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Use of EC-DC Detector for Signalization of High-Speed Intersections

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This paper describes a new detector-controller configuration intended to minimize the dilemma-zone problem at signalized intersections on high-speed roads. Included are a complete functional and electrical description of the design, the findings of a field test, and a comparison with two existing designs. The new design uses a basic, actuated, digital controller operated in the nonlocking mode. An approach that has a design speed of 89 km/h (55 mph) has an upstream detection loop located 117 m (384 ft) back from the intersection and a middle loop 77 m (254 ft) back. A loop at the stopline is 8 m (25 ft) in length and is connected to a novel extended-call—delayed-call (EC-DC) detector that is able to change from an EC model to a DC unit at the strategic moment during the green interval. In effect, the change disconnects the stopline loop, leaving the other two loops to control the extension and termination of the green. The controller and detectors are off-the-shelf units that require no internal modification. The only special-logic items are two relays mounted on the back panel. The design does not pose a maintenance problem. A test installation in Georgia significantly reduced conflicts associated with the dilemma zone. A comparison with two existing designs shows that the EC-DC configuration costs somewhat more than the EC design but is superior in three operational categories. It is less expensive than the density design and is superior in four operational aspects.

Drivers face a "dilemma zone" or "zone of indecision" at signalized intersections where approach speeds are 56 km/h (35 mph) or higher. If the yellow comes on while the driver is in this zone, an abrupt stop may produce a rear-end collision. The decision to go through, on the red, may produce a right-angle accident. The traffic engineer can install a vehicle-actuated signal controller and appropriate detection in order to attempt to minimize the untimely display of yellow. This paper describes a new detector-controller design to meet this objective.

The new design was made possible by the following three recent breakthroughs in driver-behavior research and hardware technology:

1. The boundaries of the dilemma zones for various approach speeds are now known with reasonable accuracy.
2. Digital controllers permit the unit extension to be tailored to tenths of a second.
3. Loop detectors are now available off the shelf that have both extended-call (EC) and delayed-call (DC) features as standard equipment.

A number of advanced detector-controller configurations for isolated intersections on high-speed roads have been reported in the literature. Most of these were summarized in a design manual published by the Federal Highway Administration in 1977 (1). Concurrently, Zegeer (2) reported excellent results in Kentucky with a particular configuration known as a green-extension system. In 1978, Parsonson (3) discussed the state of the art and concluded that there appears to be an unmet need for a design for high-speed roads that has the following characteristics: (a) loop-occupancy features; (b) basic, actuated controller with nonlocking detection memory; (c) EC detection; (d) short allowable gap, primarily to prevent frequent "max-out" (which may well show a yellow to a vehicle in the dilemma zone); and (e) dilemma-zone protection over a wide range of speeds. Parsonson then proposed a new detector-controller configuration to meet these objectives and analyzed it on the basis of seven criteria set forth for evaluating any proposed design. In response to a discussion of the paper by Clark (4), Parsonson modified the design in his closure (3, p. 42) and stated that his proposal would soon be field tested in Gwinnett County, Georgia.

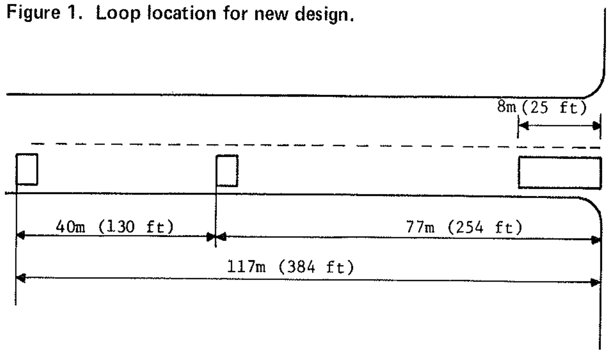
The present paper provides a complete functional and electrical description of the modified design, reports the findings of the Gwinnett field test, and compares the new configuration with the most commonly used existing designs.

FUNCTIONAL OPERATION

The design uses a basic, actuated controller operated in the nonlocking detection-memory mode. Figure 1 shows the detection loops located for approach speeds of up to 89 km/h (55 mph). The upstream detector is located 117 m (384 ft) from the intersection. The table below [from Zeeger (2)] shows that 90 percent of drivers approaching at 89 km/h will decide to stop if the yellow begins just as they reach this point (1 km/h = 0.6 mph; 1 m = 3.3 ft):

Approach Speed (km/h)	Distance from Intersection (m)	
	Probability of Stopping	
	10 Percent	90 Percent
56	31	77
64	37	86
72	46	99
80	52	107
89	71	117

Figure 1. Loop location for new design.



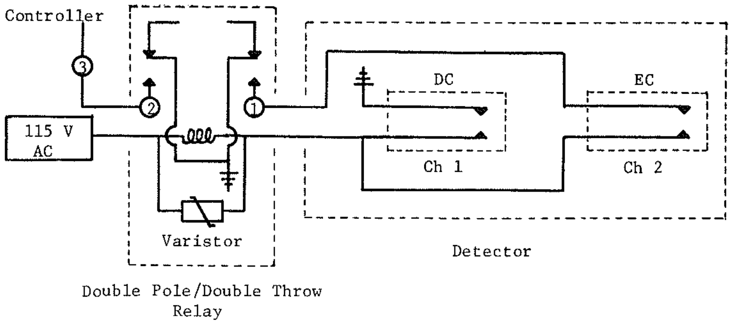
The middle loop is placed 77 m (254 ft) from the intersection. As the table indicates, this is the upstream boundary of the dilemma zone for vehicles approaching at 56 km/h (35 mph).

Both of these loops are small, perhaps 2x2 m (6x6 ft). Their "amplifiers" are of normal design (not EC). They may produce a short pulse when the vehicle enters the loops, or they may be operated in the presence mode.

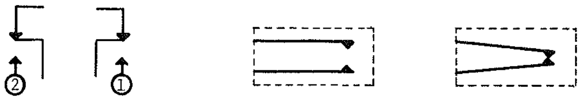
The loop at the stopline is 8 m (25 ft) in length, which is intended to be long enough to bridge the gap between waiting vehicles, thereby assuring a call from a queue. The detector is a novel EC-DC unit that is able to change from an EC model to a DC unit at the strategic moment during the green interval. Each mode of operation has its own adjustable timer.

A description of the operation of the configuration begins with a start of green. As the waiting vehicles discharge over the stopline loop, its EC-DC detector functions as an EC model. (It has a carry-over output, meaning that it holds or "stretches" the call of a vehicle for a period of seconds that has been set on an adjustable timer.) The controller, meanwhile, is timing a minimum green that Clark (4) has found may need to be as long as 12-18 s in order to meet the expectations of truck drivers. On expiration of the minimum green, probably only five or six vehicles have discharged and there is still no motion over either of the upstream loops. A "stretch" setting of approximately 2 s on the EC-DC detector is intended to produce an unbroken actuation (and an extension of the green) until motion is assured over the middle loop. By this time, discharging traffic is up to speed. A 2-s gap between vehicles appears. The EC detector at the stopline in effect "gaps out" and becomes a DC unit with approxi-

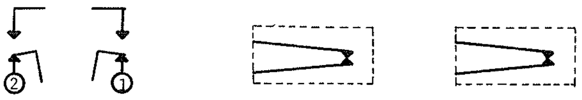
Figure 2. Electrical operation of EC-DC detection at stopline.



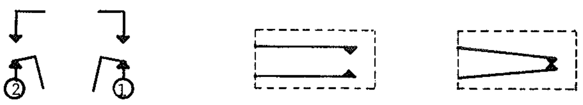
(a) NO DETECTOR OUTPUT IN ABSENCE OF ANY VEHICLES



(b) DC CHANNEL BEGINS TIMING AS FIRST CAR ARRIVES ON RED



(c) DC CHANNEL OUTPUTS FROM WAITING CARS AS GREEN BEGINS



(d) EC CHANNEL OUTPUTS AS QUEUE DISCHARGES mately 5 s of time delay. The full-speed vehicles in transit over the stopline loop do not produce a call. This loop has in effect become disconnected, and the continued extension of the green is controlled by the upstream loops and the unit extension setting of the controller.

If the upstream loops use an amplifier that produces a short pulse when the vehicle enters the loop, then the unit extension setting of the controller is selected to be 2.2 s. It is simple to show that this setting will carry vehicles approaching within the speed range of 64-89 km/h (40-55 mph) through their respective dilemma zones. For example, a vehicle arriving on the green at a speed of 64 km/h will receive a 2.2-s unit extension that will prolong the green until the vehicle reaches the middle detector. The second unit extension holds the green until the vehicle is 37 m (124 ft) from the intersection. The table above shows that this is the downstream boundary of the dilemma zone for that speed, so the design succeeds in delaying the start of the yellow until the vehicle has cleared its dilemma zone.

If the upstream loops use an electronics unit operating in the presence mode, then an actuation will not end until the rear of the vehicle leaves the loop. In this case, a unit extension of 1.9 s is used instead of 2.2 s.

It is useful to apply seven criteria to judge the effectiveness of any proposed configuration for high-speed intersections (3):

1. Does the design detect a vehicle approaching at the design speed before it reaches the dilemma zone? The table above shows that the dilemma zone for 89 km/h begins 117 m (384 ft) from the intersection. Therefore, the design of Figure 1 does meet this criterion.
2. What is the allowable gap imposed by this design? A long allowable gap produces sluggish transfer of the green, increasing both delay and the likelihood of losing dilemma-zone protection because of max-out. With a unit extension of 2.2 s, the allowable gap produced by the two upstream loops is calculated as the travel time from the first loop to the middle one, plus the 2.2 s of extension by the middle loop. A stream of vehicles at the design speed of 89 km/h would thus experience an allowable gap of 1.6 + 2.2 = 3.8 s, while a stream at 64 km/h (40 mph) would hold the green if their time headways did not exceed 2.2 + 2.2 = 4.4 s. These allowable gaps appear to be snappy enough to minimize the extension of green to a maximum interval set to 50-60 s or more.
3. On termination of the green by gap-out, will vehicles approaching at the design speed be clear of the dilemma zone? On gap-out, a vehicle approaching at 89 km/h will be 2.2 s, or 54 m (178 ft), past the middle detector. Figure 1 shows that this is 77 - 54 = 23 m (75 ft) short of the stopline. The table above indicates that at this point the vehicle has left the dilemma zone well behind.
4. On termination of the green by gap-out, will vehicles traveling more slowly than the design speed be clear of the dilemma zone? The initial explanation of this design, above, pointed out that a vehicle approaching at 64 km/h will have just reached the downstream boundary of its dilemma zone on gap-out. All approach speeds from 64 km/h to 89 km/h receive dilemma-zone protection from this design. A slower vehicle, at 56 km/h (35 mph) is also protected because the yellow will appear before the vehicle reaches its dilemma zone. The first detector's unit extension of 2.2 s is not enough to carry this straggler to the middle detector, so gap-out occurs upstream of the dilemma zone.
5. Can a queue waiting at the stopline get into motion without a premature gap-out? The amount of stretch set on the EC timer of the EC-DC stopbar loop is selected to prevent premature gap-out, as explained earlier. The stretch must be long enough to assure motion over the middle loop, yet short enough to assure that the stopbar loop "disconnects" as soon as discharging traffic gets up to speed. The stopbar loop must disconnect (by reverting to the DC mode) before full-speed traffic gaps out over the upstream detectors.
6. Can the design screen out false calls for the green [as, for example, with right turn on red (RTOR)]? The nonlocking controller mode is capable of screening out false calls that appear while the cross-street traffic is holding the green. When the green is at rest on the cross street, the DC mode of the EC-DC stopbar detector will screen RTOR vehicles that enter the approach from a driveway less than 77 m (254 ft) from the intersection. However, with the green at rest on the cross street, a false call at either of the two upstream detectors will bring the green unnecessarily.
7. During the green interval, can a queue of left-turning vehicles hold the green as they wait to filter through gaps in oncoming traffic? This is important on two-lane roads, where an occasional left-turning vehicle can cause a queue to form. When a gap in oncoming traffic appears, a gap-out may occur with some designs before the queue can get into motion over a detector upstream of the stopline. In this design, the EC-DC loop at the stopline permits a queue of left-turning vehicles to hold the green.

ELECTRICAL DESIGN

The test installation (described below) used digital loop detectors. Therefore, this section will discuss the electrical design in terms of "channels" of detection. Three two-channel detectors would be used at a two-phase intersection of a high-speed route that has a low-speed crossroad.

One channel of one detector is connected to the four upstream, small-area loops. Figure 1 shows two of these loops; the other two would be on the opposite approach.

The second channel of that detector is connected to the loops used on the crossroad. Each of these two approaches might have an 18-m (60-ft) loop at the stopline.

Both channels of the second detector are used for one of the EC-DC loops. For example, they could be used with the long loop at the stopline of the approach shown in Figure 1. Both channels of the third detector are associated with the other EC-DC loop, which would be at the opposite stopline of an expanded Figure 1. The operation of these four channels is explained with the aid of Figure 2.

Figure 2a shows a two-channel detector in the dashed-line box on the right. Channel 1 has been switched by hand to the DC mode of operation. Channel 2 has been set to the EC mode. These channels would both be assigned to a stopline loop, as explained above.

Figure 2a also shows a double-pole, double-throw relay that would be installed on the controller cabinet's back panel by the local staff. The relay is connected to the detector, cabinet power, and the controller phase's detector input terminal as shown. A metal-oxide varistor (MOV) is included to eliminate the AC noise coming from the 115-V power source. It is a model GE V150LA20.

In the absence of a vehicle in the loop, Figure 2a shows that neither detector channel is actuated; both sets of output-relay contacts are open. Similarly, the

Figure 3. Site of test installation.

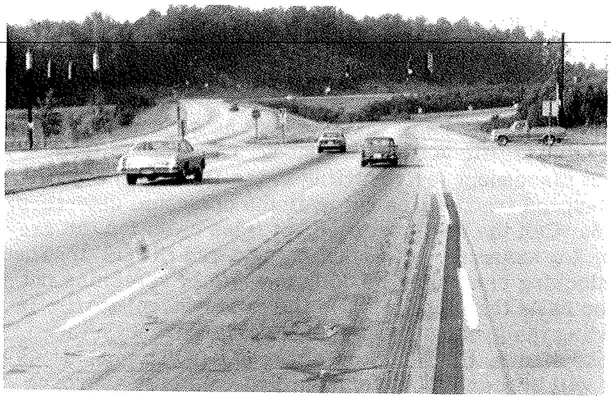
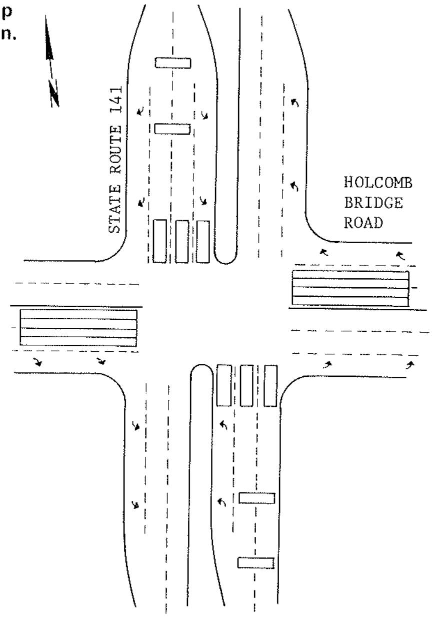


Figure 4. Detection-loop layout of test installation.



open contacts in the relay to the left indicate that no call is going to the controller.

In Figure 2b, a vehicle has arrived and come to a stop on the loop (because the signal is red). Channel 1 begins to time its delay in issuing a call; meanwhile, the channel 2 contacts close. It is clear from Figure 2a that contact 1 in the relay will not close as a result of this arrival, and no call goes to the controller.

When channel 1 times out its delay, its contacts close, as shown in Figure 2c. A ground is applied to one side of the relay's coil, energizing it and causing contacts 1 and 2 to close. A call in the form of a ground is applied to the controller phase's detector input terminal (contact 3). The controller responds by changing the green signal to this phase at the earliest opportunity.

When the first vehicle leaves the loop on the green interval, the channel 1 contacts open. That ground is removed from the coil. Channel 2 remains energized for a time, however, and the call is extended by means of the ground provided in the relay. As the queue discharges, the loop becomes occupied again and again before the set extension is able to time out. The call to the controller is unbroken; see Figure 2d. Soon the vehicles are crossing the loop at full speed and a gap appears that allows channel 2 to time out an extension.

Figure 5. Upstream loops do not detect the turn lanes.

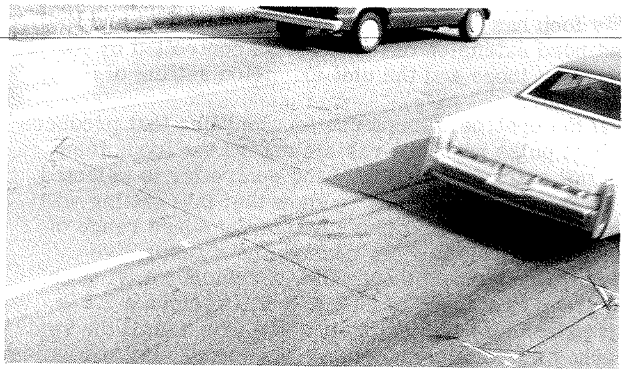
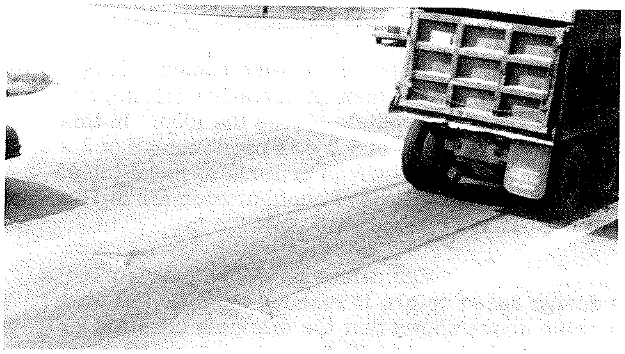


Figure 6. EC-DC loops at the stopline are only 8 m (25 ft) long.



The time-out opens the channel 2 contacts, deenergizing the coil and opening contacts 1 and 2 in the relay. The call to the controller ends, and the system returns to Figure 2a.

TEST INSTALLATION

The design was tested in July 1978, at the intersection of GA-141 and Holcomb Bridge Road in Gwinnett County (in greater Atlanta). Figure 3, looking south on GA-141, shows an open, rural intersection. The skid marks in the dilemma zone were found before the new design went into effect.

In both directions on GA-141, the peak-period speeds at the 15th, 50th, and 85th percentiles are 69, 77, and 86 km/h (43, 48, and 54 mph), respectively. Southbound volumes peak during the morning commuter rush at 550 vehicles/h. The northbound peak, in the afternoon, is close to 700. This four-lane highway has an average daily traffic (ADT) of 17 100 vehicles/day. Holcomb Bridge Road carries an ADT of 10 800 vehicles/day on four lanes.

Before the new detector-controller configuration was installed, GA-141 was signalized by using a small-area detection loop 58 m (190 ft) from the intersection. The table above can be interpolated to show that the median-speed vehicle approaching at 77 km/h (48 mph) has a 22 percent chance of stopping if shown a yellow interval at that location. Therefore, the "before" fully actuated signalization provided an insignificant amount of dilemma-zone protection.

Figure 4 shows the detection-loop layout of the test installation. The loops on the high-speed north-south GA-141 are identical to the design set forth in concept in Figure 1. The upstream loops on each of these approaches (Figure 5) do not detect the low-speed turning

Figure 7. The design requires a digital controller.

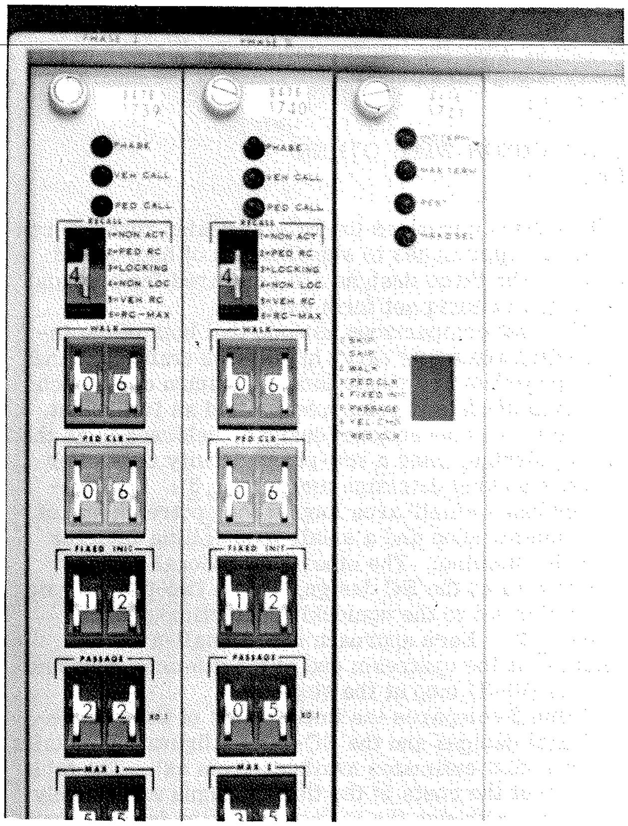
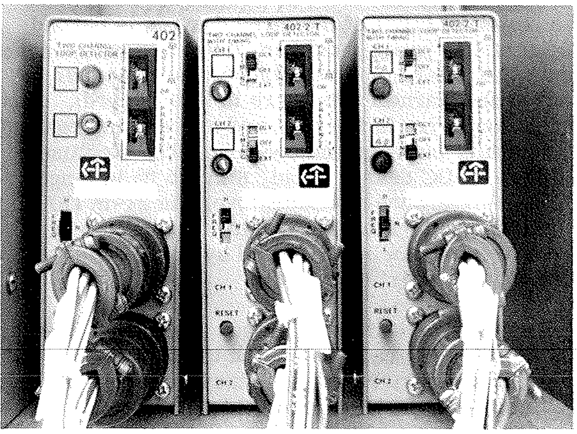


Figure 8. Six channels of detection are required.



traffic. An EC-DC loop at the stopline is shown in Figure 6. The southbound right-turn-only lane in Figure 4 has no detection loop at the stopline because vehicles are permitted to turn right on red.

The east-west cross street (Figure 4) uses conventional loop-occupancy control. Each approach lane has a quadrupole loop 18 m (60 ft) long operated in the presence mode.

The digital controller, shown in Figure 7, has the settings given below.

Item	Phase 1 (GA-141)	Phase 2 (Holcomb Bridge Road)
Detection memory	Nonlock	Nonlock
Fixed initial (s)	12	12
Passage time (s)	2.2	0.5
Maximum interval (s)	55	35
Yellow change (s)	4.3	4.3
Red clearance (s)	1.5	1.7

Figure 9. One double-pole, double-throw relay for each high-speed approach.

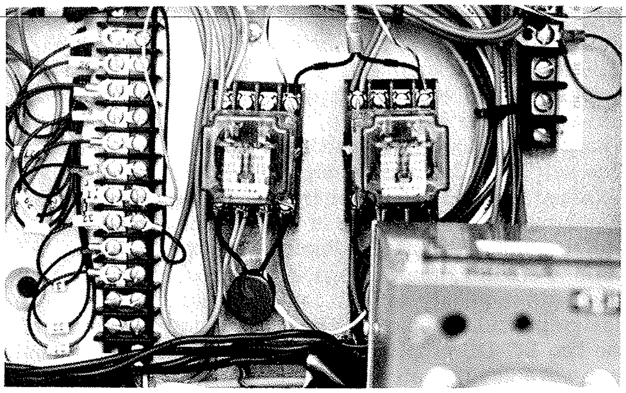
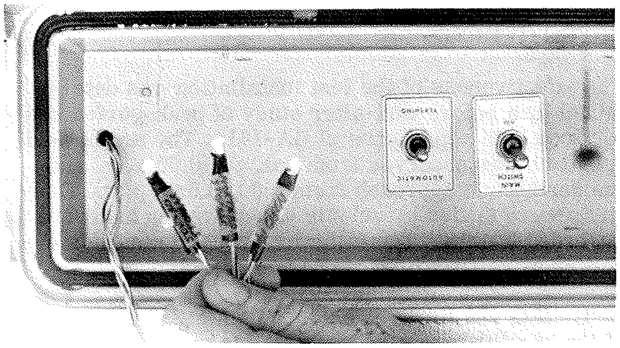


Figure 10. Three pilot lights are stored behind the police panel.



The yellow-plus-all-red clearance period is unchanged from the "before" settings. The 14 s of fixed initial plus passage time for phase 1 were derived from the Clark recommendations of 12-18 s (4). The 2.2 s of passage time was derived earlier. The maximum setting of 55 s was a compromise of the 50-60 s commonly used and would have been set higher if necessary to avoid max-outs.

The three detector units shown in Figure 8 provide the required six channels of detection. The detector on the left in the figure uses channel 1 to operate the four upstream loops on GA-141. The long stopline loops on Holcomb Bridge Road use channel 2. The center detector and the right one were designed at the factory so that any channel can be switch-selected to either the DC or EC mode of operation. The center detector, serving the stopline loop for the northbound approach on GA-141, is set to DC for channel 1 and EC for channel 2. The right detector is set similarly for the southbound approach. Switches inside these two detectors are set to time 5 s of delay and 2 s of extension at this intersection.

The double-pole, double-throw relays explained earlier are shown in Figure 9. One is associated with the center detector unit and the other with the right unit. The fact that these two relays are the only special logic in the cabinet points up the simplicity of the design. It does not pose a maintenance problem.

Figure 10 shows three pilot lights that were added for convenience in monitoring the operation of the design. The left lamp glows during GA-141 green. It was desired because the north-south signal heads are not visible from the cabinet. The center and right lamps are associated with the stopline loops on the northbound and southbound approaches, respectively. Each glows whenever its loop is outputting a call to the controller. The setting of 2 s of extension on each approach was obtained by trial and error by using these pilot lights. The lamp for an approach is extinguished when its stopline loop disconnects during the green. As explained earlier, the disconnect must occur at the strategic moment, neither too early nor too late. The design provides separate electronics units for each of the two EC-DC stopline loops. If a single two-channel unit were used, instead of the two shown at the center and right of Figure 8, then a timely disconnect of a stopline loop would become difficult. Heavy traffic in both directions would be much more likely to cause extension of the green to the maximum interval.

EFFECTIVENESS

The effectiveness of the test installation was determined by a before-and-after study of peak-period conflicts on both approaches of GA-141. The southbound approach was observed from 7:00 to 10:00 a.m. and the northbound approach from 3:00 to 6:00 p.m. Conflicts were tallied by vehicle classification and were recorded hourly. The following types of conflicts observed were suggested by Zegeer (2):

1. Run red light: A clearing vehicle is upstream of the stopline when the signal turns red.
2. Abrupt stop: A driver decides at the last instant to stop. The deceleration, particularly within 30 m (100 ft) of the stopline, causes the front end of the vehicle to dip noticeably.
3. Skid: A stop is so abrupt as to produce the sound of skidding.
4. Swerve: An erratic maneuver narrowly averts a collision.
5. Acceleration through yellow: The driver "guns" the engine in order to clear the intersection.
6. Brakes applied before clearing: The driver's indecision causes him or her to apply the brakes and then to clear the intersection.

The observers were stationed 137 m (450 ft) from the stopline and inconspicuously off to the side of the highway. Traffic cones were placed at the boundaries of the dilemma zone for the median approach speed. At each approach, 6 h of "before" and 6 h of "after" data were collected, for a total of 24 h of data. These results are summarized in Table 1, which shows that the test installation caused total conflicts for 12 h to decline from 29 to 9. The two approaches combined therefore experienced a 69 percent reduction in conflicts per hour—from 2.42 to 0.75, as shown below:

Period	No.	Mean	SD
Before	12	2.42	1.62
After	12	0.75	0.75

The t-test results (3.23) indicate that so great a difference in the means could have occurred by chance only one time in 100 ($\alpha = 0.01$). Therefore, the reduction in conflicts was highly significant statistically. The test installation was very effective, despite the fact that the "before" signalization provided a measure of dilemma-zone protection.

Delay was not a factor at this intersection either before or after the improvement. Traffic was never heavy enough to extend either phase to the maximum interval.

COMPARISON WITH OTHER DESIGNS

This section compares the EC-DC design with two conventional approaches to signalization of high-speed roads. The three designs are compared for cost and the seven criteria set forth earlier.

The cost comparisons assume that both of the intersecting roadways carry high-speed traffic and that all approaches are single lane. Common costs such as signal heads and poles are omitted as irrelevant.

One of the conventional designs, referred to as the density design, uses a two-phase density controller that has locking detection memory (1, 3). Each approach has a small-area loop at the upstream end of the dilemma zone and a small-loop calling detector near the stopline. The other conventional design, referred to as the EC design, uses a two-phase basic controller set to the nonlocking detection-memory mode (1, 3). Each approach has a small-area EC detector at the upstream end of the dilemma zone and a 21-m (70-ft) loop at the stopline.

Table 2 compares the initial costs of the two conventional designs and the EC-DC configuration (details of these cost estimates available from us). The table shows that the costs of the three designs are roughly the same, although the EC configuration is 10-15 percent cheaper than the other two designs. Overall, Table 2 suggests that the choice among the three alternatives should depend on operational features and maintainability, rather than on initial cost alone.

The maintainability of the three designs is beyond the scope of this paper; however, there are maintenance-cost data that offer some assistance (see the paper by Parsonson and Tarnoff elsewhere in this Record). The amount of loop wire in the road and exposed to breakage is an important maintenance concern. The stopline loop of the EC-DC design is only 8 m (25 ft) in length, a definite maintenance advantage over the 21-m (70-ft) stopline loop used by the EC design. Operationally, the three designs can be compared by using the seven criteria set forth earlier:

1. Inasmuch as all three designs place their upstream detector in accordance with the probability-of-stopping distances given earlier, they are equal in their ability to detect a design-speed vehicle before it reaches its dilemma zone.
2. The allowable gap imposed by the density design is reduced, usually on the basis of time waiting on the red, to the setting of the minimum gap. It is easy to calculate from the table of stopping distances that, for a typical speed of 80 km/h (50 mph), the shortest setting that would pass a vehicle through its dilemma zone is about 2.5 s. This constitutes a minimum desirable allowable gap; a shorter value would give snappier operation but could leave a vehicle in the dilemma zone. The allowable gap of the EC design is typically 5 s (3). That of the EC-DC design was calculated earlier to be about 4 s. Actually the difference is greater; the ability of the EC-DC design to disconnect its stopline loops gives it a decided superiority to the EC design in real-world operation.
3. On termination of the green by gap-out, all three designs will permit a vehicle approaching at the

Table 1. Traffic conflicts before and after at test installation.

Conflict	Automobiles		Single-Unit Trucks		Semitrailers		Total	
	Before	After	Before	After	Before	After	Before	After
Run red light	11	7	1	0	0	0	12	7
Abrupt stop	3	0	1	0	1	0	5	0
Skid	1	0	0	0	0	0	1	0
Swerve	0	0	0	0	0	0	0	0
Accelerate through yellow	3	2	0	0	0	0	3	2
Brake before clearing	7	0	1	0	0	0	8	0
Total	25	9	3	0	1	0	29	9

Table 2. Initial costs of the three designs.

Item	Cost ($)		
	DC	EC	EC-DC
Controller	3345	2200	2200
Detector units	330	650	1000
Labor	432	502	600
Loop wire	48	87	56
Lead-in wire	226	226	226
Messenger cable	160	160	160
Conduit	80	80	100
Sealant	20	45	31
Saw, blade	25	50	50
Relays	0	0	20
Total	4666	4000	4443

Table 3. Comparative of ranking the three designs.

Item	DC	EC	EC-DC
Initial cost	3	1	2
Detection at design speed	1	1	1
Allowable gap	1	2	1
Protection at design speed	1	1	1
Protection at lower speeds	2	2	1
Avoidance of premature gap-out	2	1	1
Screening of false calls	3	2	1
Left-turn queue holding green	2	1	1
Total	15	11	9

design speed to clear the dilemma zone.

4. On termination of the green by gap-out, vehicles traveling more slowly than the design speed will typically be protected by the EC and EC-DC configurations. Slow vehicles will not be protected by the density design if the minimum gap is set low, e.g., 2.5 s. There is a trade-off here between snappy operation and protection to the slower vehicles in the stream. One can be obtained only at the expense of the other. If a density design for 89 km/h (55 mph) is also to protect the vehicle approaching at only 64 km/h (40 mph), the minimum gap must be increased to 4.5 s. This is no shorter than the allowable gap of the EC-DC design. Therefore, the density design offers no allowable-gap advantages. The EC-DC design, with its middle loop, can assure that vehicles approaching at 56 km/h (35 mph) or less will gap out upstream of their dilemma zone.

5. The EC and EC-DC configurations use stopline loops to ensure that a queue can discharge without premature gap-out. The density design relies on its variable initial interval to accomplish this. Dense traffic can defeat the purpose of this feature (3); therefore, the density design is the least attractive of the three on this account.

6. The density design has no ability to screen out false calls for the green, because the controller's detection memory is of the locking type. The other two configurations are better, because of their loop-occupancy features. The EC-DC design is best; the stopline loop operates in the DC mode when the signal is red.

7. It is desirable, especially on two-lane roads, that a queue of vehicles waiting on the green to turn left be able to hold the green. The EC and EC-DC configurations can do this, but the density design cannot.

Table 3 summarizes the comparison of the three designs. For each of the criteria, 1 is assigned to the best design, 2 to the next best, etc. If the designs are equally effective, each receives 1. The table shows that the EC-DC configuration costs somewhat more than the EC design but is superior in three operational categories. It is less expensive than the density design and is superior in four operational aspects. It appears to be a worthy challenger to these conventional designs.

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