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Evaluation of Chemical and Electric Flares

A report to the National Institute of Justice

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

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EXECUTIVE SUMMARY

Traditional magnesium highway flares create substantial risks to both the officer and the surrounding area. In addition to these immediate risks, long-term environmental impacts on soil and water have been identified in previous research studies. As a result, this study identified and examined alternative highway flare systems utilizing chemical or electric sources of energy to determine their suitability and visibility.

A methodology utilizing a standardized visibility measure was designed to compare the different flares and related traffic control devices. The flares and related traffic control devices were tested in scenarios across a range of distance intervals up to and including one mile. Scenarios were developed and established based upon driver reaction and stopping distance times.

The findings suggest that the traditional highway flare, despite its inherent risks, was found to be highly visible and scored well during testing in all scenarios. The chemical and electric flares tested were less visible than the highway flare when deployed at ground level. In some cases, minor depressions in the road surface were found to completely obscure the flare’s visibility. However, when the same chemical and electric flares were elevated to a 36-inch height above the ground, their visibility scores increased dramatically and they were all visible at a distance of one mile.

Scenario testing found that the most effective and visible cone and flare combinations were those that were basic in design. Complex configurations using multiple flare types caused driver confusion and directional disorientation.

THE NATURE OF THE PROBLEM

Traditionally, law enforcement has utilized magnesium-based highway flares to identify accident locations and construction sites. These devices burn at high temperatures and create substantial risk of igniting combustible material or causing injury to the officer. These flares normally burn from 15 to 30 minutes, after which the officer is left to dispose of a hot, melted fusee. Many agencies do not address the disposal of these flare remnants in policy. Our focus group found that officers frequently kick them to the side of the road, leaving sharp metal spikes to create a future road hazard.

Other problems with traditional highway flares are the potential environment impact they have on soil and water. As identified in the literature, the byproducts of burning flares have the potential to poison a water supply. In addition, the effects of perchlorates on the human body are detrimental, especially in pregnant women.

LITERATURE REVIEW

Standard road flares have been a key component of traffic control for decades. Law enforcement officers, construction workers, and stranded motorists have utilized road flares to warn others of potential road hazards. This literature review serves to present a brief background on the use of various portable traffic control devices, theories associated with their use, and specific environmental concerns that may arise from their deployment.

Health and Environmental Consequences

For this research study, a variety of literature was reviewed in an effort to determine the characteristics of standard highway traffic flares. A vast majority of the literature indicated numerous hazardous characteristics associated with the traditional magnesium flare. These characteristics include a number of harmful environmental toxins and a high risk of personal injury to the person deploying the traffic flare.

The traditional magnesium highway flare has been noted to generate noxious smoke and fumes that can overwhelm the user, while the burning end of the flare can cause serious burns caused by the molten magnesium. It has also been documented that many of the elements that compose a traffic flare are detrimental and cause serious health problems. A key chemical component, strontium nitrate, which produces the flare's color, causes irritation to the skin, eyes, and mucous membranes (NIOSH, 2003).

Another highway flare component, potassium perchlorate similarly irritates the skin, eyes, and mucous membranes. Furthermore, absorption of the perchlorates can cause methemoglobinemia, which decreases the ability of the thyroid to process iodine and causes kidney injury (NIOSH, 2003). Current studies by the New Jersey Department of Health and Senior Services (NJDOH) have shown that exposure to potassium perchlorate caused various reproductive effects and gastroenteritis in laboratory test animals (NJDOH, 2004).

The literature has also identified several significant environmental impacts from discarding spent highway flares. According to Silva (2003), in addition to fire hazards, traditional highway flares may create a threat to water quality as the perchlorates dissolve into the water supply. Silva (2003) also cites the Santa Clara Valley Water District, which measured the leachability of perchlorate from highway/emergency safety flares (fusee) in water" (p. 4). The Santa Clara Valley Water District concluded that:

1) Incendiary flares can be a significant source of perchlorate contamination to both surface and groundwater.
2) Unburned flares improperly disposed of can contaminate water with perchlorate up to 2,000 times more than completely burnt flares.

Lavdas (1995) found that localized radiation fogs produced by the burning of highway flares posed greater hazards than widespread advection fogs (which occurs when moist air passes or is blown over a cool surface). The author concluded that this was due to the fact that drivers were able to adjust more easily to widespread fog, but were less successful when very low visibility situations were suddenly encountered.

Not only do highway flares produce a hazardous, visible smoke, a study conducted by the Rhode Island Department of Health (RIDoH) under the Unregulated Contaminant Monitoring Rule (UCMR) looked to assess the risk of perchlorate poisoning in drinking water (Veeger & Boving, 2004). The research found that, "240,000 gallons of water could be contaminated to a level of 4μ/L, by discarding a single flare in the water source" (Pp. 1).

Other unintended consequences include the unplanned ignition of the flares at inappropriate times. As a result of several trunk fires in officer's cars, a collaborative study was conducted to investigate this phenomenon (Corey, Powell, Quesnel, Windsor & Yanez, 2003). The Tucson Arizona Police Department's Crime Lab, Arson Detective Unit, in conjunction with the Tucson Fire Department Fire Investigators conducted several experiments in an attempt to discern the reason for these trunk fires. It was concluded that under the right set of circumstances, flares might be unintentionally ignited in officer's cars. To alleviate this problem, a city-wide memo was issued addressing this situation in which they state:

> "To minimize the risk of inadvertent flare ignition, which could result in a trunk fire, flares should never be readied or prepared in advance, anticipating need. Igniter and striker caps must remain intact, on the flare, until the flare is needed. Flares should be kept in their original box or placed in a container, preventing migration and minimizing movement" (Corey, Powell, Quesnel, Windsor, & Yanez, 2003: Pp. 27).

According to the National Institute for Occupational Safety and Health (NIOSH) International Chemical Safety Cards (2003), all of the elements present in these flares should be stored in tightly closed containers in a cool, dry place. Additionally, it is advised that the storage area be well ventilated and encourages users to wash their face and hands thoroughly before handling food (NIOSH, 2003).

Highway flare research is not limited to the United States; law enforcement agencies from other countries have conducted research on alternative flare technology. According to a technical memorandum by the Canadian Police Research Centre, alternatives to highway flares were examined due to their inherent problems which include:

1. They are not environmentally safe.
2. They pose an extreme hazard at oil gas spills.
3. They can damage/burn uniforms and equipment.
4. The spike remnants must be picked up after every burn.
5. The striker and cap must be disposed of after use.
6. They are difficult to extinguish after each burn.
7. The fumes are offensive and noxious.
8. A case of flares is heavy to handle and hard to store.
9. The brilliance at night is a hazard to passing motorists often distracting on-coming drivers (Hickman, 1992).

Driver and Pedestrian Safety

Any research into highway flare alternatives needs to examine factors of visual conspicuity, duration, and clarity as variables which enhance a flare's ability to be seen and recognized. In considering alternatives to traditional highway flares, issues including disorienting or blinding effects, perception of light signals, and the design of light signals are all factors that must be considered. These concerns stem from theories associated with light and a person's biological response to it.

According to Hickman (1992), the brilliance of the flares at night may distract on-coming motorists. An additional study published in the *Annals of Emergency Medicine* theorized that most of the ineffectiveness associated with light devices, is due to blinding or disorienting affects (De Lorenzo & Eilers, 1991). This study presented two major conclusions; a combination of different colored lights (white, amber, green) with red warning lights are more effective than red lights alone and that there was no evidence that flashing emergency signal lights caused seizures.

A study performed by the Department of Scientific and Industrial Research in Middlesex, England examined the effect of mixing flashing and steady lights together as they correspond to reaction times. Their research illustrated that having a flashing signal on or against a background of steady light yields the fastest response time. The positive effect of short reaction time diminishes with each addition of irrelevant flashing light (Crawford, 1963).

The "Moth Effect" represents the driver's tendency to steer into the direction of their fixation (Chatziastros, 2003), or toward emergency vehicles parked on the roadside (Younger, 1997). In 1974, a study published in the Journal of Illuminating Engineering Society found that humans tend to innately orient to light (Taylor, 1974). The orientation of drivers to the light source causes them to not only veer towards that point but to align themselves with the source.

This effect causes the driver to believe that they are driving straight when they are not, which clearly can have serious consequences for safety.

A study conducted by Lieutenant Wells of the Florida Highway Patrol (2005) tested a bi-colored light bar that was mounted on the roof of a cruiser in an effort to make the police vehicle more visible during day and nighttime traffic stops. The combination of red and blue lights on the light bar provided the greatest illumination. Additionally, it was noted that having the light pattern broken, which provided random flash patterns, made the cruiser more visible and thereby gained the attention of the test subjects more easily. The FHP study found that this randomization of the light patterns did not alter the depth perception of oncoming drivers.

Alternatives to Combustion Based Flares

Emerging technologies utilizing chemical and electric lighting systems may offer promise in reducing many of the issues associated with traditional combustion based highway flares. A vast majority of the new generation flares are reusable and offer hundreds of hours of operation. Many of these models do not produce heat, potentially reducing fire hazards and may be more cost efficient over a several year life-cycle.

Some of the modern electronic flare devices have different color lens options and may offer solutions that are applicable to changing situations or environments. In addition, as supported by the literature, the physics of light and wave dynamics dictates that colors such as green, blue and white are more visible at greater distances due to their higher wavelengths. These findings were also supported by Allen et al (1997), which found green as the most visible color on highway scenes. Despite this greater visibility, this color is not immediately recognized by drivers as a signal to proceed with caution.

Technology such as chemical illumination sticks (light-sticks and electralume attractors) were considered as a potential technology for implementation as it’s documented utility in other fields has been shown to be high (Hazina et al, 2005). This technology was included in this research as its cost-per-use and high visibility may offer a cost effective solution to traditional highway flares.

The illumination (chemical) sticks applicability as a location designator has been used as an important part of mine rescue due to the inherent dangers of igniting gases in an underground environment. According to Conti, Chasko, & Cool’s (1991) study of mine rescue team members, 73% identified green chemical light sticks as the most dominant color seen compared to other colors including red, clear, and yellow. According to Conti et al (1991), they also examined the use of different color strobe lights in a simulated smoke filled mining environment to evaluate their effectiveness. In mine rescue team simulations, five strobe light colors (red, green, blue, amber, and clear) were evaluated by 271 miners. Again, the most visible strobe color was the green light, which could be seen by the largest proportion of persons tested.

Collapsible triangles have also become common in agencies as a replacement for highway flares. A study conducted by the Indiana University

Division of Optometry examined the use of collapsible triangles and highway flares on traffic patterns and behavior on a 10-mile driving course (Allen, Miller, & Short 1971). They concluded that in the daytime, a triangle, a triangle plus a flag, and a road flare were all seen equally well on an open highway. However, during nighttime driving conditions the use of the highway flare added 6 seconds of advanced warning to the drivers. For a vehicle that is traveling at 40 mph, flares were visible for 13.66 seconds, while the triangle was only visible for 7.07 seconds. The illumination provided by the highway flare was found to be superior in both slowing traffic and detection.

Vehicle Stopping Distance

The stopping distance of a vehicle is determined by three factors: perception time of driver, reaction time of driver, and braking capability of the vehicle. The perception time (0.25 - 0.50 seconds) is how long it takes for the driver to observe a hazard and realize that some action is required. The driver's reaction time (0.25 - 0.75 seconds) is how long it takes for the driver to begin applying the brakes, changing direction, or taking some other action once a threat has been identified.

The braking capability is based on speed of the vehicle and friction of the road surface. A number of stopping distance calculators are available which allow crash investigators to insert these factors into a formula to produce a minimum stopping distance under a given set of circumstances. However, the condition of the roadway, wear of the tires and even the type of brakes on the vehicle, greatly impact the friction coefficient and ultimately the accuracy of any one given calculation.

Additional human factors, such as fatigue, poor eyesight, and drug/alcohol impairment, may substantially impact the perception of a hazard and consequently increase the overall vehicle stopping distance. As a result, a 2 second reaction time is not unusual. Therefore, a vehicle traveling at 45 mph will travel 132 feet during the reactionary period prior to braking. If that same driver is traveling 70 mph, the vehicle will travel 205 feet during the reactionary period and an additional 245 feet during braking. Therefore, a total of 450 feet may be required for an average vehicle on a highway to come to a complete stop. Consequently, it is imperative that emergency equipment is visible from the greatest distance possible to allow a driver sufficient time to identify a hazard and act accordingly.

The University of Michigan Transportation Research Institute examined the detection distance for pedestrians near a work zone. The stopping distances established by the study were 125 feet (for normal clothing) and 891 feet (for retro-reflective clothing) (Sivak, 1984).

These factors and the others identified in the literature were considered in the design and overall methodology used in this project. Additionally, this research based itself in a grounded approach and allowed the researchers the opportunity to modify scenarios and various conditions for the flare testing. An empirical foundation based upon other social science principals were utilized in data collection and subsequent reporting. The following section addresses the methodology utilized in the design and data collection of this evaluation.

METHODOLOGY

Data Collection, Measurement and Analysis

To collect the data, researchers developed a data collection instrument that captured the relevant variables. This instrument was the result of extensive field-testing, experimentation and data coder training. The data collection instrument consisted of data code sheets designed to capture the relative visibility scores of each flare system at different distance intervals.

Research Team Training

Prior to the onset of data collection, the researchers briefed and trained a research team of participant/observers. This team consisted of eight research assistants at Florida Gulf Coast University and was integral to the modified Delphi approach used to collect data.

The principal investigators conducted approximately 42 hours of training with the team, covering the data collection methodology and the modified Delphi method. The research team training was conducted over a time frame of approximately seven weeks. During this time, the principal investigators and the research team met for intervals of approximately three hours twice per week.

9-Point Visibility Scale (Primary Data Collection Measure)

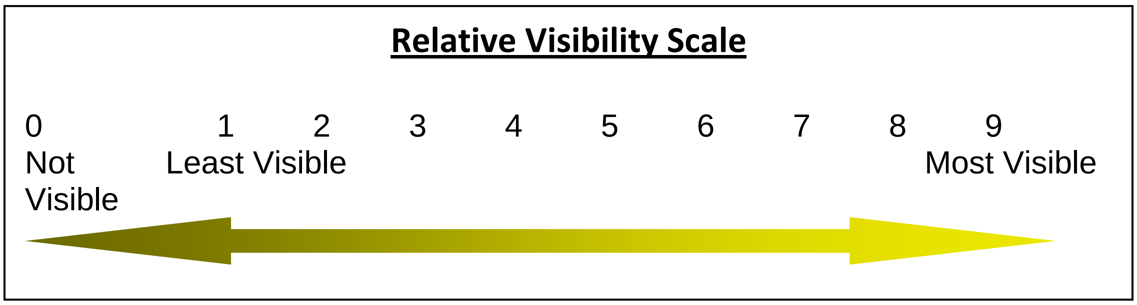
To measure visibility of the flare systems, a 9-point scaled measure was developed for this project, which became the primary data collection variable. Utilizing a segment of roadway, a standardized distance of 100 yards was used to score the flare systems from least visible (scored as a 1) to most visible (scored as a 9). A score of 0 indicated that it was not visible. A traditional highway flare was initially assigned a score of 9.

In order to remove as much subjectivity or individual perspective bias as possible, a modified Delphi approach was utilized in the formation of the scale. During the initial scale creation, the researchers arrived at consensus in determining which flare systems were the most and least visible. These levels of visibility formed the foundation of the scale anchors (least and most visible). A 9-point scale was selected as opposed to smaller scales, as this allowed for a greater range of variance in responses.

Field Data Collection

To capture the data, flare systems were placed in the selected environments at predetermined distances. The research team viewed each of the flare systems and scored the visibility of each device. Once researchers had examined each flare system and scored it individually, the scores were compared, and a consensus score was determined. In this manner, the researchers adapted the Delphi approach for the data collection. The intermediate measures are not necessarily equidistant and as such has interval qualities but is not interval or a ratio level of measurement. The following figure represents the visibility scale for this project.

Figure 1. Visibility Scale



Technologies Evaluated

The following section describes the flare systems that were evaluated. In addition to their basic functions, each flare system's dimensions, power source, construction and lighting configuration are examined.

Orion® Road Flares

These incendiary road flares range from 5 to 30 minutes of burn time and are ignited by a friction strike (similar to match) cap located at the tip. The flares tested were stabilized by a bendable wire stand incorporated into the opposite end. The Orion® Road Flare measures 11.5 inches long, and has a diameter of .75 inches.

Figure 2. Orion® Road Flare

<u>PowerFlare®</u>

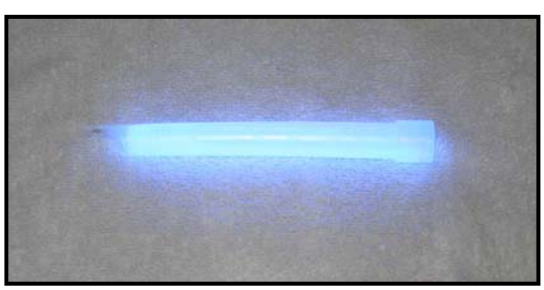
Advertised as waterproof, these are puck-shaped light devices with a 360° arrangement of L.E.D.'s around the circumference that are powered by CR123 lithium batteries. The whole unit is housed in a polymer outer shell with an attached lanyard loop. The PowerFlare® measures 1.25 inches high and 4.25 inches in diameter. It is also available in a rechargeable package that will hold six units at a time and can be connected to a car cigarette lighter. The power button doubles as a light pattern selection switch. Each time the button is pressed, it will cycle to the next light pattern. There are a total of 9 available pattern settings. The units are available in one of six colors: red, amber (yellow), blue, green, white and infrared. PowerFlare's® have an advertised 100 hour runtime per charge or single battery. A carrying bag is also available to carry PowerFlares® .

Figure 3. PowerFlare®

Cyalume® Lightsticks

Cyalume® lightsticks are chemical luminescent tubes. They are illuminated by the mixing of two chemical ingredients separated by a breakable vial. To activate, the tube is bent to the point where the inner vial containing Hydrogen Peroxide is cracked, introducing it to the outer chemicals which are a mixture of dye and Cyalume. The unit is shook until the contents are completely mixed and full illumination is reached. Once optimum illumination is reached, the light's brightness will begin to decay. No heat is generated in the mixture of the chemicals. The Cyalume® lightsticks tested have measurements of 6 inches long and weigh approximately 1 ounce. They have an advertised run time of 30 minutes for the standard intensity and 5 minutes for the high intensity lightsticks. They are waterproof, disposable, typically individually wrapped, and come in a variety of lengths and colors.

Figure 4. Cyalume® Lightstick



TurboFlare™

The TurboFlare™ is a puck-shaped, 360° L.E.D. battery operated light device. The unit's housing is made from DuPont Surlyn® and uses 4 AA batteries allowing the TurboFlare™ to run an advertised 3 hours and is available in 6 colors: amber, red, orange, blue, white, and green. The TurboFlare™ measures 2 inches high and a diameter of 8.125 inches. It has a single rotating light pattern. The manufacturer offers an optional 8-pack hard shell carrying case.

Figure 5. TurboFlare™

Tektite® ELZ™

This light is a battery operated xenon strobe system that runs on 2 C-cell alkaline batteries. The light is spring mounted vertically with a weighted base and a retro-reflective strip around the middle of the unit. Tektite® asserts the unit is water proof with an advertised runtime exceeding approximately 30 hours. The length of the unit is 9.5 inches long and has a base diameter of 6 inches. The lens caps are available in 6 colors: red, amber, blue, clear, green, and infrared. The manufacturer also offers an optional Pelican™ carrying case for the strobes.

Figure 6. Tektite® ELZ™ Traffic Safety Strobe

Galls®36" Reflective Traffic Cones

Galls® distributes these 36 inch tall bright orange cones with two retro-reflective collars and weighted bases. They are constructed from a thick plastic (PVC) and are sold in a box of 8. This cone is the standard type deployed by most law enforcement agencies for traffic control and construction site demarcation. These cones are also sold without the reflective collar.

Figure 7. Galls® 36" Reflective Traffic Cones

Traffic Safety Store™ 28" Collapsible Cones

These cones are 28 inches tall, bright orange in color, and have two retro-reflective collars. The bases have rubber feet and an internal battery-operated light which operates for an advertised run time of 30 hours. The Traffic Safety Store cones have a small switch on the base which cycles between the two modes of function: flashing or steady. Each set is distributed with 4 cones and a nylon-carrying bag.

Figure 8. Traffic Safety Store™ 28" Collapsible Cones

ProFlare™

The ProFlare™ is a disk shaped, battery operated light that has three light settings: rotary, steady on, and flashing. The ProFlare™ has a diameter of 3.5 inches and a thickness of less than 1 inch without the accessories attached to the back of the unit. A standard unit is distributed with a variety of mounting options for the device which include: belt clip, magnet, a 45° or 90° stand, Velcro armband, suction cup and holes for hardware mounting. The unit has three different patterns of operation which include flashing, steady on, or rotary. It requires 4 AAA batteries and has an advertised runtime of 100 hours depending on the unit's settings. ProFlare™ offers a carrying bag that includes all of the hardware mentioned about and four units.

Figure 9. ProFlare™

<u>Flare Alert™ Beacon Pro</u>

Advertised as being waterproof, this light has a hard plastic housing with a red lens. The Beacon Pro has a diameter of 3.75 inches and is 1.75 inches thick. The kit is sold as: 8 electronic flares, 8 metal stake mounting plates with removable weighted metal bases and a nylon carrying bag. The unit has two patterns of operation: flashing or steady. The Beacon Pro requires 4 AA batteries and has an advertised runtime of 30 hours depending on flash settings.

Figure 10. Flare Alert™ Beacon Pro

PDK Technologies Inc™, LiteFlare®

This light is a palm sized L.E.D., low profile flare system housed in a hard polymer shell. It is available in red or amber. They are similar in design, size and shape as a standard road reflector. The LiteFlare® measures 4.25 inches long, 3.78 inches wide and 1 inch thick. They are available in single, 3 and 6 unit packs. It is powered by 2 AA batteries with an advertised runtime that exceeds 400 hours. It is advertised as being resistant to snow, water, and fuel spills. The LiteFlare® is distributed with a plastic and nylon handled carry case.

Figure 11. PDK Technologies Inc™, LiteFlare®

Additional Technologies Examined

Personal Utility Lights

During the course of this study, the researchers identified a number of battery operated light systems that appeared to have utility as traffic control devices. Unfortunately, they lacked sufficient light output for this purpose. Even when placed on retro-reflective clothing, these personal utility lights did not significantly enhance the visibility of the user. However, their small size and long runtimes may offer additional applications as a work or utility light in both the private and public sectors. While this is outside the scope of this study, their utility was noteworthy. The smallest CEJAY Engineering utility light reviewed by the researchers was the GloWand MK8 (2.5”). This light and multiple sizes of the Kriana Corporation’s Krill® Light were often used during the course of this project and allowed personnel to modify flare positions without impacting the night vision of the viewers.

These advertised battery runtime of 70 – 120 hours offers utility in emergency scenarios such as power outages. Although the Krill® has an advertised runtime of 120 hours, the MK8 was substantially smaller and brighter.

Figure 12. CEJAY GloWand and Krill® Lights

Retro-reflective Clothing

The researchers examined the 5.11 Tactical Series® ANSI III reversible retro-reflective jacket as a compliment to flare technology. The researchers hypothesized that because of the reflective nature of the jackets, personal utility lights and other flare systems would reflect light off the jackets increasing visibility of the user. It was hoped that this increased visibility would translate to increased safety for the user. The jacket exterior shell is high-visibility yellow and incorporates 3M Scotchlite™ reflective tape. Class III garments are generally designed for traffic conditions in excess of 50 mph.

Figure 13. 5.11 Tactical Series® ANSI III Jackets

GENERAL FINDINGS

The various costs, operating times, and portability are all variables to be considered when purchasing traffic control devices. This section addresses these variables and factors affecting performance. Additionally, the visibility scores of the flare systems are illustrated below in both chart and table form.

Cost

The purchase cost of the different systems ranged drastically. When purchasing technology as part of a set versus purchasing individual units, the pricing changed considerably. The overwhelming majority of systems utilize off-the-shelf disposable batteries as a power source. The yearly cost of operation is determined by the cost of the batteries, the runtime, and the number of battery replacements over that time period. The PowerFlare® system was the only rechargeable technology (at the time of testing), which negated the need to purchase replacement batteries.

Durability

All of the flare systems were subjected to a substantial amount of wear and tear. With the exception of ProFlare™, no failures were noted in any of the products. During the course of the study, five separate ProFlare™ units ceased functioning; two units failed due to falls from cones, while another three ceased operating for unknown reasons. The vast majority of flare systems appeared to have been designed to survive impacts from vehicles.

PowerFlares® advertises that their product will continue to function after being driven over as well as suffering from other types of impacts. Researchers subjected PowerFlares®, LiteFlares® and TurboFlares™ to drops from increasing heights and drove over them repeatedly, but were unable to damage these products. The other products were not as durable during drop testing and this affected their functionality.

Portability/Ease of Deployment

A number of the products tested utilize or are supplied with some type of carrying case to aid in their deployment. Two companies provide a hard case to protect their product; TurboFlare™ contains eight flares while Tektite's® case contains five flares. Other companies (Flare Alert™, ProFlare™, Traffic Store™, PowerFlare® & LiteFlare®) offer a soft case that aids in transporting their respective equipment, but provide less protection. PowerFlare® offers a unique option for quick deployment in the field. A fanny pack is provided that allows an officer to pick up six PowerFlares® and rapidly deploy them. The PowerFlare® charging unit is constructed of plastic and may not be durable.

Factors Affecting Performance

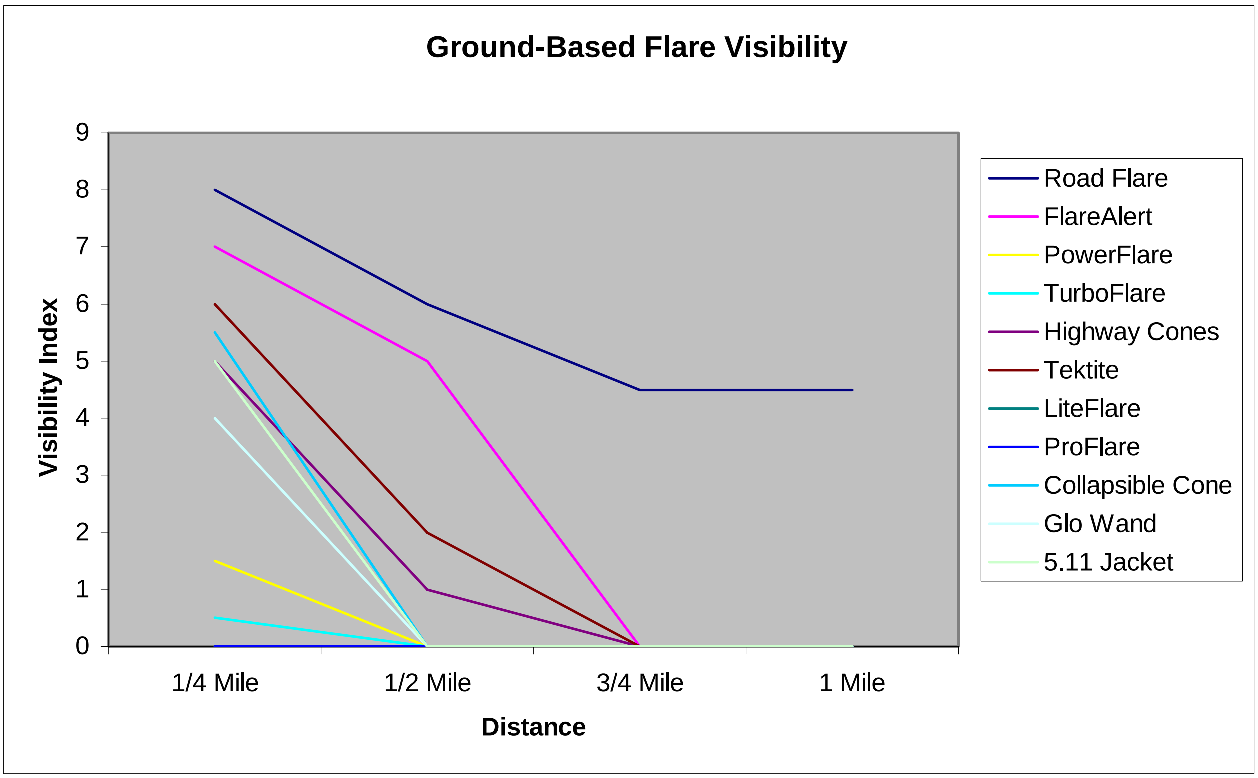
The majority of products considered and tested in this evaluation were limited to a steady or flashing light when activated. The exceptions were PowerFlare® (nine flash pattern settings) and ProFlare™ (three pattern settings). These settings allow the operator the ability to choose the most appropriate flash pattern under the circumstances. This freedom offers a great deal of utility although certain flash patterns during testing were found to be less visible.

A slow constant flash pattern was less eye catching. In contrast, the faster the flashing patterns, the greater the sense of urgency reported by the observers. The faster flash patterns also tended to draw the observers' attention faster.

Another factor substantially affecting the visibility of individual products, was their relative height above the ground. It became clear during field-testing that products that were closer to the ground received considerably lower scores. A slight depression in the roadway could obscure the flare visibility even at short distances. By elevating all the products by merely a few inches, their visibility was often increased by a ¼ mile or in some cases more. When products were placed on a cone, they frequently became visible at a distance of one mile or more.

The following figures reflect the final performances of the various flares. As a result of the testing, a second round of data collection was undertaken to examine the effect of height on flare performance. As such, a second figure provides information to display these differences.

Figure 14. Ground Based Flare Visibility Testing



During testing, the researchers placed the flares on the roadway at ¼ mile distance increments. The research team then observed the road flares, as detailed in the methodology section. The visibility scores were then recorded.

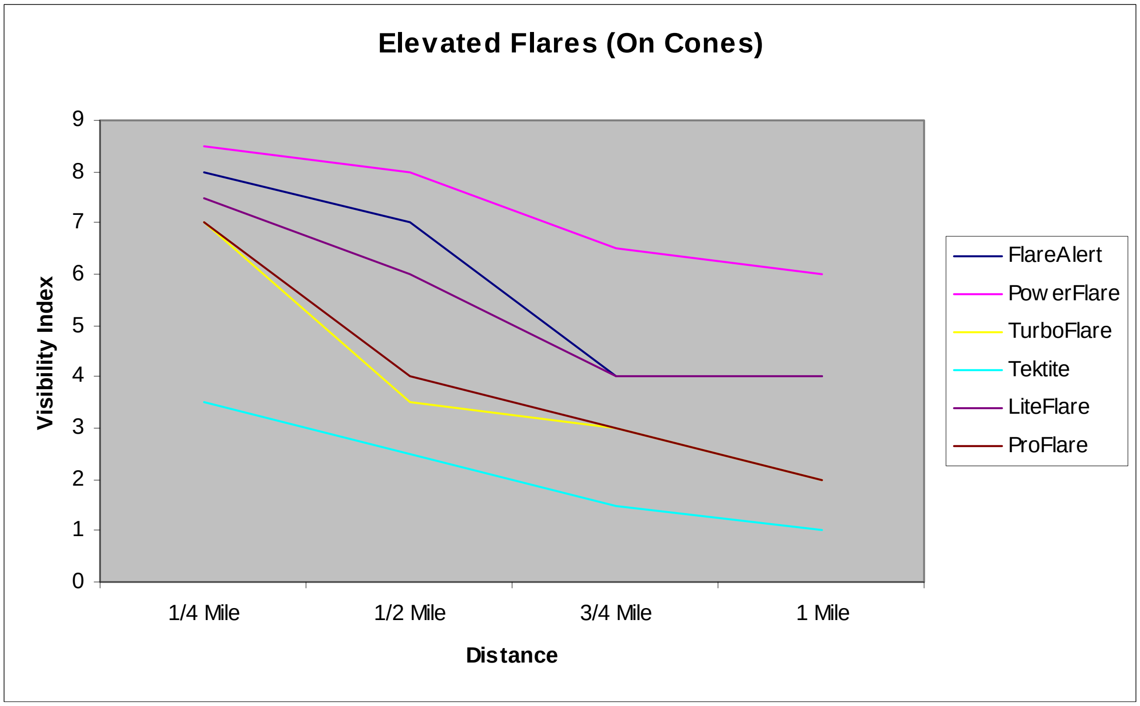
As referenced in the above figure, the traditional highway flare was the only product that was visible at the distances of ¾ of a mile and 1 mile.

As shown in the chart above, the other flare products became less visible as distance increased; the greatest reduction being between the ¼ mile and the ½ mile distance interval. Of the electric flare systems that were visible at ½ mile (Flare Alert™ and Tektite®), it is likely that they were visible as the standard product design allows them to be elevated.

Due to their proximity to the ground, the other products’ visibility scores were drastically impacted by even slight depressions or unevenness in the roadway. Additionally, the roadway selected was a well-maintained county road with no discernable defects with optimal surface conditions. Only when a laser level was placed on the road surface was the unevenness obvious.

As the researchers found such a competitive advantage was offered by the relative height of the flare above the ground, it was decided to remove this advantage and test the flare products at a standardized height (the height of a standard road cone above the ground). The following table represents the visibility of the flares at the standardized height of 36 inches.

Figure 15. Elevation Based Flare Visibility Testing



The different flare devices were placed on the top of a standard traffic cone, while the cones were deployed in a standard work zone taper. Every flare product tested in this manner benefited from the height advantage and their relative visibility scores increased at each distance interval. Each product became visible at the one-mile distance interval.

The advantage afforded elevating the flare has significance for public safety and highway road workers. Consequently this allowed every flare product to perform at a higher level. Additionally, while the standard highway flare outperformed the chemical and electrical flares in all testing, the PowerFlare® scored higher then the highway flare at distances over 1 mile or greater when afforded the height advantage of being placed on a standard road cone. When elevated the Flare Alert™ outperformed the highway flare at ½ mile. At the same ½ mile distance LiteFlare® scored equivalent to the with the standard highway flare.

As discovered in this testing, the Powerflare®, the Flare Alert™ and the LiteFlare® products appear to offer competitive market solutions when compared to a standard highway flare.

Table 1. Ground and Elevation Testing Comparison

	Ground	**Elevated**	**Ground**	**Elevated**	**Ground**	**Elevated**	**Ground**	**Elevated**
	1/4 Mile		1/2 Mile		3/4 Mile		1 Mile	
FlareAlert™	7	8	5	7	0	4	0	4
PowerFlare®	1.5	8.5	0	8	0	6.5	0	6
TurboFlare™	0.5	7	0	3.5	0	3	0	2
Tektite®	6	3.5	2	2.5	0	1.5	0	1
LiteFlare®	0	7.5	0	6	0	4	0	4
ProFlare™	0	7	0	4	0	3	0	2

As discussed earlier, all the flares benefited from a height advantage. However, it must be stated that certain products were omitted from the height testing. The highway flare was omitted as it posed a serious fire risk when placed on a plastic traffic cone. Flares and other technologies that could not be safely placed onto the cone without major modification were omitted.

The following images reflect the flares placed on the cones during elevation testing. None of the flares other than FlareAlert™ had a dedicated mounting device; consequently they were simply placed on top of the cones during testing.

Figure 16. Flares Deployed on Cones

Flare and Cone Combinations

A number of cone and flare configurations were tested in an attempt to find solutions for increased visibility. The researchers hypothesized that cones and flares in concert would offer more visibility at a taper zone. A traffic control zone was set up in an attempt to determine “better” designs for visibility. In this design flares were tested while on the ground level.

A combination of cone and flare patterns produced results with the highest visibility. This was the case with both flares at the ground level and also when they were elevated. However, when used simultaneously a combination of different flare products and cone types produced a confusing traffic control environment. In these cases a driver may not be able to discern a direction to travel in order to avoid the obstruction or accident. In the following figure, the flares are seen placed on the ground level and were alternated between cones.

Figure 17. Multiple Configurations Tested

The researchers found that the visibility of the cones and flares deployed had varied results when traveling at different speeds. At low speeds, the lighted collapsible-type cones provided more visibility whereas the larger 36-inch traffic cones were better suited for high-speed environments. In examining the collapsible cones, the researchers found that when the light source within them was a “steady on” the cones were more visible. When their internal light source was set to flash, they were found to be less visible.

The most important finding during this experiment was that simple designs with one cone-type and one flare type tended to have higher visibility than designs that mixed different flare systems. Finally, the taper zone pattern with the overall highest visibility at low speeds consisted of two flares that were placed between each cone. Alternatively, placing a single flare between each cone resulted in lower visibility score, but was still more visible than using the flares in a stand-alone manner. Thus, traffic cones should represent the base upon which a taper zone is created as they enhanced visibility scores considerably.

Complimentary Technologies

A number of complimentary technologies were examined in this evaluation as they were related to the flares. Selected in this evaluation were highway cones, collapsible cones, Glo Wands, and 5.11 jackets. The following table is incorporated to detail these other technologies visibility at various ranges.

Table 2. Complimentary Technologies

	Complimentary Technology Testing			
	¼ Mile	½ Mile	¾ Mile	1 Mile
Highway Cones	5	1	0	0
Collapsible Cones	5.5	0	0	0
GloWand	4	0	0	0
5.11 Jacket	5	0	0	0

In this case, only the highway cones were visible at one-half mile. The researchers theorized that the additional height of the traffic cones (36 inches) over the 28-inch collapsible cone gave it a slight advantage. Both the 36-inch standard cone and the 28-inch collapsible cones were outfitted with retro-reflective strips; however both require a light source to illuminate the strips. In the case of an oncoming car, the light beams of its headlights are fixed at an angle from the car toward the roadway, and as such require the beams to “reach” the cones prior to the retro-reflectivity. The retro reflective tape was not visible after ½ mile, but was visible at ¼ mile for both types of cones.

At ½ mile, the collapsible cones were more visible than the standard 36-inch highway cone because of an internal light source. While the light source allowed it to be more visible at closer ranges, this effect diminished as distance increased.

At ¼ mile, the 5.11 jackets were scored equally with the highway cones. Their retro-reflective material made them visible at closer distances; however their visibility diminished considerably beyond a ¼ of a mile.

The GloWands were selected for elevation testing as their light output was greater than the Cyalume® and Krill lights. The 2.5-inch GloWand was visible at ¼ mile. The green GloWand was most readily visible (this finding is consistent with the literature review which finds that the color green is the most readily visible light spectrum color). Despite the GloWand being visible at the ¼ mile distance interval, its color and size were not perceived by the research team as an early warning indicator for approaching traffic. The colors red, blue and orange tend to convey a greater sense of caution or danger, while the green does not.

Establishing a Temporary Traffic Control Zone

Although substantial guidance is provided for setting up traffic control zones for highway maintenance, the extant literature is virtually silent regarding a standardized method for an officer to immediately establish a safety zone at a traffic crash. Frequently, accident vehicles remain in the roadway as traffic flows uncontrolled around the scene. Often, secondary crashes occur and may serve to exacerbate an already tenuous situation. The officer's actions within the first few moments upon arrival on a traffic accident scene may determine the outcome for a series of events.

Upon arrival, the placement of the officer's vehicle is often determined by the responding officer's agency policy. Most agencies generally suggest that the officer's marked vehicle be positioned in such a manner so as to protect the crash scene and the personnel on scene. Typically the officer's vehicle is initially positioned at least fifteen feet behind the rear accident vehicle with the steering wheel (tires) turned full right, or into the curb.

A common error made by officers is the creation of a smaller than necessary transition area to taper the flow of traffic into another lane on the roadway. During the testing of the flares, it became clear that a shorter transition area was perceived as a solid, straight line of lights or cones. This transition area was not clearly recognizable as a taper designed to direct traffic into a different lane.

Certain strobe patterns gave the appearance that traffic should be directed into the opposite direction needed. This flash pattern might cause a driver to pass through the emergency work area and place personnel at risk. This confusing effect appeared to diminish at approximately 300 feet. However, this distance may not be sufficient to allow for reaction time and braking depending on the oncoming vehicles speed, tire condition, drag coefficient and operator's response time. As a result, the driver may be well past the point of no return and may not be able to successfully navigate the lane transition.

Taper Zone Configuration

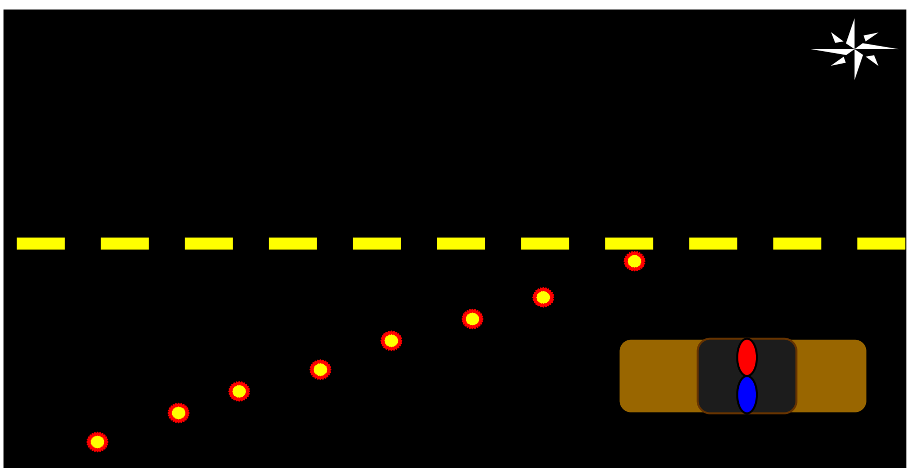
In order to examine adequate stopping distances, the researchers tested a number of different configurations of lights, cones, and strobes in order to determine an optimal layout that an officer could deploy rapidly upon arrival at the scene. The method and design (Figure 18) was created allowing a single officer to create the most favorable safety zone within the shortest amount of time.

Since time is of the essence to prevent additional crashes, officers should immediately don a retro-reflective jacket or vest to become more visible and place some type of emergency warning equipment at the rear of their vehicle. This equipment will serve as a temporary measure while the establishment of a proper warning and transition area is created. Although traffic cones are awkward, they should be used as the foundation for the transition area. Cones tend to be visible in both daytime and nighttime conditions and their retro-reflective strips are visible at up to a half mile. Further, they can be used to support other technology that can be placed or mounted on their highest point. As shown earlier in this report, the performance of flare technology can be greatly improved by elevation as a synergistic effect was observed.

Unfortunately, the placement of cones into the proper position is time consuming because they are bulky and cumbersome. As a stopgap measure, the smaller flare devices can be initially placed into the cone positions while the cones are being moved.

To create a taper zone with sufficient distance, the researchers examined various formulas to create this design. The most favorable formula utilized a 10-1 ratio; for each ten paces away from the starting point, the cone was moved over one pace. This created a transition zone that was 80 paces (approximately 240 feet long) and extended the length of a single lane of traffic. While this formula used eight cones, the configuration can be modified to meet the needs of the individual agency. The following illustration represents a basic taper zone that places the cones and flares at a 10 pace distance interval away from the emergency vehicle.

Figure 18. Taper Zone Diagram



Once the cones are in place, the additional flare technology should be positioned on the top of the cones for the added height and visibility advantage. Only one of the devices tested includes a mounting system that securely attaches it to the cone. Thus, the officer must be careful when placing the remaining flare technologies on top of the cone. The successful placement of a flare on a cone is dependent on the size and weight of the individual flare system.

CONCLUSIONS

Highway flares continue to be viewed as one of the most cost efficient options for first responders. They can be quickly deployed and are visible at great distances and under adverse conditions. The traditional highway flares have an inherent height advantage created by the wire stand.

However, traditional highway flares have a number of disadvantages. Upon completion of the burn, the remnants (the striker, cap, and unburned flare remnants) need to be picked up and disposed of properly. This places the officer in a position wherein they must find the appropriate disposal method for potentially toxic material, which is rarely discussed in agency policies. A single unburned 20-minute flare can potentially contaminate up to 2.2 acre-feet of water (Sliva, 2003). As a result of these issues, chemical and battery operated flares which are environmentally friendly, should be considered as viable alternatives.

A number of chemical lightsticks were tested and evaluated. It was originally hoped that these Cyalume® sticks would offer a rapid and effective deployment alternative. While the lightsticks provide a number of applications for law enforcement, their lack of visibility during testing precluded them from being competitive with the other products evaluated. The basic product design does not allow for adequate placement above the ground and when affixed to the cones tested, still did not supply adequate illumination to be sufficiently visible for traffic control.

Electrical light and strobe systems offer an innovative alternative to traditional highway flare systems. As shown in this report, their visibility and utility vary greatly from product to product. When used in combination with traffic and highway cones, they have the potential to outperform even a highway flare at distances exceeding a mile. The obvious advantage of this technology is that it is environmentally safe and does not pose a fire hazard. Further, the size of these devices allows a first responder to quickly establish a safety zone and reduce the potential for secondary crashes or collisions. Lastly, these devices are highly portable, compact, and some models allow for recharging.

This project also examined several personal utility lights (Krill® and the Cejay® GloWand), and the 5.11 Tactical Series™ ANSI Class III Reversible Jacket. This technology was examined in the hope of identifying additional safety devices, which would compliment flare deployments. It was theorized that these items, when used in concert with a retro-reflective jacket, would create a synergistic effect and allow the jacket wearer to be highly visible. This was not the case, as the personnel utility lights did not improve the visibility of the retro-reflective jacket.

Beyond the scope of this evaluation, the GloWand did provide a substantial amount of light output considering its small size (2½ inches). These devices could serve as an emergency work light with a runtime of approximately 70 hours and a cost of $12 per unit. During the course of this project, these personal utility lights were issued to all personnel and utilized in a broad range of tasks related to nighttime data collection. Obvious applications for personal utility lights include emergency lighting during power outages, and low light reading in conditions absent of light.

The single more important finding from this study was the discovery that the relative height placement of the flares affected visibility the most. In ground based and elevation based testing, all of the flare technologies under examination scored higher on the visibility scale when elevated. The researchers found this to be true for the testing at 36-inches of elevation. However, even a slight elevation of a few inches above the ground resulted in a substantial increase in visibility for all of the electrical and chemical flares. The wire stands in the traditional highway flare allow the light source to be elevated (at initial ignition) up to approximately 10 inches above the ground. All electronic and chemical flares tested would benefit in this manner.

Lastly, during the course of this evaluation the researchers identified the issue of directionality as an area for future research. It was found that complex cone and flare configurations could cause confusion as to which way a driver should turn when approaching a taper zone. Similarly, uncoordinated flash patterns had the same effect. When taper zones were created using multiple flare technologies, the effect of the taper was reduced as the taper line became perceived as being perpendicular to the road. This gave the zone the appearance of being a wall of light and the research team’s first instincts were to stop completely instead of merging into another lane. This instinct may be inherently more detrimental to the flow of traffic. Consequently, a traffic control taper should be a simple design (with flare devices elevated if possible) to increase visibility while creating the least amount of driver confusion.

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