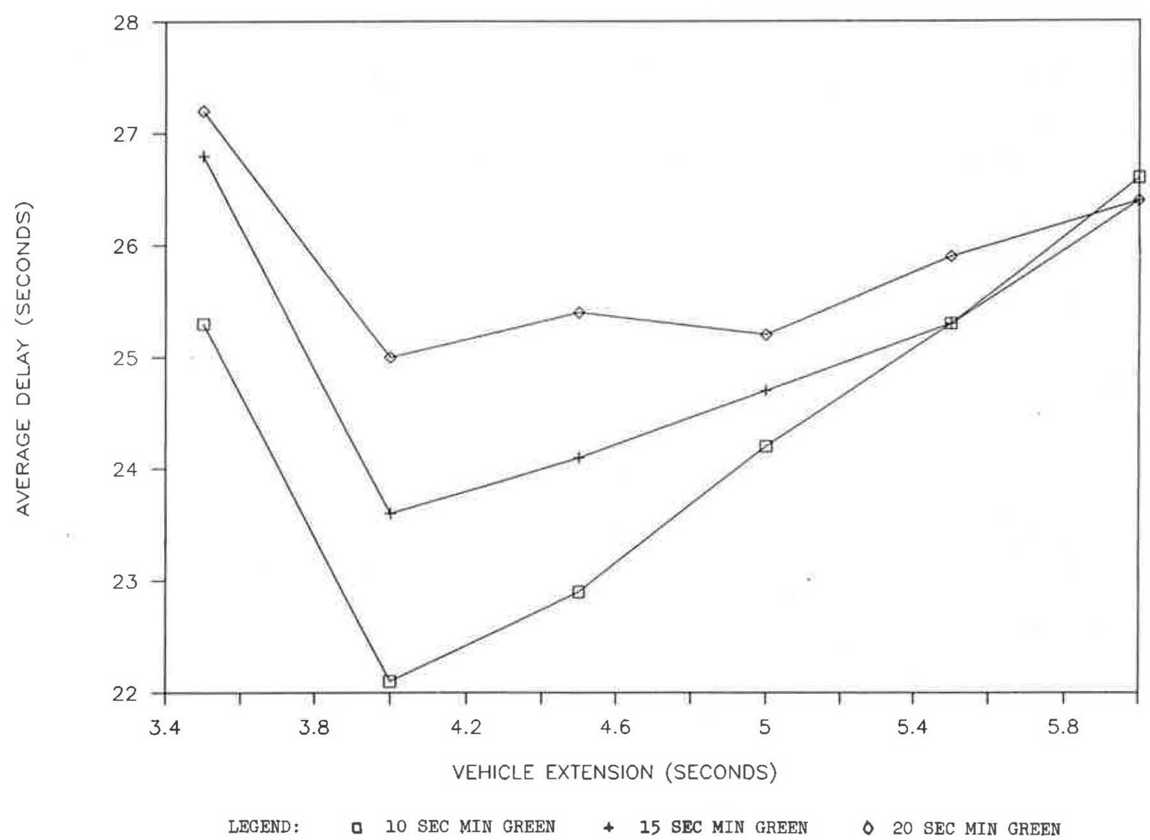

FIGURE 8 Passage detector, minimum green.

value for a single detector at 150 ft, the output is almost the same. An optimum vehicle extension of 3.5 seconds prevails with a similar delay curve structure. There is a severe penalty for short vehicle extensions. All of these results are critical only for high volumes. For lower traffic flows the vehicle extension, as with other design parameters, is relatively insensitive.

These general results for vehicle extension suggest that the efficiency of a vehicle-actuated signal is dominated by the distribution of arrival headways and the distribution of queue discharge headways. The problem of variable queue discharge headways grows when trucks are present because of their lower acceleration and longer vehicle length. The best vehicle extension should, therefore, be higher for higher truck percentages. This relationship is illustrated in Figure 6 in which the optimum vehicle extension increases as the trucks increase. Regardless of detector location, vehicle extensions of as much as 6.0 seconds may be needed for locations with heavy truck traffic.

The recommendation found in some literature to set the vehicle extension at 3.5 seconds and then to design the other parameters to this is somewhat low for delay optimization.

Minimum Green: Presence Detectors

Figure 7 shows how delay varies with minimum green. This variable is not very sensitive, although it appears that under most circumstances a minimum green of 1.0 to 3.0 seconds is appropriate.

Minimum Green: Passage Detectors

The minimum green usually is set to clear the vehicles waiting within the detectors, and for normal detector locations this setting seems to give satisfactory efficiency. This parameter does not have a significant effect on delay, although short minimums do lead to higher delays. Generally, in the recommended range for detector location of 100 to 200 ft, a normal minimum green calculation based on the detector distance gives a satisfactory result. Figure 8 shows the variation of delay with minimum green and vehicle extension.

CONCLUSIONS

The optimum design of a vehicle-actuated signal for the objective of minimizing vehicle delay is specific for some parameters but allows considerable flexibility for others.

The design and timing of the signal are critical only for high traffic flows, whereas considerable flexibility exists for low to moderate volumes. A signal designed and set to minimize delay for the peak hours, therefore, will be close to the optimum for off-peak periods. At a signal that has only moderate traffic flows (level of service B or better), the traffic delays will not be seriously affected by any reasonable detector locations or timing. In these circumstances the design criteria should be safety and driver characteristics.

For heavy traffic flows, the vehicle extension is the most critical variable affecting delay. For passage detectors the vehicle extension should be at least 4.0 seconds, but if trucks are present up to 6.0 seconds may be needed. Any variation on the low side will lead to rapidly increasing delays, whereas the penalty is less severe on the high side. For presence detectors, the vehicle extension should be as short as possible provided the detector is at least 60 ft long and there are few trucks.

The minimum green should be in the range of 1.0 to 3.0 seconds for presence detectors. For passage detectors, current design practice is satisfactory. Detector location does not have a significant effect on delay provided the locations are within 60 to 100 ft for presence detectors and 100 to 200 ft for passage detectors.

The location of detectors and the timing of key variables can be carried out with full considerations of traffic safety and driver characteristics and behavior. Within this framework there is still enough flexibility to achieve maximum operating efficiency.

ACKNOWLEDGMENTS

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