Evaluation of Change Interval Treatments for Traffic Signals at High-Speed Intersections

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EVALUATION OF CHANGE INTERVAL TREATMENTS FOR TRAFFIC SIGNALS AT HIGH-SPEED INTERSECTIONS

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16. Abstract

A large number of traffic accidents at signalized intersections on high-speed roadways occur during or just after the change interval. The green extension system (GES) has been used extensively in Kentucky as a method of alleviating the problem related to the dilemma zone. An alternate method of handling this problem involves warning drivers that the signal indication is about to change from green to red using advance warning flashers (AWF). The objectives of this study were: 1) to evaluate the alternative methods (GES or AWF) which can be used to lessen the problem associated with the dilemma zone which occurs at traffic signals, specifically on high-speed roadways and 2) to determine conditions where use of the AWF may be needed.

The GES was judged to be effective and its use was recommended to be continued at high speed intersections. The use of an AWF should be limited to locations where either an existing or high potential accident problem exists. Guidelines and evaluation factors to consider in determining the use of an AWF were identified. These factors included: accident history, speed limit, truck volume, sight distance, grade, red light violation rate, traffic volume, and adjacent bridge deck. The design of an AWF was discussed.

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INTRODUCTION

A large number of accidents at signalized intersections on high-speed roadways occur during or just after the change interval. The change interval is defined as the time interval between the end of the green indication on one road and the beginning of the green indication on the intersecting road. It consists of the length of the yellow indication, in addition to all-red time when used. Either an angle accident occurs when one driver enters the intersection during the red phase or a rear-end accident occurs when one driver stops abruptly. The angle accident is more often associated with severe injuries.

These types of accidents are related to what is commonly termed the dilemma zone which is defined as that area in advance of the signal where the motorist is indecisive as to whether to proceed or stop when the signal changes from green to yellow. Drivers who are beyond the dilemma zone will usually decide to continue through the intersection when the yellow indication is displayed while drivers who have not yet entered the dilemma zone will usually decide to stop. This zone is particularly critical when combined with steep grades and a large amount of truck traffic because this combination of factors increases the required stopping distance.

The green extension system (GES) has been used extensively in Kentucky as a method of alleviating the problem related to the dilemma zone. The effectiveness of the GES was first studied in Kentucky in 1977 (1). A GES is normally considered at isolated intersections or where the signal is the first signal in a series of signals and where the 85th percentile speed is 45 mph or greater. A GES uses presence-detection loops in the pavement at predetermined distances preceding an intersection. These loops detect the presence of a vehicle in what has been defined as the dilemma zone. If a vehicle is in this zone, the green phase will be extended, up to a maximum green time. This permits a vehicle to proceed through the intersection without having to stop abruptly or travel through the intersection during the red phase. However, the difference in braking distances between cars and trucks results in potentially different dilemma zones. An issue to be addressed is whether the current dilemma zone is adequate for the longer stopping distances required for trucks.

An alternate method of handling this problem involves warning drivers that the signal indication is about to change from green to red. Advance warning flashers (AWF) have been used to provide this warning. This type of warning device, along with related signing, has been placed at two trial locations in Kentucky.

The objectives of this study were: 1) to evaluate the alternative methods (GES or AWF) which can be used to lessen the problem associated with the dilemma zone which occurs at traffic signals, specifically on high-speed roadways and 2) to determine conditions where use of the AWF may be needed.

PROCEDURE

Literature Review and Survey of Selected States

Literature relating to the subject of traffic control procedures used to address the safety of change intervals at traffic signals on high-speed roadways was reviewed. Selected states identified in the literature review were contacted. An emphasis was placed on obtaining information related to use of the AWF procedure.

Interviews

Dicussions were held with groups of coal truck drivers who attended coal truck driver training programs in Pikeville and Prestonsburg. The drivers were asked their understanding and opinion of the AWF installations.

Accident Analysis

All intersections in the state at which a GES or AWF has been installed were identified. Accident data for the three-year period of 1991 through 1993 were used in an accident analysis. Accident rates were calculated for intersections where the GES was installed prior to 1991 and sufficient information was available to accurately locate the intersection. Some of the intersections with the highest accident rates were identified for further analysis.

Data Collection

Field data were collected at a sample of GES locations. Intersections having the highest accident rates were included. Data were taken at the two intersections where AWF devices had been installed. Data were also taken at some high speed signalized intersections which did not have a GES installation. The speed limit at all of the intersections was either 45 or 55 mph. Two types of field data were collected.

The primary type of data dealt with conflicts related to the change interval. These data consisted of noting, during each change interval, the number of vehicles that either entered the intersection (crossed the stopbar) during the red indication, abruptly stopped during the yellow indication, or accelerated rapidly through the intersection during the yellow indication. Whether the vehicle was a car or truck was noted. The data sheet used to collect these data is shown in Figure 1. Data were taken for 100 cycles at each approach. The percentage of change intervals in which a conflict occurred was used in the analysis.

A second type of data related the distance a vehicle was from the intersection when the signal indication changed to yellow to whether that vehicle stopped or proceeded through the intersection. The data sheet used to collect these data is shown in Figure 2. Cars and trucks were analyzed separately.

RESULTS

Literature Review and Survey of Selected States

A limited number of references were located which dealt with the subject of AWF. A summary of these references is given in the Appendix.

The general consensus was that an AWF is effective at intersections on high-speed highways when there is a demonstrated problem. There was agreement that an AWF should not be used as a standard type of warning device.

There has not been a general agreement concerning the design and operation of an AWF scheme. Various types of signs are used with the most common being the "Prepare to Stop When Flashing" and flashing "Red Signal Ahead" signs. The distance the signs are located from the intersection varied with the most common distance of 600 to 800 feet. The flashers would generally start prior to the end of the mainline green with this time period ranging from 4 to 13 seconds.

A few states were identified as using several of the AWF devices. Representatives from these states were contacted by telephone. It was found that formal guidelines are not typically used. The general types of criteria which have been used to determine the need for an AWF device on a high speed approach include: restricted sight distance, a high percentage of truck traffic, frequent violations of the clearance interval, and an accident problem related to angle and rear-end accidents.

Interviews

Discussions were held with groups of coal truck drivers attending coal truck driver training programs in Pikeville and Prestonsburg. They were shown slides of the AWF installation on KY 80 in Martin and asked several related questions. All of the drivers were familiar with the installation. It was evident that the drivers understood the meaning of the AWF. The drivers indicated they used the AWF to inform them that the end of the green signal indication was approaching. They felt the AWF was effective and suggested that its use be expanded.

GES and AWF Locations

Records were reviewed to determine the location of intersections having a GES installation. A file was obtained which listed current and proposed GES locations. A list of 271 intersections was obtained. At a few of these intersections, the GES was planned but had not yet been installed.

General guidelines are used for the installations of a GES. Typical installations are at isolated intersections or where the signal is the first signal in a series of signals where the 85th percentile speed is 45 mph or greater. The GES installation involves installing two loops on the approach at distances which are related to the approach grade. This distance increases for down grades. For a level approach, the loops are placed 217 and 384 feet from the stop bar. An initial green interval is set (usually 15 to 20 seconds) with this time increased at a set interval (2.5 seconds for a level approach) if traffic is detected between the loops. The time will increase to a limit (usually 90 seconds), and at this point the signal will change even if vehicles are in the dilemma zone.

The typical advance warning at GES locations are signal ahead signs. These signs have been placed as far as one mile in advance of the signal. A series of these signs have been used with a maximum of four signs in a series noted at one intersection. In some instances, a continuous flasher is placed on top of the signal ahead sign. The flasher has also been connected to the signal operation such that it starts to flash when the yellow light for the approach begins and continues through the red interval.

Counties having the highest number of GES installations were Hardin County with 18, followed by Fayette and Franklin Counties with 17, and Jefferson County with 16. Other counties with 10 or more installations were Boone, Boyd, Laurel, and Pulaski. Approximately one half of the counties (62) did not have a GES installation. Summaries by highway district revealed the largest numbers of installations in District 7, followed by District 5. The fewest numbers were in District 1, followed by District 10.

AWF devices have been placed at two intersections. Both locations are on four-lane highways with high truck volumes and a substantial downgrade on one or both mainline approaches. One intersection is in Greenup County on US 23 at its intersection with KY 750. The AWF replaced a GES at this location. The second intersection was in Floyd County on KY 80 at its intersection with KY 1210. The AWF was placed as part of the original signalization at this intersection. Both ground-mounted and overhead "Prepare to Stop When Flashing" signs are installed. Both signs have two flashers which were activated 10 to 11 seconds prior to the end of the mainline green. The signs are placed approximately 1,000 feet in advance of the intersection. Signal ahead signs are placed prior to the AWF signs. The speed limit at one location is 45 mph, while the speed limit at the other is 55 mph with a 45-mph advisory speed.

Considering the alternative signs and messages used for AWF devices across the country, the "Prepare to Stop When Flashing" sign used in the current installations appears to be appropriate. The practice of having both overhead and ground-mounted signs should also be continued.

The distance the signs should be placed from the intersection was analyzed. The stopping distance, using conservative assumptions of normal braking with a coefficient of friction of 0.2 and a perception-reaction time of 2.5 seconds, was calculated. For 55 mph, the stopping distance would be 706 feet with this distance increasing to 820 feet at 60 mph. This would indicate that, depending on the approach speeds and grade, the signs should be placed 700 to 900 feet in advance of the intersection. The time required to travel these distances would indicate the flashers should start 9 to 10 seconds prior to the end of the mainline green.

Accident Analysis

The accident analysis was conducted at intersections where the GES installation was completed prior to 1991 and where the intersection could be properly identified and matched with accident data. An effort was made to locate accurate milepoints for each intersection so that accident data could be related to the intersection. Using these criteria, accident data were analysed, using the computer data base, at 183 intersections. This included 181 locations with a GES and the two AWF locations. The accuracy of the accident analysis is limited by the accuracy of the milepoint system. Accident records would have to be manually searched to verify the computer records.

A listing of the intersections with GES installations, along with the accident data for the three-year period of 1991 through 1993 and the accident rate, is presented in Table 1. The intersections are identified with the county, major route, and intersecting route or street. Traffic volumes on all state maintained highways were obtained through a computerized file. Volumes off the state maintained system were usually obtained using intersection volume counts. In instances where no other information was available, the unknown volume was estimated using functional classification averages.

The highest number of accidents in the three-year period was 47 at the intersection of US 25 and KY 192 in Laurel County followed by 44 accidents at the intersection of US 60 and Man O'War Boulevard in Fayette County. There was an average of 14 accidents in the three-year period at the 181 intersections. The critical number of accidents was calculated to be 24 for these intersections (2). The highest accident rate was 2.3 ACC/MV at the intersection of US 27 and US 150 in Lincoln

County followed by 2.0 ACC/MV at the intersection of US 41 and KY 1682 in Christian County. The importance of conducting a review of the accident reports is illustrated by the accident records at the Lincoln County intersection. A large number of the accidents coded on the computer milepoint system as occurring at this intersection were found to be coded incorrectly such that the accident rate would be reduced substantially. However, since accident reports could not be manually checked for all the intersections, the data for this intersection reflects the same computer data as used for the remaining intersections.

The average accident rate for all the locations was 0.61 ACC/MV. A critical accident rate of 1.05 ACC/MV was calculated for this listing of intersections (2). A list of the 31 GES intersections having an accident rate equal to or higher than the critical rate is given in Table 2.

The average rate at this set of intersections can be compared to statewide intersection accident rates (3). The average rate was closest to the statewide rate for urban, minor arterial roadways. The average rate for these intersections was higher than for the statewide rural intersection classifications while the critical rate was lower. This would be the result of the relatively high traffic volumes at this set of intersections compared to all intersections in the state.

Angle accidents are the type of accident the GES or AWF are designed to reduce. The number and percentage of angle accidents at each intersection were determined. Considering all intersections, 39 percent of the accidents at the GES locations listed in Table 1 were angle accidents. This percentage was 37 percent for the 31 intersections having a critical accident rate. The highest percentage of angle accidents at the intersections having a critical accident rate was 75 percent at the intersection of US 641 and KY 80 in Marshall County.

Angle accidents in which both vehicles were going straight were analyzed separately. Considering all intersections, 12 percent of the accidents were described as this type. The percentage was also 12 percent for the intersections having a critical accident rate. The highest percentage of this type of accident at intersections having a critical accident rate was 45 percent which was also at the intersection of US 641 and KY 80 in Marshall County.

The percentage of rear-end accidents was also investigated. Considering all intersections, 42 percent of the accidents were rear end. This compares to 39 percent for angle accidents. The percentage was 31 percent for the 31 intersections having a critical accident rate as compared to 37 percent for angle accidents. The highest percentages of rear-end accidents at the intersections having a critical accident rate were 64 percent at the intersection of US 25 and KY 192 in Laurel County and 63 percent at the intersection of US 27 and the US 27 Bypass in Jessamine County.

The severity of these accidents was compared to statewide accidents. There were nine fatal accidents at these locations over the three-year period. This represents 0.36 percent of all accidents as compared to 0.54 percent statewide. The percentage of injury accidents was 31 percent compared to 25 percent statewide.

The accident rate at the AWF location in Floyd County (KY 80 at KY 1210) was 0.97 ACC/MV for 1991 through 1993. The signal was installed in October 1993. There were six accidents in 1991 and 1992 compared to two in 1993 (one after installation of the signal). The accident rate at the AWF location in Greenup County (US 23 at KY 750) was 0.76 ACC/MV for 1991 through 1993. The AWF replaced the existing GES in July 1992. There were eight accidents coded as occurring on US 23 at this intersection for the 18-month period of January 1991 through June 1992 (including two fatal accidents) compared to three accidents in the 18-month period after installation of the AWF (July 1992 through December 1993). These data show an improvement in the accident experience correponding with the replacement of the GES with the AWF.

Field Data Analysis

Conflict data were taken at 45 intersections. This included the two AWF intersections, 33 intersections with a GES, and 10 intersections with no GES. At one intersection, data were taken when the GES was not functioning and when it was repaired. Data were taken for 100 cycles on each approach.

This type of data was used as a method to analyse the effectiveness of the GES and AWF as well as to establish a criterion which could be used to determine where an AWF may be used. All of the intersection approaches had a speed limit of at least 45 mph. The speed limit changed to 35 mph just prior to the intersection on one approach.

The conflict data included noting vehicles that entered the intersection (crossed the stop bar) after the start of the red phase, vehicles that decelerated rapidly and stopped during the yellow phase, and vehicles that accelerated rapidly and entered the intersection during the yellow phase. The conflicts involving rapid deceleration or acceleration were subjective and only a few were noted. Therefore, the focus of the analysis was on conflicts involving vehicles that entered the intersection after the start of the red phase.

A summary of the conflict data is given in Table 3. The intersections were classified as having a GES, an AWF, or neither system. Data were collected at 61 approaches at the 45 intersections. A summary by type of device shows 41 approaches had a GES, four had an AWF, and 16 had neither. At most intersections, a vehicle entered the intersection during the red phase in only a very small percentage of the cycles. The highest percentage was observed on the eastbound US

60 approach to its intersection with Huntertown Road in Woodford County during a time period when the GES was not operating. The benefit of the GES is shown by noting the reduction in red light violations when the GES was repaired. The percentage of cycles with red light violations was reduced from 24 to 7 percent after the GES was repaired. On the US 60 westbound approach, this percentage was reduced from 14 to 3 percent after the repair.

The highest percentage of red light violations at a GES location was at the intersection of US 31W and KY 434 in Hardin County with 13 percent on the northbound approach. The length of the yellow had been increased to five seconds at this intersection but red light violations have continued. The effect of grade is shown at this location with a 13 percent violation rate on the northbound approach which is downhill compared to two percent on the uphill southbound approach. There was a violation rate of more than 10 percent at two other GES locations. These were the westbound US 60 approach to Man O'War Boulevard in Fayette County and the northbound US 31W approach to US 31W Business in Hardin County (West Point).

Considering all approaches, 3.0 percent of the cycles had a red light violation at the GES approaches compared to 1.8 percent at the four AWF approaches, and 5.5 percent at approaches with neither a GES or AWF (including the approaches with a non-functioning GES). This shows the reduction in red light violations achieved by adding a GES or an AWF. These average percentages can also be used to show where an abnormal number of red light violations are occurring. Using the 5.5 percent violation rate at approaches with neither a GES or AWF, a critical percentage of 12 percent was calculated.

Considering all approaches, approximately 0.4 percent of the cycles had a conflict involving an abrupt stop. Also, about 0.4 percent of the cycles had a conflict involving acceleration through the yellow. The percentages were very similar for intersections with and without a GES.

The stopping data were classified into several vehicles types, as shown in Figure 2. However, the sample size for some of the truck categories was small. This required the summary of the data to be classified into the categories of automobiles, single unit trucks, and combination trucks. Most of the data were taken where the speed limit was over 45 mph. Since there was not a wide range in operating speeds at the various intersections, the data were not categorized by speed limit.

Stopping data were obtained for a total of 7,038 vehicles. This consisted of 6,228 automobiles, 377 single unit trucks, and 433 combination trucks. About 70 percent of the vehicles included in the data stopped at the intersection. This percentage varied from 71 percent for automobiles to 67 percent for single unit trucks and 58 percent for combination trucks.

A summary of the stopping data is given in Table 4. This table gives, as a function of the distance from the intersection, the percentage of drivers that stop when observing a yellow light, rather than proceeding through the intersection. The data are listed separately for automobiles, single unit trucks, and combination trucks. The distance ranges shown in Table 4 were determined after reviewing smaller ranges. These ranges correspond to distances that had similar percentages of vehicles stopping. Differences are shown between cars and trucks. For a given distance from the intersection, the percentage of trucks that stopped was lower than for automobiles. For example, at a distance of 176 to 225 feet from the intersection, 64 percent of automobiles stopped compared to 25 percent for trucks.

The distances at which 10 percent and 90 percent of drivers stop has been used when estimating the position of loops for the GES (1). For all the vehicle types, the distance from the intersection where 10 percent of the drivers were noted to stop when confronted with a yellow signal started in the range of 126 to 175 feet. The distance where 90 percent of drivers stopped started in the range of 326 to 400 feet for automobiles and single unit trucks, and in the range of 401 to 500 feet for combination trucks.

These distances are closer to the intersection than some of those reported in several other studies for high approach speeds (1). The explanation would be that the data were collected for all vehicles regardless of speed. Observation of the traffic revealed that some drivers would slow as they approached the signal and then stop when they observed the yellow indication. Evidently, these drivers were anticipating that the green phase was about to end. This resulted in those drivers stopping when they were at a relatively short distance from the stop bar. These data represent a sample of all vehicles, and the distances given would be higher when only vehicles traveling at or above the speed limit were included.

Speed and grade were observed to be related to the distance from the stop bar at which a driver would stop when a yellow signal was observed. This distance would increase as speed increased and on downhill grades.

The distances at which drivers stop can be related to the length of the yellow. Yellow and all-red intervals were timed at over 50 intersections having a GES. The length of the yellow typically ranged from 3.5 to 5.0 seconds with an average of 4.5 seconds. Almost all the intersections had an all-red indication. The length of the all-red interval typically ranged from 0.5 to 2.0 seconds with an average of about 1.5 seconds. The total change interval (yellow plus all-red time) would be about 6.0 seconds. The maximum change interval noted was seven seconds (five second yellow plus two second all-red).

The maximum distance a driver could be from the intersection when the yellow began and enter the intersection before the end of the yellow can be calculated using the speed of the vehicle and length of yellow. Drivers traveling at speeds from 45 to 55 mph could be 298 to 364 feet from the intersection and not enter the intersection after the start of the red signal for a yellow interval of 4.5 seconds.

CONCLUSIONS

The Green Extension System was determined to be an effective method of addressing the dilemma zone at high speed intersections. However, under some types of adverse conditions, an Advance Warning Flasher could be used as an alternative. The two AWF installations show that this procedure has been effective.

RECOMMENDATIONS

The use of Green Extension Systems should be continued at high speed intersections. The use of Advance Warning Flashers should be limited to locations where either an existing or high potential accident problem exists. The following guidelines and evaluation factors should be considered when determining the need for the use of an AWF. A signalized intersection meeting several of the guidelines or evaluation factors would be a candidate for use of an AWF.

1. Accident History

An AWF should be considered when the intersection has a high accident rate. Statewide intersection accident rates were determined in a previous research report (3). The statewide critical rate for intersections on a rural, principal arterial highway, which would apply to most of these intersections, was determined to be 1.39 ACC/MV. The critical rate for the set of relatively high volume GES intersections was 1.05 ACC/MV.

Intersections that have a high number or percent of angle accidents should receive strong consideration for an AWF. Intersections having a critical rate with 50 percent or more angle accidents should be investigated.

2. Speed Limit

Use of an AWF should be limited to locations where the speed limit or 85th percentile speed is above 45 mph.

3. Truck Volume

An AWF should be considered when a signalized intersection with approach speeds over 45 mph is on the extended-weight coal haul system.

4. Sight Distance

Restricted sight distance to the signal head would indicate that an AWF should be considered. For a speed limit of 55 mph, the sight distance should be about 700 feet to stop on a level surface using normal braking (coefficient of friction of 0.2) with a design perception reaction time of 2.5 seconds.

5. Grade

A steep downgrade increases the distance required to stop and would be a consideration in determining the need for an AWF. A downgrade in excess of the maximum of four percent given in the Policy on Geometric Design of Highways and Streets (4) for a rural arterial having a design speed of 60 mph in a rolling terrain would indicate that an AWF should be considered.

6. Red Light Violation Rate

A high percentage (12 percent or above) of cycles in which a vehicle enters the intersection after the end of the yellow phase indicates that an AWF should be considered.

7. Traffic Volume

An approach having a high traffic volume which results in the maximum green time being used a substantial amount of time limits the effectiveness of the GES and would indicate consideration of an AWF.

8. Adjacent Bridge Deck

When a bridge deck is located adjacent to an intersection at the location where GES loops should be placed, either the location of the loops must be moved or a GES system cannot be installed. When the characteristics of the intersection approach warrants use of a GES system, an AWF could be installed as an alternative.

The AWF design should include both ground and overhead signs with the message "Prepare to Stop When Flashing". The signs should be located in a range of 700 to 900 feet from the intersection. The flashing operation should begin between 9 seconds, if the sign is 700 feet from the intersection, to 10 seconds, if the sign is 900 feet from the intersection, before the start of the yellow and continue until the end of the red phase.

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Figure 1. CONFLICT DATA

DATE ______________ LOCATION ____

APPROACH ________________________________

TIME STARTED______________ TIME ENDED ______________ PAGE NO. __________

	CONFLICTS*			
CYCLE NUMBER	NONE	RAN RED	ABRUPT STOP	ACCELERATION THROUGH YELLOW

* A-Auto; S-single unit truck; SCE-empty single unit coal truck; SCL-loaded single unit coal truck; C-tractor trailer; CCL-loaded coal tractor-trailer, CCE-empty coal tractor trailer.

Figure 2. STOPPING DATA

DATE ____________________ LOCATION ____

APPROACH ____

TIME STARTED ___________________ TIME ENDED ________________ PAGE NO. __________

VEHICLE TYPE*	LOCATION**	ACTION***

* A-Auto; S-single unit truck; SCE-empty single unit coal truck; SCL-loaded single unit coal truck; C-tractor trailer; CCL-loaded coal tractor-trailer, CCE-empty coal tractor trailer.

** Distance from stop bar when yellow starts.

*** NS-Normal Stop, AS-Abrupt Stop, T-Through (on yellow), AT-Accelerated Through (on yellow), RR-Ran Red.

TABLE 1. GES LOCATIONS

COUNTY	INTERSECTING ROUTE	ROUTE	ACCIDENTS* 1991	1992	1993	TOTAL	ACCIDENT RATE (ACC/MV)
Allen	US 31 E	KY 100	2	3	5	10	1.35
Allen	US 31 E	US 231	7	4	10	21	1.70
Allen	US 31 E	KY 101	1	0	0	1	0.09
Anderson	US 127	US 127 B	3	3	2	8	0.50
Anderson	US 62	US 127 B	4	3	4	11	0.53
Barren	US 31 E	KY 1297	3	6	7	16	0.74
Barren	US 31 E	US 31 B	5	0	1	6	0.22
Bell	US 25 E	KY 441	9	8	8	25	0.90
Boone	US 25	KY 338	4	4	3	11	1.04
Boone	KY 20	KY 237	2	4	0	6	0.34
Boone	US 25	KY 842	7	6	1	14	0.62
Boone	KY 18	Greenview Drive	4	5	0	9	0.21
Boone	US 42	KY 237	7	7	6	20	1.21
Boone	KY 18	KY 237	6	9	5	20	0.78
Bourbon	US 27	US 460	7	5	5	17	0.93
Bourbon	US 27	Fordsmill Road	1	1	1	3	0.19
Boyd	US 60	KY 1134	7	2	2	11	0.40
Boyd	US 60	KY 716	3	2	1	6	0.21
Boyd	US 23	I-64	1	6	6	13	0.39
Boyd	US 23	KY 757	2	0	2	4	0.31
Boyd	US 60	KY 538	4	3	3	10	0.36
Boyd	US 60	KY 766	6	2	3	11	0.41
Boyd	KY 180	KY 3291	1	1	0	2	0.15
Boyd	US 60	Summit Road	7	4	1	12	0.44
Boyd	US 60	KY 180	2	6	2	10	0.56
Boyd	US 60	Midland Road	1	0	1	2	0.08
Boyd	US 60	Eagle Road	0	1	1	2	0.09
Boyle	US 127 B	KY 37	7	6	1	14	0.80
Boyle	US 127 B	KY 34	3	2	2	7	0.32
Boyle	US 127 B	US 150	6	4	2	12	0.75
Bullitt	US 31 E	KY 44	6	11	16	33	1.54
Carter	US 60	KY 1	1	6	4	11	0.76
Carter	KY 1	I-64	6	11	4	21	1.05
Christian	US 41	KY 1682	14	7	7	28	2.03
Christian	US 41	KY 380	6	10	4	20	0.95
Christian	US 41 A	KY 911	11	10	8	29	1.14
Christian	US 41 A	Gate Four	15	5	10	30	0.69
Christian	US 41 A	KY 400	8	5	3	16	0.34
Christian	US 41 A	KY 117	4	3	6	13	0.74
Clark	KY 1958	KY 1927	3	1	3	7	0.39
Daviess	KY 54	KY 1456	1	4	5	10	0.60
Daviess	US 60	KY 331	4	4	2	10	0.62
Daviess	US 60	KY 144	4	4	12	20	0.68
Fayette	US 60	Ft. Harrods Drive	4	4	4	12	0.36
Fayette	US 60	Elkhorn Drive	16	13	8	37	1.36

TABLE 1. GES LOCATIONS (continued)

COUNTY	INTERSECTING ROUTE	ROUTE	ACCIDENTS* 1991	1992	1993	TOTAL	ACCIDENT RATE (ACC/MV)
Fayette	US 25	Oakwood Drive	2	0	0	2	0.11
Fayette	KY 922	Nandino Blvd.	15	8	4	27	0.63
Fayette	US 60	Man-O-War Blvd.	14	16	14	44	1.02
Fayette	US 27	Southpoint Drive	6	5	2	13	0.28
Fayette	KY 922	Sugar Maple Lane	8	5	2	15	0.36
Fayette	US 25	Jerrico Drive	6	5	4	15	0.50
Fayette	US 60	Eastland Pkwy.	9	6	3	18	0.63
Fayette	US 60	I-75	6	6	6	18	0.65
Fayette	US 60	Keeneland	9	6	4	19	0.47
Fayette	KY 922	Holiday Inn	4	1	1	6	0.16
Fleming	KY 11	KY 32	0	0	4	4	0.50
Floyd	KY 80	KY 122	4	0	2	6	0.36
Floyd	US 23	KY 979	4	4	6	14	0.61
Floyd	US 23	Velocity Mkt.	3	1	2	6	0.30
Floyd	US 23	KY 2555	1	3	0	4	0.22
Floyd	US 23	KY 1428	1	5	4	10	0.45
Franklin	KY 676	Limestone Drive	5	2	7	14	0.62
Franklin	KY 676	KY 1659	6	3	10	19	0.82
Franklin	US 127	Franklin Square	3	5	3	11	0.42
Franklin	US 60	KY 2817	1	4	1	6	0.51
Franklin	US 127	US 421	5	5	4	14	0.33
Franklin	KY 676	Collins Lane	4	7	7	18	0.88
Franklin	US 421	Schenkel Lane	16	8	6	30	1.09
Franklin	US 60	I-64	1	4	0	5	0.23
Graves	US 45	KY 1276	5	4	1	10	0.61
Greenup	US 23	KY 1725	4	1	2	7	0.25
Greenup	US 23	KY 2	2	3	0	5	0.25
Hancock	US 60	KY 657	1	1	0	2	0.25
Hardin	US 31 W	KY 313	0	6	5	11	0.44
Hardin	US 31 W	KY 61	1	3	4	8	0.64
Hardin	KY 3005	Pear Orchard Road	0	3	2	5	0.32
Hardin	US 31 W	KY 3005	14	16	13	43	1.05
Hardin	US 31 W	Towne Center	11	14	13	38	0.89
Hardin	US 62	KY 3005	11	6	7	24	1.04
Hardin	US 62	French Street	5	5	6	16	0.98
Hardin	US 31 W	Elizabethtown Mall	2	1	3	6	0.14
Hardin	US 31 W	KY 434	5	7	9	21	0.72
Hardin	US 31 W	Elm Street	3	5	2	10	0.28
Hardin	US 31 W	Blackjack	8	4	4	16	0.77
Harlan	US 421	KY 72	2	2	4	8	0.28
Harlan	US 119	KY 179	1	2	0	3	0.29
Harlan	US 421	Central Street	9	1	1	11	0.43
Henderson	US 41	Watson Lane	13	9	9	31	0.64
Henderson	US 41	Marywood Drive	6	5	5	16	0.33
Henderson	US 60	KY 136 - KY 425	0	2	3	5	0.36

TABLE 1. GES LOCATIONS (continued)

COUNTY	INTERSECTING ROUTE	ROUTE	ACCIDENTS* 1991	1992	1993	TOTAL	ACCIDENT RATE (ACC/MV)
Hopkins	US 41 A	KY 336	3	3	8	14	0.65
Jefferson	US 42	Fox Harbour Drive	2	4	9	15	0.37
Jefferson	US 42	KY 22	11	8	14	33	1.16
Jefferson	KY 1934	Lower Hunters Trace	3	6	1	10	0.54
Jefferson	US 60	Snyder Freeway	6	10	10	26	1.73
Jefferson	US 31 E	Cedar Look Drive	1	0	0	1	0.03
Jefferson	US 31 W	Watson Lane	14	4	13	31	1.18
Jefferson	US 60	English Station Road	1	2	0	3	0.20
Jessamine	US 27	US 27 X	7	4	6	17	1.29
Jessamine	US 27	US 27 X	18	9	11	38	1.44
Jessamine	US 27	Catnip Hill Road	8	4	7	19	0.49
Jessamine	US 27 X	KY 169	2	10	9	21	0.88
Jessamine	US 27	Edgewood Drive	2	1	3	6	0.34
Jessamine	US 27	Shun Pike	0	2	4	6	0.32
Jessamine	US 27	Etter Drive	7	0	3	10	0.56
Kenton	KY 17	KY 1303	4	9	5	18	0.34
Kenton	KY 17	Dudley Road	4	2	6	12	0.33
Knox	US 25 E	KY 1629	4	6	4	14	0.87
Knox	US 25 E	KY225	2	3	0	5	0.21
Knox	US 25 E	KY 312	15	14	7	36	1.81
Knox	US 25 E	KY 11	3	8	8	19	0.73
Larue	KY 61	KY 84	3	3	1	7	0.58
Larue	KY 31 E	KY 61	1	2	1	4	0.48
Laurel	US 25	KY 192	13	19	15	47	1.10
Laurel	US 25 E	US 25	7	10	7	24	0.59
Laurel	KY 192	KY 363	11	8	2	21	0.96
Laurel	KY 192	KY 1006	5	1	8	14	0.55
Laurel	KY 80	KY 192	3	6	5	14	0.82
Laurel	KY 9006	KY 472	3	4	3	10	0.49
Laurel	KY 192	KY 229	3	2	2	7	0.35
Laurel	US 25 E	KY 1223	5	10	8	23	0.93
Lawrence	US 23	KY 3	5	1	3	9	0.78
Lawrence	KY 3	KY 2565	5	2	11	18	1.36
Lawrence	KY 3	KY 2566	3	1	4	8	0.66
Lincoln	US 27	US 150	10	13	18	41	2.30
Lincoln	US 27	KY 1247	4	1	6	11	1.24
Lyon	US 62	KY 93	2	3	3	8	0.74
McCracken	US 62	US 68	2	4	7	13	0.60
McCracken	US 45	KY 1322	1	1	1	3	0.13
McCreary	US 27	KY 478	3	2	3	8	0.59
McCreary	US 27	KY 92	6	2	4	12	1.03
Marshall	US 62	KY 9003	9	5	4	18	1.20
Marshall	US 641	KY 80	9	4	8	21	1.37
Marshall	US 641 A	KY 58	0	1	0	1	0.19
Marshall	US 62	KY 95	6	2	3	11	1.20

TABLE 1. GES LOCATIONS (continued)

COUNTY	INTERSECTING ROUTE	ROUTE	ACCIDENTS* 1991	1992	1993	TOTAL	ACCIDENT RATE (ACC/MV)
Mason	US 62	KY 10	7	8	3	18	0.72
Meade	US 31 W	KY 1638	0	0	6	6	0.22
Meade	US 31 W	US 60	0	1	4	5	0.19
Muhlenberg	KY 181	KY 189	3	4	5	12	0.91
Muhlenberg	KY 189	Green Drive	4	3	5	12	0.72
Nelson	US 62	KY 245	1	3	3	7	0.38
Perry	KY 15	KY 9006	4	6	11	21	1.01
Perry	KY 9006	Hazard Village Shopping	0	0	1	1	0.10
Perry	KY 15	Hazard Bypass	5	7	3	15	0.70
Perry	KY 15	Hazard Bypass	3	2	5	10	0.50
Perry	KY 9006	Morton Blvd.	0	0	1	1	0.10
Perry	KY 15	Black Gold Blvd.	0	0	1	1	0.06
Pike	US 23	Weddington Plaza	0	2	6	8	0.28
Pike	US 23	Weddington Plaza	8	8	2	18	0.62
Pike	US 23	Shoney's	4	6	1	11	0.48
Pike	US 23	KY 1426	0	4	1	5	0.14
Pike	US 23	US 119	1	4	5	10	0.26
Pike	US 119	KY 1426	2	2	1	5	0.40
Pike	US 119	Southside Mall	2	3	2	7	0.33
Pulaski	US 27	KY 1642	4	6	7	17	0.46
Pulaski	US 27	KY 2292	1	5	2	8	0.20
Pulaski	US 27	Grand Central Place	8	11	7	26	1.08
Pulaski	US 27	KY 1642	8	6	6	20	0.54
Pulaski	US 27	KY 90	5	8	5	18	0.79
Pulaski	KY 80 B	KY 39	8	6	10	24	1.29
Pulaski	KY 9008	KY 3263	1	2	1	4	0.22
Rowan	KY 32	Fraley Drive	2	3	6	11	0.45
Russell	US 127	KY 80	0	3	3	6	0.27
Russell	US 127	KY 619	4	1	2	7	0.54
Simpson	US 31 W	KY 1788	1	0	0	1	0.09
Taylor	US 68	KY 55	6	10	14	30	1.51
Taylor	KY 55	KY 3138	3	1	3	7	0.66
Warren	US 231	KY 622	2	1	7	10	0.60
Warren	US 231	Cypresswood Way	0	1	1	2	0.13
Warren	US 231	KY 880	4	8	21	33	0.89
Warren	US 31 W	KY 1402	8	13	10	31	1.10
Warren	KY 446	Corvette Plant	2	5	2	9	0.60
Washington	US 150	KY 555	7	9	11	27	1.43
Wayne	KY 90	KY 90 X	0	8	4	12	0.67
Wayne	KY 90	KY 1275	2	4	6	12	1.26
Wayne	KY 90	KY 92	0	6	7	13	1.16
Wolfe	KY 15	KY 191	6	4	2	12	0.99
Woodford	US 60	Big Sink Pike	13	4	10	27	1.05
Woodford	US 60	Merewood Drive	4	7	5	16	0.63
Woodford	US 60	Paddock Drive	2	1	1	4	0.16
Woodford	US 60	Huntertown Road	16	4	2	22	0.54

* Based on computer data. Must be verified with manual search of accident reports.

TABLE 2. GES LOCATIONS WITH CRITICAL ACCIDENT RATE

COUNTY	INTERSECTING ROUTE	ROUTE	ACCIDENTS* 1991	1992	1993	TOTAL	CRITICAL ACCIDENT RATE
Lincoln	US 27	US 150	10	13	18	41	2.30
Christian	US 41	KY 1682	14	7	7	28	2.03
Knox	US 25 E	KY 312	15	14	7	36	1.81
Jefferson	US 60	Snyder Freeway	6	10	10	26	1.73
Allen	US 31 E	US 231	7	4	10	21	1.70
Bullitt	US 31 E	KY 44	6	11	16	33	1.54
Taylor	US 68	KY 55	6	10	14	30	1.51
Jessamine	US 27	US 27 X	18	9	11	38	1.44
Washington	US 150	KY 555	7	9	11	27	1.43
Marshall	US 641	KY 80	9	4	8	21	1.37
Allen	US 60	Elkhorn Drive	16	13	8	37	1.36
Lawrence	KY 3	KY 2565	5	2	11	18	1.36
Allen	US 31 E	KY 100	2	3	5	10	1.35
Pulaski	KY 39	KY 80 B	8	6	10	24	1.29
Jessamine	US 27	US 27 X	7	4	6	17	1.29
Wayne	KY 90	KY 1275	2	4	6	12	1.26
Lincoln	US 27	KY 1247	4	1	6	11	1.24
Boone	US 42	KY 237	7	7	6	20	1.21
Marshall	US 62	KY 95	6	2	3	11	1.20
Marshall	US 62	KY 9003	9	5	4	18	1.20
Jefferson	US 31 W	Watson Lane	14	4	13	31	1.18
Wayne	KY 90	KY 92	0	6	7	13	1.16
Jefferson	US 42	KY 22	11	8	14	33	1.16
Christian	US 41 A	KY 911	11	10	8	29	1.14
Laurel	US 25	KY 192	13	19	15	47	1.10
Warren	US 31 W	KY 1402	8	13	10	31	1.10
Franklin	US 421	Schenkel Lane	16	8	6	30	1.09
Pulaski	US 27	Grand Central	8	11	7	26	1.08
Hardin	US 31 W	KY 3005	14	16	13	43	1.05
Carter	KY 1	I-64	6	11	4	21	1.05
Woodford	US 60	Big Sink Pike	13	4	10	27	1.05

* Based on computer data. Must be verified by manual search of accident reports.

TABLE 3. CONFLICT DATA

COUNTY	INTERSECTING ROUTE	ROUTE	APPROACH	SPEED LIMIT (MPH)	TYPE OF SYSTEM	NUMBER OF CONFLICTS * RAN RED	ABRUPT STOP	ACCELERATION THROUGH YELLOW
Bell	US 25 E	KY 441	North	45	GES	3	0	2
Boyd	US 60	KY 766	West	55	GES	0	0	0
Christian	US 41	KY 1682	South	55	GES	1	1	0
	KY 1682	US 41	East	55	None	1	0	0
Clay	US 421	KY 80	South	45	None	2	1	0
Fayette	US 60	Elkhorn	East	55	GES	4	1	1
	US 60	Man O' War	East	55	GES	5	0	1
	US 60	Man O' War	West	55	GES	12	3	0
	US 27	Man O'War	North	45	None	3	0	0
	US 27	Southpoint	North	45	GES	3	1	0
	KY 1974	Man O' War	North	45	GES	0	1	0
	KY 922	Nandino	North	50	GES	5	1	0
	KY 922	Nandino	South	50	GES	7	0	0
Floyd	US 23	KY 979	South	55	GES	4	2	0
	US 23	KY 1428	North	55	GES	2	0	0
	US 23	KY 1428	South	55	GES	3	1	0
	KY 80	KY1210	East	55	AWF	4	0	0
	KY 80	KY1210	West	55	AWF	2	0	0
Franklin	US 60	Schenkle	North	55	GES	0	0	0
	US 60	Hanley	West	50	None	3	0	2
Green	US 68	KY 61	East	55	None	2	0	0
	US 68	KY 61	West	55	None	2	0	0
Greenup	US 23	KY 750	North	45	AWF	0	0	0
	US 23	KY 750	South	45	AWF	1	1	0
	US 23	KY 207	North	45	None	5	1	0
	US 23	KY 207	South	45	None	9	0	0
Hardin	US 31 W	KY 434	West	55	GES	13	1	2
	US 31 W	KY 434	South	55	GES	2	0	0
	US 31 W	US 31 W B	North	45	GES	12	1	2
	US 62	KY 3005	North	45	GES	2	1	0
Jefferson	US 31 W	Pendleton	North	50	None	8	0	1
	US 31 W	Pendleton	South	50	None	4	1	0
	US 31 W	Flowervale	North	50	None	8	1	0
	US 31 W	Flowervale	South	50	None	7	0	1
	US 31 W	Watson Lane	South	50	GES	4	0	0
	KY 1065	Nat'l Turnpike	East	55	None	2	0	0
	KY 1065	Nat'l Turnpike	West	55	None	2	0	1

TABLE 3. CONFLICT DATA (continued)

COUNTY	INTERSECTING ROUTE	ROUTE	APPROACH	SPEED LIMIT (MPH)	TYPE OF SYSTEM	NUMBER OF CONFLICTS * RAN RED	ABRUPT STOP	ACCELERATION THROUGH YELLOW
Jessamine	US 27	US 27 X	North	55	GES	1	0	0
	US 27	US 27 X	South	55	GES	1	1	0
	US 27	KY 169	North	55	GES	3	0	1
	US 27	KY 169	South	55	GES	7	0	0
Knox	US 25 E	US 312	South	45	GES	0	0	1
Laurel	KY 192	US 25	East	55	GES	1	1	0
Lawrence	KY 3	KY 32	North	45	GES	0	0	0
	US 23	KY 3	North	45	GES	2	0	0
Lincoln	US 27	US 150	North	35	GES	0	0	0
Lyon	US 62	KY 93	East	45	GES	0	1	0
Madison	KY 876	KY 52	East	45	None	1	0	1
	KY 876	KY 52	West	45	None	2	0	1
Marshall	US 62	Purchase Pkwy	East	55	GES	0	0	1
	US 641	KY 80	South	55	GES	0	0	0
Perry	KY 15	KY 15 B	North	45	GES	0	0	0
Pike	US 119	KY 1426	North	55	GES	4	0	3
	US 119	Mill Road	South	45	GES	3	0	2
Rowan	US 60	Trumbo	East	55	GES	0	0	0
	US 60	Trumbo	West	55	GES	0	0	0
Warren	US 31 W	KY 1402	East	55	GES	3	0	1
Washington	US 150	KY 55	North	55	GES	3	0	0
Woodford	US 60	Huntertown	East (1)	55	GES **	24	0	3
	US 60	Huntertown	East (2)	55	GES	7	4	0
	US 60	Huntertown	West (1)	55	GES **	14	0	0
	US 60	Huntertown	West (2)	55	GES	3	0	0
	US 60 X	Merewood	East	55	GES	3	0	1

* The number of the 100 cycles, or change intervals, for which data were collected in which one or more of these conflicts occurred.
** GES not functioning.

TABLE 4. SUMMARY OF STOPPING DATA

DISTANCE FROM INTERSECTION (FEET)	AUTOMOBILE	PERCENT STOPPED TYPE OF VEHICLE SINGLE-UNIT TRUCK	COMBINATION TRUCK
Less than 126	1.6	1.4	1.7
126-175	17.9	11.8	16.0
176-225	63.8	50.0	25.0
226-325	85.3	79.1	62.3
326-400	94.3	93.3	86.8
401-500	97.0	98.1	92.6
Over 50	99.7	100.0	99.2

APPENDIX

REVIEW OF LITERATURE

"A Study of the Use and Operation of Advance Warning Flashers at Signalized Intersections," Minnesota Department of Transportation, November 1992.

The study concluded that Advanced Warning Flashers (AWF) can be useful in reducing right-angle and rear-end accidents at high speed intersections. For locations having a higher than average number of accidents, AWFs tend to reduce the accident rate. However, AWF devices should only be installed in response to a specifically correctable problem and not in anticipation of a future problem. In general, dynamic devices should be used sparingly since overuse might tend to reduce their effectiveness. Use of this device is not recommended at low speed approaches (under 45 mph).

A survey of the procedures used by various agencies did not identify a clearly superior location/operations scheme. No standard policy or criteria for installation or operation was evident from the survey. A comparison of schemes used in Minnesota resulted in the recommendation to use the less expensive location/operations scheme at a minimum setback distance of 550 feet. The recommended AWF timing is based on a travel distance from a sign recognition point immediately downstream of the decision zone. The sign recognition point is 1.3 seconds upstream of the AWF. The decision zone is defined as the 90 percent probability of stopping point (5.0 seconds upstream from the stopbar, 400 feet) and the 90 percent probability of not stopping (2.5 seconds from the stopbar, 200 feet).

The proposed method uses the 550-foot AWF location and places the main street detector approximately 840 feet upstream of the stop bar. Before leaving main street green, the AWF flashing period is timed, adding 7 to 12.5 seconds to the main street green. The optimized location scheme is based on an "empty area" produced immediately in front of the approach detectors at the beginning of AWF flash operation produced by traffic signal controller phase gap-out. The location of the detector and the time settings allow the "empty area" to move toward the stop bar as the AWF times. The optimized condition is produced when the gap produced "empty area" overlaps the "decision zone" at the instant that the AWF times out and the main street yellow time begins.

A red violation study was performed. The study involved counting the number of vehicles which entered the intersection during the red indication and the number of cycles. The red violation ratio was used as an indication of intersection decision zone performance. The red violation study indicated that the highest percentage of violations occurred at the non-AWF equipped intersection with substantially lower percentages at the AWF locations.

The agency usage survey determined approximately 350 signs. All types of signs were in use. The three largest users of AWF equipment were the States of Maryland (100), Ohio (64) and Connecticut (35). The most popular signs were "Be Prepared to Stop When Flashing", "Symbolic Signal Ahead" sign and the "Prepare to Stop When Flashing" sign. The majority of sign legend sizes were 6, 8 and 10 inches. The sign locations ranged from 180 to 1,400 feet from the intersection with the most frequent locations ranging from 600 to 800 feet. The locations listed for traffic signal detectors included 450 feet upstream, 5 to 7 seconds upstream of the stop bar at the approach speed, at the stop bar, and at the upstream end of the dilemma zone. AWF operation was almost equally split between: 1) beginning flasher operation near the end of green and continuing through the yellow and red and reset at the next beginning of green and 2) beginning flasher operation at the beginning of yellow continuing through the yellow and red and reset at the next occurrence of green. Times ranging from 4 to 13 seconds prior to the start of the yellow were given. Fail safe units were not normally used with AWF equipment. No tort liability problems were reported.

"Supplemental Advance Warning Devices - A Synthesis of Highway Practice," National Cooperative Highway Research Program Synthesis 186, 1993.

This synthesis describes the state of the art with respect to traffic control devices used to provide motorists with advance warning of various roadway situations. This was accomplished through a questionnaire. One category used was for "signal changes". The purpose of this type of advance warning device was to warn motorists that a stop is required at a signalized intersection where the approach has insufficient sight distance to the signal heads or where high speeds create excessively large dilemma zones.

The survey identified 10 different text messages currently used by 10 states and five cities. The most widely used message is "Prepare to Stop When Flashing" which was noted to be used in six different configurations. Of the 15 agencies found to use this type of device, three states and one city use more than one device to warn of signal changes. The survey revealed that 23 percent of the agencies responding to the questionnaire used this type of device.

"Active Advance Warning Signs at High-Speed Signalized Intersections: Results of a Study in Ohio," Transportation Research Record 1368, 1992.

The effectiveness of several active warning signs at high-speed signalized intersections in Ohio was evaluated. The signs included Prepare to Stop When Flashing (PTSWF), Flashing Symbolic Signal Ahead (FSSA), Continuously Flashing Symbolic Signal Ahead (CFSSA), and Passive Symbolic Signal Ahead (PSSA) signs. The measures of effectiveness included vehicular speeds at various segments of the intersection approach, vehicle conflict rates, and ratings by drivers.

The study revealed that the effects on drivers varied among intersections with tangent and curved approaches. The PTSWF or FSSA signs generally encouraged high speeds when the flasher was inactive and when the signal indication was either green or yellow. Fewer motorists related the PTSWF sign to the traffic signal. In general, active advance warning signs should be discouraged at high-speed signalized intersections, particularly at intersections with a tangent approach. At high-speed signalized intersections with a curved approach, the CFSSA sign was preferable to the PTSWF sign for reducing speed.

"Active Advance Warning Signs at High-Speed Signalized Intersections: A Survey of Practice," Transportation Research Record 1010, 1985.

A literature review and a survey of current practice were combined to obtain a synthesis of practice on active warning devices. Hidden intersections and rural expressways where signals are unexpected are the two circumstances creating problems at high-speed signalized intersections. Rear-end accidents are the major problem, followed by right-angle accidents and red violations. Although results indicated that truck accidents were not a significant problem, 59 percent of the state agencies indicated that trucks were given special consideration. Only when conventional countermeasures such as detectors or continuously flashing Signal Ahead signs fail to solve the problem will agencies use dynamic devices. Active devices are installed selectively so that their effectiveness is not diminished by overuse.

The most popular dynamic devices are the flashing Red Signal Ahead sign, the Prepare to Stop When Flashing sign, and flashing strobe lights. At the state level, the flashing Red Signal Ahead sign was the most widely used dynamic device with more than 300 installations nationwide. More than 200 Prepare to Stop When Flashing signs were reported with more than one-half of these being ground mounted. Only 12 strobe installations were reported nationwide.

In general, the flashing Red Signal Ahead signs was the most effective dynamic sign. Flashing strobe lights were the least effective of the three active devices. It was concluded that activation of flashing near the end of green is more effective than activation at the beginning of yellow. For state agencies, about two-thirds of the dynamic devices were activated at a predetermined time before the start of red. There are no general warrants or guidelines for the use of active warning devices at high-speed signalized intersections.

The overhead Prepare to Stop When Flashing sign was the most expensive to install, costing about $5,000 per intersection approach. The ground-mounted Prepare to Stop When Flashing signs and flashing Red Signal Ahead signs had approximately the same installation costs of $2,500. The most costly devices to maintain were the overhead and ground-mounted Prepare to Stop When Flashing signs.

"Driver Response to Active Advance Warning Signs at High-Speed Signalized Intersections, FHWA/RD-86/130, FHWA, October 1985.

A driving simulator was used to test various aspects of driver awareness under simulated high speed situations. The signs included Red Signal Ahead and Prepare to Stop When Flashing signs and passive Symbolic Signal Ahead signs. The results showed that the symbolic signal ahead sign with flashers had the greatest identification. No difference was noted between ground mounted and overhead signs. All of the active devices were better than the passive devices.

"Evaluation of High Speed Isolated Signalized Intersections in California," FHWA-PB91-229344.

The Red Signal Ahead, Symbolic Signal Ahead signs with flashers and Prepare to Stop When Flashing signs were evaluated as accident countermeasures at isolated high speed signalized intersections in California. Only the Prepare to Stop When Flashing sign was connected to the traffic signal to start the flashing operation. High speed approaches with the advance warning flashers had significantly lower accident rates than those with no such devices.

"Evaluation of the Flashing Red Signal Ahead Sign," Maryland, PB84-154533.

The sign evaluated was a sign with a red neon "red" legend and a static "signal ahead" legend. The red sign is displayed starting near the end of the green and continues through the red signal. This sign is used at locations with limited sight distance. The accident analysis indicated that right angle accidents were reduced after installation of the signs but rear end and total accidents tended to show increases. It was noted that this sign is not in common use in other states and is being replaced in Maryland.

"Truck Characteristics for Use in Highway Design and Operation," Federal Highway Administration, FHWA-RD-89-226, August 1990.

Highway geometric design and traffic operations are based in part on consideration of vehicle characteristics. This report reviews truck characteristics that need to be considered. Relative to vehicle change intervals, the finding was that trucks require vehicle change intervals between 40 and 110 percent longer than passenger cars, depending on approach speed, approach grade, and intersection width. However, existing guidelines for vehicle change interval timing should not be revised without an analysis to assess the extent of operational and safety problems that would be created by reduced levels of service at intersections.