Research Report
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GREEN-EXTENSION SYSTEMS AT HIGH-SPEED INTERSECTIONS

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Synopis. The purpose of this study was to determine the effectiveness of green-extension systems (GES) for reducing the dilemma-zone problem associated with the amber phase of traffic signals at high-speed intersections. Reactions of 2,100 drivers were noted during the amber phase at nine intersections, and the dilemma-zone distances with respect to the stop bar were determined.

Before-and-after studies made at three green-extension sites showed a 54-percent reduction in total accidents and a 75-percent reduction in rear-end accidents after GES installation. Accident severity was unaffected.

Conflict, volume, delay, and speed data were taken before and after GES installation at two sites. A 62-percent reduction in yellow-phase conflicts was noted after green extension was provided, and conflict rates decreased significantly at both sites. No significant change was found in vehicle delay due to green extension.

Expected present-worth benefits due to GES installations were found to range from \$29,000 to \$420,000, depending on the history of rear-end accidents. Benefit-cost ratios ranged from 6 to 70.

When approaching a traffic signal during the green phase in the general range of 35 to 55 mph (15.6 to 24.6 m/s), a driver confronts the alternative of proceeding through the intersection or anticipating a change to amber and attempting to stop, referred to as the "dilemma zone" with reference to the decision-making required by the driver. Inappropriate decisions by some drivers result in numerous rear-end and right-angle collisions at intersections where the flow of traffic is at a fairly high speed.

There have been attempts to decrease the number of rear-end and right-angle collisions by installing green-phase extension systems (GES systems) *(1)*. These systems include presence-detection loops in the pavement preceding the intersection which transmit messages to a receiver in the signal control box. An extension of the green phase occurs only if a vehicle is passing over the detector within an interval which has been predetermined as the dilemma zone. An extension of the green phase at this point permits the vehicle to proceed onward through the intersection without having to stop abruptly to avoid running a red light.

Kentucky presently has 25 intersections with various modifications of GES systems, and plans have been made for several more. While these systems should theoretically increase safety and reduce rear-end and right-angle accidents, very little data are available to verify their effectiveness. Also, since the green phase is extended on the major approaches only, delay would be expected to increase on the side streets. The extent of such added delay has not been determined for various traffic volumes.

Dilemma Zone. To determine the length of the dilemma zone, driver responses were recorded at nine high-speed intersections in Lexington and Louisville. All intersections were on four-lane, divided arterials. At each approach, distances were measured from the stop bar to the end points of each dashed-type lane stripe back to about 600 feet (183 m). A state car was parked on the right shoulder about 200 feet (61 m) back from the intersection.

Two observers were used to record the data: one monitored the speed of each vehicle approaching the intersection, and the other watched for the yellow indication. The instant that the yellow was displayed, the location of any vehicle within 600 feet (183 m) of the intersection was observed in terms of a specific paint stripe. The vehicle speed was also recorded along with the vehicle type and whether it stopped or proceeded through the intersection. Responses of about 2,100 drivers to the yellow phase were recorded in this manner.

Motorists included in the data collection were travelling straight with no left- or right-turning vehicles included. No data were recorded under congested conditions or when the speed of a vehicle was influenced by any other vehicle. All classifications of vehicles were recorded, and trucks (six tires and larger) were analyzed separately from cars. No significant differences in driver reactions were noted between cars and trucks. However, only straight, level intersection approaches were used. The response of truck drivers on downgrade approaches should also be tested.

Responses were first grouped into 5-mph (2-m/s) intervals. The next data summary was by "stopping" and "non-stopping" vehicles. Ranges of distances of 10 feet (3 m) were used for tabulating the number of drivers in each group. A set of curves for speeds of 35 to 55 mph (16 to 25 m/s) was drawn from the data as shown in Figure 1.

The probability of stopping is shown for five different speeds as related to the distance of the vehicle from the intersection in Figure 1. At 55 mph (25 m/s), about 20 percent of all motorists will stop if the yellow appears when they are 255 feet (78 m) from the intersection. The dilemma zone has been defined as the distance interval with a probability of stopping between 10 and 90 percent *(1)*. For example, the dilemma zone for motorists travelling 45 mph (20 m/s) is from 152 to 325 feet (46 to 99 m).

Dilemma zone distances from the Kentucky data were compared with data reported by other investigators *(1, 2, 3, 4, 5, 6)*. The Kentucky data are very close to most of the references for a 10-percent stopping probability. At the 90-percent probability level, the distances for Kentucky data are slightly higher than the others at 35 to 45 mph (16 to 20 m/s). The high-speed distances are in close agreement with the other studies. The spacing of both loops of a two-loop GES system can be easily found for any vehicle speed from Figure 2. This figure was constructed using the distances corresponding to different speeds with probabilities of stopping of 10 and 90 percent from Figure 1.

The grade of an approach leg can significantly affect the stopping distances of vehicles. The formula for minimum safe stopping distances was used to determine adjustments to be used when computing loop distances:

$$D = 1.47\ Vt + V^2/30\ (f \pm G)$$

where D = minimum safe stopping distances,

V = vehicle speed in mph,

t = driver reaction time (2.5 seconds),

f = coefficient of friction (skidding) when wet, and

G = grade, in percent.

The coefficient of friction was assumed to be 0.3 and pertains to wet-road conditions at speeds around 60 mph (27 m/s). Comparing the minimum safe stopping distances (D) for vehicle speeds of 35 to 55 mph (16 to 25 m/s) with grades between -8 and +8 percent, a set of curves for adjusting loop distances was constructed as shown in Figure 3. The value of D for each grade was compared with the D of zero grade, and the difference was plotted for various speeds. These values are slightly higher (using 0.30 for f) than adjustments given by AASHTO *(7)*.

Use of Green-Extension Systems. Green-extension systems (GES) extend the green phase of a traffic signal to allow a vehicle or a platoon of vehicles to clear the intersection before the yellow indication is given. Green extension is normally installed on both intersection approaches of a major arterial street. However, they may be installed on only one approach in case of a steep downgrade or on all four approaches where two high-speed arterials intersect *(1, 8)*. Either two or three multilane, vehicle-detection loops are normally placed in advance of the signal on each approach. Two loops are the most common; three loops are sometimes needed on approaches with steep downgrades, where high truck volumes exist, or where average traffic speeds exceed 45 mph (20 m/s). Loop distances upstream from the stop bar should be based on the dilemma zone. The loop spacings usually correspond to travel times of about 2 to 5 seconds in advance of the stop bar. The 85th-percentile speed is normally used for determining loop spacings.

Loop 1 in a green extension setup refers to the first loop encountered by a vehicle approaching the intersection. In most cases, Loop 1 on one approach is connected in parallel to Loop 1 on the opposite approach. The second loops are connected in a similar manner. Such loops are made to cover all traffic lanes and are generally 4 feet long. The passage of a vehicle over Loop 1 activates the extension timer which stretches the green time for a pre-determined number of seconds. Another extension of green time is made after passage over Loop 2 to assure clearance of the vehicle through the intersection. More details of the operation of green extension systems are available from several sources *(1, 8, 9)*.

Installation of GES is considered when accidents (particularly rear-end type) occur at a high rate or when a stopping or dilemma-zone problem is found. Green extension is considered with the installation of a new signal when the intersection has a sight distance deficiency, excessive grade on one or more approaches, or where approach speeds exceed 40 mph (18 m/s).

The use of GES with an existing signal system is applied in three different manners in Kentucky. The ideal situation is in a rural area where traffic volumes are not high enough during any period of the day to cause congestion. Traffic speeds remain high and adequate gaps exist on the major street so that sufficient green intervals are given to side-street vehicles. In this case, the green extension is not preset to shut off for an excessive side-street delay. A second case is where traffic is generally free flowing except for certain times when traffic may temporarily become congested. In this case, a preset maximum time is used to cut off the extended green after a specified period (usually 99 seconds) and gives the green phase to the side street. The third situation involves traffic which is congested daily during morning and afternoon peak hours. In this case, the green light extension is automatically turned off during these times.

Accident Analysis. To determine the effect of green extension in reducing traffic accidents, before and after analyses were made at three sites. Sites used for these analyses must have had a green extension system installed at an existing signal location and have been in operation sufficiently long for after accident data to be available.

The first location analyzed was US 41A (four-lane, divided highway) at Gate 6 in Ft. Campbell in Christian County (AADT = 15,408). It was a three-phase, fully-actuated signal at a T-intersection with GES loop spacings on US 41A at 500 and 150 feet (154 and 46 m). The second location was US 25E at KY 312 in Corbin in Laurel County (AADT = 7,043). It was an eight-phase, fully-actuated signal at a four-way intersection with GES loop spacings on US 25E of 600, 500, and 175 feet (183, 154, and 53 m). The third location was on US 25E at KY 225 in Barbourville, Knox County (AADT = 11,000). It was a two-phase, fully-actuated signal at a four-way intersection. Loop spacings were set at 575 and 200 feet (175 and 61m).

Because of the small number of locations, accident data were gathered for several years before GES installation and all available after data were used to increase the sample size. For the accident analysis, a combined total of 8.5 years of before data and 3.7 years of after data were used for the three locations. There were a total of 70 accidents before GES and 14 accidents after, or 8.2 and 3.8 accidents per year, respectively. This was a reduction of about 4.4 accidents per year, or 54 percent.

Accidents were classified by type as shown in Table 1. Rear-end accidents were reduced about 75 percent (from 3.3 to 0.8 per year). Right-angle accidents decreased about 31 percent (from 3.9 to 2.7 per year), and other types of accidents experienced minor reductions. Summaries of property damage (PDO), injury, and fatal accidents are also shown in Table 1. The number of each type of accident was reduced approximately by a half after installation of GES.

To determine the change in severity of an average accident, the severity index was calculated *(10)*. Using the cost of each type of accident and injury and the number of accidents and injuries, weighting factors for the various injury types were obtained to compute a severity index:

$$SI = (9.5(K + A) + 3.5(B + C) + PDO)/N$$

where SI = severity index,

K = number of fatal accidents,

A = number of A-type injury accidents,

B = number of B-type injury accidents,

C = number of C-type injury accidents,

PDO = number of property damage only accidents, and

N = the total number of accidents.

Accidents by type of injury are given in Table 1 and were used to calculate the severity index. The severity index for the before period was 2.54; it was 2.57 after the GES installation. This is not surprising since rear-end accidents are usually not too severe and inasmuch as these types of accidents experienced the greatest reduction. The percentages of PDO, injury, and fatal accidents were also found to be virtually unchanged.

Data Collection. The next objective of this study was to determine the effect of green-extension systems on conflicts, speeds, and delays at high-speed, signalized intersections. To accomplish this, data were taken before and after installation of GES at two locations at which the only change between the before and after period was the addition of the GES. The two intersections selected were US 23 at Hoods Creek Pike in Ashland and US 27 at US 150 in Stanford. The sites offered contrasting geometric and traffic conditions and selected for GES installation because of high-speed, downgrade approaches and large numbers of right-angle and rear-end accidents. One day of before and after data were taken in Ashland. Two days of data collection were completed for each of the before and after periods at Stanford because of low traffic volumes. Data collection began at 8:00 a.m. and ended at 6:00 p.m. each day. Data were collected and recorded in 15-minute intervals. One 15-minute break was usually taken each hour. A 30- to 45-minute lunch break was also taken during each test day.

Traffic Conflict Analysis. A traffic conflict is a traffic violation or an evasive action, such as braking or weaving, which is forced upon a driver to avoid an accident. Traffic conflicts are measures of accident potential and operational problems. Conflicts may be used to quickly evaluate changes in road design, signing, signalization, and environment. Also, conflict studies can be completed with significant quantities of data in as little as two or three days of observation. An adequate sample of data for a before-and-after accident evaluation would take several years.

The first formal procedure for collection of traffic conflicts data was developed by the General Motors Research Laboratories in 1968 *(11)*. This procedure is currently the basis for routine collection of intersection conflicts in the states of Ohio, Virginia, and Washington, although modifications have been made *(12)*. The conflicts used in the study reported herein were revisions of the General Motors method and were adapted to the dilemma-zone problem. The six types of conflicts, which should theoretically be reduced by the installation of an effective green-extension system, included the following: run red light, abrupt stop, swerve-to-avoid collision, vehicle skidded, acceleration through yellow, and brakes applied before passing through the intersection.

Summaries of the numbers of conflicts at the two sites are shown in Table 2. In Ashland, there were 126 conflicts during the before period and 66 during the after period. The most frequent conflicts before GES was installed were run red light (89), abrupt stop (20), and brakes applied before passing through (10). During the after period, those conflicts totaled 52, 9, and 1, respectively.

In Stanford, the number of conflicts decreased from 123 to 19 after installation of GES. The majority of conflicts in the before period were acceleration through yellow (46), abrupt stop (39) and run red light (27). In the after period, those values were reduced to 9, 7, and 1, respectively. The conflicts at Stanford were for a total of 4 days of data collection, compared with only 2 days in Ashland.

To determine the statistical reliability that the GES reduces conflicts, a mean difference test (t-test) was used. The sampling periods were the 15-minute intervals for recording conflicts and volumes. The sample size, n, for Ashland was 29 in the before period (n_1) and 25 in the after period (n_2). The sample sizes for Stanford were 27 and 29. Where sample sizes are small (n less than 30), the normal distribution is not valid, and the t-test is applicable *(13)*.

The mean conflicts per 15-minute period in Ashland were 4.34 and 2.64 for the before and after periods, respectively. In Stanford, the mean decreased from 4.22 to 0.66 after green extension. The t values were 2.17 for Ashland and 7.00 for Stanford. This corresponds to a probability of only .05 that the reduction in conflicts in Ashland was due to chance variation. The probability level for Stanford was only 0.001.

Based on the mean number of conflicts per period, the number of conflicts per hour decreased after green extension from 17.4 to 10.5 in Ashland and from 8.4 to 1.3 in Stanford. This represents a reduction in conflicts of 40 percent in Ashland and 85 percent in Stanford. The average reduction in conflicts per hour at the two sites was 62 percent.

In Ashland, conflicts were few before 11:00 a.m. and were roughly the same before and after GES installation. The number of conflicts per hour then increased between noon and 1:00 p.m. to about

27 and 21 for the before and after periods, respectively. Conflicts then declined during early afternoon before peaking between 4:00 and 5:00 p.m. to 32 (before period) and 12 (after period) (Table 3). In Stanford, conflicts before GES installation varied between 6 and 9 per hour before increasing steadily up to 20 per hour from 3:00 until 6:00 p.m. The conflicts after green extension in Stanford remained between 0 and 3 per hour throughout the day (Table 4).

In Ashland, average hourly traffic volumes increased 15 percent from 1,398 in the before period to 1,610 in the after period (about 10 months later). In Stanford, a six-percent increase in hourly traffic volumes occurred during the after period from 425 to 452. As volumes increase during the day, conflicts also tend to increase. This can be seen more clearly in Tables 3 and 4, which give traffic volumes and conflicts by time of day for the before and after periods.

Plots of traffic conflicts per hour versus hourly traffic volumes at the Stanford site are shown in Figure 4. In Stanford, an r^2 of 0.73 indicated an excellent correlation between volume and conflicts during the before period. A lower correlation was found for the after period ($r^2 = 0.39$) where the conflicts were virtually insensitive to volume (practically a zero slope of the line). At the Ashland site, there was a positive, linear relationship between hourly conflicts and volumes during the before period where the r^2 value was 0.54. There was no correlation for the after data at Ashland ($r^2 = 0.02$) where the GES significantly reduced conflicts.

Because of the direct relationship between conflicts and volumes before the GES's were installed, the increase in volume during the after period would indicate an expected increase in conflicts if no improvements were made. The large decrease in conflicts in spite of the volume increase further illustrates the effectiveness of green extension in reducing traffic conflicts.

An analysis was made of conflicts and conflict rates for cars and trucks to further evaluate green extension. To compute conflict rates, random counts were made of the number of turning vehicles on the two major approaches of both intersections. Right- and left-turning vehicles accounted for about 42 and 20 percent in Stanford and Ashland, respectively. Traffic volumes were adjusted to compute "through" volumes on the major street at each intersection, which were divided into the number of conflicts to obtain conflicts per 1,000 through vehicles (Table 5).

In Ashland, the number of car conflicts decreased from 115 to 56; truck conflicts decreased slightly from 11 to 10. Conflict rates for cars decreased from 15.3 to 7.3 (conflicts/1,000 vehicles) but remained nearly the same for trucks (about 22). Truck conflict rates exceeded those for cars during both periods. The most common conflicts for cars and trucks in Ashland were running red light, although the number and rate of these conflicts were reduced to half after green extension was provided.

Truck conflict rates in Stanford were nearly double those of car rates in the before period (58 to 31). In the after period, the truck and car rates dropped to 3.8 and 5.1, respectively. Acceleration through yellow and abrupt stops were the most common conflicts for cars and trucks at Stanford in the before period, and they were drastically reduced by green extension. Note the conflict problem for all vehicles seems to have been solved in Stanford, while the dilemma-zone problem was not totally solved for trucks in Ashland.

An analysis of traffic conflicts by approach was also made at each intersection (Table 6). In Stanford, there were large reductions in conflicts -- 96 percent on the northbound approach (46 to 2) and 78 percent on the southbound approach (77 to 17). In Ashland, there was a 60-percent reduction on the southbound approach but only a 39-percent reduction on the northbound approach (this approach had a four-percent downgrade and limited sight distance). Both Stanford approaches are on about three-percent downgrades, and the sight distance is excellent on the northbound approach and only slightly limited by a railroad overpass on the southbound approach. This analysis suggested that sight distance may be a major safety concern at high-speed intersections.

The analysis for each approach showed that the conflict rate (conflicts per 1,000 through vehicles) in Stanford was about twice the rate in Ashland before green extension was provided. In Ashland, the rate dropped from 19.1 to 11.2 on the northbound approach and from 12.4 to 5.0 on the southbound approach. The rates in Stanford dropped from 33.8 to 1.2 and from 34.5 to 7.8 on the northbound and southbound approaches, respectively.

In any analysis employing traffic conflicts, an important consideration is rater consistency. Although great care was taken during field testing to rate conflicts consistently, an independent check was made in Ashland to determine reliability of the raters. Two raters independently counted conflicts on both approaches for 36 periods of 15 minutes each. The average number of conflicts per 15-minute period was 1.31 for Rater A and 1.36 for Rater B. The r^2 value was 0.75. Traffic conflict data were, therefore, judged to be highly reliable.

Traffic Efficiency. An important consideration in the installation of green extension systems is their effect on traffic flow. The indicators used in this analysis were traffic speeds (free-flow), vehicle delay, number of non-stopping vehicles on the side street (no-stops), and stopped vehicles on the side street. All comparisons were made between the before and the after conditions.

Traffic Speeds -- Average speeds at the Ashland site were 40.2 mph (18.0 m/s) in the before period (sample of 1,668 vehicles). During the after period, the average was 41.7 mph (18.6 m/s) (sample of 1,039 vehicles), an increase of 1.5 mph (0.7 m/s). Northbound vehicles (downhill approach) were about 3 mph (1.3 m/s) faster than southbound vehicles (level approach). In Stanford, speeds also increased slightly from 40.8 mph (18.2 m/s) to 43.6 mph (19.5 m/s) (sample sizes of 598 and 794). The grades and geometrics of both approaches are virtually identical.

Stopped Vehicles -- A t-test was used to determine whether there was a significant change in the number of stopped vehicles on the side street after green extension was provided. In all cases, there was no significant change in the number of stopped vehicles after green extension was provided.

Vehicle Delay -- Hourly delays were computed for side-street vehicles at each site in terms of total delay (seconds). Plots were made of total hourly delay versus time of day (Figures 5 and 6). At both sites, the before and after periods showed reasonably similar values throughout the testing day. However, at both sites, the after period had lower delays around the noon rush hour and higher delays during the afternoon rush hour. No significant increase was found in side-street delay at either site.

No-Stop Vehicles -- Another measure of traffic efficiency is the number of non-stopping vehicles on the side street. A reduction in the percentage of no-stop vehicles would suggest a reduction in the efficiency of traffic flow on the side street. The percentage of no-stops in Stanford during the before period was 28.3 compared to 23.0 during the after period. The average number of no-stops per hour for vehicles on the side street was 35.1 during the before period and 27.8 during the after period. There was a significant reduction in percent of no-stops within a 0.01 probability. Right-turning vehicles were not considered in this analysis due to the allowable right-turn-on-red in Kentucky. Reliable no-stop counts were not available for the Ashland site because the high traffic volumes kept the observers occupied with collection of other data.

Economic Analysis. The benefits of green extension were determined from an economic standpoint. The cost of an average accident to the highway user in Kentucky is $7,112. This cost was determined from National Safety Council accident cost data and the distribution of fatalities, injuries, and property damage accidents in Kentucky *(14)*. An annual interest rate of eight percent was selected. For installation of a green extension system to an existing signal system, initial cost is approximately $2,750; and maintenance costs for a 10-year period are about $500 per year.

Accident data showed that there was a 75-percent reduction in mainline, rear-end accidents after green extension was provided. This percentage was used with the $7,112 cost per accident to determine the annual accident savings for 1 to 12 rear-end accidents per year. While there were also small reductions in several other accident types, only the reduction in rear-end accidents was statistically significant (within 95-percent probability) *(15)*. Present-worth benefits, benefit-to-cost ratio, and total net benefits due to the installation of GES were computed for various numbers of rear-end accidents each year based on an estimated 10-year life. Benefit-cost ratios ranged from 6 for 1 rear-end accident per year to 70 for 12 rear-end accidents per year. Total net benefits which might be expected from green extension (over the 10-year life) varied from about $29,000 to over $420,000, depending on accident history.

In the economic analysis, no delay costs were included since there was no significant change in vehicle delay at the two sites investigated. However, there is a possibility of increased delay at some high-volume intersections after green extension is provided. The current policy in Kentucky is not to provide green extension wherever unusual traffic delays would result. If increases in delay are later found to be a direct result of green extension, delay costs should be considered in any economic analysis.

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TABLE 1. ACCIDENT SUMMARIES BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEMS (THREE LOCATIONS)

TYPE OF ACCIDENT	ACCIDENTS		ACCIDENTS PER YEAR	
	BEFORE PERIOD (8.5 YEARS)	AFTER PERIOD (3.7 YEARS)	BEFORE PERIOD	AFTER PERIOD
Rear End	28	3	3.3	0.8
Right Angle	33	10	3.9	2.7
Sideswipe	4	0	0.5	0.0
Other	5	1	0.6	0.3
Total	70	14	8.2	3.8
Property Damage Only	46	10	5.4	2.7
Injury	22 (44)*	4 (6)	2.6 (5.2)	1.1 (1.6)
Fatal	2 (3)	0 (0)	0.2 (0.4)	0 (0)
Total	70	14	8.2	3.8
Property Damage Only	46	10	64**	71**
C-type Injury	9	0		
B-type Injury	7	2	33**	29**
A-type Injury	6	2		
Fatal	2	0	3**	0**
Total	70	14	100**	100**
Severity Index	2.54	2.57		

*( ) Number of injuries
**Percent of total accidents

TABLE 2. DISTRIBUTION OF CONFLICTS BEFORE AND AFTER INSTALLATION OF GREEN-EXTENSION SYSTEMS

LOCATION	TYPE OF CONFLICT	BEFORE PERIOD NUMBER	BEFORE PERIOD PERCENT	AFTER PERIOD NUMBER	AFTER PERIOD PERCENT
Ashland (2 days of data)	Run red light	89	71	52	79
	Abrupt stop	20	16	9	14
	Vehicle swerved to avoid collision	0	0	0	0
	Vehicle skidded	0	0	3	5
	Acceleration through yellow	7	5	1	1
	Brakes applied before passing through	10	8	1	1
	Totals	126	100	66	100
Stanford (4 days of data)	Run red light	27	22	1	5
	Abrupt stop	39	32	7	37
	Vehicle swerved to avoid collision	2	2	0	0
	Vehicle skidded	3	2	0	0
	Acceleration through yellow	46	37	9	47
	Brakes applied before passing through	6	5	2	11
	Totals	123	100	19	100

TABLE 3. TRAFFIC VOLUMES AND CONFLICTS FOR THE ASHLAND SITE*

PERIOD	TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL) CARS	TRUCKS**	TOTAL	NUMBER OF CONFLICTS PER HOUR***
Before installation of GES system	8:00 to 9:00 a.m.	932	95	1,027	4
	9:00 to 10:00	853	85	938	11
	10:00 to 11:00	956	94	1,050	4
	11:00 to 12:00	1,222	84	1,306	21
	12:00 to 1:00 p.m.	1,320	83	1,403	26
	1:00 to 2:00	1,390	90	1,480	25
	2:00 to 3:00	1,548	96	1,644	23
	3:00 to 4:00	1,607	97	1,704	19
	4:00 to 5:00	1,431	75	1,506	32
	5:00 to 6:00	1,867	56	1,923	25
After installation of GES system	8:00 to 9:00 a.m.	1,188	72	1,260	8
	9:00 to 10:00	967	104	1,071	7
	10:00 to 11:00	1,051	100	1,151	9
	11:00 to 12:00	1,290	98	1,388	15
	12:00 to 1:00 p.m.	1,416	90	1,506	22
	1:00 to 2:00	1,471	97	1,568	7
	2:00 to 3:00	1,856	92	1,948	4
	3:00 to 4:00	1,853	113	1,966	8
	4:00 to 5:00	1,819	77	1,896	12
	5:00 to 6:00	2,290	52	2,342	9

*Based on 2 days of data collection
**Vehicles with six or more tires were classified as trucks
***Adjusted to hourly counts

TABLE 4. TRAFFIC VOLUMES AND CONFLICTS FOR THE STANFORD SITE*

PERIOD	TIME OF DAY	TRAFFIC VOLUMES (TWO-DIRECTIONAL) CARS	TRUCKS**	TOTAL	NUMBER OF CONFLICTS PER HOUR***
Before installation of GES system	8:00 to 9:00 a.m.	291	49	340	7
	9:00 to 10:00	328	46	374	6
	10:00 to 11:00	339	50	389	9
	11:00 to 12:00	324	62	386	6
	12:00 to 1:00 p.m.	319	51	370	9
	1:00 to 2:00	303	42	345	6
	2:00 to 3:00	329	55	384	6
	3:00 to 4:00	410	60	470	10
	4:00 to 5:00	554	58	612	13
	5:00 to 6:00	530	53	583	20
After installation of GES system	8:00 to 9:00 a.m.	389	61	450	3
	9:00 to 10:00	299	69	368	0
	10:00 to 11:00	316	67	383	0
	11:00 to 12:00	351	50	401	1
	12:00 to 1:00 p.m.	346	63	409	1
	1:00 to 2:00	344	62	406	2
	2:00 to 3:00	328	64	392	1
	3:00 to 4:00	440	65	505	1
	4:00 to 5:00	517	65	582	1
	5:00 to 6:00	567	54	621	4

*Based on 4 days of data collection
**Vehicles with six or more tires were classified as trucks
***Adjusted to hourly counts

TABLE 5. CONFLICT RATES

LOCATION	TYPE OF CONFLICT	BEFORE PERIOD NUMBER CARS	BEFORE PERIOD NUMBER TRUCKS	BEFORE PERIOD RATE (CONFLICTS PER 1,000 VEHICLES) CARS	BEFORE PERIOD RATE (CONFLICTS PER 1,000 VEHICLES) TRUCKS	AFTER PERIOD NUMBER CARS	AFTER PERIOD NUMBER TRUCKS	AFTER PERIOD RATE (CONFLICTS PER 1,000 VEHICLES) CARS	AFTER PERIOD RATE (CONFLICTS PER 1,000 VEHICLES) TRUCKS
Ashland (2 days of data)	Run red light	80	9	10.7	18.2	44	8	5.8	17.6
	Abrupt stop	18	2	2.4	4.0	8	1	1.0	2.2
	Vehicle swerved to avoid collision	0	0	0	0	0	0	0	0
	Vehicle skidded	0	0	0	0	2	1	0.3	2.2
	Acceleration through yellow	7	0	0.9	0	1	0	0.1	0
	Brakes applied before passing through	10	0	1.3	0	1	0	0.1	0
	Totals	115	11	15.3	22.2	56	10	7.3	22.0
Stanford (4 days of data)	Run red light	20	7	6.3	16.3	1	0	0.3	0
	Abrupt stop	31	8	9.8	18.6	6	1	1.8	1.9
	Vehicle swerved to avoid collision	2	0	0.6	0	0	0	0	0
	Vehicle skidded	3	0	0.9	0	0	0	0	0
	Acceleration through yellow	37	9	11.7	20.9	9	0	2.7	0
	Brakes applied before passing through	5	1	1.6	2.3	1	1	0.3	1.9
	Totals	98	25	30.9	58.1	17	2	5.1	3.8

TABLE 6. NUMBER OF CONFLICTS AND CONFLICT RATES AT TEST SITES

LOCATION	APPROACH	NUMBER OF CONFLICTS BEFORE PERIOD	NUMBER OF CONFLICTS AFTER PERIOD	NUMBER OF CONFLICTS PERCENT REDUCTION	CONFLICT RATE* BEFORE PERIOD	CONFLICT RATE* AFTER PERIOD	CONFLICT RATE* PERCENT REDUCTION
Ashland	Northbound	76	46	39	19.1	11.2	41
	Southbound	50	20	60	12.4	5.0	60
Stanford	Northbound	46	2	96	33.8	1.2	96
	Southbound	77	17	78	34.5	7.8	77

*Number of conflicts per 1,000 through vehicles

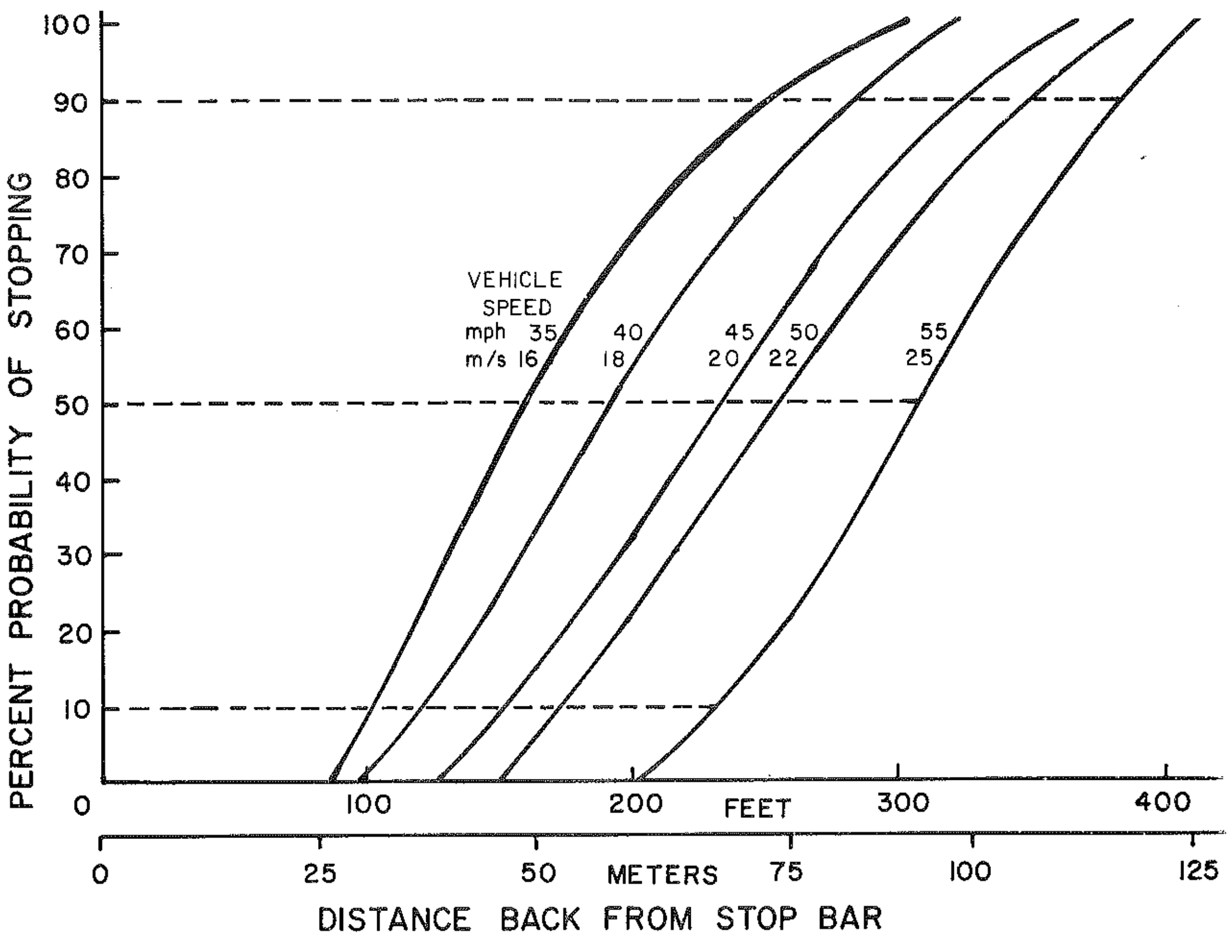
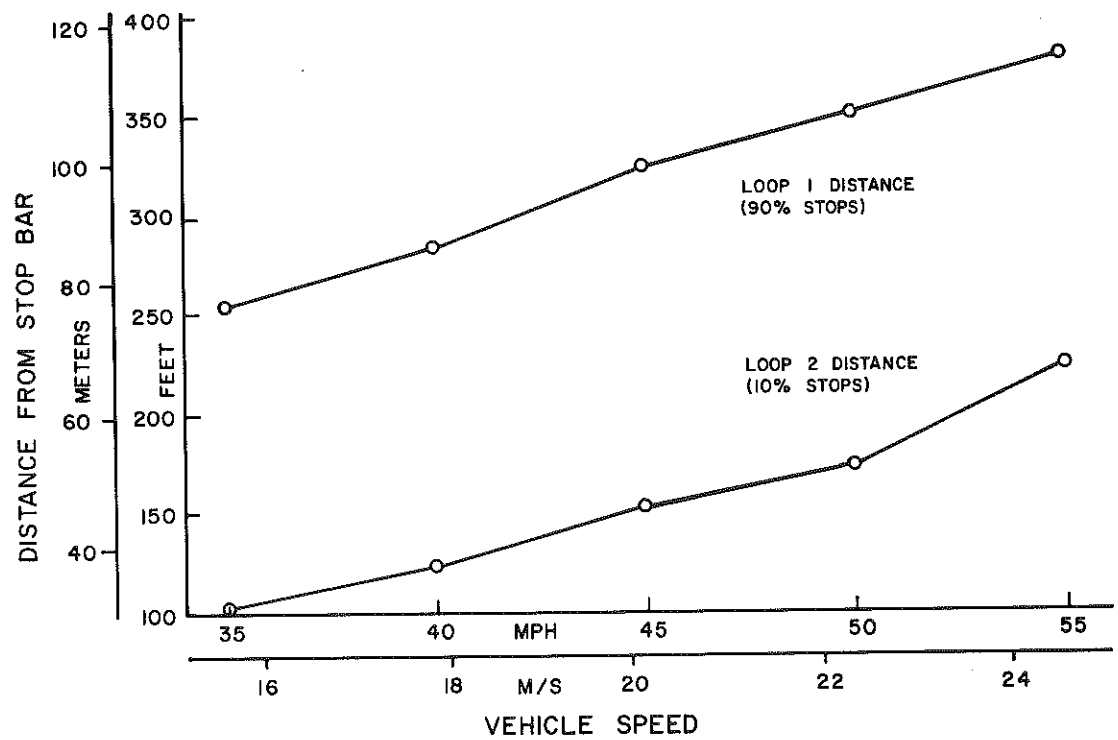


Figure 1. Dilemma-Zone Curves for Kentucky Drivers.

Figure 2. Proposed Vehicle-Loop Spacings for GES Systems.



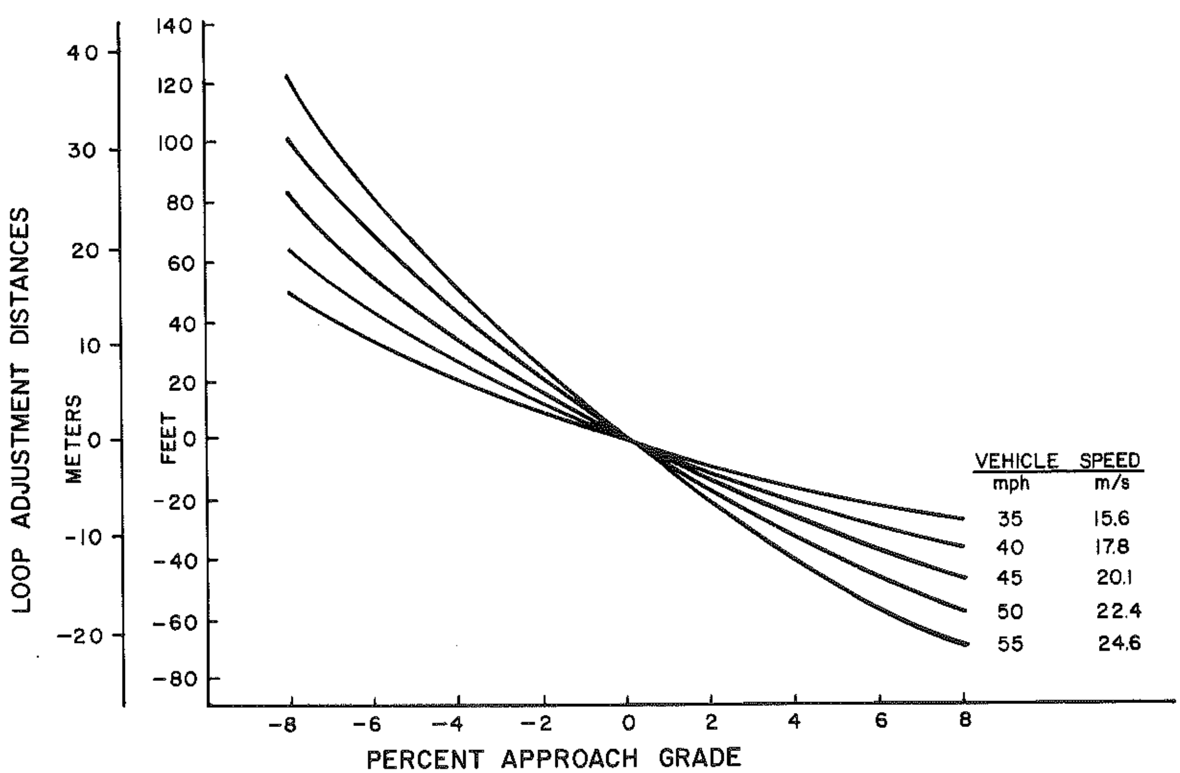


Figure 3. Adjustments for Loop Spacings for Approach Grades.

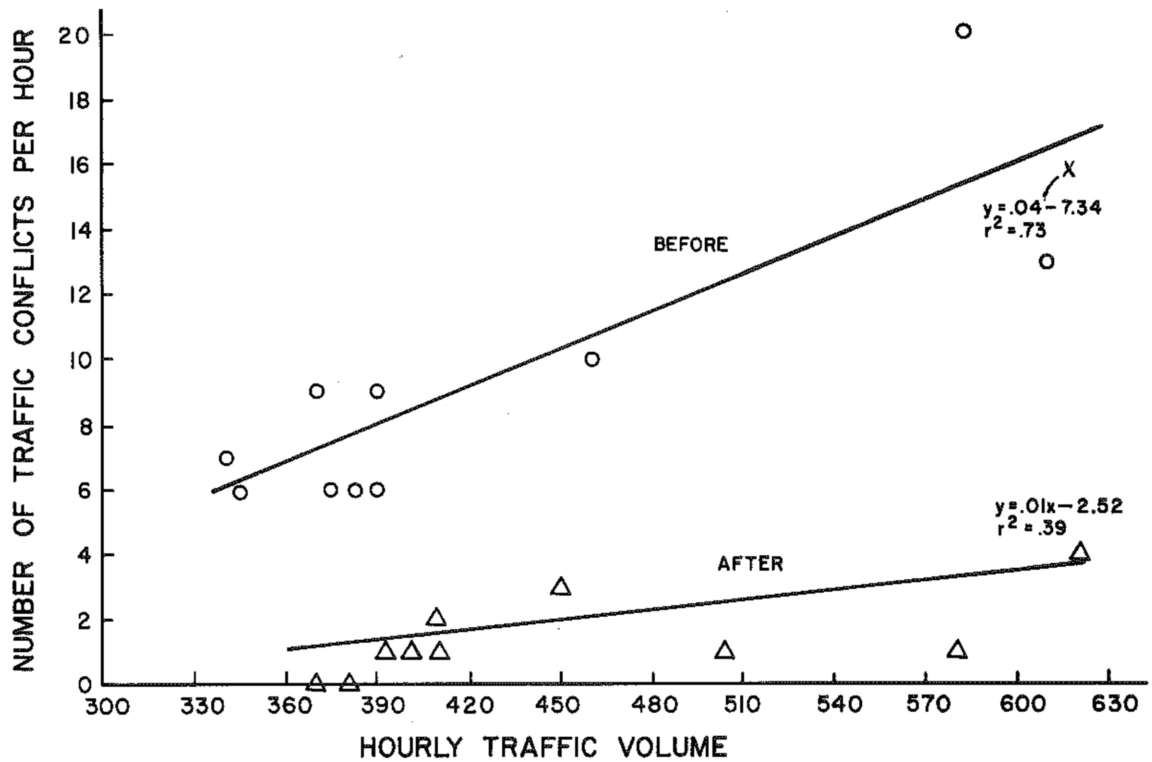


Figure 4. Relationship between Traffic Conflicts and Hourly Volumes at Stanford Site before and after GES Installation.

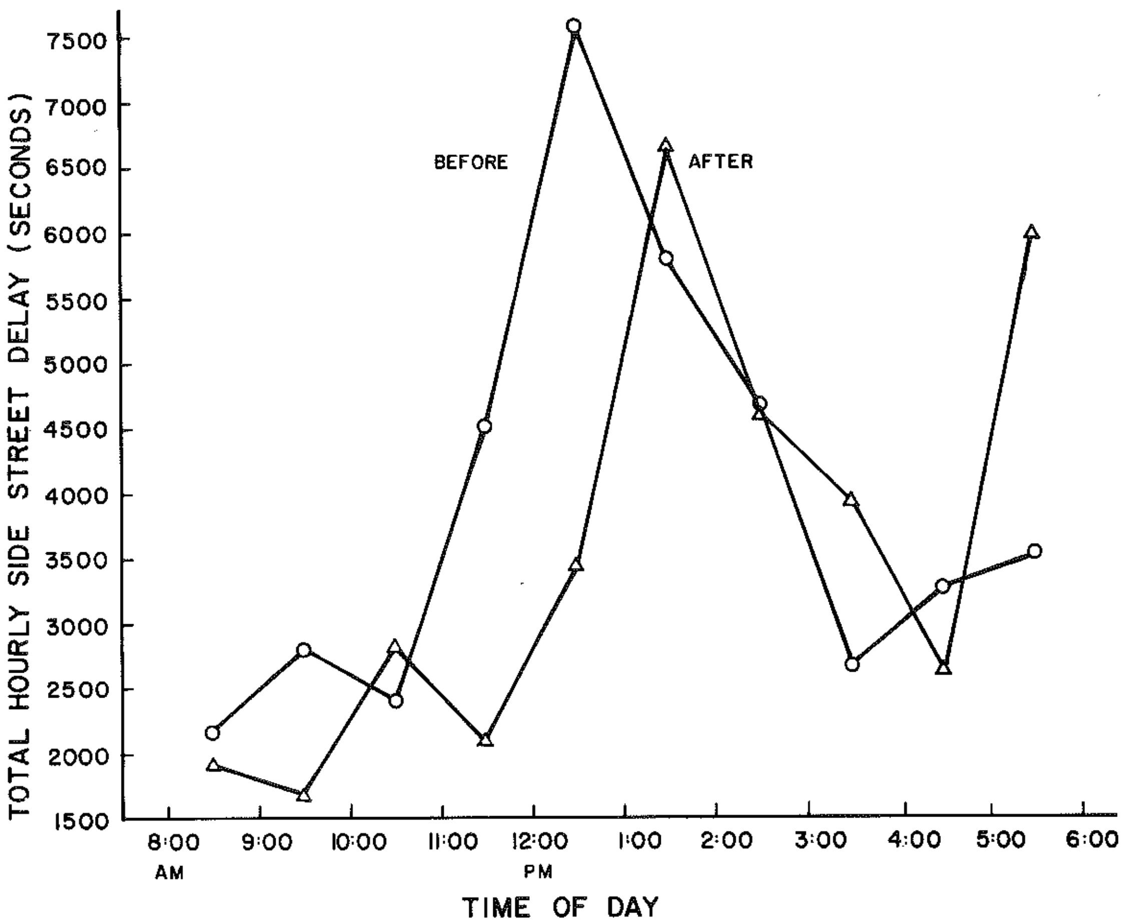


Figure 5. Side-Street Delay versus Time of Day at the Ashland Site before and after GES Installation.

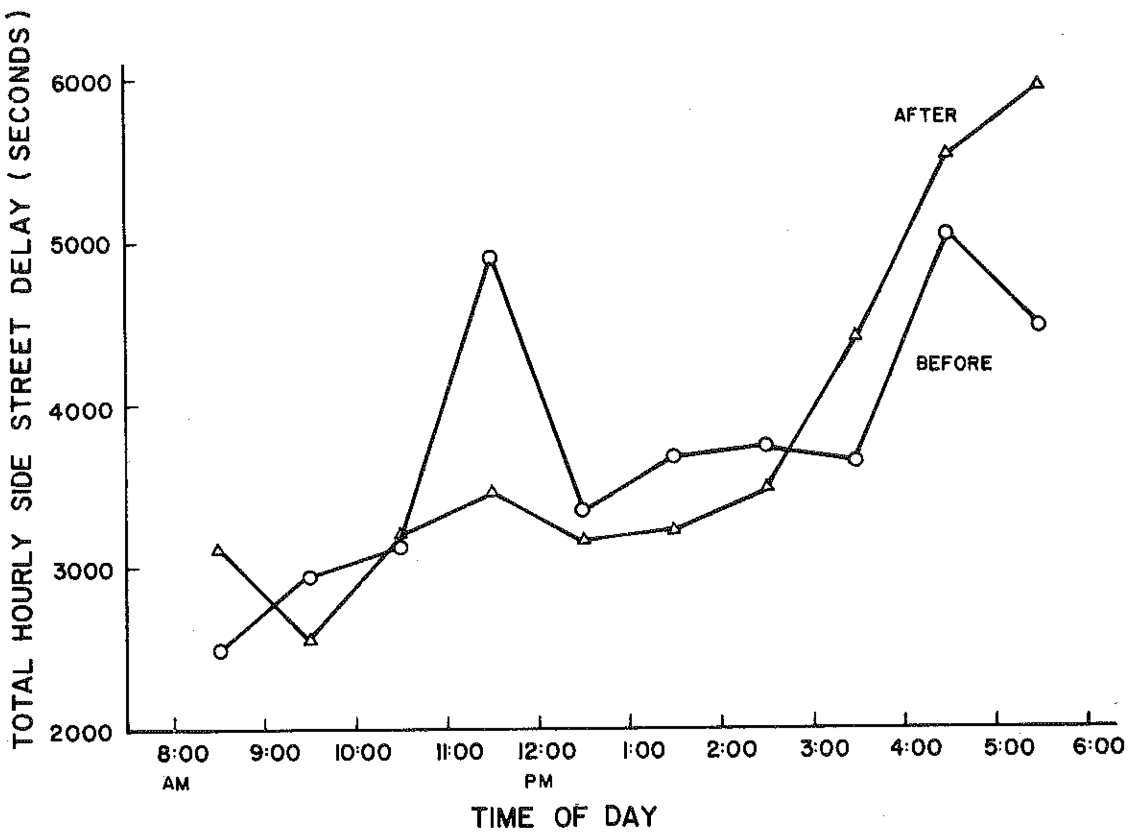


Figure 6. Side-Street Delay versus Time of Day at the Stanford Site before and after GES Installation.