Safety Evaluation of Ultraviolet-Activated Fluorescent Roadway, Delineation: Preliminary Field Experiment

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FOREWORD

This technical report is intended for those parties interested in highway safety research. The report highlights the results of a field test conducted to examine drivers' opinions of ultraviolet (UV) headlamps used in conjunction with fluorescent paint as roadway delineation. The study also measured distance and general visibility of the fluorescent roadway markings as compared to standard roadway markings. The experiments reported here summarize a preliminary research study.

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Research and Development

NOTICE

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16. Abstract

A new technology is being developed in Sweden to improve visibility for nighttime driving. This technology consists of Ultraviolet (UV) headlights in combination with fluorescent traffic control devices. Vehicles will be equipped with headlamps that supply UV radiation in a high-beam pattern, along with conventional halogen or metal halide low-beam headlamps. UV light is not visible to the human observer, but after striking certain materials it will cause them to "fluoresce," that is, the UV radiation is converted to longer wavelengh, visible light. UV-activated fluorescent materials can be incorporated into roadway delineation, such as pavement markings.

A field test was conducted to examine the effectiveness of using UV headlights, with fluorescent pavement markings, in increasing the visibility of roadway delineation. This included measurement of both a visibility distance and subjective ratings. The study examined drivers opinions of the UV light as well as measured distance and general visibility of the fluorescent roadway markings as compared to standard roadway markings.

Results showed that UV headlights provided a significant increase in UV-activated fluorescent pavement marking delineation visibility.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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INTRODUCTION

Nighttime driving is one of the motorist's most difficult tasks. The risk of having an accident on the road at night is two to three times greater than during the daytime. Since the basic difference between night- and daytime driving is the absence of light at night, the increase in the accident rate in periods of darkness may be attributed to poor visibility conditions. During nighttime driving, the visibility distance largely depends upon the availability of artificial light, the source of light being the vehicle headlamps or fixed overhead lighting. High object visibility is an essential characteristic of traffic control devices and a significant factor in highway safety. Therefore, researchers have investigated ways of making objects and pedestrians more visible at night, including using ultraviolet (UV) headlamps combined with low beams.

A new technology is being developed in Sweden to improve visibility for nighttime driving. This technology consists of UV headlamps in combination with fluorescent traffic control devices. Vehicles will be equipped with headlamps that supply UV radiation in a high-beam pattern, along with conventional halogen or metal halide low-beam headlamps. UV light is not visible to the human observer, but after striking certain materials it will cause them to "fluoresce," that is, the UV radiation is converted to longer wavelength, visible light. UV-activated fluorescent materials would be incorporated into roadway delineation, such as pavement markings and post-mounted delineators.

Although some preliminary research on visibility with UV headlamps has been conducted by the Swedish Road and Traffic Research Institute, changes in design of the UV headlamps and differences between European Economic Community (EEC) and U.S. low-beam headlight limit the ability of this research to be generalized. Driver performance using UV/fluorescent technology needs to be studied. In order to determine the performance improvements possible from fluorescent pavement markings, experimental work was conducted in the field using a roadway installation of UV materials. Before describing this study, however, it is prudent to review the current literature on the use of UV head lamps, including the categories of The Role of Head Lamps in Visibility, Using UV Head Lamps to Enhance Nighttime Visibility, and Safety Issues of UV Lighting.

LITERATURE REVIEW

The purpose of this literature review was to identify information that might document how UV headlamps can enhance nighttime visibility. A comprehensive search was made of journals and reports in appropriate subject areas, and a listing was made of articles and reports with potential relevance to this project. Emphasis was placed on the application of UV technology for highway visibility enhancements. Because this is a recent technology, the amount of existing research was limited. Nevertheless, a number of significant articles and papers have been written on the subject. This section highlights the most relevant.

The Role of Headlamps in Visibility

The vehicle's headlamps are the main source of illumination available to the driver. The condition and potency of these lamps will directly impact the driver's ability to see objects at night.

The main factors involved in nighttime accidents and fatalities are alcohol, inadequate visibility, and driver fatigue (Vanstrum and Landen, 1984). Of those factors, only visibility can be enhanced through safety engineering. For example, Vaswani (1977) concluded that inadequate visibility of road signs and pavement markings at night contributed to incorrect driving maneuvers. He described a concept which delineates the limits of nighttime visibility under low-beam headlamps, and then applied his concept to the placement of signs, markings, and additional devices that help guide motorists.

In addition, Olson, Sivak and Henson (1981) found that low beams do not provide adequate visibility under many driving conditions. The major limitations to improved headlamp design were characteristics of the human vision system as well as practical problems associated with headlamp mounting and conditions of use. Some limitations arising from the human visual system are limited contrast sensitivity at night, problems of glare, and sharpness of central versus peripheral vision.

A suggestion to counteract the limitations of the human visual system and improve visibility is the use of UV headlamps. In general, small objects can be seen most clearly when wavelengths of light as small as or smaller than the objects themselves are reflected from them. Since UV wavelengths are extremely small, objects not readily seen can be more easily and clearly detected.

The Use of UV Headlamps to Enhance Nighttime Visibility

UV light has a shorter wavelength than ordinary light and is invisible to the human eye. However, when UV light is reflected in certain materials, it is returned on longer wavelengths and becomes visible. This phenomenon, known as fluorescence, makes objects more visible and therefore offers a large potential for improving safety.

Most of the research in the application of UV headlamps for enhancing highway visibility has been conducted in Europe, particularly by the Swedish National Road Administration under the ARENA Program.

ARENA is a Swedish National Road Administration (SNRA) project which uses field tests to study how road traffic and safety can be improved by advanced technology. The project, based in Gothenburg in 1992, carries out field tests with the cooperation of industry and other organizations. Under the area of traffic safety, a project called "UV Light" was conducted. UV headlamps, with emission spectra between 320 nm and 400 nm, and fluorescent road markings were used to create a full light effect in conditions of poor visibility without blinding the oncoming traffic. Pedestrians were seen much more clearly and the path of the roadway could be seen far beyond oncoming vehicles.

Barrie (1989) described the Swedish trials on UV vehicle headlamps. The UV light alone did not enable drivers to see where they were going. However, they were able to highlight anything that contained fluorescent pigments. These included road signs, road markings, and protective clothing. UV headlamps greatly improved visibility allowing drivers to identify objects 200 m away, compared with a low-beam range of 50 m; they also worked well in fog.

Currently, UV lamps are being tested by the Swedish car manufacturers, Saab and Volvo, on various cars and a bus. Since 1990, Saab, Volvo and Philips have been involved in a joint development company called Ultralux, which is developing a viable lamp. In the United States, the Ford Motor Company, in its Contour concept car, has incorporated prototypes of a High Intensity Discharge (HID) lighting system. This system, scheduled to be in production in about 2 years, also emits UV-A light.

Work on the dangers and problems of the UV light is being carried out by the Swedish Road and Traffic Research Institute, which found that UV beams from headlamps do not constitute a health hazard. By using filters, all the harmful UV-B and UV-R rays are eliminated. The remaining UV-A intensity is very low compared to that found in normal daylight. Because of the filters, the lamps appear black in the daylight and glow faintly blue when switched on in the dark. In addition to the use of filters, the Swedish Road and Traffic Research Institute proposed that sensors be placed in the cars to determine when the car is moving at speeds in excess of 49 km. The UV lighting system will be designed to operate only at speeds greater than 49 km to minimize any potential health threat to pedestrians. However, future research is needed to assess the need of this proposal.

Ultralux (1994) found that road markings could be seen at a distance of 150 m with UV light (plus low beams), compared with 60 to 70 m with low beams alone. The corresponding visibility distance for roadside posts was even better. The posts were visible at more than 200 m with UV light. However, the percentage of improvement in road safety as a result of greater visibility varies among studies. According to Road Transport Research, the percentage reduction in accidents associated with improved lighting is 20 percent on average. In some cases, the number of accidents is reduced by 56 percent.

In addition, Ultralux (1994) found that pedestrians and other unprotected road users are seen more easily when they are illuminated by UV lighting. Different clothes, depending on the material and color, have different levels of fluorescence. For example, jeans could be seen at approximately 100 m, while white cotton clothes and synthetic fabrics could be seen at greater distances. Dark clothes like black wool, however, were no more visible with UV light than with normal low beams. In addition, washing can improve the fluorescent properties of garments due to the optical whiteners present in many detergents. The detergents used for washing dishes and clothing generally have a number of additives such as bleaches, brighteners, and abrasives. Bleaches whiten fabrics by destroying dirt and colors. Brighteners are chemicals that convert normally invisible UV light into visible light. Because of the brighteners, additional light reflects back from the fabric, making it seem more vivid, or "whiter."

An important finding in the Ultralux (1994) study was that, when combined with low beams, UV light, has a unique possibility of increasing the visibility of fluorescent objects on the road without blinding drivers in oncoming cars. In addition, fabrics of relatively low fluorescent efficiency, like jeans, could be detected at a distance of about 100 m even in the presence of glare from the lights of oncoming cars. When there was no glare to reduce the visibility, detection distances of more than 150 m were achieved, even for clothes with a low fluorescent efficiency.

Ultralux (1994) also studied motorists' experiences with UV light in traffic. The National Swedish Road Administration equipped approximately 100 km of road with fluorescent properties. Forty drivers were interviewed after driving cars with UV lamps on roads with and without fluorescent properties. The results provided a positive account of the effect UV light has on driving in the dark and showed that the visibility of road markings more than doubled when using UV light. The test drivers also found that the fluorescent markings improved visibility by 40 percent over low beams only. UV beams in combination with low beams received a higher rating for visibility than low beams alone in all cases. The drivers experienced a greater improvement in visibility on freeways and main roads than in city traffic with street lighting. Additionally, 78 percent of the drivers found that the new road markings could be seen more easily in the daylight. Finally, Fast (1994) documented how supplementary high-beams near UV headlamps fluoresced road markings and clothes which could then be seen at much greater distances.

In a comprehensive study of detection distances of obstacles on the road when using UV headlamps, Helmers, Ytterbom and Lundkvist (1993) investigated whether low-beam illumination supplemented by UV headlamps could provide long and safe detection distances. The detection distances were measured in a full-scale simulated opposing situation between two vehicles on a straight level two-lane road closed to traffic. The opposing car was stationary in the opposing traffic lane. The subject's car was driven in the driving lane towards the stationary car. The task of the subjects, as well as the driver, was to detect obstacles to the right in the driving lane. Upon detection, subjects pushed a hand-held switch. The obstacles were square plates, with each side measuring 0.4 m. The flat plates were covered with cloth and had one of three reflectances: black, light gray, or white. The results showed a nondetectable or minor increase in the detection distances for the black and the light gray targets using UV and low beams instead of low beams alone. However, the detection distance for the white targets was twice as long when the ordinary low-beam illumination was supplemented by UV radiation. The relation between the reflectance of clothes and the power to emit visible light in UV radiation was also studied. The increase in luminance related to the increase in whiteness of the garments was positive and approximately 30 times larger in UV lighting than in ordinary headlight illumination. Further, the ability to emit visible light in UV radiation increased more rapidly than the ability to reflect ordinary light when the reflectance of the clothes increased.

In additional support of UV headlamps, a positive effect on the visibility of pedestrians and on road design elements was demonstrated by Staehl, Oxley, Berntman and Lind (1994), who tested two systems developed to enhance visibility during nighttime driving: the Volvo UV light system and the Jaguar night vision system. Using these systems may give older drivers more confidence when driving at night and should improve both their own safety and that of other vulnerable road users such as pedestrians.

Finally, although there is evidence that UV headlamps can improve the visibility of the roadway and of roadway objects, there is another important safety aspect of the UV headlamp to consider. The potential health hazard presented by UV radiation must not be ignored. Schoon and Schreuder (1993) describe the function and types of application of headlamps. The light emission of a low-beam headlamp, as stipulated by European Economic Community regulation R20, is dealt with extensively. The paper also presents the results of a study into HID (e.g. UV) lamps in the United States and European research through EUREKA 'VEDELIS.' Schoon and Schreuder conclude that: 1) the proposed light emission of the low beam for HID lamps is higher than the current EEC standard for virtually all measurement parameters; and 2) the orientation of the light-beam emission should pay greater attention to the position of vulnerable road users. This indicates that UV lights may pose a health hazard for humans.

Health Safety Issues of UV Lighting

The work summarized in the previous sections seems to indicate that UV lighting has an enormous potential to enhance nighttime driving visibility. One issue that remains is the potential danger of UV radiation (UVR) exposure to humans.

Only recently have scientists begun to understand the full effects of UV light on living organisms. Human exposure to longer-wavelength UV radiation is necessary for the production within the body of vitamin D, a substance that helps promote and maintain proper bone development. UV radiation also causes the production of melanin in skin cells, resulting in a suntan. However, scientists have established a strong correlation between exposure to shorter-wavelength UV radiation, genetic mutation in basal skin cells, and skin cancer. Therefore, it is recommended that sun bathers apply suntan lotions to block or absorb the high-energy and harmful portions of UV light.

Fortunately, the shortest wavelengths of UV radiation, which causes serious tissue damage, are absorbed by gases such as ozone in the earth's atmosphere. The effects of chemical pollution on the gases in the ozone layer are being closely monitored in an attempt to preserve these protective layers. The blocking effects of the atmosphere are crucial to the survival of many organisms.

UV radiation can produce direct and indirect effects upon the human body. The direct effects are limited to the surface skin because the rays have low penetrating power. Direct effects include sunburn, suntan, and progressive adaptation to heavier doses. UV burns can be mild, causing only redness and tenderness, or they can be so severe as to produce blisters, swelling, seepage of fluid, and sloughing of the outer skin. The blood capillaries, which are tiny blood vessels in the skin, dilate with groups of red and white blood cells to produce the red coloration. A suntan occurs when the pigment in cells in the deeper portion of the skin tissue are activated by UV radiation, and the cells migrate to the surface of the skin. When these cells die, the pigmentation disappears. The degree of pigmentation is directly related to the length of UV exposure and the body's inherent ability to produce pigments. Tanning is a body's natural defense to help protect the skin from further injury.

Frequent overexposure to sunlight induces thickening of the skin, more rapid skin aging, and a higher frequency of skin disorders, including cancer, particularly in persons with fair skin. There is an increase in skin temperature, skin respiration, and skin cholesterol after frequent exposure to UV radiation. Similarly, there is a decrease in pain sensitivity, perspiration, and mineral levels in the body's tissues.

The indirect effects of overexposure of UV radiation are for the most part caused when the damaged skin cells release histamine, causing swelling. The respiratory tract becomes more vulnerable to bronchitis and pneumonia, and calcified scar tissue may form in the lungs after overexposure to UV radiation. Histamine stimulates the stomach to produce more secretions and a stronger acid concentration than normal; this, in turn, can lead to inflammation of the stomach lining, or ulcers.

Furthermore, exposure to UVR will lead to a fall in blood pressure and an increase in the quantity of red blood cells, white blood cells, and clotting proteins. There may be loss of weight, increase in appetite, and a reduction in the respiration rate. Despite all of these harmful effects, UV radiation is generally not lethal, but it can kill individual tissue cells and organisms such as bacteria.

Sliney (1987) evaluated the risks from unintentional exposure to UV radiation and determined that safety standards for UV radiation emitted by lamps was a challenge. Sliney (1993) later provided a good summary of UV's known biological hazards (adverse effects) to the skin and eye which have been considered in the development of existing occupational exposure limits (EL's):

- Skin: Erythema (sunburn), accelerated aging of the skin, and photocarcinogenesis (skin cancer) are initiated by UV photochemical effects.

- Eye: Photokeratoconjunctivitis (acute inflammation of the cornea and conjunctiva as in "welders" flash) has been defined for wavelengths from 200 nm to 400 nm and cataractogenesis (lens cataract) has been demonstrated principally in the wavelength range from 290 to 320 nm, and perhaps occurs at greater wavelengths.

Sliney (1993) states that all the aforementioned biological effects, except for carcinogenesis, are acute effects and would not occur unless UV exposure limits exceeded a particular threshold. Thresholds vary depending on skin pigmentation and other factors.

Sliney, Fast, and Ricksand (1995) documented the safety aspects of several types of UV headlamps and showed that most individuals do not experience a strong visual stimulus from the UV-A light, unless standing directly in front of the source.

Sliney, et al. state that, at the time of their study, there were no device-specific UV safety standards for UV lamps or illumination systems, except for sunlamps and sunbeds. They provide equations to compute permissible exposure durations and they recommend the following safety requirements to limit potentially hazardous exposure:

- Limit emission duration when auto is stopped.
- Disable the UV light emission automatically if protective features (outer envelope of a sealed-beam lamp or filter in a projection system) are damaged
- Filter out shortest wavelengths (below 330 nm).
- Maximize retinal image size.

Sliney, et al. conclude that the UVR exposures from the UV prototype headlamp were basically the same as that experienced when exposed to a conventional white-light headlamp, and that there is no hazard to the eye or skin.

Summary

UV headlamps can considerably increase detection distances, particularly those to pedestrians, compared with the use of only ordinary low beams. Even with clothes of relatively low fluorescent efficiency, in the presence of glare from oncoming cars, the detection distance with UV head lamps may double. The use of UV headlamps in automobiles may also significantly increase highway safety by increasing detection distances, even in the presence of glare from oncoming cars. Further, UV headlamps pose no health risk.

The purpose of the study described below was to investigate the utility of UV headlamps on fluorescent pavement markings using a twofold approach, including both a visibility distance (static) and a subjective rating (dynamic) section.

METHODOLOGY

Overview

A two-part field test was conducted to examine the effectiveness of using UV headlamps in increasing the visibility of roadway delineation. The study examined drivers' opinions of the UV lights as well as measured distance and general visibility of the fluorescent roadway markings as compared to standard roadway markings when using the UV headlamps. The experiments reported here summarize a preliminary research study.

The field trials were conducted during October and November of 1995 in dry weather between the hours of 7:00 p.m. and 11:00 p.m. A section of the Clara Barton Parkway between the David Taylor Model Basin and Cabin John exits in Maryland was the location for the study (see appendix A).

The Clara Barton Parkway is a four-lane divided highway with a grass median. The roadway has curbs and no shoulders with an 80 km posted speed limit. There are a few post mounted reflectors. There are no overhead street lights.

A 1995 Volvo, series 950, was equipped with three rectangular UV lamps that were activated by a toggle switch located in the cabin of the Volvo. UV lamps were always used in addition to standard SAE low-beam headlamps.

Dynamic Test Preparations

Six 91-m segments of roadway were selected as sites for the study. Three different roadway marking materials were used for the tests: 1) worn and faded standard white paint (WP), 2) recently installed thermo-plastic (NT), and 3) recently installed thermoplastic containing fluorescent material (referred to as UV). For each type of marking material, two relatively straight segments of roadway were chosen.

Each segment was marked with a 100 mm by 300 mm piece of removable pavement marking tape that was placed perpendicular to the right edge line. One piece was placed at the beginning of the test area and a second piece was placed 91 m downstream. These markings were necessary for the experimenter to know exactly where to cue the subjects. The markers were obscure and did not interfere with the test condition markings.

Static Test Preparations

A work zone right lane closure was set up each night using advance warning signs, a changeable message sign (CMS), an arrow board and orange and white retroreflective barrels and cones. The static test took place within the closed lane using a relatively straight segment of roadway where fluorescent roadway markings were installed. This site was within, but not part of, the dynamic test course.

Markers were placed in the lane closure for the purpose of consistently positioning and parking the test vehicle within the lane during the stationary portion of the experiment. All post mounted reflectors were covered.

Four traffic cones with reflective collars were placed on the grass to the right of the roadway. They were spaced at 30.5 m intervals beginning at 107 m and ending at 198 m from the Volvo. They were used as points of reference for the subjects when the static tests were conducted.

Subject Pool

Subjects were recruited from the Turner Fairbank Highway Research Center (TFHRC) subject bank. Only licensed drivers who, at least occasionally, drove at night, took part in the study. Two age groups were used in the experiment: drivers 25 to 45 years old (younger group) and 65 years old and older (older group).

A total of 41 subjects were tested, including 5 for pilot testing. Data for 36 subjects were analyzed. The final subject pool included 7 older males, eight older females, 13 younger males and 8 younger females.

Research Team

The research team consisted of four people. Two individuals were stationed at the field site. Their responsibilities included setting up and monitoring the work zone, directing the driver to the correct lane placement for the static test, and confirming the proper working order of the UV lamps. One of these researchers also rode in the back seat of the Volvo and observed and recorded traffic data. A third individual drove the Volvo and administered the dynamic and static tests. The fourth person greeted subjects, conducted a vision screening test, and read the preliminary instructions.

Experimental Design

The experimental design for the dynamic portion of the study was a 2 (headlamps) X 3 (roadway delineation type). The independent variable was headlamps (low beam alone versus low beam with UV). The dependent variable was subjective rating of roadway delineation type (NT, WP or UV).

The experimental design for the static portion of the study was a 2 (headlamps) X 1 (subjective rating) X 1 (number of skip) X 1 (visibility distance). The independent variable was headlamps (low beam alone versus low beam with UV). Dependent variables were subjective rating of visibility of roadway markings, number of skip lines counted, and estimation of visibility distance.

Procedure

Subjects arrived at TFHRC and were given a brief visual acuity test. A minimum of 20-40 static visual acuity was required to continue participation in the study. A researcher gave the subjects an overview of the study and read the preliminary instructions (see appendix B).

While each subject was taking the vision test, the driver prepared the study vehicle by cleaning the windshield and all headlamps including the UV lamps.

The subject was escorted to the study vehicle and was asked to sit in the right, front passenger seat. A clipboard, data form, pen and penlight were given to the participant. The driver explained that they would be driving to the Clara Barton Parkway which was about 8 km away.

During the ride to the test location, the driver again explained the focus of the study. After arriving at the lane closure, the driver read the instructions for the dynamic test to the subject (see appendix C). The subject was told to record his/her opinion of the roadway markings on the data form by using the pen and penlight provided.

The subjects used a 5-point rating scale to quantify their opinion of the roadway markings in regards to delineation and lane guidance. The subject was told to rate how well the markings indicated where to drive their vehicle. The subject was reminded that 1 meant poor and 5 meant excellent. After exposure to each site, the subject was told to look down, turn on their penlight and circle the number that represented their opinion of the markings. It was explained that their opinion was to be based on the roadway markings that they would see during the experiment and to compare those markings to all other roadway markings they had seen in the past. The driver then answered any questions that the subject asked and explained that they would drive the entire course one time as a practice run. There was one data collection page for each loop of the course; each data page had six parts, one for each of the six segments (see appendix D for Dynamic Test Data Collection Form). Three orders of presentation were used so that a third of the subjects would be exposed first to the NT sites, a third to the WP sites first, and a third to the UV sites first.

After the instructions were read, the team member who recorded traffic conditions entered the test vehicle. For each test exposure, the number of vehicles (in front of, behind, passing and across the median oncoming) in the vicinity of the study vehicle during the exposure period was recorded. Also, a researcher recorded a subjective distraction rating of these vehicles. For this study, distraction was defined as glare, other vehicle interference and/or vehicle(s) in the exposure area. The distraction rating used a 5-point subjective scale. A rating of 1 meant no distraction and a rating of 5 meant very distracting. A sample of the data form for this information appears in appendix E.

Each subject was driven through the test course three times (three loops). The practice loop was always conducted with just the low-beam headlamps on. At the beginning of the second and third loop, the Volvo headlamps were set for either low beam only or low beam and UV lamps and remained on the particular setting for the entire loop. The order of headlight use was counterbalanced.

At the conclusion of the dynamic test, the subject was driven to the lane closure and parked in a predetermined location. The instructions for the static test were read (see appendix F).

The static test consisted of three activities repeated under both the low-beam and the UV headlight conditions. First, the subject was asked to use the same 5-point scale to rate the overall visibility of the roadway markings at the static test site (see appendix G for Static Test Data Collection Form). Next, the subject was asked to count as many dashed lane lines as they could see. That number was recorded by the observer in the back seat. Last, the subject was asked to determine where the Volvo headlamps no longer illuminated the right edge line. The previously mentioned cones on the shoulder were used to help the subject respond to the question. The subject could say that the headlamps ended at the first, second, third, fourth, or anywhere in between the traffic cones; that response was recorded. The UV lamps were turned on and the three questions were repeated.

Subject comments about the UV lamps were noted. At the conclusion of the static test, the subject was driven back to TFHRC.

RESULTS

Dynamic Testing

During the dynamic testing, the subjects rated the pavement markings using a 5-point subjective scale where 1 was the worst and 5 was the best. The three different types of pavement markings (WP, NT, and UV) were rated. Testing was done with the test vehicle low beams and with the low beam supplemented by the UV driving lights. Results of the dynamic testing are shown in table 1.

Table 1. Dynamic Test: Mean visibility Ratings for UV, NT and WP With and Without UV Headlamps

Headlamps	Fluorescent (UV)	New Thermoplastic (NT)	Worn Paint (WP)	Row Means
UV-ON	4.40	3.92	2.50	3.60
UV-OFF	3.46	3.89	2.51	3.28
Column Means	3.93	3.91	2.50	

There was a main effect of UV Headlamps (UV-ON versus UV-OFF), $F(1,35)=13.99$, $p<.01$. Subjects reported being able to see farther with the UV lights ON (mean=3.60) versus UV lights OFF (mean=3.28). There was also a main effect of markings (UV, NT and WP), Wilks = .23, approximate $F(2,34)=54.46$, $p<.01$. There was no difference between the means of the UV (mean=3.93) and the NT (mean=3.90) using an orthogonal contrast. However, an orthogonal contrast showed that there was a difference between the UV plus the NT (mean=3.91) versus the WP (mean=2.50). It made sense in this orthogonal contrast to compare the mean of the UV and the mean of the NT, as well as the UV mean plus the NT mean, to the WP, since the UV is "state-of-the-art" and NT was new paint and both would thus be expected to provide drivers with better pavement marking visibility distances.

Lastly, there was a significant interaction effect between UV Headlamps (UV-ON/UV-OFF) and pavement markings, Wilks = .49, approximate $F(2,34)=17.72$, $p<.01$ (see figure 1). In comparing the UV, NT and WP ON/OFF means, you can see from table 1 that the greatest difference between means occurs at UV markings, with visibility best with the UV headlamps ON (versus UV-OFF). The difference between UV-ON and UV-OFF rating means were .94 in the UV condition, and only .03 and .01 in the NT and WP conditions, respectively. It is logical that there would not be any difference in the NT and the WP conditions between UV-ON and UV-OFF since there was no fluorescent material in the NT or WP pavement markings.

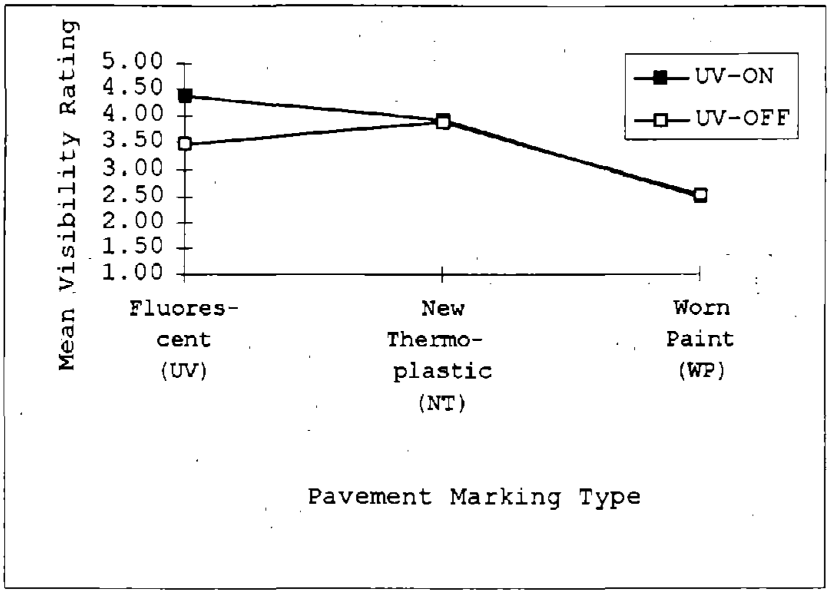


Figure 1. Dynamic Test: Mean Visibility Ratings for UV, NT and WP With and Without UV Headlamps

In summary, the UV-activated fluorescent markings with UV-headlamps-on received a higher mean rating than either the NT or WP conditions with or without use of UV headlamps. The UV headlamps had no effect on either the NT or the WP.

As described previously, a second researcher rode in the back seat of the test vehicle recording information about the degree of headlight glare from oncoming and following vehicles while the subject was evaluating the test segments. Since testing was conducted after the evening rush hour, and traffic was relatively light, it is not surprising that glare conditions during most of the testing were rated as low. Attempts to identify a relationship between the degree of glare and the effectiveness of UV-activated delineations were unsuccessful, due to the smaller number of test sessions that involved high-glare conditions. The performance of the UV-activated fluorescent materials in high-glare conditions will be addressed in future research.

Static Testing

During the static testing, subjects were asked to indicate how many center skip lines they could see and how far they could see the right lane edge line. In addition, the subjects were asked to provide a subjective evaluation of the marking effectiveness. The testing location had UV-activated fluorescent pavement markings. Data for test sessions with the UV headlamps ON were compared with data for sessions with the UV headlamps OFF.

Results showed a significant difference in the UV headlight condition between UV-ON and UV-OFF for 1) center skip line count, $t(35)=11.13$, $p<.01$; 2) visibility of right lane edge line distance, $t(35)=7.26$, $p<.01$; and 3) subjective visibility rating, $t(35)=8.75$, $p<.01$. Subjects could count more skip lines with the UV-ON (mean=9.8 lines) versus UV-OFF (mean=7.6 lines) and could see a farther distance with the UV-ON (mean=180 m) versus UV-OFF (mean=144 m). On a scale of 1 (poor visibility) to 5 (excellent visibility), subjects gave higher visibility ratings of the pavement markings when using UV-ON (mean=4.72) versus UV-OFF (mean=3.22).

In addition to the objective measures that were recorded, the subjective reaction of the subjects was collected. It is notable that there were no negative comments (see appendix H for Subject Feedback on UV Lamps).

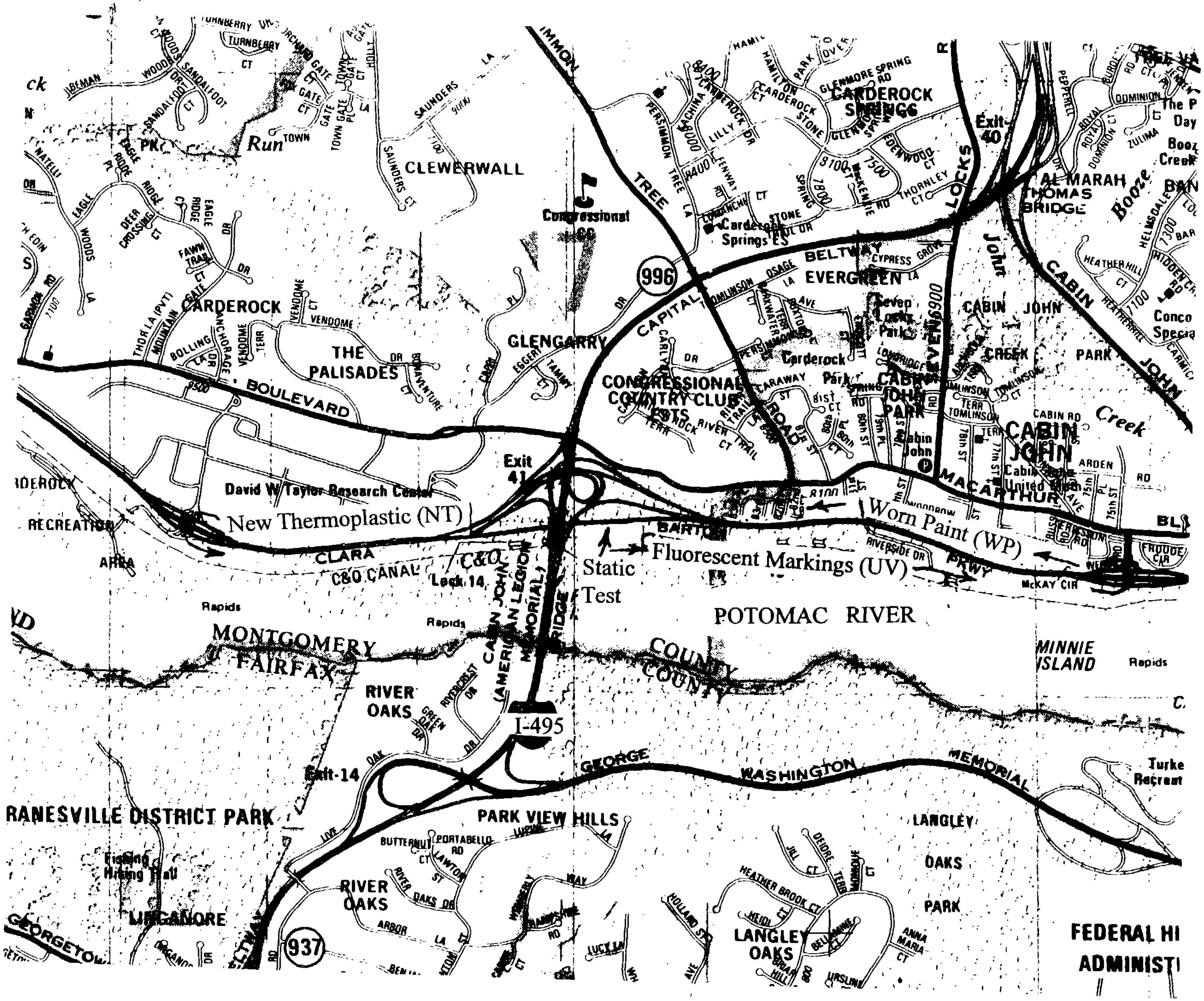
CONCLUSION

The UV headlamps provided a significant increase in UV-activated fluorescent pavement marking delineation visibility. In dynamic testing, the mean subjective rating of the UV roadway delineation was higher than both the NT and the WP with the UV lights on. In addition, on the UV pavement markings, visibility increased from a mean rating of 3.46 (of a possible 5) with regular low beams to a mean rating of 4.40 with the UV headlamps. In the static testing, subjects were able to see an average of 36 m more of edge line with the UV-headlamps on versus off. The number of center lane skip lines that were visible increased an average of 2.2 from use of the low beams to use of the UV headlamps. In the static testing, the subjective rating of visibility increased 1.5 with use of the UV headlamps.

The results of this preliminary evaluation suggest that UV-activated fluorescent pavement marking technology can significantly increase visibility of roadway delineation. Additional testing of the UV headlamps is currently underway at TFHRC and will involve determining the effect of UV headlamps on the visibility of roadway delineation, post-mounted delineators, and pedestrians.

APPENDIX A

Map of Clara Barton Parkway



APPENDIX B

INSTRUCTIONS TO SUBJECTS

READ TO SUBJECTS:

On most roads, the lanes and the edges of the road are marked to help drivers see where to drive. Tonight, you will be shown sections of roadway and we will ask you how well the markings tell you where to drive your car. We will ask you to try to imagine that you are driving. Look at the roadway as you normally would so that you notice the road both near the car and especially farther down the road. We are interested in your **opinion**: This is not a test with right or wrong answers. We are not testing your eyesight. We are testing different kinds of markings and different kinds of headlamps.

You will be given a clipboard with data forms, a penlight, and a marking pen. We will ask you to judge each section of the roadway by using a five-point scale. As you can see from the data form (show sample form), if you circle the five it means you think the roadway markings are Excellent and if you circle a one it means you think the roadway markings are Poor. We will let you know when to begin judging a section of the roadway by saying "**GET READY, LOOK AT THE ROAD AHEAD NOW**." After a short time, (approximately five seconds) we will say, "**PLEASE STOP LOOKING, TURN ON YOUR PENLIGHT AND CIRCLE YOUR RESPONSE.**"

When you look at each section of the roadway, we would like you to compare it to all other roadway markings that you have seen in the past. Tell us how well the markings work at telling you where to drive your car.

Please remember that we want your opinion. This is not a test of you or your eyesight.

You will have an opportunity to practice before we actually begin. We'll go outside to our car now and drive you to our study area. Our driver will answer any other questions that you may have while you are taking a practice run. (Tell them they will be gone about fifty minutes and check to make sure they are ready, bathroom, etc.)

APPENDIX C

DYNAMIC TEST INSTRUCTIONS

DRIVER READS TO SUBJECT AT LANE CLOSURE

We would like you to imagine that you are driving. Look at the roadway as you normally would by looking both near the car and especially farther down the road. We would like you to compare it to all other roadway markings that you have seen in the past.

By using the 1-5 rating, please tell us how well the markings work at telling you where to drive your car.

I will let you know when to start judging a section of the roadway by saying, "GET READY, LOOK AT THE ROAD AHEAD NOW." After a short time (about five second), I will say, "PLEASE STOP LOOKING, TURN ON YOUR PENLIGHT AND CIRCLE YOUR RESPONSE."

We will begin now by doing a practice run which will give you a chance to see how this works and to ask any questions you might have.

Please remember that this is not a test and that we are specifically interested in your opinion of the roadway markings that you are about to see.

End of loop 2, announce:
We are now going to drive to the lane closure and stop the car where we will conduct one last activity.

APPENDIX D

DYNAMIC TEST DATA COLLECTION FORM

PAGE ONE

SECTION A

1 Poor	2	3	4	5 Excellent

SECTION B

1 Poor	2	3	4	5 Excellent

SECTION C

1 Poor	2	3	4	5 Excellent

SECTION D

1 Poor	2	3	4	5 Excellent

SECTION E

1 Poor	2	3	4	5 Excellent

SECTION F

1 Poor	2	3	4	5 Excellent

DYNAMIC TEST DATA COLLECTION FORM

APPENDIX E

TRAFFIC CONDITIONS/DISTRACTION RATING

LOOP 1

SECTION A
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

SECTION B
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

SECTION C
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

SECTION D
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

SECTION E
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

SECTION F
Yes fog___

NUMBER OF VEHICLES ONCOMING:____________
NUMBER OF VEHICLES PASS/AHEAD:__________

	NOT				VERY
oncoming	1	2	3	4	5
pass/ahead	1	2	3	4	5

APPENDIX F

STATIC TEST INSTRUCTIONS

DRIVER READS TO SUBJECT AT LANE CLOSURE:

Please turn to your last page. Notice that it is divided into two sections. For this activity, we will look at the road markings ahead and ask you to do three different things.

First, using the top half of your data sheet, please give us your opinion of how visible the roadway markings are ahead. Use the five point scale on your data sheet and circle your response.

Next, please count the white dashed lane lines starting with the one just after the farthest traffic cone. Count as many lane lines as you can see and tell me what that number is.

Third, look at the solid white road edge line on the right. Notice that we have set out reflectors on the brassy shoulder. We would like to know where our headlamps no longer illuminate the edge line. Please tell us which reflector is closest to that point. (Important, we are not interested in how far you can see or how many reflectors you can see, but rather where the headlamps no longer illuminate the solid white edge line.)

Now I am going to change the lights and using the bottom portion of your form lets repeat the three activities again.

APPENDIX G

STATIC TEST DATA COLLECTION FORM

Participant #:_________Date:_________Weather:_________Final Page

FINAL PAGE PARKED ON ROADWAY

NUMBER 1 LIGHTS

1	2	3	4	5
Poor				Excellent

NUMBER 2 LIGHTS

1	2	3	4	5
Poor				Excellent

STATIC TEST DATA COLLECTION FORM

APPENDIX H

SUBJECT FEEDBACK ON UV LAMPS

The following were direct quotes from subjects, regarding the UV lamps, collected during the static test.

"Can see as far as with low beams but better." (71-year-old female)

"Can see as far as with low beams but brighter." (29-year-old female)

"The green light goes a lot further." (71 year-old female)

"Aahh, there we go, this is much better. I like that better." (35-year-old male)

"Now, it's different, these are far superior to what we had." (44-year-old male)

"I like this one." (35-year-old female)

"What is this blue light called? I can see wonderfully well now, I really can!" (75-year-old female)

"That's made it much more visible, excellent!" (42-year-old) male)

"I think that shows up much better than anything I've seen before." (41-year-old female)

"This is a superior light. I like this. Is it possible to use this now on a car? Everything this light touches is brighter." (76-year-old male)

"That's very cool." (30-year-old male)

"It looks really good. You must have put some kind of lens on. I've seen better so I shouldn't say excellent, but it looks really good." (31-year-old male)

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