The Impact of Highway Safety Flares on Driver Behavior

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Abstract

Annually, nearly 350,000 parked/disabled motor vehicle crashes occur in the U.S. in which an average of 507 occupants and non-motorists are killed and over thirty thousand people are injured. Among the safety measures aimed at reducing the frequency and severity of this type of crash, the deployment of flares is widely recommended and publicly accepted. The research documented in the present paper supplements the literature on highway safety flare by addressing the relative nighttime effectiveness of the number of flares, flare placement and spacing, and the use of flares with and without the additional activation of a police vehicle's light bar. The behavior of almost 4,000 passing vehicles was unobtrusively observed through the use of roadway sensors. The sensors counted the number and type of vehicles passing the study area and measured passing vehicle speed, lane distribution, and lateral separation from the roadway edge. Flares were found to have a significant and positive impact on all the dependent variables.

INTRODUCTION

Traffic crashes in the United States have an enormous societal cost. In 2002 alone there were over 6.3 million police-reported motor-vehicle crashes in which 42,815 occupants and nonmotorists were killed and nearly three million people were injured (NHTSA 2003). The National Highway Traffic Safety Administration estimates that the economic cost of traffic crashes in 2000 amounted to 230.6 billion dollars (NHTSA 2003). In addition, the National Safety Council (2003) determined that motor-vehicle crashes were the leading cause of unintentional injury deaths in 2002.

Crashes involving collisions with parked/disabled motor vehicles (i.e., PDMV) play a part in these alarming statistics. Annually, nearly 350,000 PDMV crashes occur in which an average of 507 occupants and non-motorists are killed and over thirty thousand people are injured (de la Riva, 2003). This represents 5.4 percent of all traffic crashes, 1.2 percent of all traffic fatalities, and 1.6 percent of all traffic injuries. PDMV crashes are the fourth most common type of crash by manner of collision, behind angle and rear-end collisions. Also, PDMV crashes are the most frequent type of collision among crashes with objects not fixed (about one-half of the crashes in this category are PDMV-related).

Among the safety measures aimed at reducing the frequency and severity of PDMV crashes, the deployment of flares is widely recommended and publicly accepted. Most U.S. non-commercial drivers' manuals suggest flare usage in emergency road situations (de la Riva 2003). Also, the Federal Motor Carrier Safety Administration (FMCSA) mandates that motor carriers shall be equipped with warning signals such as road flares (49 CFR § 392.22, 393.95). The Uniform Vehicle Code contains similar provisions for any kind of truck, bus or any motor vehicle towing a house trailer (UVC § 12-407).

Flare deployment is also deeply embedded in the procedures to be followed by police personnel while working in a traffic accident/incident scene (NHTSA 1986). In fact, the majority of road flares annually manufactured in the United States are purchased by municipal, county and state police departments (NHTSA, 1986). In spite of this, an evaluation of the combined safety effect of road flares and police car's roof-mounted light bar has not been quantitatively measured.

Previous studies of flares' effectiveness have analyzed the effect of either one, two, or three road flares on the behavior of passing traffic (Allen et al., 1971; Consumer Reports, 1977; Lyles, 1980; Knoblauch and Tobey, 1980, Ulmer et al., 1982). Still, only one of these studies (Allen et al., 1971) formally analyzed flare configuration effectiveness by varying number of flares as part of the same experiment.

The overall finding of this past research was that deployment of one, two, or three road flares has a positive safety effect, although, the use of fewer units tends to be less effective. Also, the above-mentioned studies and regulations recommend and stipulate that the leading flare (i.e., the unit furthest away form the disabled vehicle) should be placed approximately 200-to-300 feet to the rear of the disabled vehicle. The location of the leading flare is a factor that has further safety implications for the person actually deploying the flares. Although it has not been properly quantified, due to the user's higher exposure to traffic while deploying the flares, there is a temporary increased risk of a pedestrian accident which, if occurs, is more likely to be serious or fatal (NHTSA 1986). The research documented in the present paper will supplement the literature on highway safety flare by addressing the relative effectiveness of the number of flares, flare placement, and the use of flares with and without the additional activation of a police vehicle's light bar.

Objective

Every day, police and other first responders put themselves at risk along the U.S. roadways as part of their job. Whether conducting a routine traffic stop, attending to an accident scene, or assisting a disabled motorist, police officers place themselves in close proximity to a high volume of traffic traveling at high rates of speed. To reduce the human and property risk involved in these emergency events, roadside safety professionals typically employ emergency road flares and high-intensity light bars to (1) lower the speed of passing traffic, (2) reduce the volume of traffic driving in the right lane of travel, and (3) increase the distance between the passing traffic and the emergency event (lateral separation). A reduction in speed and traffic volume in the travel lane and an increase in lateral separation create time and space for passing traffic to safely maneuver by the emergency event, effectively creating a "safety zone."

This study was designed to assist roadside safety professionals and first responders in determining how to enhance safety during emergency events by quantifying passing motorist behaviors (speed, lateral placement, and lane distribution) in reaction to emergency road flares and the presence of a police car with an activated light bar.

Test Configurations

Four primary roadway scenarios were examined in this study:

1. **"Baseline"**: no disabled car, no police car present, no flares deployed.
2. **"Police Car Present, No Flares"**: disabled car parked on the right edge of the right shoulder of the road, with a police car parked behind it with the light bar activated, no flares deployed.
3. "**Police Car Present With Flares"**: disabled car parked on the right edge of the right shoulder of the road, with a police car parked behind it with the light bar activated and flares deployed (Figure 1). The flares used in this study were Orion non-waxed, 30-minute flares with wire stand attached. Flare deployment was varied within the test protocol as follows:
   a.) Three flares at 5 paces (nominally 15 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edge on a diagonal. The closest unit to the police car was located on the roadway edgeline, the middle unit located in the center of the shoulder, and the furthest unit located on the edge of the shoulder.
   b.) Three flares at 10 paces (nominally 30 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edge on a diagonal. The closest unit to the police car was located on the roadway edgeline, the

middle unit located in the center of the shoulder, and the furthest unit located on the edge of the shoulder.

c.) Six flares at 5 paces (nominally 15 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edge on a diagonal. The closest unit to the police car was located on the roadway edgeline; the second, third, fourth, and fifth units located 24, 48, 72, and 96 inches, respectively, from the edgeline; and the furthest unit located on the edge of the shoulder.

d.) Six flares at 10 paces (nominally 30 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edge on a diagonal. The closest unit to the police car was located on the roadway edgeline; the second, third, fourth, and fifth units located 24, 48, 72, and 96 inches, respectively, from the edgeline; and the furthest unit located on the edge of the shoulder.

4. **"Disabled Vehicle with Flares, No Police Car"**: disabled car parked on the right edge of the right shoulder of the road, with flares deployed. Flare deployment was varied within the test protocol in the same manner as described above.

DATA COLLECTION

Scope and Overview

1. The research employed naturalistic observation techniques. The behavior of passing vehicles was unobtrusively observed through the use of roadway sensors. The sensors counted the number and type of vehicles passing the study area and measured passing vehicle speed, lane distribution, and lateral separation from the roadway edge.
2. A flat and straight segment of a four-lane, limited-access divided highway with a posted speed limit of 65 mph was selected for this study. Data collection was restricted to clear weather and dry pavement conditions during nighttime hours.

Site Selection

The impact of road geometry and the general road environment were controlled by careful and methodical site selection. The following general criteria were considered for the selection of the test site:

1. Traffic volumes large enough to obtain adequate sample sizes,
2. No traffic control devices that could limit the free flow of vehicles,
3. Exit and entrance ramps located no closer than one mile from the test site to avoid accelerating and decelerating vehicles,
4. No artificial illumination of the highway segment,
5. Sufficiently flat grades through the test site to diminish an influence on speed,
6. A long enough tangent section to ensure that measurements were not influenced by horizontal curvature, and
7. Use of the roadway by both trucks and cars.

Furthermore, using nation-wide data from the Fatality Analysis Reporting System (FARS) for a seven-year period (1996 - 2002), de la Riva [2003] found that 37 ± 3 percent of fatal PDMV crashes occur on primary highways (i.e., Interstates, freeways, and expressways). A high percentage (51 ± 4) of these crashes was determined to occur in locations with a posted speed limit between 55 and 75 mph. Nine out ten (91 ± 5 percent) occurred on non-junction roadway segments. Moreover, the vast majority (85 ± 6 percent) occurred on straight and level (76 ± 6 percent) roadway sections.

Based on these criteria, a test site located on northbound Interstate 99 (I-99), approximately 1,500 feet north of milepost 43 (between the Bellwood [Exit 41] and Tipton [Exit 45] interchanges) in Antis Township, Blair County, Pennsylvania, was selected (Figure 2).

I-99 is classified as a principal arterial and is a divided, two-way, four-lane, concrete-paved, limited-access highway with a posted speed limit of 65 mph. The I-

99 section was selected as being typical of the rural and suburban roadways on which many collisions with parked or disabled motor vehicles occur. The 2002 average daily traffic volume (ADT) on this northbound section of I-99 was 5,988 vehicles, of which 19 percent was trucks (PennDOT District 9-0, [2003]). The road segment has two 12-foot-wide lanes in each direction, with 10-foot-wide shoulders of Portland cement concrete. An intermittent rumble strip pattern with 6-foot-long corrugations every 60 feet is ground into the shoulder. A 30-foot depressed grass median separates the vehicles traveling in opposite directions. The test site was located on a straight and level segment of the highway (grades of no more than 2 percent). Northbound motorists approaching the test site came out of a right-hand curve and had approximately 3,500 feet of travel along a tangent section before passing the test site. Motorists approached the site on a constant -1.69 percent downgrade.

Equipment

The passing vehicle data were collected by an automated data collection system developed by the Pennsylvania Transportation Institute. The major components of the system included:

1. Automatic Traffic Recorders (ATRs) that stored accurate time-stamps (1/10,000 second) each time a vehicle axle passed over the sensors.
2. A communication system used to download data from the ATRs to a computer.
3. Pneumatic tubes that transmitted an air pulse when vehicle presence was detected.
4. Two automatic computer programs that transformed the raw data into a useful format for data analysis.

To determine vehicle counts and speed, two pairs of pneumatics tubes were laid 80 and 25 feet apart parallel to one another and across the travel and passing lanes, respectively (Figure 3). In addition, two parallel, diagonally placed pneumatic tubes laid at a 45° angle were used to detect lateral placement within the travel lane. Lane straddling was automatically detected by inspection of the time-stamp pattern obtained for vehicles in the travel lane. That is, if a vehicle was detected by the speed sensors but not by the diagonal sensors, then the vehicle was straddling.

The Traxpro software provided by JAMAR Technologies, Inc. was used to download the raw data from the ATRs. TraxproPSU (a data export utility specifically developed for this project) was run to export the raw data to an easy-to-read format; the measures of effectiveness were obtained using a set of programmed Microsoft® Excel worksheets developed for this purpose (Figure 4).

Field trials conducted at the PTI Test Track Facility indicated that lateral placement measurements were accurate to within ± ⅓ ft. Pneumatic tubes are black, easily deformable, and have a very low profile (the Mini and Half-Round [D] tubes used had an internal diameter of $^{3}/_{16}$ inch and ¼ inch, respectively). These characteristics, in combination with the high traveling speed at the test site, made the pneumatic tubes practically imperceptible to passing motorists.

Once the test site was identified, the specific location of the police car, disabled vehicle, and flares for each of the four base configurations were marked on the road shoulder. The marking was done to ensure a uniform application of the treatments with the ultimate intention of minimizing experimental errors.

For the installation of the roadway sensors, a work zone was deployed in accordance with PennDOT's Publication 203, *Work Zone Traffic Control* (Figure 5). The template shown in figure 18 of PennDOT's publication (stationary or slow-moving short-term operation, divided or one-way highway, work area in the passing or travel lane) was chosen for this purpose.

Duration and Time

1. Data were collected beginning at the start of flare activation and lasting about 30 minutes. When the flares were extinguished, approximately two to four minutes was taken to deploy a new test treatment and remove the previous one. Flare duration was monitored and the roadway sensor data were time-linked to flare activation.

2. Each treatment was tested on consecutive weekdays from Monday through Thursday during the evening, resulting in four replications per treatment. These days were chosen because traveling conditions fluctuate less then than on weekends.
3. With the exception of Tuesday 10/21/03, weather conditions were clear when testing was conducted; the roadway was dry and there was no snow or ice buildup along the shoulder area. Testing commenced after full darkness, about 8 p.m., and concluded at approximately 1 a.m. Data collection started on October 20 and ended on October 30. Enforcement and accident scenarios were tested during the first week, and baseline data were collected during the second week.

Data Reduction

To ensure uniform and comparable test conditions, all data collected passed through a rigorous screening process. The test specifications and procedure dictated which data were to be kept and which were removed. Any non-ordinary event occurring on the test nights that was believed to affect passing vehicle response to the treatments (e.g., pedestrian presence near the test vehicle or emergency vehicles passing through the test site) was recorded in a time log designed for that specific purpose. Later, when the data were being processed, all vehicles passing the test site during the time period in which the event occurred were removed from the database.

Passing Vehicle Classification and Lane of Travel

To test the relative treatment effects on passenger cars and trucks, the data collected were differentiated by type of vehicle using a straightforward binary classification system: cars (i.e., any motorized vehicle with four wheels and only two axles), and trucks (i.e., any motorized vehicle with three or more axles). Data were collected for vehicles in the travel (right) and passing (left) lanes.

STATISTICAL ANALYSES

Given that two of the response variables were continuous (i.e., travel speed and lateral separation) and one categorical (i.e. lane changing), two separate statistical models were used. A general linear analysis of variance model (ANOVA) for the continuous variables, and a logistic regression model for the categorical variable. Treatment comparisons to determine whether a statistically significant difference existed between or among the treatments were investigated using the Tukey and Bonferroni multiple comparisons procedures. From all the possible treatment comparisons that could be made, only a few relevant pairwise comparisons were conducted to answer the specific research questions stated in the objectives of the study. The level of significance used in the statistical tests was the conventional 0.05 level (P-value). The statistical software MINITAB was employed to obtain all the exact computations for these methods.

FINDINGS AND RESULTS

Traffic Volumes

On average, every night approximately 1,100 vehicles passed through the study area in a time period of four to five hours, from approximately 8 p.m. to 1 a.m. Approximately 20-25 percent of the passing traffic consisted of trucks.

Sample Size

Vehicle sample sizes by treatment are presented in Table 1. The sample sizes are listed in four groups, the total number of vehicles observed for speed, lane changing, lateral separation and lane straddling.

Baseline Results

1. Speed

The overall average speed (i.e., average speed for left and right lanes combined) was 69.2 mph. The highest and lowest speeds recorded (99.1 mph and 33.7 mph) corresponded to cars traveling in the left and right lane respectively. While the average speed of all vehicles was 69.2 mph, over 85 percent of the vehicles were traveling in excess of 73 mph.

As expected, vehicles in the passing lane were moving faster (71.0 mph) than vehicles in the travel lane (68.9 mph). The 85th percentile speed was 76.8 mph in the left lane and 73.6 mph in the right lane. On average, cars were moving faster (69.6 mph) than trucks (67.4 mph). When speed is categorized by lane and type of vehicle, cars in the passing and traveling lane moved faster (71.3 and 69.4 mph, respectively) than trucks (69.1 and 67.3).

2. Lane Changing

Table 2 shows that under the Baseline condition the vast majority of vehicles (3,296 of 3,825) traveled in the right lane (86.2 percent versus 13.8 percent in the left lane). When the type of vehicle is taken into account, a higher proportion of trucks traveled in the right lane compared to cars (91.1 and 84.9 percent, respectively). Moreover, when data are grouped by day of week, a virtually steady daily lane distribution pattern is observed from Monday through Thursday. As the night hours passed and traffic volumes decreased, vehicles increasingly shifted to the right lane (84.5 percent at 8 p.m. versus 90.6 percent at midnight). In addition, if the same hourly data are tabulated by type of vehicle, it can be seen that the above-mentioned hourly shift is somewhat more noticeable for trucks (from 84.1 percent at 8 p.m., to 92.4 percent at midnight) than for cars (84.5 to 89.2 percent).

3. Lateral Placement

The data reveal that the average vehicular lateral placement under Baseline conditions was 37.7 inches from the right edgeline. Figure 6 illustrates this finding by showing that the average lateral placement of passenger cars and commercial vehicles is to the right of the lane's centerline. The closer-to-the-edge positioning of trucks may in part be explained by their larger track width in comparison to passenger cars. No statistically significant differences were observed in the average lateral placement as a function of time of day, where less than two inches of difference between the highest and lowest lateral placement values were observed.

Police Car Present With Flares Deployed

1. **Speed**

   a. Comparison to Baseline: The deployment of flares with a police car present with activated light bar decreased the speed of passing vehicles by a minimum of 9.6 mph (to 59.6 mph) or a 13.9 percent reduction compared to the Baseline (Table 3). The greatest reduction in speed, 11.2 mph (to 58 mph) or a 16.2 percent reduction compared to the Baseline, was recorded when six flares deployed at a spacing of five paces.

   b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario resulted in a speed reduction of 8.1 mph or an 11.7 percent reduction compared to the Baseline. The addition of six flares to a Police Car Present, No Flares scenario further reduced the speed of passing cars by an additional 3.1 mph or an additional 5.1 percent, representing a 16 percent speed reduction from Baseline.

2. **Lane Changing**

   a. Comparison to Baseline: The deployment of flares with a police car present with activated light bar caused a massive shift of vehicles into the left (passing) lane. While there were differing results depending upon the number and spacing of flares deployed, at a minimum the number of vehicles traveling in the right (travel) lane was reduced by 79.6 percent compared to Baseline. The greatest reduction in right-lane volume, 81.9 percent, was recorded when six 30-minute flares were deployed at 5 paces.

   b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario reduced the number of vehicles driving in the right lane by 76.6 percent compared to Baseline. The addition of six flares to a Police Car Present, No Flares scenario further reduced the number of vehicles driving in the right lane by an additional 5.3 percent (95.7 percent changed lanes).

3. **Lateral Separation**

a. Comparison to Baseline: The deployment of flares with a police car present with activated light bar caused vehicles driving in the right lane to move a minimum of 25.6 inches farther away from the disabled vehicle, an increase of at least 67.9 percent, when compared to Baseline. The greatest increase in right-lane lateral separation, 32.2 inches or an 85.4 percent improvement above Baseline, was recorded when six flares were deployed spaced 10 paces apart.

b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario caused vehicles driving in the right lane to move 22.4 inches farther away from the disabled vehicle, an increase of 59.4 percent, when compared to Baseline. The addition of six flares at 10 paces to a Police Car Present, No Flares scenario further increased the lateral separation by an additional 9.8 inches or 16.3 percent.

Disabled Vehicle, No Police Car, With Flares Deployed

1. **Speed**

a. Comparison to Baseline: The deployment of flares behind a disabled vehicle with no police car at the site decreased the speed of passing vehicles by a minimum of 6.6 mph (to 62.5 mph) or a 9.5 percent reduction compared to Baseline. The greatest reduction in speed, 8.4 mph (to 60.7 mph) or a 12.1 percent reduction compared to Baseline, was recorded when six flares where deployed at 10 paces.

b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario resulted in a speed reduction of 8.1 mph or an 11.7 percent reduction compared to Baseline. That said, the use of flares behind a disabled vehicle was nearly as effective as having a police car present with an activated light bar in reducing passing traffic speed. In fact, deploying six flares at 10 paces behind a disabled vehicle caused an 8.4 mph speed reduction as compared to a 8.1 mph speed reduction for a police car with an activated light bar alone.

2. **Lane Changing**

a. Comparison to Baseline: The deployment of flares behind a disabled vehicle with no police car on site decreased the number of vehicles driving in the right lane by a minimum of 71.1 percent. The greatest decrease in right lane volume was recorded when three flares were deployed at five paces.

b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario reduced the number of vehicles driving in the right lane by 76.6 percent compared to Baseline. The use of flares behind a disabled vehicle was nearly as effective as having a police car present with an activated light bar in moving passing traffic to the left lane. In fact, when three flares at five paces were deployed behind a disabled vehicle, 93.2 percent of passing traffic moved to the left lane versus 90.4 percent moving over when there was a police car on site with an activated light bar.

3. **Lateral Separation**

a. Comparison to Baseline: The deployment of flares behind a disabled vehicle with no police car on site caused vehicles driving in the right lane to move a minimum of 25.0 inches further away from the disabled vehicle, an increase of 66.3 percent when compared to Baseline.

b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario caused vehicles driving in the right lane to move 22.4 inches farther away from the disabled vehicle, an increase of 59.4 percent when compared to Baseline. That said, the use of flares behind a disabled vehicle was more effective than having a police car present with an activated light bar in increasing the lateral separation between passing traffic in the right lane and the disabled vehicle.

Police Car Present With Flares - Impact on Passing Trucks

1. **Speed**

   a. Comparison to Baseline: The deployment of flares with a police car present with activated light bar decreased the speed of passing trucks a minimum of 6.0 mph (to 61.4 mph) or a 9 percent reduction compared to Baseline. The greatest reductions in speed, 7.2 mph (to 60.2 mph) or a 10.7 percent reduction compared to Baseline, were recorded when six flares where deployed at five paces.

   b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario resulted in a speed reduction for trucks of 4.7 mph or a 6.9 percent reduction compared to Baseline. The addition of six flares to a police car presence reduced the speed of passing trucks by an additional 2.5 mph or 4.1 percent. The deployment of flares (3 or 6) was more effective than Police Car Present, No Flares scenarios in reducing the speed of passing trucks during an emergency event.

2. **Lane Changing**

   a. Comparison to Baseline: The deployment of flares with a police car present with an activated light bar caused a massive shift of trucks into the left (passing) lane. At a minimum, the number of trucks traveling in the right (travel) lane was reduced by 89.5 percent compared to Baseline. The greatest reduction in right lane volume, 100 percent, was recorded when three flares were deployed at five paces.

   b. Comparison to Police Car Present, No Flares: The Police Car Present, No Flares scenario reduced the number of trucks driving in the right lane by 89 percent compared to Baseline. The deployment of flares (3 or 6) was more effective than Police Car Present, No Flares scenarios in reducing right lane volume during an emergency event.

Effect of Flare Burning Time on Passing Vehicle Speed

Since flares are reduced in size as they burn, it was speculated that their effectiveness may be reduced over time, particularly in the last 5 to 10 minutes of combustion. To test this hypothesis, the speed database was arranged into two categories by flare burning-time: the first 20-minutes and the last 10 minutes. An analysis of variance revealed that the small difference in speed by burn time was not statistically significant (Table 4). In other words, 30-minute flares were as effective in the last 10-minutes of flare combustion as in the first 20 minutes of combustion.

Summary of Results

When flares were deployed along with a police presence at night:

- the speed of passing traffic was reduced 16.2 percent or 11.2 mph, representing a 5.1 percent improvement (3.1 mph decrease) as compared to a police car alone;
- 95.7 percent of the passing traffic changed lanes to avoid the emergency event, representing a 5.3 percent improvement compared to the police car alone; and
- lateral separation (for those few vehicles that did not change lanes) increased 85 percent (an additional 32.2 inches) over baseline, representing a 16.3 percent improvement (or an additional 9.8 inches) compared to a police car alone.

In all deployment scenarios involving a police car with flare deployment, the use of six flares created a larger safety zone than that created by using three flares (i.e., when six flares were deployed instead of three, the speed of passing traffic was further reduced, more vehicles moved to the left lane, and lateral separation from the emergency event increased). The most significant speed reduction and lane-changing behavior occurred with flares spaced five paces apart. While testing constraints only allowed for a comparison of three versus six flares spaced five and ten paces apart, real-world variables will dictate the actual number of flares needed and placement (e.g., traffic volume and speed, lighting conditions, terrain, atmospheric conditions, and severity of event).

In regard to trucks, when flares were deployed along with a police presence at night:

- the speed of passing trucks was reduced 11 percent or 7.2 mph, representing a 4.1 percent incremental improvement (2.6 mph decrease) as compared to a police car alone;
- 98 percent of all trucks changed lanes to avoid the emergency event, thereby enlarging the safety zone.

The use of emergency road flares without any police presence caused passing traffic to undertake significant speed reduction (12.2 percent or a decrease of 8.4 mph), dramatic lane-changing behavior (79.4 percent) and increased lateral separation from the emergency event (97.6 percent or an increase of 36.8 inches). The data illustrate that a disabled vehicle deploying flares on Interstates at night will create a safety zone around the emergency event nearly equal to that created by a police car with activated light bar. Future research is planned to evaluate the effectiveness of these devices on conventional roadways and during daylight hours.

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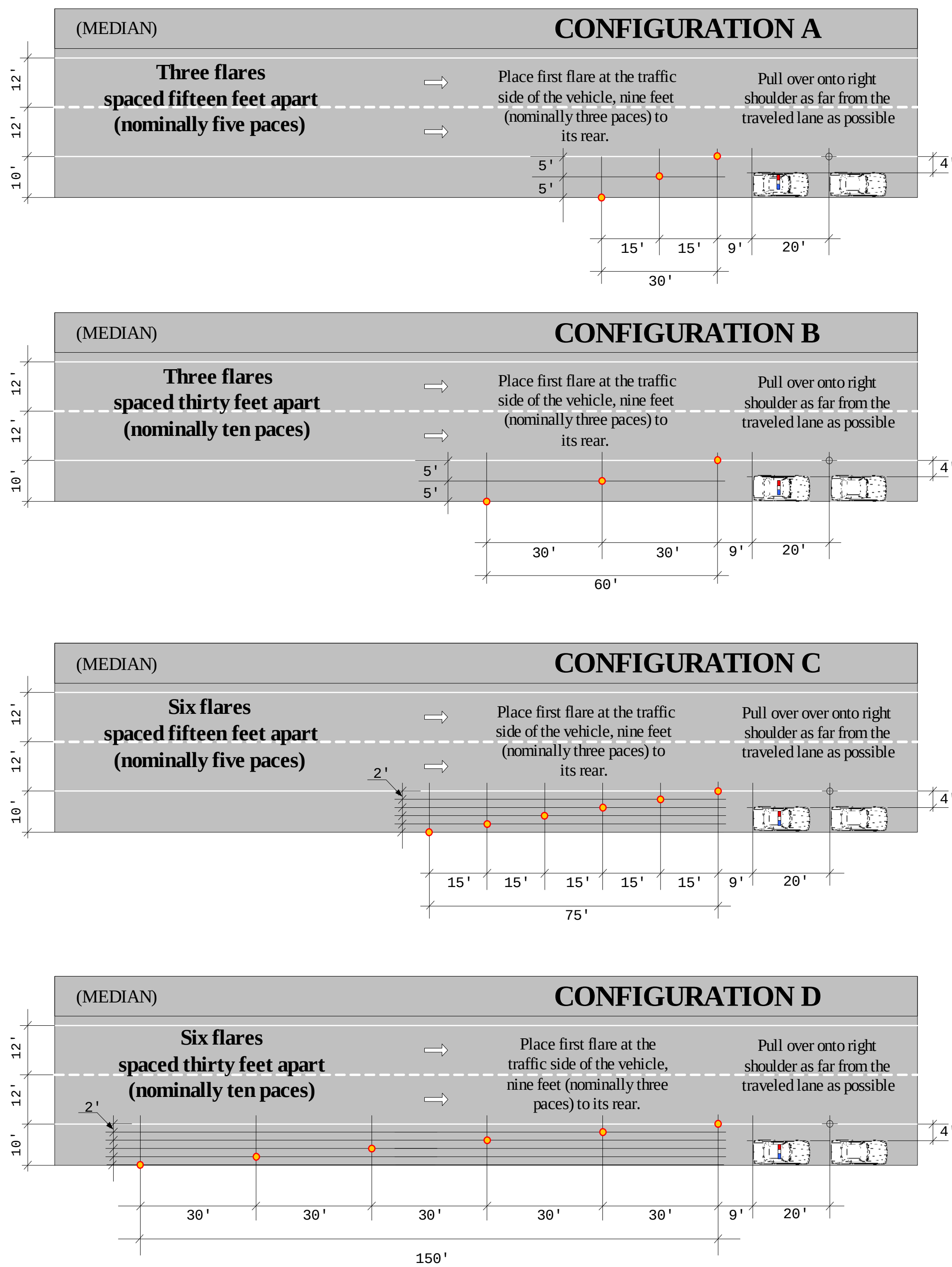
Figure 1. Test conditions.



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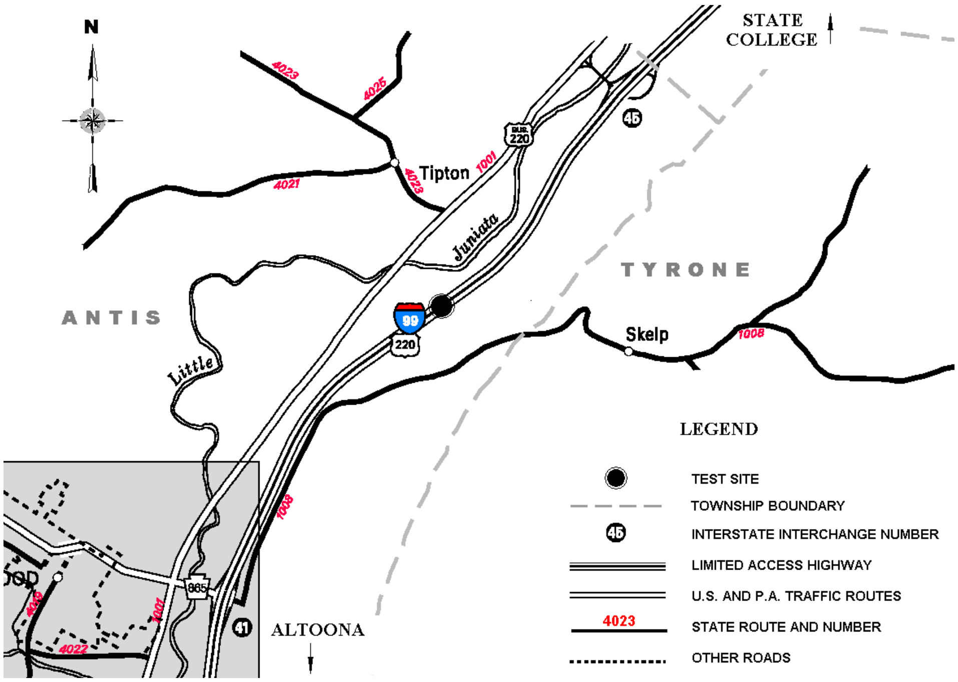

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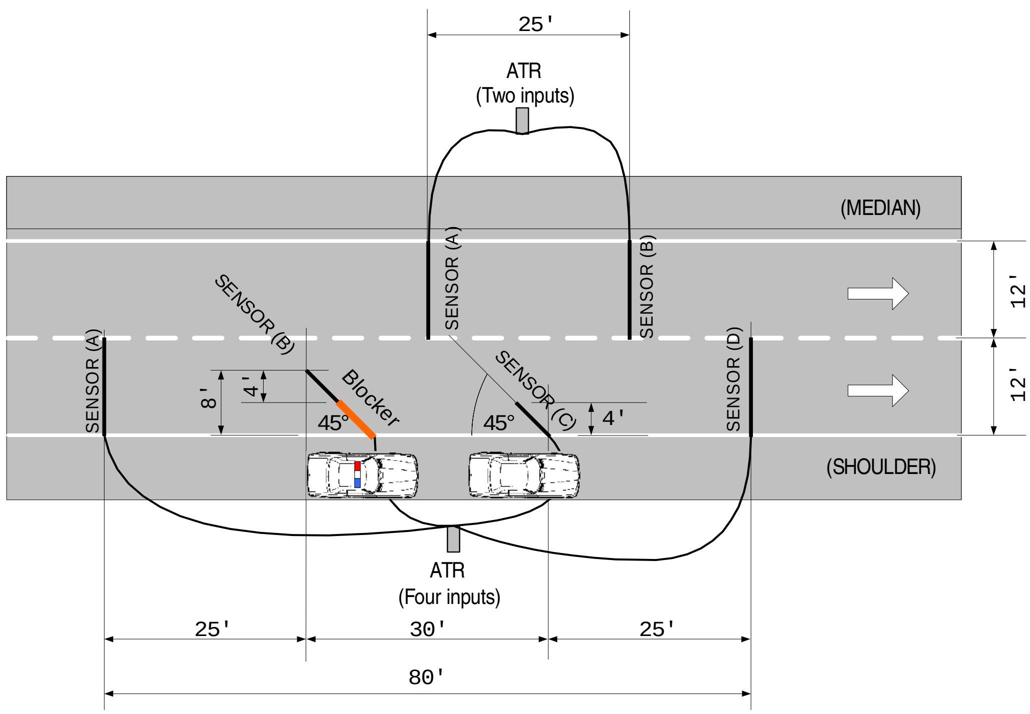

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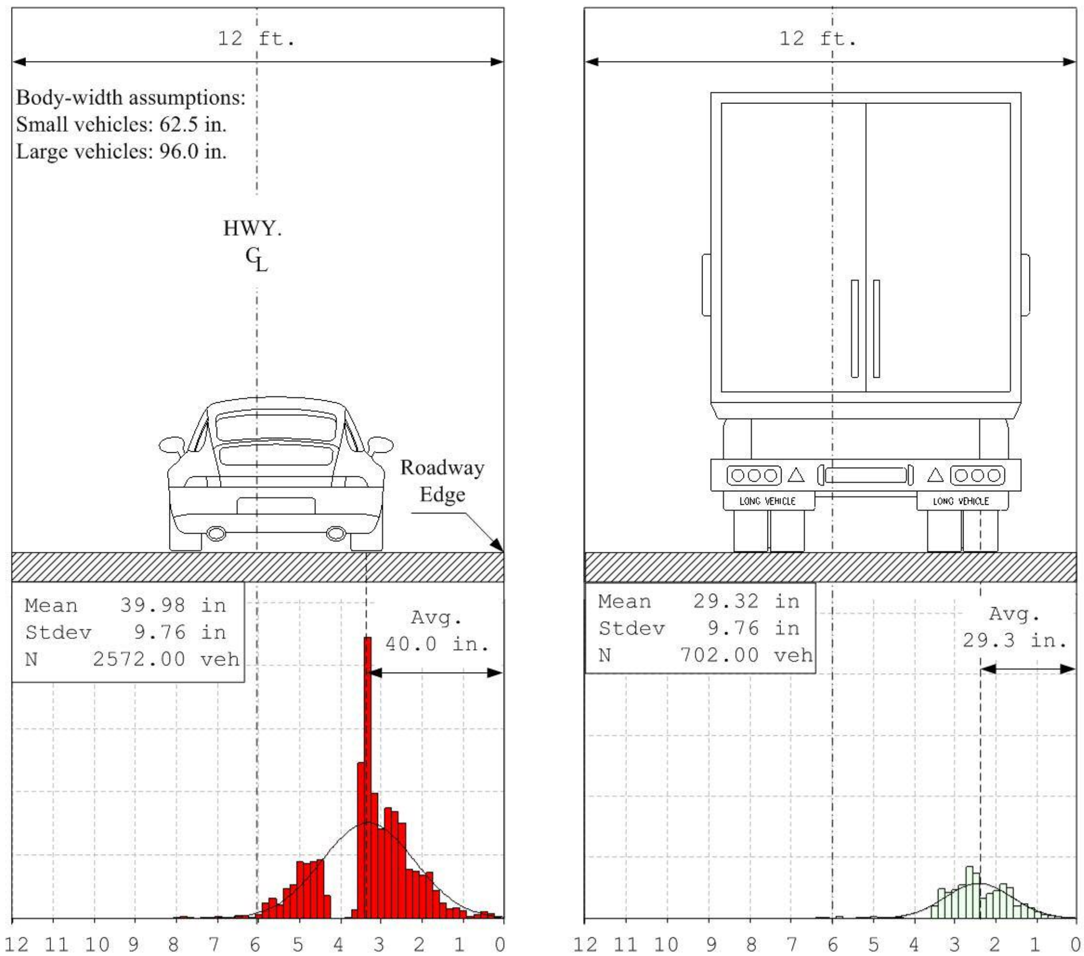

Traffic Scenario		Measures of Effectiveness								
		Speed			Lane Distribution			Lateral Separation [LS] and Lane Straddling [LSD]		
		Lane		Total	Lane		Total	Right Lane		Total
		Left	Right		Left	Right		[LS]	[LSD]	
Baseline		529	3,296	3,825	529	3,296	3,825	3,274	22	3,296
Enforcement (No flares)		271	22	293	206	22	228	19	3	22
Disabled vehicle and police car with flares	3 flares at 5 paces	431	17	448	329	17	346	15	2	17
	3 flares at 10 paces	452	18	470	255	18	273	16	2	18
	6 flares at 5 paces	544	14	558	315	14	329	10	4	14
	6 flares at 10 paces	432	25	457	386	25	411	17	8	25
Disabled vehicle, no police car, with flares	3 flares at 5 paces	211	10	221	137	10	147	4	6	10
	3 flares at 10 paces	392	37	429	260	37	297	20	17	37
	6 flares at 5 paces	370	38	408	239	38	277	25	13	38
	6 flares at 10 paces	256	37	293	208	37	245	30	7	37

Table 1. Sample size (number of vehicles).

Description		Total Vehicles	Left Lane		Right Lane	
			Vehicles	Percentage	Vehicles	Percentage
		3,825	529	13.8%	3,296	86.2%
Type of Vehicle	Cars	3,041	459	15.1%	2,582	84.9%
	Trucks	784	70	8.9%	714	91.1%
Day of Week	Monday	1,024	134	13.1%	890	86.9%
	Tuesday	1,172	171	14.6%	1,001	85.4%
	Wednesday	1,064	150	14.1%	914	85.9%
	Thursday	565	74	13.1%	491	86.9%
Time of Day	20:00	1,050	163	15.5%	887	84.5%
	21:00	1,051	164	15.6%	887	84.4%
	22:00	827	117	14.1%	710	85.9%
	23:00	557	53	9.5%	504	90.5%
	Midnight	340	32	9.4%	308	90.6%
Time of Day (Cars)	20:00	899	139	15.5%	760	84.5%
	21:00	869	141	16.2%	728	83.8%
	22:00	637	107	16.8%	530	83.2%
	23:00	414	47	11.4%	367	88.6%
	Midnight	222	24	10.8%	198	89.2%
Time of Day (Trucks)	20:00	151	24	15.9%	127	84.1%
	21:00	182	23	12.6%	159	87.4%
	22:00	190	10	5.3%	180	94.7%
	23:00	143	5	3.5%	138	96.5%
	Midnight	118	9	7.6%	109	92.4%

Table 2. Lane distribution during baseline condition.

Traffic Scenario		Total Vehicles	Average (Mph)	Standard Deviation*	Difference in Average Speed from Baseline (mph)
Baseline		3,825	69.2	5.6	
Police Car Present, No Flares		293	61.1	6.3	-8.1
Police Car Present with Flares	3 flares at 5 paces	448	59.4	6.8	-9.8
	3 flares at 10 paces	470	59.6	6.0	-9.6
	6 flares at 5 paces	558	58.0	6.3	-11.2
	6 flares at 10 paces	457	58.8	6.0	-10.4

Table 3. Effect of flares and police car on travel speed.

Flare Burning-time	Total Vehicles	Average Speed (mph)	Standard Deviation
First 20 minutes	1,697	60.2	6.5
Last 10 minutes	1,076	60.0	7.1

Table 4. Effect of flare burning time on passing vehicle speed.