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16. Abstract

The increase in accidents involving personnel in construction and maintenance zones prompted a review of the use of high visibility safety garments. This review led to laboratory and field studies intended to identify those materials and garment designs that would enhance conspicuity. As a result, a modified version of the currently used orange, fluorescent vest enhanced with lime-yellow, reflective material was recommended for further study.

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HIGH VISIBILITY GARMENTS FOR USE IN WORK ZONES

by

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and

Mark Stuart

Research Report 262-4
on
Research Study No. 2-18-79-262
Safety Devices for Highway Work Zones

Sponsored by

Texas State Department of Highways and Public Transportation

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The U.S. Department of Transportation
Federal Highway Administration

October 1982

Texas Transportation Institute
The Texas A&M University System
College Station, Texas

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KEY WORDS

Safety Vests, Safety Garment, High Visibility Garments, Personnel Safety, Work Zones.

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High Visibility Garments for Use in Work Zones

ABSTRACT

The increase in accidents involving personnel in construction and maintenance zones prompted a review of the use of high visibility safety garments. This review led to laboratory and field studies intended to identify those materials and garment designs that would enhance conspicuity. As a result, a modified version of the currently used orange, fluorescent vest enhanced with lime-yellow, reflective material was recommended for further study.

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INTRODUCTION

Motorists are alerted to the existence of construction sites by the presence of signs, warning lights, barricades and other devices. But the movement of personnel within the site, even when expected by motorist, may not be detected. This can and does occur when there are visual distractions such as heavy traffic, movement of work vehicles or "busy" commercial signing. Lack of detection can also occur when there is insufficient contrast between the personnel and their background. Each of these situations can be exacerbated by driver impairment due to alcohol or drugs. Regardless of cause, any reduction in the ability of motorists to detect the presence of working personnel in construction and maintanence areas increases the probability of a pedestrian type accident.

In order to enhance the likelihood that individual workers will be detected by motorists, it is necessary to increase their attention value or conspicuity. The primary technique for increasing the conspicuity of individuals is the use of high visibility materials.

These materials have been available for some time as have garments made from them: however, their use is not wide-spread and accidents continue to happen. The lack of use has been attributed to poor garment design, inadequate first-line supervision, and/or lack of knowledge concerning the extent of the construction zone pedestrian accident problem.

This latter point can be appreciated by understanding that accident records are not rigidly maintained in this category, and information is disseminated only when catastrophic events occur.

PROBLEM IDENTIFICATION

The history of pedestrian accidents in construction zones in Texas must be extrapolated from those pedestrian type accidents that occurred on roadways where construction was present. In order to ascertain if the accident involved personnel actually working at the site, it would be necessary to obtain a copy of the accident report itself.

The information summarized in the following tables is based on an overview of three years of pedestrian accidents in construction zones. While it is highly likely that these accidents involve construction or maintenance personnel, the accident records were not pulled to verify this assumption.

It should also be noted that these tables were derived from records of both on-system and off-system accidents. They represent the entire problem from the city, county and state level as well as the public employee and private contractor.

Accident Frequency - The frequency of pedestrian accidents by severity classification is presented in Table 1 for the years, 1978, 1979, and 1980. As can be seen in this table, the frequency of accidents has increased over time as has accident severity.

The pedestrian accident frequency for this three year period has been reclassified by on/off system, and day/night accidents and is presented in Table 2. The data presented on this table indicate an increase in on-system and off-system nighttime accidents. The nighttime accidents correspond to a practice of nighttime maintenance in some urban areas.

Driver Characteristics - The driver population in the State of Texas can be divided roughly into quarters by age with 25 years and younger representing the lower 25% and 52 years and older the upper quarter. The groups of 26 to 36 years and 35 to 51 years represent the two middle quartiles. Using these age groupings Table 3 was developed to display any noticeable overrepresentation by an age group of drivers involved in pedestrian accidents. However, as can be seen from this Table, no noticeable trends are present.

TABLE 1

SEVERITY OF PEDESTRIAN ACCIDENTS IN CONSTRUCTION ZONES (3 year period)

Category	Year 1978	1979	1980
Total Accidents	27	31	40
Fatalities	4	2	7
Incapacitating Injuries	16	21	20
Non-Incapacitating Injuries	7	10	21
Number of Pedestrians Affected	27	33	48
Pedestrians Per Accident	1.00	1.06	1.20

TABLE 2

PEDESTRIAN ACCIDENTS CLASSIFIED DAY OR NIGHT AND ON SYSTEMS BY YEAR

YEAR	SYSTEM	DAY	NIGHT	TOTAL
1980	on	23	3	26
	off	14	0	14
1979	on	15	2	17
	off	13	1	14
1978	on	16	1	17
	off	8	2	10

TABLE 3

AGE OF DRIVERS INVOLVED IN PEDESTRIAN ACCIDENTS IN CONSTRUCTION ZONES

	Age of Driver			
	under 25	26-35	36-51	52 and over
Percentage of Driver in State	25.0	25.9	25.7	23.4
Percentage of Drivers Involved in Accidents				
1980	29.0	21.6	29.7	18.7*
1979	33.3	22.2	11.1	33.3
1978	45.0	30.0	20.0	5.0

*Percentages do not sum to 100 due to rounding.

The sex of the drivers involved in these accidents is presented in Table 4. The data on this table display an increase in the percentage of male drivers involved in construction zone accidents with a corresponding decrease in female involvement.

Contributing Factors - The driver control factors that contributed to the pedestrian accidents are presented in Table 5. There are a great many accidents with no cause or contributing factor specified. Such large errors in the data prohibit useful conclusions.

Another type of data was provided by the Insurance Division of the State Department of Highways and Public Transportation (SDHPT). These data were collected for construction zone accidents involving department personnel only for a two and one half year period ending in February 1982. They are summarized in Table 6. These data show that of the 44 personnel involved in accidents:

- 75% were not wearing safety vests.
- 52% were inside a barricaded/coned area.
- Of the 48% of the personnel outside a protected area,
  71% were not wearing safety vests.
- 36% were fatalities of whom:
  56% were not wearing safety vests
  62% were outside protected area.

PROBLEM SOLUTION

Even if the accident records presented are somewhat in error, a problem does exist. There is an increasing trend in pedestrian accidents in construction zones.

Both the Manual for Uniform Traffic Control Devices (MUTCD) and the equivalent Texas Manual (TMUCD) state, "The use of orange clothing such as a

TABLE 4

SEX OF DRIVERS INVOLVED IN PEDESTRIAN ACCIDENTS IN CONSTRUCTION ZONES (Three Year Period)

Year	Percentage of Male	Percentage of Female
1980	67.5	32.5
1979	61.3	38.7
1978	59.1	40.9

TABLE 5

DRIVER CONTROL FACTORS CONTRIBUTING TO PEDESTRIAN ACCIDENTS IN CONSTRUCTION ZONES

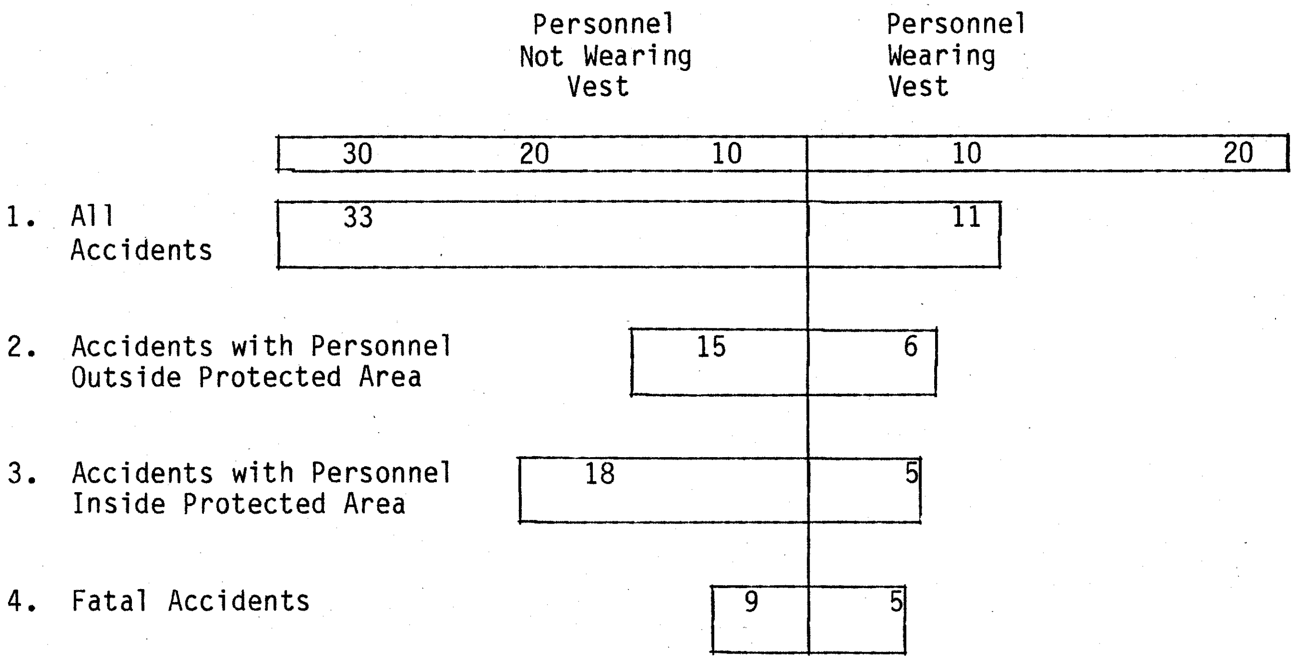
Contributing Factor (by percentage)

Year	Speeding	DWI	Other	None Given
1980	28.2	5.1	35.9	30.7*
1979	35.4	3.2	35.4	25.8
1978	25.9	11.1	18.5	44.4

*Total not equal to 100% due to rounding.

TABLE 6

SDHPT ACCIDENT
SUMMARY AND SAFETY
VEST USAGE



vest, shirt, or jacket shall be required for flaggers. For nighttime conditions similar outside garments shall be reflectorized." (1,2) The department also encourages the use of safety vests and hard hats by all personnel in construction zones. There is, however, an apparent disregard for the "benefits."

Part of the problem exists because, "Even when they are aware of the importance of the problem, work safety officials may believe that the responsibility may rest with traffic safety officials and not work safety officials. --They may believe that the burden rests instead with the highway department or some other government agency." (3)

There is also an expressed need by urban areas to increase nighttime maintenance activities which will compound the conspicuity problems. "Occupational pedestrians are killed many people believe, because either the worker or motorist or both were careless, drunk or somehow negligent. An obvious cause is too often overlooked, misunderstood or underestimated: 'I just didn't see him.'" (3)

Now more than ever, it is essential to develop some type of garment that possesses high target value both day and night that will be acceptable to the personnel in the field.To this end, a project was commissioned by the SDHPT to research work previously accomplished in this field and develop a garment for use by its personnel.

This project had the following Tasks:

1. Define Garment Requirements
2. Assemble Appropriate Materials
3. Test the Materials
4. Fabricate Garments
5. Test Garments
6. Provide Specifications (Conclusions and Recommendations)

The performance of these Tasks as well as the final recommendations are presented in the following sections.

TASK PERFORMANCE

TASK 1. DEFINITION OF GARMENT REQUIREMENTS

PREVIOUS RESEARCH-The vulnerability of personnel working in construction and maintenance areas has not escaped the attention of researchers both in the transportation field and in private industry. The bulk of their work has centered on increasing the conspicuity or attention value of the individual worker by providing materials in colors and patterns that provide contrast against ordinary backgrounds. The general notion is that garments made from these materials would, when worn by construction crews, be easily detected and avoided by passing motorists.

Conspicuity/Visibility-Visibility can be defined as the capacity of radiant energy to evoke the phenomenon of brightness. It is the ability to see or detect the presence of an object. Conspicuity (conspicuousness), on the other hand, is the capacity of an object to stand out against its background so it is easily detected by an observer. In other words, to be conspicuous the object must have at least enough energy to be visible and probably more.

Both visibility and conspicuity are perceptual terms; that is, they deal with the radiant energy required to evoke a certain response in a person under certain conditions. Although the energy emitted by a light source (illumination) and the energy reflected by an object (luminance)* can be fairly accurately measured and held constant, the perceptual phenomena of visibility and conspicuity may vary greatly.

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*The reader is referred to NCHRP report 130, 1972, Appendix J for a detailed discussion of the measurement of light.

As stated by Taylor et al., "The visibility of an object depends on several factors including its size, its shape, the viewing angle, the distance to the observer, the recent exposure of his eyes, the distribution of color and brightness on the surface, the type and beam pattern of light illuminiating the object, the background, and the transmission characteristics of the atmosphere."(4) These factors represent characteristics of the object, the observer and the environment that must be considered when measurements are taken.

In the highway system context, attempts to enhance the conspicuity of working personnel must also consider the same factors. The characteristics of the environment can be controlled to the extent of providing illumination on sites worked at night or electing not to work at night at all. The characteristics of the observer, in this case the motorist, cannot be controlled at all but still must be considered. One characteristic in particular that must be allowed for is the effect of alcohol.

Hazlett and Allen reported a statement made by Goldberg which suggested, "Alcohol has the same effect on vision as the setting of grey glass in front of the eyes, or driving with sunglasses in twilight or darkness; a stronger illumination is needed for distinguishing objects, and dimly lit objects will not be distinguished at all; when a person is dazzled by sharp light it takes a longer time before he can see clearly again." (3) The same report suggests that alcohol can induce nystagmus, reduce the visual field and produce other symptoms similar to hypoxia.

The limited control available over the driver and the environment means that extra care must be given the object, i.e., the construction worker. In this area, there is ample room for exploring new methods of enhancing conspicuity. One of the most thoroughly researched is the use of high visibility materials.

Materials-High visibility materials are those that provide unusually good contrast against standard backgrounds. These materials are of three types:

1. Phosphorescent - Materials that absorb radiant energy and re-radiate after the energy is removed.
2. Fluorescent - Materials that convert non-visible, ultra-violet energy into visible light. (Photoluminescence)
3. Reflective - Materials having a built-in optical system that redirects incoming light (6,7,8).

Phosphorescent materials have not found wide spread use as aides to conspicuity primarily because they are not highly visible during daylight and require frequent recharging at night.

Fluorescent materials, on the other hand have found wide spread daytime use by the military, hunters and by construction workers. These materials are particularly useful when illumination levels are decreased at twilight. They are not highly visible at night or under artificial lights of long wavelengths (6,7).

Reflective materials are widely used to increase conspicuity at night. There are three types of reflection:

1. Diffuse - microscopic roughness that scatters light in all directions.
2. Mirror - Smooth surface that returns light at the angle of incidence
3. Retro-Reflection - Prismatic or spherical optical system that returns light directly to its source (8).

It is the retro-reflective materials that are most commonly used on the highways. The painted stripes have spherical beads impregnated to enhance their visibility. Postmounted delineators or raised reflective pavement markers between stripes are examples of prismatic reflectors.

The best combination of materials for all around use would include fluorescent materials for day and twilight and retro-reflective material for night.

Color-It has been well established that greatest sensitivity of the human eye occurs at the wavelength associated with the color yellow-green. In recent years this sensitivity has been extended to fluorescent materials as well (7,8). However, the color recommended for use in traffic control work has been a red-orange color. This color was perhaps chosen because of its association with other coding schemes where the color red represents a hazard or perhaps because of its consistency with other signing colors in construction zones. The detection distances between the two colors are not markedly different; however, the red-orange color might have a tendency to blend with other signing and equipment.

Retro-reflective materials also come in assorted colors. The highest reflectivity, however, comes from those materials with little color to absorb light energy. Consequently, clear, white or silver reflective materials provide the highest brightness (9). Newly developed materials of a yellow-green color should also be bright at night while having the added advantage of high target value during daylight hours (10).

Size and Brightness-The relationship between size and brightness is a complex one. In general when comparing objects of equal brightness but different sizes, the larger objects will be conspicuous at greater distances. If, however, the smaller objects are made brighter through color saturation, increased luminance contrast, or reflectivity, then brightness becomes the more important influence on detection (11). Given these relationships it would be possible to investigate the size, measured in units of square area, that material must be for enhanced conspicuity by holding brightness constant. This method ignores the interactive influence of brightness but has been used to ascertain minimum size requirements.

Austin et al. stated that the measured area of an average adult is:

981 sq. in. in the front view
675 sq. in. in the side view
956 sq. in. in the rear view

They also state that this large an area is not necessarily required to attract attention when using fluorescent or reflective material (12). Estimates on the size of fluorescent material required range from 186 to 256 sq. inches (9,10,13). As for relective materials, sizes ranging from as little as four square inches to several square feet have been studied. The only size recommendation being made is for motorcycle helmets, at least four square inches on a side (11,14).

Pattern-The research studies dealing with patterns that enhance conspicuity have focused on reflective materials. These materials have generally been applied to fluorescent vests which are solid. This does not preclude the application of the guidelines developed to both types of materials.

Although many different patterns have been studied the consensus was that patterns that depict a humanoid shape are most easily recognized (9,10,11,15).

In a recent, comprehensive study, Blomberg, Leaf and Jacobs stated, "Identification of the targets as pedestrians requires more than mere early detection. Anthropomorphism of the target shape greatly aids recognition." Thus "Shapes which did not represent human figures, articles of clothing of other visual forms associated with the human figure--spots and stripes--did not enhance and may actually inhibit recognition of the pedestrian figures." "Hence for improved safety, it would appear best to outline the body as completely as possible with the brightest material available." (9)

Solomon, in considering the patterns for use by fire fighters, stated, "The improved visibility by use of a combination of greenish yellow color with reflective and fluorescent materials might be applied to the entire surface of wearing apparel-coats, boots, helmets, and gloves.

If, for special reasons, it is desirable to treat an area less than the whole garment, then applications could be made in outline form in such a way to aid in the identification of the object as a fireman. It is important that both vertical as well as horizontal applications be made.

Since motion is a factor in visibility, retroreflective/fluorescent application should first be made on or near the hands and feet where motion is maximized. Gloves and boots should be treated, as should cuffs and sleeves.

It is also desirable to make sure that applications are located near the ground to avoid a "Disembodied" effect and to assist visual spatial location so a person looks like he is walking on the ground rather than floating."(9)

Garments-The most frequently studied garment has been the vest. They are commercially available because of the demand and acceptibility found in the transportation industry. There have been suggestions for other applications, particularly when using retro-reflective materials for nighttime use.

In the motorcycle industry, the addition of reflectorized material to the helmet has been advised (14,16). In transportation, gauntlets, leglets and hats with reflective materials have been recommended in addition to vests (17). Other possibilities for fluorescent garments include rain ponchos, slickers, aprons, jackets, coats, gloves, etc. Each of these could be furnished with reflective material to make them usable around the clock.

A consideration of any garment used in construction areas is that sufficient fluorescent and reflective material be used to allow conspicuity regardless of body position. It would also be advantageous to add material to body extremities thereby enhancing conspicuity using motion (9,12).

INTERVIEWS-Although the Literature review provided a great deal of information concerning design requirements for a high visibility, nighttime use garment, there was one major point that was only tangentially addressed. That point concerned the acceptability of the garment to the user. A garment with excellent conspicuity properties would do little to solve the problem if it was not worn. This requirement, along with several others was recognized by Shubert who stated, "You have to offer a product that's attractive to customers. If it's a garment, it must stand up to repeated washings. It can't look funny in daylight. The fabric can't be too heavy, too rough textured, or too unbreathable. And it can't cost too much." (18)

In order to gain a better understanding of the acceptability requirement of garments used for increasing nighttime visibility, a series of interviews were cconducted with maintenance personnel and supervisors in the Houston District of the Highway Department.

These interviews were of a non-structured nature where everyone was encouraged to voice an opinion. The interviewer attempted to summarize the prevailing concerns and obtain a concensus. As might be expected these interviews began with problems that had been encountered with equipment currently in use. The current traffic vest, for example, was reported to be extremely hot with little wicking capability, as well as capable of producing spectral glare which caused facial sunburns. There were also reported difficulties with the vinyl plastic hard hats. Apparently these hats can fall or be knocked from the head with wind gusts or simply by bending over. Under certain conditions they could pose more hazard than protection.

As for visibility at night, most people interviewed felt that any high visibility garment would be acceptable. The concern for safety overrode any objections made on the basis of comfort or attractiveness. A separate garment, specifically for use at night, was not thought to be impractical, nor was the idea of adding reflective material to garments normally in use such as: aprons, gloves, vests, hard hats, etc.

The results of these interviews were combined with the knowledge gleaned from the literature and other human factors engineering experience to produce the following set of general requirements for high visibility garments for nighttime use:

1. The garment must be visible from a distance that exceeds the stopping sight distance required at 50 MPH (496 ft). This implies that the garment must have sufficient retro-reflective material to be conspicuous at night and sufficient fluorescent material for twilight. The features that can be used to enhance conspicuity are high contrast colors with a minimum area of 256 sq. inches combined in a pattern that suggests a human shape.
2. The unit cost of any garment developed should be within reasonable consideration. Since an estimated 10,000 such garments would eventually have to be supplied, a per unit cost as close to the cost of the existing garment (approximately $4.65) would be desirable.

3. As has been pointed out, one major constraint governing the utility of any safety garment is its acceptability to the user. Therefore a design that meets the visibility and cost criteria would have to be reviewed or tested by a user group to satisfy the acceptability requirement.

TASK 2 ACQUISITION OF MATERIALS

There are numerous companies that retail and wholesale high visibility garments; however, only a few actually manufacture the materials from which they are made. Surprisingly, it was difficult to locate these manufacturers and the appropriate representative who could authorize purchases or donations in small lots for research purposes. Once these representatives were located, they were very helpful and accommodating.

The intent of this task was to acquire as many different types of reflective and/or fluorescent materials as possible so they could be empirically tested for visibility properties prior to their incorporation into garments. The logic, of course, was that the materials that had the best visibility performance characteristic would make the best garment barring any unfortuitious interaction with the garment design. A list of the materials acquired is presented in Table 7.

Rather than measure the radiant energy of the materials supplied or use the specifications of the manufacturer, the performance characteristics were to be determined by having subjects make relative comparisons under various lighting conditions. These comparisons are described in the next section.

TASK 3 TEST MATERIALS

ANNEX STUDIES-A Field Experiment was conducted at the Texas A&M Research Annex to determine which of the reflective and/or fluorescent materials was most visible under three different ambient lighting conditions - day, twilight, and night. Twilight was defined to be 30 minutes before and after the official sunset. Nineteen different reflective and fluorescent materials were studied (see Appendix A for a complete list of the materials studied as well as a detailed description of the methodology used).

TABLE 7

REFLECTIVE AND FLUORESCENT MATERIALS STUDIED

FLUORESCENT	FLUORESCENT AND REFLECTIVE	REFLECTIVE
Red/Orange Traffic Vest Coated Nylon Material		Bright Silver (8910)-Scotchlite
	Lime/Yellow-Reflexite	Bright Silver Transfer Tape (8710)-Scotchlite
	Lime/Yellow Fabric (8987)-Scotchlite	
	Red/Orange-Reflexite	Silver Fabric (8630)-Scotchlite
		White Fabric (8960) Scotchlite
		White Transfer Tape (8760)-Scotchlite
	Red/Orange Fabric (8986)-Scotchlite	Red/Orange Early Warning-Scotchlite
		Yellow-Reflexite
		White-Reflexite
		Dark Green-Reflexite
		Silver High Intensity Sheeting-3M
		Red Engineering Grade Sheeting-3M
		White Engineering Grade Sheeting-3M

Each subject was presented the materials after they were divided into four different groups. The subject would make the visibility judgements for each group at distances of 250 and 500 feet. The subjects would then make one more set of judgements based upon a presentation composed of the materials judged to be the most visible during the four previous presentations.

The results were tabulated by recording the number of times each material was selected to enter the final visibility competition. The top six candidates are presented in Table 8. The number of times that each of these materials was selected as most visible from the final competition is presented in Table 9.

These six materials were selected for further study in which durability was considered.

LAB STUDIES-To establish a baseline for the soon to be described degradation studies, the most visible materials under the three different ambient conditions of the Annex Study were examined under simulated day and night conditions. During the simulated night condition, a simulated distant condition was also studied.

The six most visible materials from the Annex Study were used in this Lab Study. The materials used were the Bright Silver Fabric (8910) by Scotchlite, the Lime/Yellow Reflexite, the Lime/Yellow Fluorescent Fabric (8987) by Scotchlite, two versions of the Red/Orange Reflexite, and the Bright Silver Transfer Tape (8710) by Scotchlite.

For each simulation condition each subject would rank order the materials from the most visible down to the least visible. The subjects were separated from the materials by a distance of sixty feet. For a detailed description of the methodology used, refer to Appendix B.

TABLE 8

FREQUENCIES THAT THE TOP-RATED MATERIALS REACHED THE FINAL VISIBILITY COMPETITION ACROSS ALL AMBIENT CONDITIONS

	DAY		TWILIGHT		NIGHT		CUMULATIVE
	500'	250'	500'	250'	500'	250'	FREQUENCY
Red/Orange Reflexite	3	3	4	2	0	1	13
Red/Orange Reflexite	5	5	3	4	0	1	18
Lime/Yellow Fabric	4	4	2	1	1	1	13
Lime/Yellow Reflexite	2	3	2	3	2	5	17
Bright Silver Tape	0	0	0	1	4	3	8
Bright Silver Fabric	0	0	0	0	6	6	12

TABLE 9

FREQUENCIES THAT THE TOP-RATED MATERIALS WERE SELECTED AS MOST VISIBLE ACROSS ALL AMBIENT CONDITIONS

	DAY		TWILIGHT		NIGHT		CUMULATIVE
	500'	250'	500'	250'	500'	250'	FREQUENCY
Red/Orange Reflexite	0	1	1	1	0	1	3
Red/Orange Reflexite	2	3	1	2	0	0	8
Lime/Yellow Fabric	2	3	1	2	0	0	8
Lime/Yellow Reflexite	1	0	1	1	0	0	3
Bright Silver Tape	0	0	0	0	2	2	4
Bright Silver Fabric	0	0	0	0	6	4	10

By referring to Table 10 one can observe that the Lime/Yellow Reflexite was judged to be most visible during the day simulation with the Lime/Yellow Fluorescent Fabric (8987) by Scotchlite and the Red/Orange Reflexite coming in second place. For the night simulation, the Red/Orange Reflexite was judged to be most visible with the Lime/Yellow Reflexite coming in second place. Under the night/distant simulation condition, the Bright Silver Fabric (8910) by Scotchlite and the Bright Silver Transfer Tape (8710) by Scotchlite were both judged to be most visible.

Degraded Condition-The six reflective and fluorescent materials used during the Lab Study were "weathered" for a period of three weeks and then the Lab Study was replicated. The weathering of the materials consisted of exposing the six materials previously studied to the ambient weather for 15 days. During the period of time in which the materials were weathered, they were also machine washed in warm water four times. It was during this time that two of the materials, one version of the Red/Orange Reflexite and the Bright Silver Transfer Tape, were damaged and subsequently, could not be used during the Lab Study replication. The Red/Orange Reflexite which was damaged was the same type of material in the other version of the Red/Orange Reflexite studied, and the Bright Silver Transfer Tape was the same material as the Bright Silver Fabric, so essentially nothing was lost from the study.

The results of the degraded condition are compiled in Table 11. The Red/Orange Reflexite was judged to be most visible during the day simulation. For the night simulation, the Bright Silver Fabric was judged to be the most visible with the Red/Orange Reflexite coming in second place. Under the night/distant simulation condition, the Bright Silver Fabric was again judged to be the most visible material.

During the Lab Study replication it was observed that the Lime/Yellow Reflexite dropped in position for each of the three conditions when compared to

TABLE 10

RESULTS OF RANK ORDERING OF MATERIALS
ACROSS SUBJECTS WITHIN EACH SIMULATION CONDITION

DAY SIMULATION

MATERIALS	TOTAL POINTS
Lime/Yellow Reflexite	27
Lime/Yellow Fluorescent Fabric (8987)	26
Red/Orange Reflexite	26
Red/Orange Reflexite	23
Bright Silver Fabric (8910)	13
Bright Silver Transfer Tape (8710)	11

NIGHT SIMULATION

MATERIALS	TOTAL POINTS
Red/Orange Reflexite	30.5
Lime/Yellow Reflexite	24.5
Bright Silver Transfer Tape (8710)	23
Bright Silver Fabric (8910)	22
Red/Orange Reflexite	19
Lime/Yellow Fluorescent Fabric (8987)	7

NIGHT/DISTANT SIMULATION

MATERIALS	TOTAL POINTS
Bright Silver Fabric (8910)	27.5
Bright Silver Transfer Tape (8710)	27.5
Lime/Yellow Reflexite	25
Red/Orange Reflexite	22
Red/Orange Reflexite	14
Lime/Yellow Fluorescent Fabric (8987)	10

TABLE 11

RESULTS OF RANK ORDERING OF MATERIALS ACROSS SUBJECTS WITHIN EACH REPLICATED SIMULATION CONDITION

DAY SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Red/Orange Reflexite	23
Lime/Yellow Fluorescent Fabric (8987)	16
Lime0Yellow Reflexite	14
Bright Silver Fabric (8910)	7

NIGHT SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Bright Silver Fabric (8910)	19
Red/Orange Reflexite	18
Lime/Yellow Reflexite	16
Lime/Yellow Fluorescent Fabric (8987)	7

NIGHT/DISTANT SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Bright Silver Fabric (8910)	18
Red/Orange Reflexite	16
Lime/Yellow Reflexite	15
Lime/Yellow Fluorescent Fabric (8987)	9

the results of the original study. The other three materials maintained their relative position. This may have occurred because the "weathering" more adversely affected the Lime/Yellow Reflexite than the other three materials. These results may have also occurred because of a tendency for the Lime/Yellow Reflexite to slightly absorb other colors that surround it. This absorption process could have very easily occurred when the material was washed, since all of the materials were washed together.

Even though the Lime/Yellow Reflexite dropped in relative position, it was still judged to be more visible than the Bright Silver Fabric during the Day Simulation replication and more visible than the Lime/Yellow Flourescent Fabric during the other two replications. A word of caution given regarding the use of this material is that perhaps it should never be washed, or, if it is, perhaps washed separately.

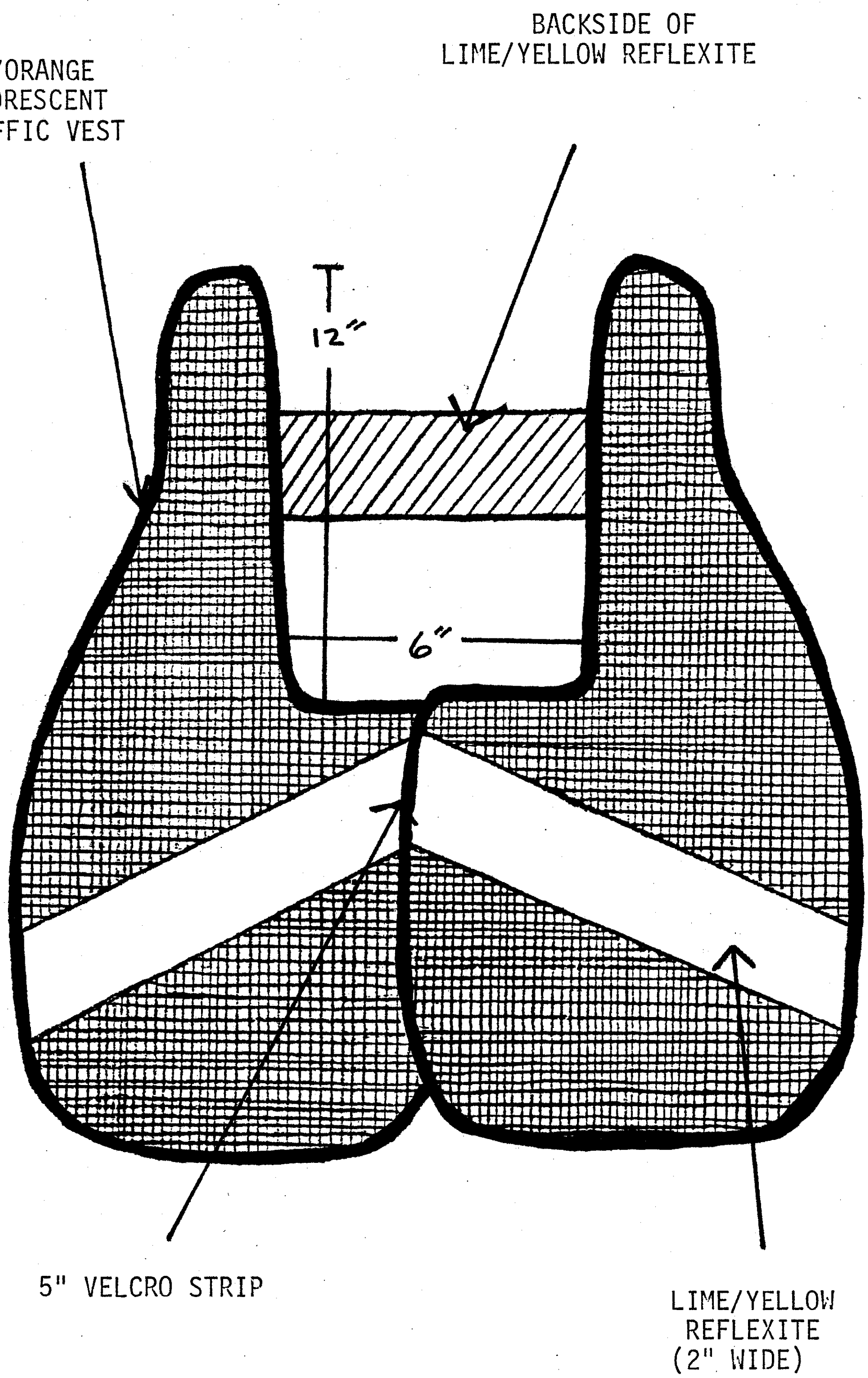
TASK 4 FABRICATE GARMENTS

The information gathered from the interviews with field personnel suggested that the current traffic vest was perhaps the most convenient garment for use provided it could be made more acceptable. Consequently a modification was made to this red/orange fluorescent traffic vest. The redesigned vest was scooped down lower in the front and back. This was done so that workmen wearing them would be able to stay cooler and so that they would have more freedom of movement.

A chevron pattern of reflective and fluorescent material was stitched to the front and back of the improved vest. A chevron was selected since it is believed that moving targets with this particular pattern are more likely to give the perception of motion (See Figure 1).

FIGURE 1

A FRONTAL VIEW OF THE IMPROVED VEST



NOTE: The back of the vest is cut as low and wide as the front of the vest. A Chevron of Lime/Yellow Reflexite is also stitched on the back.

The reflective and fluorescent material selected to be sewn onto the improved vest was Lime/Yellow Reflexite. This material was selected since it provided good visibility under all lighting conditions. Even though the Red/Orange Reflexite also had a high rating, the Lime/Yellow Reflexite would provide a better color contrast when sewn onto the red/orange fluorescent traffic vest. The Bright Silver materials by Scotchlite were rated the highest during the night/distant simulation, but fared very poorly during the day simulation and the night simulation, and consequently they would not serve for an all purpose garment.

To determine whether or not visibility could be further enhanced, reflective helmet, arm, and leg bands would also be studied.

TASK 5 TEST GARMENTS

FIELD USE-After fabrication of the Improved Vests, several of them were loaned to the Hempstead SDHPT so that their road workers could wear them on the job.

After several weeks had transpired, some of the Hempstead crew were questioned about their opinions regarding the Improved Vests. Generally, the new vests were preferred over the old ones. The road workers liked the scooped front and back design because they were cooler and were less prone to cause a rash from the vest's reflectance. The use of the Lime/Yellow reflective stripes was also liked because it was thought to provide better contrast.

The workers, especially the smaller ones, suggested that different size vests be provided. There was trouble with the shoulder straps slipping down. It was also recommended that the back reflective strip be adjustable so that it might improve the vest's fit.

ANNEX STUDIES-The Improved Vest, in two different configurations, was compared to two other vests in a visibility study conducted at night (see Appendix D for a complete description of the methodology used). One of the two vests was constructed out of Scotchlite Bright Silver Fabric (8910) by 3M while the other was the vest currently used by the Texas SDHPT.

The three vests were studied in four different configurations. Configuration A consisted of placing the 3M workvest and a white work helmet on a wooden mannequin. Configuration B used the workvest currently used by the SDHPT. Configuration C used the Improved Vest while Configuration D, the Enhanced Configuration, used the Improved Vest but also had a strip of Lime/Yellow Reflexite around the helmet, a strip around each wrist and upper arm, and a strip around each ankle.

As can be observed in Table 12, Configuration A had the greatest mean visibility distance of 1519.6 feet. Configuration D was second highest with a mean of 1159.8 feet. Configuration B had a mean of 760.2 feet while Configuration C had a mean of 552.3 feet.

The 3M safety vest was judged to be more visible than the other vests studied. This was somewhat expected when one compares this vest's reflectivity specifications to the specifications of the Reflexite material. But the difficulty here is that those specifications, as well as the subject ratings of this study, were for night viewing only. As was determined during the previously mentioned Annex and Lab Studies, the Scotchlite Bright Silver Fabric (8910) fared very poorly during the daytime conditions. This is a major flaw in this fabric since the majority of highway/construction work is done during the day.

Another advantage of the Enhanced configuration over the 3M vest is that the former, because of the attached Reflexite legbands, was often perceived as being "humanlike" by the subjects. Subjects reported that with the 3M vest that they simply knew that something was there, and it could just as well have been a traffic sign as a person.

TABLE 12

VISIBILITY DISTANCES, IN FEET, FOR EACH CONFIGURATION

Configuration	Run	SUBJECTS 1	2	3	4	5	Range
A-Bright Silver Fabric Vest	1	1648	774	1705	1797	1670	774-1797
	2	649	1633	1919	1671	1565	649-1919
	3	1641	1641	1938	1756	1507	921-1938
B-Currently Used D Vest	1	240	455	1024	711	965	240-1024
	2	409	722	863	683	1025	409-1025
	3	483	801	1185	652	1185	483-1185
C-Modified Vest	1	228	282	1050	585	205	228-1050
	2	281	451	1094	1024	935	281-1094
	3	318	907	1131	878	1031	318-1131
D-Enhanced Vest	1	549	1164	1280	906	654	549-1280
	2	828	1586	1850	1127	925	828-1850
	3	890	1437	2094	1068	1039	890-2094

CONCLUSIONS, RECOMMENDATIONS, SPECIFICATIONS

CONCLUSIONS

The information gathered during the course of the project suggested the following:

1. Accidents involving motor vehicle personnel working in construction and maintenance areas are increasing.

2. The use of high visibility garments by personnel on job sites has the potential for reducing a portion of these accidents - particularly those that occur during night work activities.

3. There are many fluorescent and reflective materials available that can serve to attract attention and enhance conspicuity.

4. These materials can be incorporated into garments, either all purpose (day-night) or special use (night only), that, when used will add an increased measure of safety.

5. To ensure garment use, the prospective user must perceive them as needed, effective, and comfortable.

6. To ensure garment availability they must also be relatively inexpensive.

RECOMMENDATIONS

There are many possible configurations that would satisfy the requirements for high visibility garments. The design developed during the course of this project is but one. It is advantageous that this vest was field tested to some degree because it was discovered that further improvements could be made.

With the criticisms of the road workers of the Hempstead SDHPT in mind, the first improved vest was modified somewhat. For a description and drawing of the second improved vest, refer to the next section of this report.

For the present, it is recommended that both versions of the improved vest design be fabricated in larger lots and distributed to different Highway Districts for evaluation. In addition to the use of the improved vests, it is recommended that reflective materials be added to the hard hat and that reflective arm, wrist, and leg bands be issued for wear during nighttime work activities.

Even though the cost of outfitting highway construction workers in either version of the improved vest and the Scotchlite reflective bands would be greater than the current cost, the new vests are still cheaper than most of the other vests now on the market today. It is contended that the additional expenditure will be more than worthwhile, since this study has concluded that highway construction workers wearing such reflective material would be more visible than workers wearing the currently used vests.

After a suitable evaluation period (6 months) evaluation surveys should be conducted to ascertain the performance of each improved vest. If either of the improved vests are determined to be acceptable, a fabrication and replacement program for all vests currently in use should be undertaken. If the evaluation results indicate that further modifications are required, they should be accomplished and the modified vest should be evaluated following the procedure outlined above.

SPECIFICATIONS

As was previously mentioned, the first improved vest is a modification of the vest currently used by the SDHPT (see Figure 1). The vest was scooped 12 inches lower in the front and back and the distance between the two shoulder straps was six inches. Two five-inch strips of Velcro were sewn onto the front of the vest to enable quick opening and closing of the vest.

A chevron consisting of two-inch wide strips of Lime/Yellow Reflexite was stitched onto the front and back of the Improved vest. A strip of Lime/Yellow Reflexite was also stitched horizontally across the back of the vest connecting the two shoulder straps.

Arm, leg, and helmet (head) bands of reflective fabric are now on the market. These are manufactured by Scotchlite, and they sell for approximately $1.50 per band.

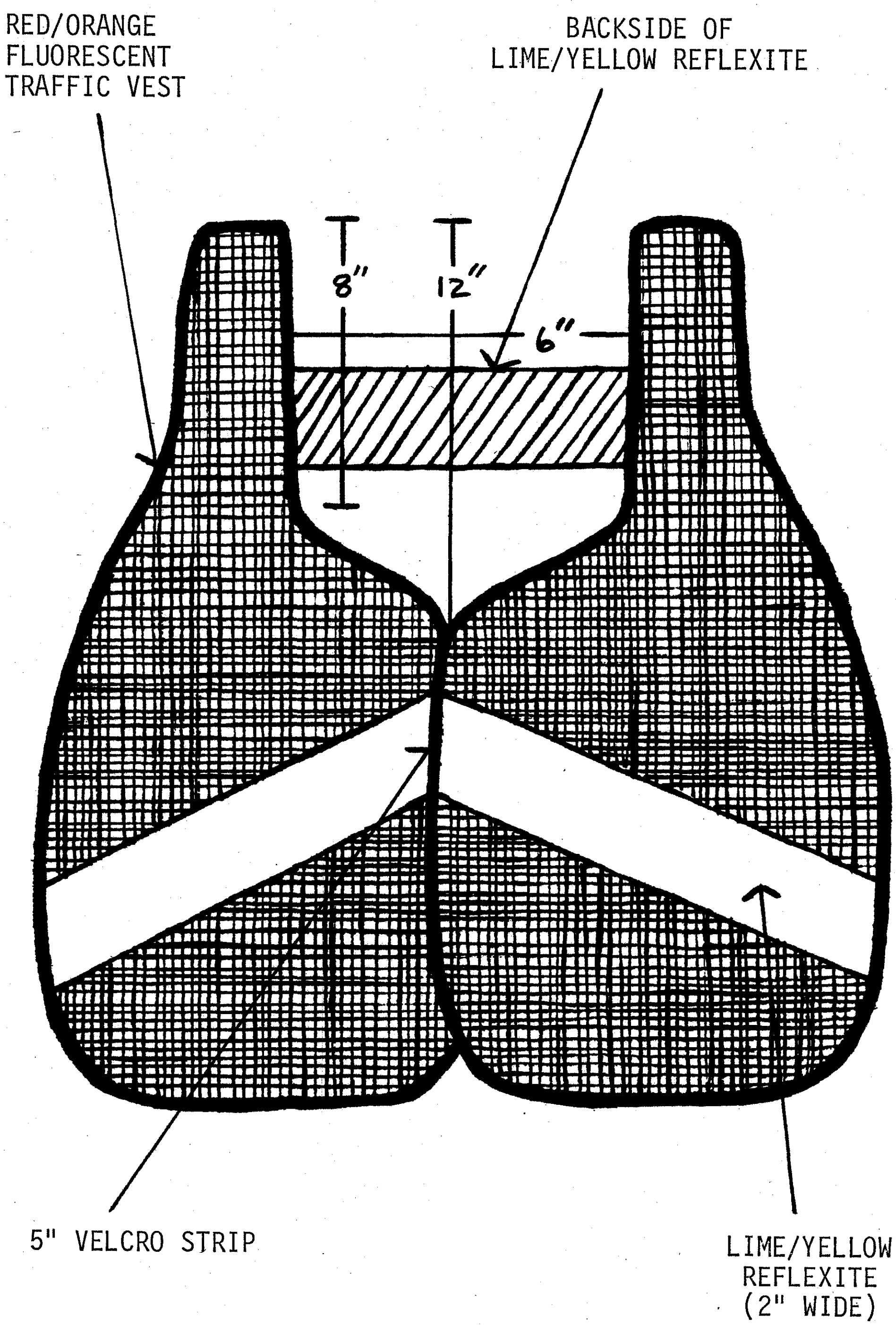
The cost of fabricating the first improved vest would be approximately $6.00. Seven Scotchlite reflective bands, at $1.50 each, would cost approximately $11.00. So, the entire cost of outfitting a highway construction worker with the first improved vest and the Scotchlite reflective bands would be approximately $17.00.

Because of some problems discovered with the first vest, certain modifications were made. This modified vest is referred to as the second vest. For an illustration of the second vest, refer to Figure 2. To prevent the problem of the straps slipping off of the shoulder, the front of the second vest was not scooped down at right angles. Instead, at a point approximately eight inches below the top of the vest, the vest was scooped down at 45° angles, to a point of convergence 12 inches from the top.

Since the modifications made on the second Improved vest were small, then the costs of fabrication and the Scotchlite reflective bands would be the same ---- approximately $17.00.

FIGURE 2

A FRONTAL VIEW OF THE SECOND IMPROVED VEST



NOTE: The back of the vest is cut as low and wide as the front of the vest. A Chevron of Lime/Yellow Reflexite is also stitched on the back.

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APPENDIX A

FIELD EXPERIMENT

APPENDIX A
METHOD

A Field Experiment was conducted to determine which of the reflective and fluorescent materials was most visible under three different ambient lighting conditions - day, twilight, and night. For the study, twilight was defined as 30 minutes before and after the official sunset. The most visible materials from the Field Experiment were then studied in a Laboratory Experiment to determine which of these materials was most visible under two different lighting conditions - day simulation and night simulation.

FIELD EXPERIMENT

Subjects

The subjects used for the Field Experiment were male and female volunteer employed by the Texas Transportation Institute. Five subjects were used for the day conditions, four for the twilight condition, and six for the night condition.

Apparatus

Nineteen different reflective and fluorescent materials were studied (see Table 1).

Each material was mounted on a six-inch by six-inch piece of aluminum. A table approximately three feet tall and four feet long was used to set the materials on. Each material was placed at a 90° angle with respect to the table. The table was placed perpendicular to a 12-foot wide straight-segment of track. One cone was placed 250 feet from the table while another one was placed 500 feet away. A track car owned by Texas A&M University was used to transport the subjects down the track.

TABLE 1

REFLECTIVE AND FLUORESCENT MATERIALS STUDIED

MATERIAL NUMBER	NAME
1	White Reflexite
2	Early Warning by Scotchlite
3	Red/Orange Fluorescent Fabric (8986) by Scotchlite
4	Bright Silver Fabric (8910) by Scotchlite
5	White Transfer File (8760) by Scotchlite
6	Red/Orange Fluorescent Traffic Vest
7	Lime/Yellow Reflexite
8	Yellow Reflexite
9	Lime/Yellow Fluorescent Fabric (8987) By Scotchlite
10	Red/Orange Reflexite
11	White Fabric (8960) by Scotchlite
12	High Intensity Sheeting by 3M
13	Engineering Grade Signing Material Red
14	Engineering Grade Signing Material White
15	Bright Silver Transfer Tape (8710) By Scotchlite
16	White Reflexite
17	Red/Orange Reflexite
18	Silver Fabric (8630) by Scotchlite
19	Dark Green Reflexite

Procedure

The procedure was the same for all three ambient lighting conditions except that lowbeam headlights were used for the night condition. Each subject viewed either four or five materials placed on the table top at the two distances - 500 feet and 250 feet. This procedure was repeated four times so that all 19 of the materials could be viewed. The order of presentation for the displays was completely randomized for each subject.

For each presentation, the subject would be driven by an experiementer down the approach track. The experimenter would stop at each cone and ask the subject which of those materials displayed was most visible. The subject was told that he or she could select any number of materials as the answer, including zero. Each subject would refer to a specific material by using the material's numerical position (e.g. the left-most material would be number one and the right-most material would be either numbers four or five).

After viewing the display set at both distances, the experimenter would driver the car up to a second experimenter and tell him what both of the selections were. Then, while the first experimenter drove the subject back to the first cone, the second experimenter would remove the best selection(s) from the previously used display set and then put the next display set on top of the table. After viewing all 19 of the materials by making four runs down the track, the second experimenter would then make up another display set by using each of the most visible materials selected earlier. A material would be used here if it was selected most visible at some point, regardless of whether it was selected at only one distance or if it was selected with other materials at the same time. If the total number of materials selected as most visible exceeded seven in number, then two more display sets were created instead of only one. For this new set of materials the subject was again asked to indicate which of the materials was most visible at the two cones. At this point the session would be over.

Results

Results were tabulated by recording the number of times each material was selected as most visible during one of the four regular runs (referred to as the Regular runs) and during the last display set(s) where each of the materials previously selected as most visible was then compared to each other (referred to as the Best run). The tabulations can be observed in Table 2, 3, and 4.

As Table 2 indicates, for the day condition the Lime/Yellow Fluorescent Fabric (8987) by Scotchlite and the Red/Orange Reflexite material were selected as most visible during the Regular runs and during the Best runs approximately the same number of times at both observation points.

According to Table 3, two versions of the Red/Orange Reflexite material were rated most visible more frequently than the other materials at 500 feet during twilight. At 250 feet during twilight, the Red/Orange Reflexite, Lime/Yellow Reflexite, and Lime/Yellow Fluorescent Fabric (8987) had the most tabulated points.

During the night test condition (see Table 4) the Bright Silver Fabric (8910) by Scotchlite came out most visible the highest number of times at both 500 feet and 250 feet.

TABLE 2

MATERIALS JUDGED TO BE MOST VISIBLE AT DAY TIME AT 500 AND 250 FEET

500 FEET

MATERIAL	REGULAR	BEST
Red/Orange Reflexite	6	2
Lime/Yellow Fluorescent Fabric (8987)	5	2
Red/Orange Fluorescent Traffic Vest	4	1
Red/Orange Fluorescent Fabric (8986)	3	1
Lime/Yellow Reflexite	3	1
Red/Orange Reflexite	3	0
White Transfer Film (8760)	1	0
White Engineering Grade Signing Material	1	0

250 FEET

MATERIAL	REGULAR	BEST
Red/Orange Reflexite	5	3
Lime/Yellow Fluorescent Fabric (8987)	4	3
Red/Orange Reflexite	3	1
Red/Orange Fluorescent Traffic Vest	3	1
Red/Orange Fluorescent Fabric (8986)	3	1
Lime/Yellow Reflexite	3	0
White Engineering Grade Signing Material	1	0

TABLE 3

MATERIALS JUDGED TO BE MOST VISIBLE AT
TWILIGHT AT 500 AND 250 FEET

500 FEET

MATERIAL	REGULAR	BEST
Red/Orange Reflexite	4	1
Red/Orange Reflexite	3	1
Lime/Yellow Fluorescent Fabric (8987)	2	1
Lime/Yellow Reflexite	2	1
Red/Orange Fluorescent Traffic Vest	1	1
Red/Orange Fluorescent Fabric (8986)	1	1
White Fabric (8960)	1	0
White Engineering Grade Signing Material	1	0

250 FEET

MATERIAL	REGULAR	BEST
Red/Orange Reflexite	4	2
Lime/Yellow Fluorescent Fabric (8987)	1	2
Lime/Yellow Reflexite	3	1
Red/Orange Reflexite	2	1
Red/Orange Fluorescent Traffic Vest	2	0
Red/Orange Fluorescent Fabric (8986)	2	0
White Transfer Film (8960)	2	0
White Reflexite	2	0
Red Engineering Grade Signing Material	1	0
White Fabric (8960)	1	0
Bright Silver Transfer Tape (8710)	1	0
White Reflexite	1	0

TABLE 4

MATERIALS JUDGED TO BE MOST VISIBLE AT
NIGHT AT 500 AND 250 FEET

500 FEET

MATERIAL	REGULAR	BEST
Bright Silver Fabric (8910)	6	6
Bright Silver Transfer Tape (8710)	4	2
White Reflexite	5	1
High Intensity Sheeting	4	0
Lime/Yellow Reflexite	2	0
White Fabric (8960)	2	0
White Engineering Grade Signing Material	2	0
White Transfer Film (8760)	1	1
Red/Orange Fluorescent Fabric (8986)	1	0
Yellow Reflexite	1	0
Lime/Yellow Fluorescent Fabric (8987)	1	0
Red Engineering Grade Signing Material	1	0

250 FEET

MATERIAL	REGULAR	BEST
Bright Silver Fabric (8910)	6	4
Bright Silver Transfer Tape (8710)	3	2
Lime/Yellow Reflexite	5	0
White Reflexite	5	0
High Intensity Sheeting	4	0
White Engineering Grade Signing Material	2	0
White Transfer Film (8760)	2	0
Red/Orange Fluorescent Fabric (8986)	1	0
Yellow Reflexite	1	0
Lime/Yellow Fluorescent Fabric (8987)	1	0
Red/Orange Reflexite	1	0
White Fabric (8960)	1	0
Red Engineering Grade Signing Material	1	0
Red/Orange Reflexite	1	0

APPENDIX B

LABORATORY EXPERIMENT

APPENDIX B

LABORATORY EXPERIMENT

For the Laboratory phase of the study, the most visible materials under the three different ambient conditions of the Field Experiment were examined under simulated day and night conditions. During the simulated night condition, a simulated distant condition was also studied.

Subjects

The subjects used for this phase were male and female volunteers, all employed by the Texas Transportation Institute. Six subjects were used for each of the three conditions - day simulation, night simulation, and night/distant simulation.

Apparatus

The six most visible materials from the Field Experiment were used in the Laboratory Experiment. The materials used were the Bright Silver Fabric (8910) by Scotchlite, the Lime/Yellow Reflexite, and Lime/Yellow Fluorescent Fabric (8987) by Scotchlite, two versions of the Red/Orange Reflexite, and the Bright Silver Transfer Tape (8710) by Scotchlite. The materials were placed on a tabletop approximately three feet in height. Sixty feet in front of this table was placed a second table of the same height. Two slide-projectors were placed 18 inches apart and positioned in such a way that, if turned on, their beams of light would shine directly upon the materials placed on the first table. An answer sheet was given to each subject so that rank orders could be written down.

Procedure

For the day simulation condition, each subject observed the six materials placed upon the first table while seated at the second table sixty feet away. The subjects would then rank order the materials from the most visible down to the least visible. The order of presentation of the six different materials was completely randomized for each subject. The lighting for the day simulation condition was the ambient lighting of the test facility when the overhead lights were turned on.

The procedure used for the night simulation condition was the same as that described above, except that all lights in the test facility were turned off and the two slide-projectors were turned on, thus casting two beams of light upon the six materials observed.

The procedure used and the ambient lighting was the same for the night/distant simulation as that used for the night simulation, except that when each subject observed the displays, his or her head was lowered in such a way that their chin would make contact with the top of the table. This procedure was followed in order to simulate the perception of distance, since the materials viewed from this point would be at the horizontal line-of-sight, and the horizontal line-of-sight is approached when viewing objects at greater distances.

Results

The results for the Laboratory Experiment were retabulated by assigning six points to a material if it was selected as being most visible, five points for the next ranked material and continuing in this manner until one point would be assigned to the material judged to be the least visible. Totals were then computed by summing across all subjects within a specific treatment condition.

As Table 5 indicates, the Lime/Yellow Reflexite was judged to be most visible during the day simulation with the Lime/Yellow Fluorescent Fabric (8987) by Scotchlite and the Red/Orange Reflexite material coming in second place. For the night simulation, the Red/Orange Reflexite was judged to be most visible with the Lime/Yellow Reflexite coming in second place. Under the night/distant simulation condition, the Bright Silver Fabric (8910) by Scotchlite and the Bright Silver Transfer Tape (8710) by Scotchlite were both judged to be most visible.

TABLE 5

RESULTS OF RANK ORDERING OF MATERIALS
ACROSS SUBJECTS WITHIN EACH SIMULATION CONDITION

DAY SIMULATION

MATERIALS	TOTAL POINTS
Lime/Yellow Reflexite	27
Lime/Yellow Fluorescent Fabric (8987)	26
Red/Orange Reflexite	26
Red/Orange Reflexite	23
Bright Silver Fabric (8910)	13
Bright Silver Transfer Tape (8710)	11

NIGHT SIMULATION

MATERIALS	TOTAL POINTS
Red/Orange Reflexite	30.5
Lime/Yellow Reflexite	24.5
Bright Silver Transfer Tape (8710)	23
Bright Silver Fabric (8910)	22
Red/Orange Reflexite	19
Lime/Yellow Fluorescent Fabric (8987)	7

NIGHT/DISTANT SIMULATION

MATERIALS	TOTAL POINTS
Bright Silver Fabric (8910)	27.5
Bright Silver Transfer Tape (8710)	27.5
Lime/Yellow Reflexite	25
Red/Orange Reflexite	22
Red/Orange Reflexite	14
Lime/Yellow Fluorescent Fabric (8987)	10

APPENDIX C

LABORATORY EXPERIMENT REPLICATION

APPENDIX C
LABORATORY EXPERIMENT REPLICATION

The previously described Laboratory Experiment was replicated after the most visible reflective and fluorescent materials were "weathered" for a period of three weeks.

Subjects

The subjects used for this phase of the experiment were male and female volunteers, all employed by the Texas Transportation Institute. Six subjects were used for each of the three conditions-day simulation, night simulation, and night/distant simulation.

Apparatus

The apparatus used for the Laboratory Experiment Replication was the same as that used in the Laboratory Experiment.

Procedure

The procedure used for this phase of the study was the same as that used for the Laboratory Experiment, with the exception of the "weathering" of the materials before the replication of the Laboratory Experiment.

The "weathering" of the materials consisted of exposing the six materials previously studied to the ambient weather for 15 days. The materials were left outside from 8 a.m. until 5 p.m. each day. The ambient weather was mostly hot and sunny with a few scattered showers.

During the period of time in which the materials were weathered, they were also machine washed in warm water four times. It was during this time that two of the materials, the Red/Orange Reflexite (#10) and the Bright Silver Transfer Tape (#15), were damaged and subsequently, could not be used during the Replication. The Red/Orange Reflexite which was damaged was the same type of material as the other version of Red/Orange Reflexite (#17) studied, and the Bright Silver Transfer Tape was the same material as the Bright Silver Fabric (#4), so essentially nothing was lost from the study.

Results

The results for the Laboratory Experiment Replication were tabulated by assigning four points to a material if it was selected as being most visible, three points for the next ranked material, and continuing in this manner until one point would be assigned to the material judged to be the least visible. Totals were computed by summing across all subjects within a specific treatment condition.

Referring to Table 6, one can observe that the Red/Orange Reflexite was judged to be most visible during the day simulation. For the night simulation, the Bright Silver Fabric was judged to be the most visible with the Red/Orange Reflexite coming in a close second place. Under the night/distant simulation condition, the Bright Silver Fabric was again judged to be the most visible material.

During the Replication it was observed that the Lime/Yellow Reflexite (#7) dropped in position for each of the three conditions when compared to the results of the original study. The other three materials maintained their relative position. This may have occurred because the "weathering" more adversely affected the Lime/Yellow Reflexite than the other three materials. These results may have also occurred because of a tendency for the Lime/Yellow Reflexite to absorb other colors that surround it. This absorption process could have very easily occurred while the material was washed, since all of the materials were washed together.

Even though the Lime/Yellow Reflexite dropped in relative position, it was still judged to be more visible than the Bright Silver Fabric during the Day Simulation Replication and more visible than the Lime/Yellow Fluorescent Fabric during the other two replications. A word of caution given regarding the use of this material is that perhaps it should never be washed or, if it is, perhaps washed separately.

TABLE 6

RESULTS OF RANK ORDERING OF MATERIALS ACROSS SUBJECTS WITHIN EACH REPLICATED SIMULATION CONDITION

DAY SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Lime/Yellow Reflexite	14
Lime/Yellow Fluorescent Fabric (8987)	16
Red/Orange Reflexite	23
Bright Silver Fabric (8910)	7

NIGHT SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Red/Orange Reflexite	18
Lime/Yellow Reflexite	16
Bright Silver Fabric (8910)	19
Lime/Yellow Fluorescent Fabric (8987)	7

NIGHT/DISTANT SIMULATION REPLICATION

MATERIALS	TOTAL POINTS
Bright Silver Fabric (8910)	18
Lime/Yellow Reflexite	15
Red/Orange Reflexite	16
Lime/Yellow Fluorescent Fabric (8987)	9

APPENDIX D

STUDY OF DIFFERENT WORK VESTS

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This phase of the study consisted of the investigation of three different types of workvests. A visibility study was conducted at night for each of the three vests, while one of the vests was studied under two different conditions.

Subjects

The subjects used for this study were four female and one male volunteers. The five subjects ranged in age from 23 to 45 years of age.

Apparatus

Three different reflective workvests were studied. The first vest studied was constructed out of Scotchlite Bright Silver Fabric (8910) by 3M (see Table 7 for reflectivity values of Scotchlite 8910).

The second vest studied was the one currently used by the State Department of Highways and Public Transportation (SDHPT). This safety vest consists of a red/orange fluorescent traffic vest with two one-inch wide strips of White Reflexite tape running up the front of the vest and crisscrossing on the back of vest.

The third safety vest studied, referred to as the Improved Vest, was a modification of the vest currently used by the SDHPT. A Red/Orange fluorescent traffic vest was used, but the material was scooped down lower in the front and back (see Figure 1). This was done so that workmen wearing them would be able to stay cooler. A chevron consisting of two-inch wide Lime/Yellow Reflexite was stitched onto the front and back of the Improved Vest (see Table 8 for a price list of Reflexite and Table 9 for reflectivity values of Reflexite). A strip of Lime/Yellow Reflexite was also stitched horizontally across the back of the vest connecting the two shoulder straps. Lime/Yellow Reflexite was selected over the conventionally used white Reflexite because of its relatively high ratings in the previously mentioned Field and Laboratory Experiments.

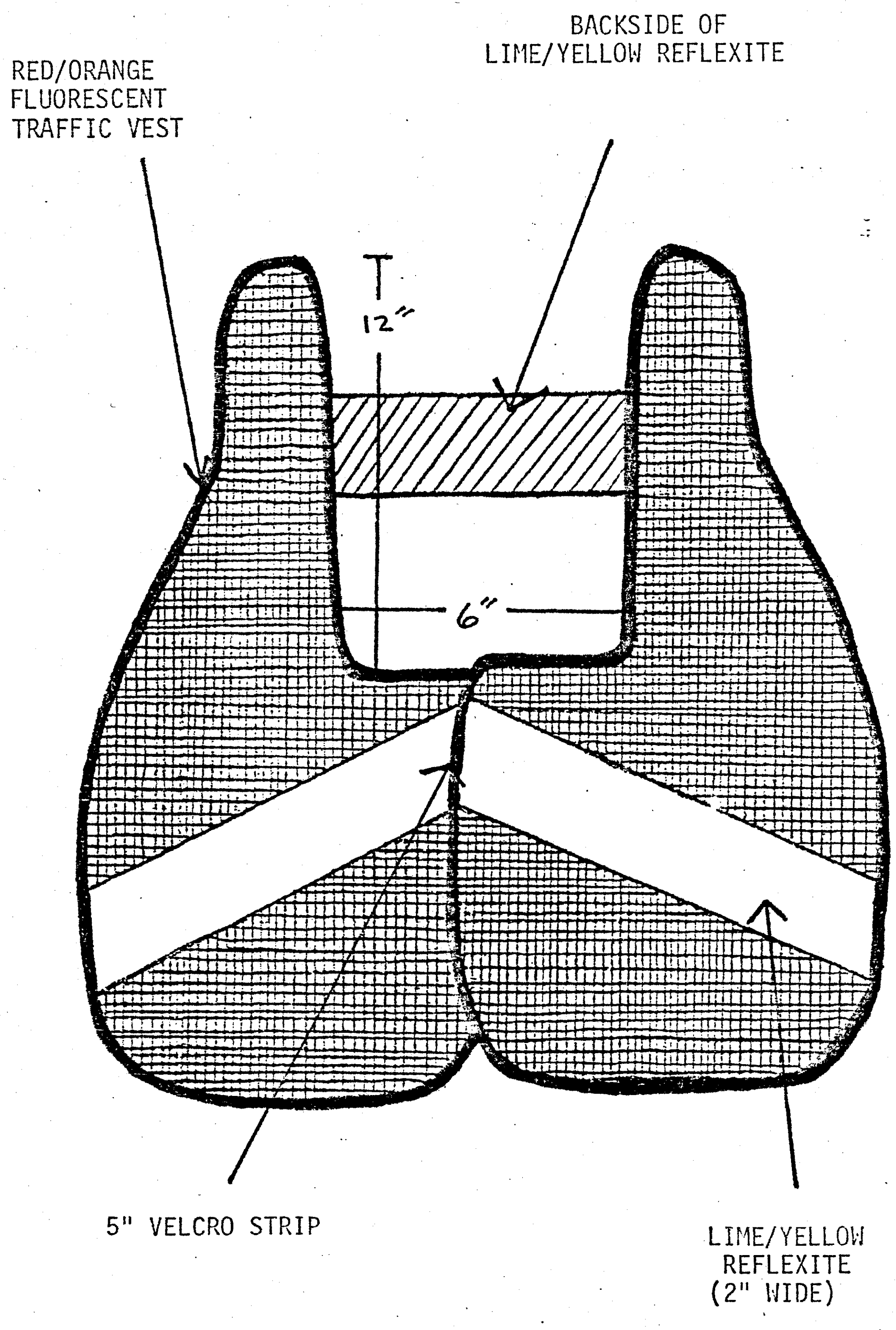
TABLE 7

REFLECTIVITY VALUES FOR SCOTCHLITE BRIGHT SILVER FABRIC (8910)
GIVEN IN CANDLEPOWER PER FOOTCANDLE PER SQUARE FOOT.

ENTRANCE ANGLES	OBSERVATION ANGLE .2°
-4°	450
40°	95

FIGURE 1

A FRONTAL VIEW OF THE IMPROVED VEST



NOTE: The back of the vest is cut as low and wide as the front of the vest. A Chevron of Lime/Yellow Reflexite is also stitched on the back.

TABLE 8

PRICE LIST OF LIME/YELLOW REFLEXITE

CENTS PER FOOT	QUANTITY ORDERED
.3366	<5,000 ft.
.3198	≥5,000 ft. but <10,000 ft.
.3029	≥10,000 ft. but <20,000 ft.
.2861	≥20,000 ft.

TABLE 9

REFLECTIVITY VALUES FOR LIME/YELLOW REFLEXITE GIVEN IN CANDLEPOWER PER FOOT CANDLE PER SQUARE FOOT.

ENTRANCE ANGLES	OBSERVATION ANGLE .2°	.5°	2°
-4°	83	60	4.5
15°	68	56	3.8
30°	30	23	3

Four wooden mannequins were used. These were approximately six-feet tall and were cut from plywood. Pieces of styrofoam approximately one-foot square and four-inches thick were attached to the front and back of each mannequin. Each mannequin was also spray-painted with blue paint.

The workvests were studied in four different configurations. Each configuration had a standard white work helmet placed on the mannequin's head. Configuration A used the 3M workvest. Configuration B used the workvest currently used by the SDHPT. Configuration C used the Improved Vest. Configuration D, the Enhanced Configuration, used the Improved Vest but also had a strip of Lime/Yellow Reflexite around the helmet, a strip around each wrist and upperarm, and a strip around each ankle.

A track located at the Texas A&M Research and Extension Center was used (see Figure 2). As can be seen from the diagram, the Configurations were placed at four different locations.

A 1979 Pontiac Grand AM was used as the test vehicle. A trailing fifth wheel, Tracktest Fifth Wheel DD-2, was employed so that the driver/experimenter would be provided a continuous digital readout of distance traveled.

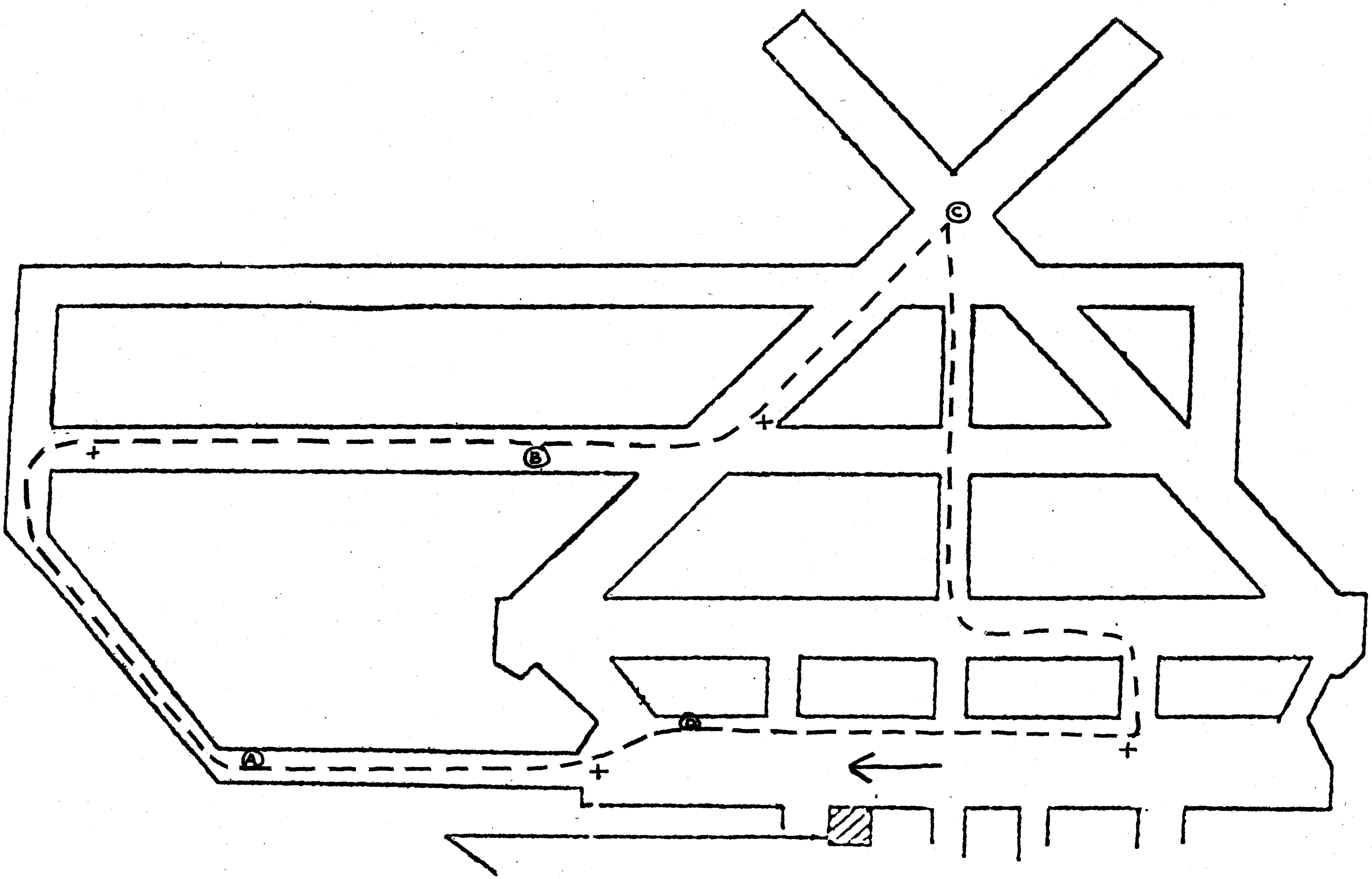
Procedure

Instructions and a statement concerning the nature of the experiment were read to each subject. The subject was told that, once the testing began on the track, to keep his/her eyes down until the experimenter told him/her to look up. The subject was to then look for the mannequin on the track and was instructed to say "I see it" when he/she saw the mannequin. At this point the subject was to look back down away from the windshield and to not look up again until the experimenter said to do so. The subject was told that this would continue for several trials.

The testing took place at night (greater than one hour after the official sunset). The experimenter tested each subject separately while the experimenter drove the car and the subject sat on the passenger's side of the front seat of the car.

FIGURE 2

Diagram of Test Track and Location of each Mannequin
and "Heads up Points"



O Location of Mannequin
+ "Heads Up" Point

The first trial was to establish a baseline. A mannequin without a helmet or workvest was placed at location A (see Figure 2).

The procedure was the same for the experimental trials as was that used to establish the baseline. When the experimenter would reach a specific location on the track (see Figure 2), he would tell the subject "Heads up". The subject would then look ahead until he/she thought that they saw the mannequin. When the subject saw the mannequin, he/she would say "I see it". At this point the experimenter would reset the distance on the meter located on the dash of the car and he would continue driving along the track until the car was even with the mannequin. He would then record the distance that was displayed on the meter. The procedure was continued in this manner until all four of the configurations were viewed a total of three times per subject.

Results

Visibility distances (in feet) were recorded for each subject (see Table 10). It was determined that Configuration A had the greatest mean visibility distance of 1519.6 feet. Configuration D was the second highest ranked with a mean of 1159.8 feet. Configuration B had a mean of 760.2 feet while Configuration C had a mean of 552.3 feet.

The visibility distances were rank ordered across each run by assigning one point for the furthest viewed configuration and the assignment was continued in this manner until four points were assigned to the nearest viewed configuration. Points were then summed across each configuration. As can be observed from Table 11, Configuration A had the lowest cumulative points with 18, while Configuration D was ranked second with 31 cumulative points.

TABLE 10

VISIBILITY DISTANCES, IN FEET, FOR EACH CONFIGURATION

Configuration	Run	SUBJECTS 1	2	3	4	5	Range
	1	1648	774	1705	1797	1670	774-1797
A-Bright Silver	2	649	1633	1919	1671	1565	649-1919
Fabric Vest	3	1641	1641	1938	1756	1507	1507-1938
B-Currently	1	240	455	1024	711	965	240-1024
Used	2	409	722	863	683	1025	409-1025
	3	483	801	1185	652	1185	483-1185
C-Improved	1	228	282	1050	585	205	228-1050
Vest	2	281	451	1094	1024	935	281-1094
	3	318	907	1131	878	1031	318-1131
D-Enhanced	1	549	1164	1280	906	654	549-1280
Vest	2	828	1586	1850	1127	925	828-1850
	3	890	1437	2094	1068	1039	890-2094

TABLE 11

RANK ORDERINGS OF CONFIGURATION VISIBILITY SCORES WHERE ONE POINT MEANS MOST VISIBLE AND FOUR POINTS MEANS LEAST VISIBLE

CONFIGURATIONS	SUBJECTS 1			2			3			4			5			CUMULATIVE POINTS
RUN NO.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
A	1	2	1	2	1	1	1	1	2	1	1	1	1	1	1	18
B	3	3	3	3	3	4	4	4	3	3	4	4	2	2	2	47
C	4	4	4	4	4	3	3	3	4	4	3	3	4	3	4	54
D	2	1	2	1	2	2	2	2	1	2	2	2	3	4	3	31

Discussion

The 3M safety vest, Configuration A, was judged to be more visible than the other vests studied. This was somewhat expected when one compares this vest's reflectivity specifications (see Table 7) to the specifications of the Reflexite material (see Table 9). But the difficulty here is that these specifications, as well as the subject ratings of this study, were for night viewing only. As was determined during the previously mentioned Field and Laboratory Experiments, the Scotchlite Bright Silver Fabric (8910) fared very poorly during the daytime conditions. This is a major flaw in this fabric since the majority of highway construction work is done during the day.

Another major drawback of the 3M safety vest is its cost. Each one costs $45. The Enhanced Configuration, which was rated as the second best configuration, costs approximately $17.00.

Still another advantage of the Enhanced Configuration over the 3M vest is that the former, because of the attached Reflexite legbands, was often perceived as being "humanlike" by the subjects. Subjects reported that with the 3M vest that they simply knew that something was there and it could just as well have been a traffic sign as a person.