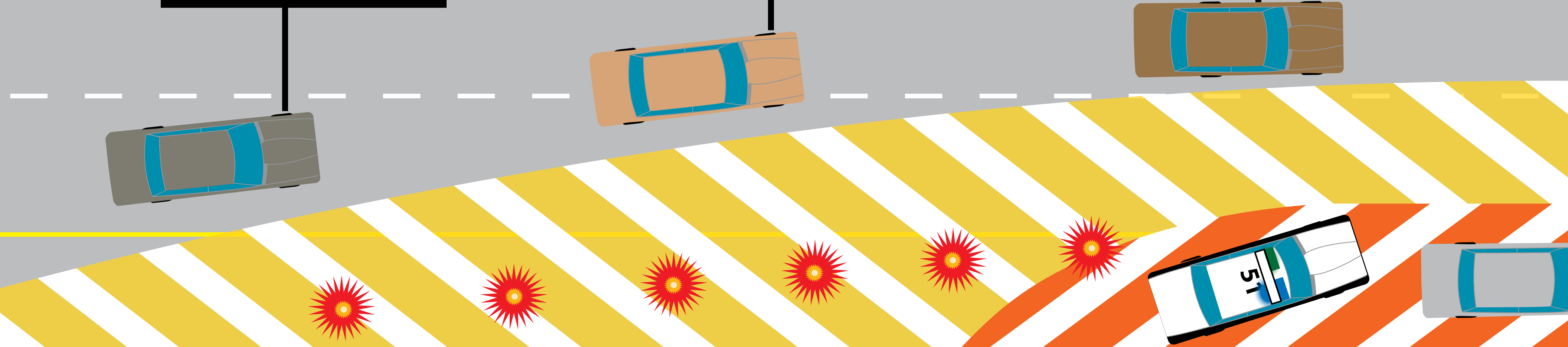
ORION SAFETY BULLETIN

PENN STATE STUDY QUANTITATIVELY DEMONSTRATES
FLARES DRAMATICALLY INCREASE THE SAFETY ZONE

Flares Cause 16% Reduction in Speed
- Earlier perception of emergency ahead
- Increased braking distance
- Dramatic expansion in depth of safety zone

Flares Cause 85% Increased Lateral Separation
- Gets passing traffic farther from emergency scene

Flares Cause 89% Right Lane Volume Reduction
- Creates better visibility around emergency scene
- Dramatic lateral expansion of safety zone



FLARE SAFETY ZONE

NO FLARE SAFETY ZONE

- **Safety response in passing traffic improves as more flares are deployed**
- **Use of road flares with police cruiser light bar activated maximizes safety zone**
- **Increasing the safety zone will save lives...maybe yours!**

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STUDY REGARDING EMERGENCY ROAD FLARE EFFECTIVENESS IN ENHANCING THE "SAFETY ZONE"

Prepared for
Orion Safety Products

FINAL REPORT

May 3, 2005

By M. de la Riva, P. M. Garvey, M. T. Pietrucha,
R. Ghebrial and C. Ramaswamy

PENNSTATE

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Motorist behavior (passing speed, lateral separation from a disabled vehicle, and lane distribution) was evaluated under several roadway scenarios using various safety flare configurations. The treatments were installed on a flat and straight segment of a four-lane limited-access divided highway (I-99) with a posted speed limit of 65 mph. Roadway sensors were used to unobtrusively observe passing vehicle behavior. Data were collected for a period of two weeks, one week of baseline data and one week of test data. A total of over 7,000 vehicles passed through the test location during the evaluation.
A significant number of vehicles passing the flare configurations moved from the right to the left lane (in the baseline condition 86.2 percent of vehicles were in the right lane whereas in the test conditions this was reduced to only 8.5 percent); vehicles that remained in the right lane moved on average 27 inches further away from the shoulder compared to baseline, and operating speeds were reduced by an average of 9.0 mph (a 15 percent reduction from baseline). In traffic scenarios with police presence and light bar activated, the addition of roadway safety flares produced an extra traffic safety benefit. In traffic scenarios without police presence, the use of roadway flares provided a safety benefit equivalent to having a patrol car present with light bar activated.</td></tr>
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I. INTRODUCTION

A. Study Sponsor and Penn State

Orion Safety Products, the worldwide leader in manufacturing and distributing emergency road flares for use by police, fire and other safety professionals, commissioned this study. As the emergency flare "expert," Orion sought to gather quantitative data to assist roadside safety professionals and other first responders in determining how to enhance safety in inherently dangerous situations. Penn State was selected as the independent third-party entity to perform the project based upon its proven research expertise in highway signage, traffic flow analysis and highway administration. In 2005, Penn State ranked first nationally in Fulbright Scholarships, 11th in total research and development expenditures, and third in industry-sponsored research. The Pennsylvania Transportation Institute (PTI) is an interdisciplinary research unit at Penn State's College of Engineering with focus on transportation operations; transportation infrastructure; and vehicle systems and safety. Founded in 1968, PTI has grown from a small research facility to one of the nation's leading university transportation centers with annual research expenditures of $12 million and active projects valued at over $35 million. A major research and testing facility of the University is the PTI Test Track Facility. The 5,042-foot-long, oval-shaped track provides the needed place for a wide range of transportation-related research. This closed-loop test track was used extensively to safely develop and test the field data collection equipment and protocols used in the present study.

B. General Premise and Terminology

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 (collectively, an "emergency event"), police officers place themselves in close proximity to a high volume of traffic traveling at high rates of speed. To lessen 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 (the travel lane), and (3) increase the distance between the passing traffic and the emergency event giving rise to the presence of police and other safety professionals (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” surrounding the emergency event.

C. Specific Objective

This study was designed to generate raw data from actual roadway conditions, which would assist roadside safety professionals and first responders in determining how to enhance safety during emergency events by quantifying passing motorist behaviors in reaction to signals customarily deployed, specifically emergency road flares and police car presence with activated light bar.

D. Test Configuration

Four primary roadway scenarios are discussed 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 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 light bar activated and flares deployed. 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 edgeline 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 shoulder edgeline.
   - b.) Three flares at 10 paces (nominally 30 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edgeline 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 shoulder edgeline.
   - c.) Six flares at 5 paces (nominally 15 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edgeline 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 shoulder edgeline.

d.) Six flares at 10 paces (nominally 30 feet) apart, placed upstream of the police car from the roadway edgeline to the shoulder edgeline 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 shoulder edgeline.

4. **"Disabled Vehicle, No Police Car, With Flares"**: 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 in Section I.D.3 immediately above.

E. Hypotheses

1. The combined effect of police presence with activated light bar and deployment of emergency road flares will generate the greatest impact on the behavior of passing motorists, creating a significantly larger safety zone than police presence with activated light bar and no emergency road flares.
2. Deploying more flares will have a greater impact on the behavior of passing motorists than configurations with fewer flares – use of more flares enlarges and enhances the safety zone.
3. Deployment configurations with flares spaced more closely together (5 paces apart) will have a greater impact on the behavior of passing motorists than flares spaced farther apart (10 paces apart).
4. The combined effect of police presence with activated light bar and deployment of emergency road flares will generate the greatest impact on the behavior of passing trucks, creating a significantly larger safety zone than police presence with activated light bar and no emergency road flares.
5. The deployment of emergency road flares, even in the absence of a police presence with activated light bar, will have a dramatic safety impact on the behavior of passing motorists by enlarging the safety zone around the emergency event.

II. DATA COLLECTION

A. 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.
3. The flares used in the testing were Orion non-waxed, 30-minute flares with wire stands. This is the most popular flare size and type used by emergency responders in the United States.

B. 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.

Based on these criteria, a test site located on northbound 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 1).

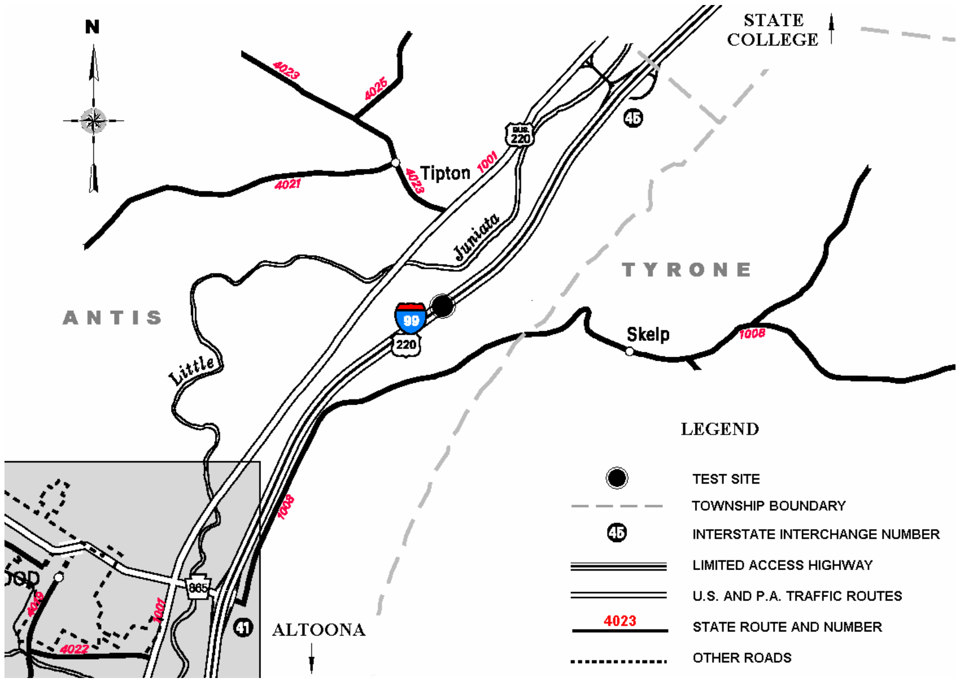

Figure 1. Test site location.

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 straight travel before passing the test site. Motorists approached the site on a constant -1.69 percent downgrade.

C. 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 vehicular 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 2). 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.

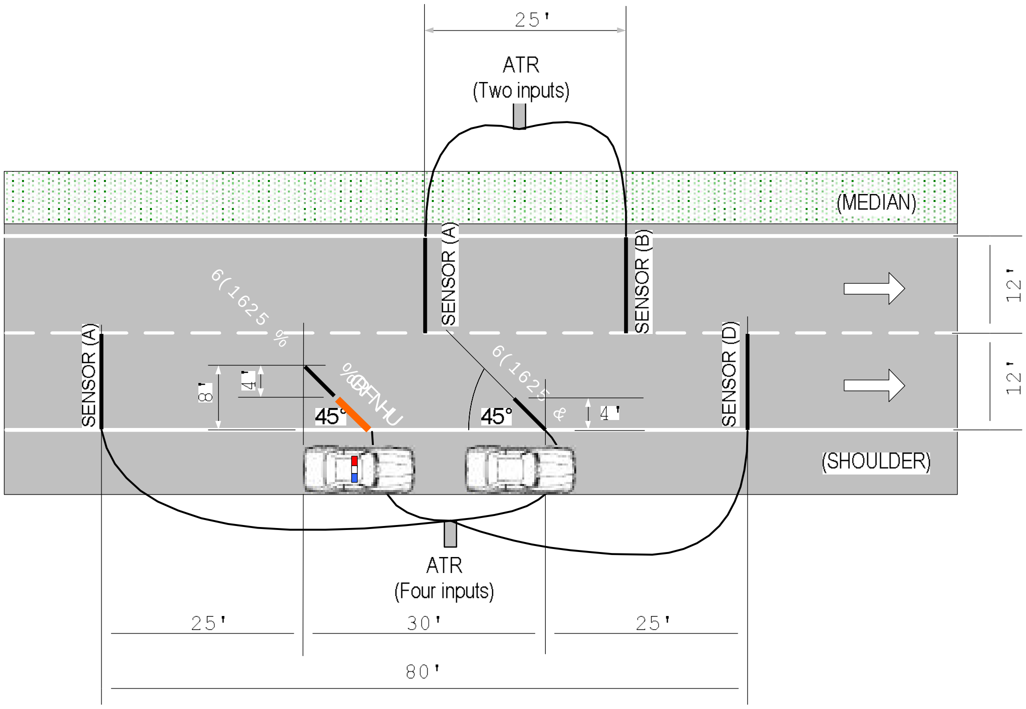

Figure 2. Roadway sensor layout.

The Traxpro software available from 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; from there results the measures of effectiveness were obtained using a set of programmed Microsoft® Excel worksheets developed for this purpose (Figure 3).

Field trials conducted at the PTI Test Track Facility indicated that lateral placement measurements were accurate to within ± ? 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 basically imperceptible to passing motorists.

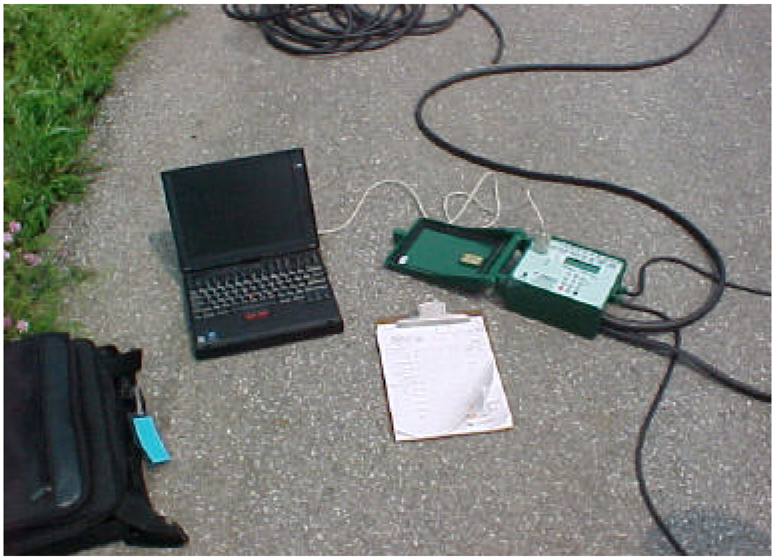
Figure 3. Downloading traffic data from the ATR to a PC.

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 4). The template shown in Appendix A, 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.

Figure 4. Work zone deployment and installation of roadway sensors.

D. 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 Monday mornings, Fridays, and 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.

E. Data Reduction

To ensure uniform and comparable test conditions, all data collected passed through a rigorous screening process. The test specifications and procedure dictated what data were to be kept and what 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 form 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.

F. 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.

III. FINDINGS AND RESULTS

A. 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 daily passing traffic consisted of trucks.

B. 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 spot-speed, lane changing, lateral separation and lane straddling.

Table 1. Sample size (number of vehicles).

Traffic Scenario		Measures of Effectiveness								
		Speed			Lane Changing			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
Police car present 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
	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, 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

C. Baseline Results

Refer to Section I.D.1. above for a definition of “Baseline.”

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, respectively) corresponded to cars traveling in the left and right lane. While the average speed of all vehicles was 69.2 mph, over 85% 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 traveling 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).

Table 2. Lane distribution during baseline condition.

Description		Total Vehicles	Left Lane Vehicles	Left Lane Percentage	Right Lane Vehicles	Right Lane 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%

3. Lateral Separation

The data reveal that the average vehicular lateral separation under Baseline conditions was 37.7 inches from the right edgeline. Figure 5 illustrates this finding by showing that the average lateral separation 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 separation as a function of time of day, where less than 2 inches of difference between the highest and lowest lateral separation values were observed.

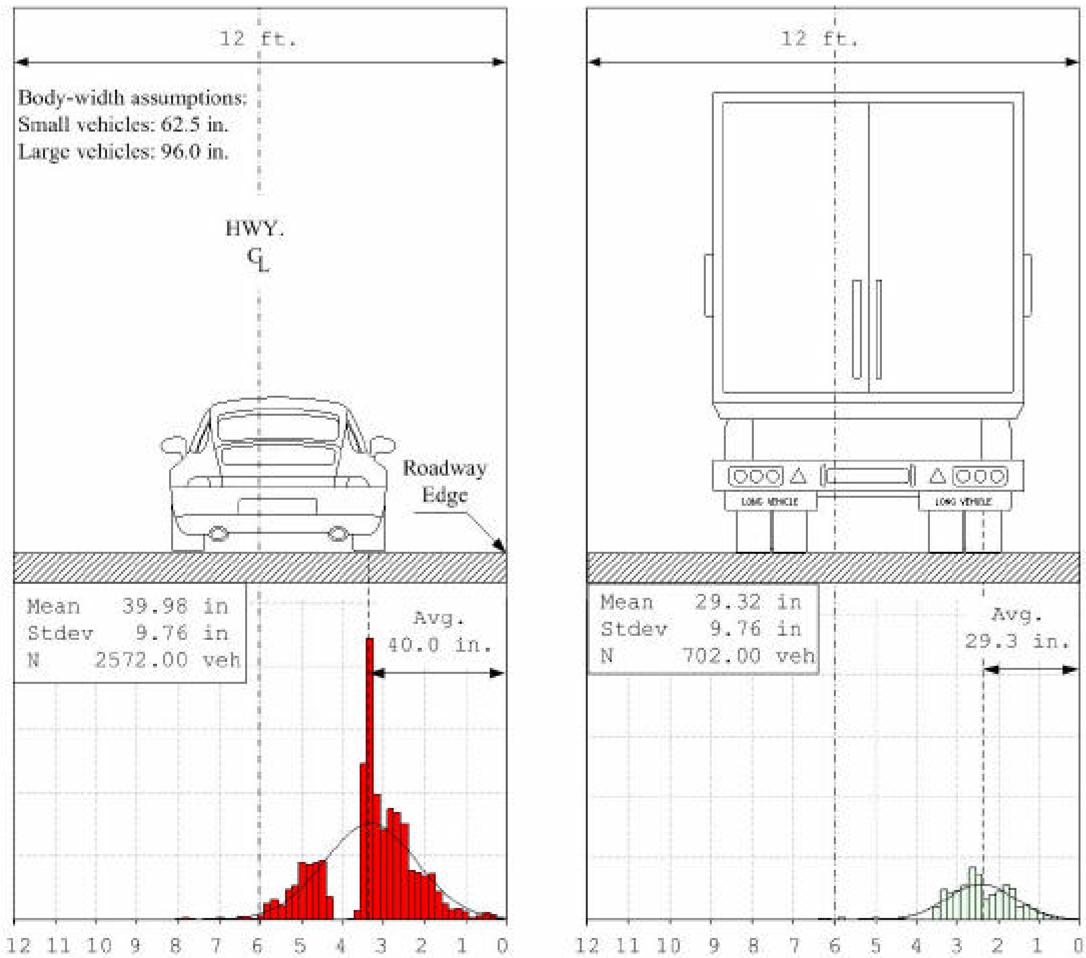

Figure 5. Lateral separation from the right edgeline by vehicle type during baseline condition.

D. Police Car Present With Flares Deployed

Refer to Section I.D.3 above for a definition of "Police Car Present With Flares."

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% reduction compared to the Baseline (see Table 3). The greatest reduction in speed, 11.2 mph (to 58 mph) or a 16.2% reduction compared to the Baseline, was recorded when six 30-minute flares where deployed at a spacing of 5 paces. When considering that the speed of 85% of the vehicles tested at the Baseline was in excess of 73 mph, the Police Car Present With Flares scenario resulted in a speed reduction of more than 15 mph, or a 20% improvement.

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% reduction compared to the Baseline. The addition of six 30-minute 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%, representing a 16% speed reduction from Baseline. The deployment of flares (3 or 6) was more effective than Police Car Present, No Flares in reducing the speed of passing vehicles (9.6 mph versus 8.1 mph) during an emergency event.

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

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

*The scatter or spread of data to either side of the average result; the higher the standard deviation, the greater the spread and the less likely any given observation will be close to the average result.

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 (Table 4). 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 (driving) lane was reduced by 79.6% compared to Baseline. The greatest reduction in right-lane volume, 81.9%, 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% compared to Baseline. The addition of six 30-minute 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% (95.7% changed lanes).

The deployment of flares (3 or 6) was more effective than Police Car Present, No Flares in reducing right-lane volume during an emergency event.

Table 4. Effect of flares and police car on lane changing.

Traffic Scenario		Total Vehicles	Vehicles				Percentage Change in Right Lane Volume from Baseline
			Left Lane		Right Lane		
			Vehicles	Percentage	Vehicles	Percentage	
Baseline		3,825	529	13.8%	3296	86.2%	
Police Car Present, No Flares		228	206	90.4%	22	9.6%	(76.6%)
Police Car Present With Flares	3 flares at 5 paces	346	329	95.1%	17	4.9%	(81.3%)
	3 flares at 10 paces	273	255	93.4%	18	6.6%	(79.6&)
	6 flares at 5 paces	329	315	95.7%	14	4.3%	(81.9%)
	6 flares at 10 paces	411	386	93.9%	25	6.1%	(80.1%)

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%, when compared to Baseline (Table 5). The greatest increase in right-lane lateral separation, 32.2 inches or an 85.4% 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%, when compared to Baseline. The addition of six 30-minute 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%. The deployment of flares (3 or 6) was more effective than Police Car Present, No Flares in increasing the lateral separation between passing traffic and the disabled vehicle.

Table 5. Effect of flares and police car on lateral separation.

Traffic Scenario		Total Vehicles	Average Lateral Separation (Inches)	Standard Deviation	Difference in Average Lateral Separation from Baseline (inches)
Baseline		3,274	37.7	13.6	
Police Car Present, No Flares		19	60.1	13.6	22.4
Police Car Present With Flares	3 flares at 5 paces	15	66.7	18.5	29.0
	3 flares at 10 paces	16	63.3	18.2	25.6
	6 flares at 5 paces	10	66.3	6.7	28.6
	6 flares at 10 paces	17	69.9	11.7	32.2

E. Disabled Vehicle, No Police Car, With Flares Deployed

Refer to Section I.D.4 above for definition of Disabled Vehicle, No Police Car, With Flares.

1. Speed

a. Comparison to Baseline: The deployment of flares behind a disabled vehicle with no police car on site decreased the speed of passing vehicles by a minimum of 6.6 mph (to 62.5 mph) or a 9.5% reduction compared to Baseline (Table 6). The greatest reduction in speed, 8.4 mph (to 60.7 mph) or a 12.1% reduction compared to Baseline, was recorded when six 30-minute flares where deployed at 10 paces. When considering that the speed of 85% of the vehicles tested at Baseline was in excess of 73 mph, the Disabled Vehicle, No Police Car, With Flares scenario resulted in a speed reduction of more than 12 mph or a 17% improvement.

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% 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 activated light bar in reducing passing traffic speed. In fact, deploying six 30-minute 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 activated light bar.

Table 6. Effect of flares alone on travel speed.

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
Disabled Vehicle, No Police Car, With Flares	3 flares at 5 paces	221	62.5	7.1	-6.6
	3 flares at 10 paces	429	62.3	6.1	-6.9
	6 flares at 5 paces	407	61.6	7.9	-7.6
	6 flares at 10 paces	293	60.7	7.3	-8.4

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% (Table 7). The greatest decrease in right lane volume was recorded when 3 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% compared to Baseline. That said, the use of flares behind a disabled vehicle was nearly as effective as having a police car present with activated light bar in moving passing traffic to the left lane. In fact, when 3 flares at 5 paces were deployed behind a disabled vehicle, 93.2% of passing traffic moved to the left lane versus 90.4% moving over when there was a police car on site with activated light bar.

Table 7. Effect of flares alone on lane changing.

Traffic Scenario		Total Vehicles	Vehicles: Left Lane		Vehicles: Right Lane		Percentage Change in Lane Distribution from Baseline
			Vehicles	Percentage	Vehicles	Percentage	
Baseline		3,825	529	13.8%	10	86.2%	
Police Car Present, No Flares		228	206	90.4%	22	9.6%	(76.6%)
Disabled Vehicle, No Police Car, With Flares	3 flares at 5 paces	147	137	93.2%	10	6.8%	(79.4%)
	3 flares at 10 paces	297	260	87.8%	37	12.5%	(73.7%)
	6 flares at 5 paces	277	239	86.3%	38	13.7%	(72.5%)
	6 flares at 10 paces	275	208	84.9%	37	15.1%	(71.1%)

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% when compared to Baseline (Table 8). While flare deployment again enhanced the safety zone relative to lateral separation, the fact that nearly all vehicles moved to the left lane when either flares or a police car with activated light bar was evident rendered the data statistically insignificant.

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% when compared to Baseline. That said, the use of flares behind a disabled vehicle was more effective than having a police car present with activated light bar in increasing the lateral separation between passing traffic in the right lane and the disabled vehicle.

Table 8. Effect of flares alone on lateral separation.

Traffic Scenario		Total Vehicles	Average Lateral Separation (Inches)	Standard Deviation	Difference in Average Lateral Separation from Baseline (inches)
Baseline		3,274	37.7	13.6	
Police Car Present, No Flares		19	60.1	13.6	22.4
Disabled Vehicle, No Police Car, With Flares	3 flares at 5 paces	4	74.5	6.7	36.8
	3 flares at 10 paces	20	66.1	15.8	28.4
	6 flares at 5 paces	25	64.1	15.3	26.4
	6 flares at 10 paces	30	62.7	20.5	25.0

E. Police Car Present With Flares - Impact on Passing Trucks

Refer to Section I.D.3 above for definition of Police Car Present With Flares.

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% reduction compared to Baseline (Table 9). The greatest reductions in speed, 7.2 mph (to 60.2 mph) or a 10.7% reduction compared to Baseline, were recorded when six 30-minute flares where deployed at 5 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% reduction compared to Baseline. The addition of six 30-minute flares to a police car presence reduced the speed of passing trucks by an additional 2.5 mph or 4.1%. 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.

Table 9. Effect of flares and police car on passing truck speed.

Vehicle Type	Traffic Scenario	Total Vehicles	Average Speed (mph)	Standard Deviation	Difference in Speed from Baseline (mph)
Trucks With Police Car Present	Baseline	784	67.4	4.1	
	No Flares	60	62.8	5.0	-4.7
	3 flares at 5 paces	86	61.4	6.6	-6.0
	3 flares at 10 paces	103	61.3	4.2	-6.1
	6 flares at 5 paces	109	60.2	5.2	-7.2
	6 flares at 10 paces	82	60.5	4.0	-6.9

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 trucks into the left (passing) lane (Table 10). At a minimum, the number of trucks traveling in the right (driving) lane was reduced by 89.5% compared to Baseline. The greatest reduction in right lane volume, 100%, was recorded when three 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 trucks driving in the right lane by 89% 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.

Table 10. Effect of flares and police car on passing truck lane changing.

Vehicle Type	Traffic Scenario	Total Vehicles	Vehicles				Percentage Change in lane distribution from Baseline
			Left Lane		Right Lane		
			Vehicles	Percentage	Vehicles	Percentage	
Trucks With Police Car Present	Baseline	784	70	8.9	714	91.1	
	No Flares	48	47	97.9%	1	2.1%	(89.0%)
	3 flares at 5 paces	62	62	100.0%	0	0.0%	(100%)
	3 flares at 10 paces	74	73	98.6%	1	1.4%	(89.7%)
	6 flares at 5 paces	72	71	98.6%	1	1.4%	(89.7%)
	6 flares at 10 paces	64	63	98.4%	1	1.6%	(89.5%)

G. Effect of Flare Burning Time on Passing Vehicle Speed

Since flares grow smaller as they burn, it was speculated that some of their effectiveness could become impaired over time, particularly in the last 5-10 minutes of combustion. To test this hypothesis, the speed database was arranged in two categories by flare burning-time: first 20-minutes and last 10 minutes. An analysis of variance revealed that the small difference was not statistically significant (Table 11). 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.

Table 11. Effect of flare burning time on passing vehicle 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

CONCLUSIONS & SUMMARY RESULTS

The conclusions and results of the project are summarized in Table 12.

Table 12. Project conclusions and summary results.

HYPOTHESIS	CONCLUSIONS & SUMMARY RESULTS
1. The combined effect of police presence with activated light bar and deployment of emergency road flares will generate the greatest impact on the behavior of passing motorists, creating a significantly larger safety zone than police presence with activated light bar and no emergency road flares.	True. When flares were deployed along with a police presence and activated light bar: (i) the speed of passing traffic was reduced 16.2% or 11.2 mph, representing a 5.1% improvement (3.1 mph decrease) as compared to a police car alone with no flares; (ii) 95.7% of the passing traffic changed lanes to avoid the emergency event, representing a 5.3% improvement compared to the police car alone with no flares; and (iii) lateral separation (for those few vehicles that did not change lanes) increased 85% (an additional 32.2 inches), representing a 16.3% improvement (or an additional 9.8 inches) compared to a police car alone with no flares. To maximize the safety zone, flares should be deployed in combination with an activated police light bar.
2. Deploying more flares will have a greater impact on the behavior of passing motorists than configurations with fewer flares – use of more flares enlarges and enhances the safety zone.	True. In all deployment scenarios involving a police car with flare deployment, the use of 6 flares created a larger safety zone than that created by using 3 flares (i.e., when 6 flares were deployed instead of 3, the speed of passing traffic was further reduced, more vehicles moved to the left lane and lateral separation from the emergency event increased). While testing constraints only allowed for a comparison of 3 versus 6 flares, real-world variables will dictate the actual number of flares needed (i.e., traffic volume and speed, lighting conditions, terrain, atmospheric conditions, severity of event, etc.).
3. Deployment configurations with flares spaced more closely together (5 paces apart) will have a greater impact on the behavior of passing motorists than flares spaced farther apart (10 paces apart).	Primarily true. The most significant speed reduction and lane-changing behavior occurred with flares spaced 5 paces apart.

Table 12. Project conclusions and summary results (continued).

HYPOTHESIS	CONCLUSIONS & SUMMARY RESULTS
4. The combined effect of police presence with activated light bar and deployment of emergency road flares will generate the greatest impact on the behavior of passing trucks, creating a significantly larger "safety zone" than police presence with activated light bar and no emergency road flares.	True. When flares were deployed along with a police presence and activated light bar (i) the speed of passing trucks was reduced 11% or 7.2 mph, representing a 4.1% incremental improvement (2.6 mph decrease) as compared to a police car alone with no flares; and (ii) 98% of all trucks changed lanes to avoid the emergency event, thereby enlarging the safety zone.
5. The deployment of emergency road flares, even in the absence of a police presence with activated light bar, will have a dramatic safety impact on the behavior of passing motorists by enlarging the safety zone around the emergency event.	True. The use of emergency road flares without any police presence or activated light bar caused passing traffic to undertake significant speed reduction (12.2% or a decrease of 8.4 mph), dramatic lane-changing behavior (79.4% improvement) and increased lateral separation from the emergency event (97.6% improvement or increase of 36.8 inches). The data illustrate that a disabled vehicle deploying flares will create a safety zone around the emergency event nearly equal to that created by a police car with activated light bar.