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HIGHWAY WORKER VISIBILITY
State of the Practice and Policy Considerations
FINAL REPORT

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16. Abstract

As of December 2005, about 75% of the State Departments of Transportation (DOTs) had adopted all or part of the American National Standards Institute's consensus standards on high-visibility safety apparel (HVSA). The standards (ANSI/ISEA 107-2004) are quite clear on minimum coverage areas of fluorescent and retroreflective materials on garments, photometric requirements for retroreflectivity, and material durability performance levels. The standards allow for some flexibility, however, in garment color choices, retroreflective shapes and configurations, garment type applications, and background contrast. The lack of direction can be frustrating for a DOT seeking guidance on HVSA; as a result, there is limited commonality in DOT practices. This report examines HVSA and pedestrian visibility research findings, as pertains to worker visibility, as well as current practices and standards. About ten different colors or color combinations for daytime apparel were being used by DOTs. About half of the DOTs had HVSA practices for headwear only. The research findings indicated that bicolor garments featuring fluorescent yellow, green, orange and-or red, ANSI Class 3 and Class E apparel for flaggers at all times, Class 2 apparel for daytime construction and maintenance work, large retroreflective shapes for nighttime wear, and special provisions for high temperatures should be incorporated into HVSA practices. Further study is needed on colors, shapes, patterns, contrast, and the effectiveness of HVSA. In the absence of this additional research, and to expedite current HVSA needs, a retroreflective safety vest design for UDOT workers is proposed.

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Highway worker safety; highway construction; roadway construction; high-visibility apparel; high-visibility clothing; high-visibility garments; highway worker visibility

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EXECUTIVE SUMMARY

The goal of this research was to facilitate the development of practices, and ultimately policies, regarding the usage of high-visibility apparel in highway construction and maintenance work in Utah. The objectives of the research were to review the highway worker visibility literature, including federal and state studies, and scientific research, review standards and recommendations regarding high-visibility apparel, identify State DOT, contractor and insurance provider practices and requirements, and develop suggested guidelines for practice and policy. Additional objectives were to determine, as best as possible, suggested applications and users of high-visibility apparel, the *effectiveness* of highway worker visibility practices, and best practices. As part of the efforts to meet these objectives, the personal protective equipment (PPE) products being used were identified, and performance metrics that might be used to ascertain and compare their effectiveness were extracted from literature and practice reviews.

Early on in the research, the technical advisory committee (TAC) developed a framework of high-visibility apparel concerns. The PI organized the concerns into four categories:

- Appearance – color, contrast, coverage, driver recognition, retroreflectivity, shape, uniqueness
- Application – construction workers, flaggers, maintenance workers, non-work zones, work zones
- Clothing management – availability, durability, replacement schedules
- Time – daytime, nighttime, summer, winter

The study investigated each of these issues with respect to the research literature, industry standards, State practices, and safety organization literature.

A google (web) survey of State DOT practices found that ten different **colors** of highway worker apparel were being used for vests, headwear or both: fluorescent orange, fluorescent orange-red, fluorescent red, fluorescent yellow-green, lime green, orange, white, yellow, yellow-green, and a combined yellow-green and fluorescent orange. Non-fluorescent colors were identified as either “strong” or “bright” by the respective agencies. The most popularly used color was orange. The general findings from the scientific literature, based on various field experiments and fabrics, were that **fluorescent yellow-green** and **fluorescent orange-red** are the most recognizable colors during the daytime. Fluorescent yellow-green appeared to be the most conspicuous color under many conditions; the widespread adoption of this color combination for traffic signs confirms its acceptance. Fluorescent orange-red may be the most conspicuous color under certain conditions; one researcher, for example, found that an increase in red stimuli improved conspicuity among color-blind drivers. The TAC and PI agreed that a garment featuring a combination of these colors would be conspicuous under a variety of ambient conditions, and to a wide selection of drivers.

There has been only a limited amount of research on **contrast**. A Texas DOT study found that fluorescent yellow-green performed well against a variety of backgrounds, with the exception of white. At least one DOT observed that orange was most conspicuous in rural areas, while yellow or yellow-green was most conspicuous in urban, built-up environments. To contrast with light-colored backgrounds during the day, and to be seen in silhouette against glare at night, dark-colored stripes on the clothing are useful. **Areas of coverage** are firmly established in the American National Standards Institute/ International Safety Equipment Association consensus standards for high-visibility apparel (ANSI-ISEA 107-2004). The minimum area requirements for different clothing performance classes are shown in a table on page 12 of this report.

There is only a minimal understanding of **driver recognition**, expectancy and familiarity. It is commonly known that different drivers have different visual acuities. It is also recognized that age, cognition, fatigue, impairment, illumination, lighting, visibility and other factors affect what drivers see. Little is understood, however, about what drivers *expect* to see. A small number of studies have demonstrated that drivers are more likely to recognize pedestrians when they expect to see them than when the drivers are not alerted. There may also be an associative factor, in that a driver will connect a certain color, configuration or shape with an object or human. In choosing high-visibility apparel, it may be important to use colors, configurations and shapes that are associated with highway workers. Red-orange, for example, may be more readily linked to construction work than yellow-green.

Retroreflectivity is required for nighttime visibility under motor vehicle headlamp illumination. While the colors of retroreflective stripes are not critical, their sizes and shapes are. ANSI/ISEA 107-2004 recommends that retroreflective stripes completely encircle the article of clothing (e.g., around the head, torso, arms or legs) to allow for 360^o visibility. Because headlamps are intended to help the driver see the pavement, their aim is directed toward the ground. Wearing retroreflective stripes around the ankles may enhance nighttime visibility. While the ANSI/ISEA 107-2004 consensus standards for areas of coverage indicate the **sizes** of retroreflective stripes, there is little to no information on **configuration**.

The literature from safety organizations recognizes three types of highway worker: construction workers, maintenance workers, and flaggers. **Flaggers** are considered to be the most vulnerable, having the greatest exposure to motor vehicles. While the *Manual on Uniform Traffic Control Devices* recommends that flaggers wear Class 2 apparel, the American Traffic Safety and Services Association recommends, and some States require, that flaggers wear Class 3 apparel. DOT requirements for construction and maintenance workers range from headwear only to Class 2 apparel during the day and Class 3 apparel at night. The literature suggests that **construction workers** should *at least* wear hardhats equipped with retroreflective stripes. **Maintenance workers** who may not be protected by work zone signing and barriers should wear *at least* Class 2 apparel and retroreflective softcaps.

In a telephone conversation, Barb Mallon from the Iowa DOT noted that the high-visibility apparel market was very competitive. Safety vest prices had been falling, and DOTs were able to select suppliers through competitive bidding processes. In a buyers-oriented market, DOTs should be able to obtain customized safety vests. Innovative fabrics, stitching and other aspects of garment manufacturing were resulting in high-quality products, many of which were available in the form of free samples to DOTs. **Availability**, therefore, should not be a problem. The ANSI/ISEA 107-2004 consensus standards specify requirements for the performance of high-visibility garments in a number of areas, including colorfastness, stability, mechanical properties, and water interaction (see Section 4.2). There is little information, however, on garment **durability**. Agencies should require their suppliers to meet all of the ANSI/ISEA 107-2004 specifications. High-visibility apparel should be observed periodically for flaws, defects, fading, and other imperfections that might render the clothing ineffective. Barb Mallon of the Iowa DOT suggested that a replacement cycle of two to three years should be expected.

The time of day and season of the year are important considerations in the selection of high-visibility clothing. **Daytime** garments require bright, strong or fluorescent colors, while

nighttime garments require retroreflective stripes. Combined materials garments can be worn during the day and at night, featuring both conspicuous colors and retroreflection. One of the primary seasonal concerns is the outdoor temperature. In cold, **winter** weather, Class E apparel (trousers) that meets ANSI/ISEA 107-2004 consensus standards can be worn, in addition to Class 2 or 3 apparel for the upper body. During high **summer** temperatures, some DOTs have reported that safety vests – particularly the retroreflective stripes – can impede ventilation. Mesh vests are available, but they must be worn over bright clothing; otherwise, the mesh vests are not as visible as solid vests. Some DOTs were allowing their workers to wear high-visibility T-shirts during the summer.

The report concludes with a **proposed safety vest design**, developed by the TAC in conjunction with the PI. The vest incorporates many of the elements of the research findings, including dual coloration (lime green and red-orange), retroreflective stripes in an "X" shape on the front and back, and black stripes for contrast against light backgrounds. The proposed design is shown in Figure 4. A future study would evaluate the "success" of the vest, including its durability and safety performance. Other considerations for a subsequent study would include the establishment of high-visibility clothing requirements for UDOT employees and contractors, the enforcement of the requirements, safety performance measurement techniques, durability evaluation methods, safety vest costs, and contractor selection procedures.

CHAPTER 1. Introduction

1.1 Research Goals and Objectives

The goal of this research was to facilitate the development of practices, and ultimately policies, regarding the usage of high-visibility apparel in highway construction and maintenance work in Utah. The objectives of the research were to review the highway worker visibility literature, including federal and state studies, and scientific research, review standards and recommendations regarding high-visibility apparel, identify State DOT, contractor and insurance provider practices and requirements, and develop suggested guidelines for practice and policy. Additional objectives were to determine, as best as possible, suggested applications and users of high-visibility apparel, the *effectiveness* of highway worker visibility practices, and best practices. As part of the efforts to meet these objectives, the personal protective equipment (PPE) products being used were identified, and performance metrics that might be used to ascertain and compare their effectiveness were extracted from literature and practice reviews.

1.2 Problem Statement and Discussion

The National Institute for Occupational Safety and Health (NIOSH) defines a highway work zone as "the area between the first warning sign and the last traffic control device, as well as non-roadway areas (e.g., shoulders and drainages), and ancillary areas that serve as staging areas, or support areas for the work zone (e.g., temporary batch plants). This definition is broader than the work zone described in the MUTCD, which does not include ancillary areas that serve as staging areas, or support areas (e.g., temporary batch plants) for the work zone." NIOSH also defines a work space as the "portion of a highway that is closed to road users," and an activity area as "where the work takes place" (www.cdc.gov/elcosh/docs/d0400/d000461/glossary.html). The reference to the MUTCD (*Manual on Uniform Traffic Control Devices*) pertains to a broader concern over the lack of a uniform definition; many State Departments of Transportation (DOTs) have their own definitions that are tied to regulations.

Highway work zones are a safety concern because of the conflicts between passing motorists and relatively vulnerable construction, maintenance and utility employees. To deter speeding in work zones, for example, 30 States require drivers to pay twice the normal fine. In 14 States, workers must be present; in 16 States, workers need not be present. Five States – Georgia, Nevada, New Mexico, South Carolina, and West Virginia – have legislated jail time (up to 12 months in Georgia) for certain speeding-related violations in work zones. The Utah Code's penalty for speeding in work zones is *at least* twice the normal fine; workers must be present. The other 15 States have less severe penalties. All 50 States, however, have some form of enhanced work zone fine legislation. All of the existing legislation is fairly recent, with the oldest being Delaware's from 1990 (http://wzsafety.tamu/edu/files/laws1.stm).

Highway work zones – particularly construction zones – are also a safety concern because of the mixture of heavy equipment and workers. There have been numerous on-site incidents involving workers and construction vehicles. Pratt et al. (2001), for example, described 29 highway construction worker fatalities occurring between 1992 and 2000. In Minnesota in 1993, a worker was killed after being run over by a dump truck. In New Jersey in 1994, a laborer was killed after falling underneath the wheel of a front end loader. In Iowa in 1996, worker was killed after being run over by an asphalt machine. It is unclear if high-visibility apparel would have saved the life of any of these workers, but the notion is that such garments *have the potential* to enhance worker safety. Early on in this research, it was apparent that there were no studies that either proved or quantified the effectiveness of high-visibility apparel. It was logical and sensible, however, to examine the research on high-visibility clothing, to better understand its *potential* usefulness. Further research on effectiveness is needed.

1.3 Utah Highway Work Zone Incident Data

Data on incidents occurring in "construction or work areas" in Utah were obtained from UDOT's Crash Data Delivery System (CDDS). The data are summarized in Table 1. A total of 7,857 motor vehicle incidents in construction or work areas were recorded between 1992 and 2004. It is not known if the data include incidents involving passing motorists only, or also those involving construction and maintenance vehicles. A total of 429 incidents (5.5%) resulted in incapacitating injuries, including workers and motorists. An additional 41 incidents (0.5%) were fatal. Overall, more than half of the incidents occurred on freeways, particularly after 1995. This may reflect an increased amount of freeway construction and maintenance activities, especially along I-15.

Table 1. Motor Vehicle Incidents in Construction or Work Areas in Utah: 1992-2004

Year	Total	On Freeways*		Incapacitating Injury	Fatal	
1992	310	106	(34.2%)	24	3	* Freeways include: I-15, I-70, I-80, I-84, SR 201 and I-215.
1993	330	107	(32.4%)	22	3	
1994	347	64	(18.4%)	27	1	
1995	472	191	(40.5%)	25	2	
1996	571	349	(61.1%)	41	3	
1997	856	467	(54.6%)	46	4	
1998	743	462	(62.2%)	42	4	
1999	666	437	(65.6%)	36	7	
2000	804	558	(69.4%)	38	1	
2001	830	511	(61.6%)	41	5	
2002	587	307	(52.3%)	20	3	
2003	569	266	(46.7%)	27	1	
2004	772	565	(73.2%)	40	4	
SUM	7,857	4,390	(55.9%)	429	41	

Salt Lake County witnessed the most construction-work area incidents between 1992 and 2004, with 3,076 (39.1% of the State's total). The total number of work zone incidents in Davis, Salt Lake, Utah and Weber Counties was 6,317, or 80.3% of the State's total. Fatal work zone incidents tended to occur on freeways, with I-15, I-70, I-80, I-84 and I-215 accounting for 29 (70.7%); 21 of these occurred on I-15.

Embedded within the data in Table 1 are motor vehicle-pedestrian incidents that occurred in construction or work areas. There were 58 of these, representing 0.7% of all construction or work area incidents. Three of the motor vehicle-pedestrian incidents that occurred in construction or work areas were fatal (5.2% of all pedestrian-related incidents in work areas). There was no observable trend in the incidents; the annual number ranged from one to eight.

A simple linear regression analysis was performed on the total and fatal incident data to determine if there were any trends. That is, one null hypothesis was that the number of highway work zone incidents involving motor vehicles increased according to a linear trend between 1992 and 2004. The second null hypothesis was that the number of *fatal* highway work zone incidents increased linearly between 1992 and 2004. The first hypothesis was not rejected; that is, there was a positive, linear trend in the number of motor vehicle-related work zone incidents in Utah between 1992 and 2004. The average annual increase in incidents was 34.5%, representing between 4.1% and 11.1% of each preceding year's incidents. The regression equation describing the relationship is as follows:

Work zone incidents involving motor vehicles in year i = -68,304.7 + 34.489(Year)
(valid for years after 1980)

The second hypothesis was rejected; that is, there was no observable trend in the number of fatal work zone incidents between 1992 and 2004.

1.4 Highway Work Zone Visibility

Visibility during the construction-work area incidents is partially explained by the lighting conditions. Table 2 summarizes these data. A total of 6,036 (76.8%) of the incidents occurred during daylight; the remainder occurred at dawn, dusk or nighttime. As expected, incapacitating injury and fatal incidents occurred at a greater rate at nighttime, particularly where there was no overhead lighting, than at other times. For example, 1.4% of the nighttime-no lighting crashes were fatal, versus 0.3% of those occurring during daylight. Similarly, 8.1% of the nighttime-no lighting collisions resulted in an incapacitating injury, versus 5.0% of those occurring during daytime. One possible conclusion is that workers are at greater risk for a serious injury or fatality in a crash at night than during other times.

Table 2. Lighting During Construction or Work Area Motor Vehicle Incidents in Utah: 1992-2004

Lighting	Total	Incapacitating Injury	Fatal
Daylight	6,036	300	19
Darkness, no roadway lights	1,130	91	16
Darkness with roadway lights	464	22	3
Dawn	155	8	1
Dusk	153	7	2

One safety strategy has focused on increasing the visibility of workers through their garments. The Occupational Safety and Health Administration (OSHA) has made the following recommendations regarding highway workers and high-visibility apparel:

- All (highway) workers should wear high visibility apparel.
- (Highway) worker visibility during dawn or dusk conditions may be enhanced by the use of fluorescent colored high-visibility apparel.
- The use of colors such as yellow-green for the worker apparel may help to differentiate the worker from the orange colored work vehicles, signs, drums, etc.

OSHA considers high-visibility apparel to be the "first line of defense to protect workers against being struck by a vehicle or piece of equipment operated by someone who otherwise would not be able to see them during the day or at night." The MUTCD concurs with OSHA policy in specifying high-visibility clothing for flaggers, law enforcement officers and others involved in managing work zone traffic. The International Safety Equipment Association (ISEA) has developed the American National Standard for High-Visibility Safety Apparel (ANSI/ISEA 107-2004), which defines three different garment categories based on the conspicuity of the work being done. Highway workers may be in Class 2 or 3, where 3 requires the highest level of visibility. The standard is not a law or regulation, but is, according to ISEA, based on a "voluntary industry consensus." OSHA suggests that ANSI/ISEA 107-1999 (the predecessor of ANSI/ISEA 107-2004) be considered by employers as a way to comply with their high-visibility apparel recommendations (www.safetyequipment.org/visible.htm).

1.5 Findings of 1996 UDOT Study

A limited study of flagger safety vests and hardhats was funded by UDOT in 1996 (Hopson 1996). The objective of the study was to determine appropriate recommendations for the UDOT Standards Committee regarding flagger safety vest and hardhat colors. The color of and area occupied by vest striping was also considered. State DOTs that were studying vest and hardhat colors were interviewed by telephone. The study recommended continued use of orange, red-orange, or fluorescent versions of these colors for flagger safety vests and hardhats. Hopson recommended that fluorescent strong yellow-green striping or non-fluorescent strong yellow-green striping with reflective white/silver tape be fastened to vests. The striping should be fastened in a straight-line configuration. The minimum areas of the striping would be 250 cm^2 (38.75 in^2) on the front of each vest and 250 cm^2 (38.75 in^2) on the back of each vest. The findings were to be implemented by revised pertinent specifications recommended to the UDOT Standards Committee by the UDOT Traffic and Safety Division. The outcomes of the recommended implementation are not known.

The Hopson study was completed several years before the publication of the ANSI/ISEA 107-1999 and ANSI/ISEA 107-2004 standards on high-visibility apparel. Hopson did not refer to any garment classes. It is interesting to note that Hopson's striping areas are between three and eight times *smaller* than those recommended by ANSI/ISEA. Hopson's numbers, therefore, would not meet current criteria.

CHAPTER 2. Appearance of Workers and Apparel

2.1 Literature Review

The topics that were pertinent to this study included the following:

- Visual acuity, ability and perception of motorists
- Driver expectancy
- Garment and pedestrian conspicuity and visibility (daytime)
- Garment and pedestrian conspicuity and visibility (nighttime)

The literature on visual acuity, ability and perception is vast, including documents that transcend engineering, the arts and medicine. There are also multiple concerns related to transportation, including stopping and passing sight distances, traffic sign legibility and visibility, and changeable message sign text lengths. The extensive literature on these subjects was not reviewed for this research; such a review could prove beneficial if included as part of a future study. The critical concern is that visual acuity and perception vary among drivers based on their ages, visual abilities, cognition, levels of impairment, and other factors. Similarly, visual acuity and perception can vary *for the same driver* depending on factors such as fatigue, distractions, and ambient lighting. AASHTO's general rule-of-thumb of a 2.5 sec PIEV time (perception-identification-emotion-volition) is generally accepted as greater than the central tendency PIEV time of all drivers, and should thus be used in highway and work zone designs.

Driver expectancy is a little-understood aspect of visual perception. The notion is that the visibility of a pedestrian or worker can be improved simply if the driver *expects* to see him or her. The research on this subject has been limited. In reference to garment conspicuity and visibility, multiple factors are involved, including the color, coverage area, reflectivity, and shapes of high-visibility materials. These factors are in addition to those listed above. The literature on highway worker visibility is somewhat scant; the volume of readings is expanded with the inclusion of pedestrian visibility studies, along with studies specific to the other topics listed above.

Driver Expectancy

Shinar (1985), as summarized in greater detail below, alluded to the impacts that driver expectancy can have on the visibility of pedestrians at night. Similarly, Mortimer (1996) found that the nighttime visibility distance to a pedestrian dummy was twice as great when drivers expected the pedestrian than when the dummy was unexpected. The author admitted, however, that this finding may not necessarily be generalized to all night driving conditions. He recommended that more work be done on driver expectancy. On a purely theoretical level, Brehmer (1994) described driving as "self-regulated behavior" functioning under "two levels of control:" automated behavior and deliberate behavior. Automated behavior is "overlearned," and information is acted upon merely as signals, whereas deliberate behavior involves decision-making, and information is treated as symbolic. Decisions at the deliberate level set the conditions under which the automated behavior operates. Collisions and incidents occur when the *automated* skills of the driver are overtaxed. His findings can be transferred directly to driver encounters of work zones and highway workers. If the driver's behavior is in the deliberate mode upon encountering a work zone, then the workers may stand a better chance of being seen and avoided than if the driver is on "auto-pilot." High visibility apparel may facilitate this behavior alteration, although advance warning signs and other features may be the first defenses.

Daytime Garment and Pedestrian Conspicuity and Visibility

Michon et al. (1969) found **fluorescent orange** to be better for traffic safety clothing than fluorescent or **non-fluorescent yellow**; the latter, however, did not lose its color under various conditions. All three colors were preferable to white, which accounted for 50% of all unnoticed garments. The authors suggested that white be combined with a contrasting color. **Fluorescent red** was ascertained to be equally as good as fluorescent orange for persons with normal color vision, but not for those with defective color vision. Hughes and Cole (1986) defined an object's "attention conspicuity" as its ability to attract the attention of observers who are not looking for the object. An object's "search conspicuity" was defined as its ability to be found or identified by observers who are aware of its presence, and who are actively looking for it. The authors confirmed that lab experiments can replicate field tests. Lesley (1995) suggested a comprehensive approach to improving pedestrian conspicuity. The approach would feature high-visibility, fluorescent materials in combination with an understanding of basic human vision and perception, situations needing enhanced conspicuity, strategies for use, product development, specifications, guidelines, standards, public education, and awareness.

Isler et al. (1997) found that **fluorescent lime-yellow** test garments for the upper body stood out more conspicuously than fluorescent orange, green-red, high-contrast, white and black test garments in daylight and during twilight against a pine forest background. Turner et al. (1997) studied 11 different safety clothing colors, including eight fluorescent, two non-fluorescent and one semi-fluorescent configurations. The mean detection distance was greatest for **fluorescent red-orange**, followed by fluorescent red mesh, **fluorescent yellow-green**, and a **fluorescent red-orange/ fluorescent yellow-green combination**. The authors recommended each of these "top-ranking" color combinations for use in safety garments, except for fluorescent red mesh, which may have reduced visibility when worn over dark clothing. Finally, Zwahlen and Schnell (1997) observed that **fluorescent yellow-green** targets were better detected peripherally than other fluorescent and non-fluorescent color targets. A fairly large target size was found to improve the detection distance of peripheral targets, regardless of their color. Conversely, they determined that a target that is too small would not be detected peripherally, regardless of the conspicuousness of its color.

Nighttime Garment and Pedestrian Conspicuity and Visibility

The predominance of conspicuity and visibility studies have concentrated on nighttime visibility. In these studies, it is presumed that the pedestrian or worker is being viewed with the illumination of motor vehicle headlights. Headlight intensity, height, angle and direction are all factors, therefore, in addition to those associated with garment conspicuity and visibility. Beith et al. (1982) found that **retroreflective configurations on the belt, arms (armbands), torso, and back** ("zebra-shirt") were similarly detectable, and were significantly more detectable than retroreflective tape on the cap or helmet only. Shinar (1984) noted that nighttime detection distances were twice as long when pedestrians wore retroreflective tags than when they wore dark clothes. The visibility distance with the tag exceeded the stopping sight distance for motor vehicles traveling at 90 km/h or less. Pedestrians underestimated their own visibility by 1.4 to 2 times, depending on the intensity of the headlight beam. Shinar (1985) discovered that the visibility distance of pedestrians at nighttime increases with driver expectancy (i.e., the driver expected to see pedestrians on the road). He also determined that visibility distance was greatest when pedestrians wore retroreflective tags on their clothing. When the driver did not expect to see a pedestrian, the tag was not helpful *unless* the driver was aware of an association between the tag and a pedestrian.

Owens et al. (1994) found that nighttime pedestrian-in-motion conspicuity was better with **retroreflective markings on the limbs** than on the torso. Markings that incorporated biological motion performed better than arbitrarily positioned stripes on limbs. Similarly, Luoma et al. (1996) determined that retroreflective markings attached to the limbs of pedestrians led to recognition distances 60-80% longer than those with retroreflective markings attached to the torso. Pedestrians were more recognizable when crossing a road than when approaching a road. Luoma and Penttinen (1998) repeated the Luoma et al., 1996 study, but with Finnish drivers instead of Michigan drivers. The differences between the recognition distances of various retroreflector configurations were smaller in Finland than in Michigan. Zwahlen and Schnell (1999) discussed various aspects of nighttime visibility modeling. The authors pointed out the various factors involved, including driver age, headlamp illumination intensity, windshield transmittance, glare, reflectance, atmospheric transmissivity, exposure time, color, contrast and target size. They found that measured illuminance was strongly dependent on the prevailing weather conditions, such as overcast versus clear.

Schnell et al. (2001) found that clothing reflectance was a stronger factor in detection distance than headlamp illumination. Dark covers on vehicle headlamps were determined to filter out up to 88% of headlamp illumination, thereby having a detrimental effect on pedestrian visibility. In contrast to a previous study, Moberly and Langham (2002) concluded that biomotion clothing did *not* significantly increase detection distance for either moving or stationary pedestrians in comparison to a standard retroreflective vest in a high-clutter environment. Moving pedestrians were detected significantly farther away than stationary pedestrians with both biomotion and standard retroreflective clothing in the cluttered environment. Sayer et al. (2002) discovered that color deficiency among drivers has a measurable but limited influence on the effect of color on detection distance. To adjust for color deficiency, the relative value of red stimuli should be increased. Discrepancies in color vision may be accounted for by the size of retroreflective markings, as a function of visual angle, at the point of first detection.

Arditi et al. (2004) tested six vests for their nighttime effectiveness. Vest III, a **yellow mesh fabric with silver-colored retroreflective material**, and Vest VI, a **yellow texture with silver retroreflection**, outperformed the others (orange fabric with yellow retroreflection, and yellow mesh with silver). Vests III and VI did not have as much retroreflective material as the others. Vest performance was dependent on the vest characteristics, along with site characteristics. The authors emphasized that tests need to be conducted at many more sites. Sayer and Mefford (2004) found that configuration of the retroreflective trim, trim color, placement in the work zone, and driver age significantly affect pedestrian conspicuity. Intensity and the amount of retroreflective trim were not significant factors. Finally, Tyrrell (2004) confirmed the findings of Shinar (1984), in that pedestrians consistently overestimated their visibility and underestimated the benefit of conspicuity treatments. Their conclusion was that pedestrians need to be educated on the dangers of nighttime walking, and about safety treatments.

Garment and Pedestrian Conspicuity and Visibility: General Findings

Pratt et al. (2001) recommended that regular inspections be done to ensure that the color of high-visibility apparel has not faded, and that retroreflective properties have not been lost. The authors also recommended that seasonal variations in landscape and foliage should be considered when choosing colors to ensure that workers do not “blend” into the background. To increase worker visibility, the authors suggested the use of high-visibility armbands and hats, vests with strobes, and fluorescent materials on headgear and gloves. Finally, the authors encouraged federal agencies to establish guidelines, mandates, policies and requirements for high-visibility safety apparel.

Barton et al. (2002) took a rigorous approach in developing a model of object conspicuity, based on the human visual system’s contrast-sensitivity functions. Using the model, the authors recommended that an object can be made more conspicuous by increasing its conspicuity along three visual axes: black-white, red-green, and blue-yellow. Burns and

Donahue (2002) recommended that commercial bispectral fluorescent colorimeters be used to reliably describe and reproduce the properties of fluorescent-retroreflective materials.

Daigler (2002) proposed three classes of garments: users *not* exposed to traffic at high speed, users needing greater visibility in inclement weather and in activities occurring near roadways, and users working in a wide range of weather conditions. Finally, Langham and Moberly (2003) cautioned that, because of the wide range of factors affecting conspicuity, it is unlikely that certain retroreflective garments will perform equally well in different road environments. Opposing headlight beams decrease pedestrian conspicuity, leading to poorer detection accuracy than with no opposing beams. Many studies, based on *search* conspicuity, may be worth repeating to determine *attention* conspicuity. Also, the efficacy of novel conspicuity aids may decrease with increasing driver familiarity.

2.2 Standards

American National Standards Institute

In September 2004, the American National Standards Institute (ANSI), in conjunction with the International Safety Equipment Association (ISEA), issued ANSI/ISEA 107-2004, the *American National Standard for High-Visibility Safety Apparel and Headwear*. The issue represented an update to ANSI/ISEA 107-1999. In the words of the ANSI:

> ANSI/ISEA 107-2004 is a *voluntary* consensus standard that specifies requirements for PPE (personal protective equipment) that is capable of visually signaling the user's presence and represents a revision to the 1999 version. Since 1999, the standard has been recognized by various federal, state and local authorities as well as private industry entities. Significant changes to the first edition (ANSI/ISEA 107-1999) include recognition of headwear as high-visibility products, the distinction between woven and knitted fabrics as background material, and removal of previous test criteria that added no value. The appendices have been expanded to include additional examples of garment designs and now include standard test reports and an apparel and headwear compliance certificate.

The following are excerpts from ANSI/ISEA 107-2004, emphasizing key elements, definitions and measures.

Scope. Performance requirements are included for color, retroreflection, and minimum areas, as well as the suggested configuration of the materials. Performance requirements are also provided for the physical properties of background materials used in the construction of high-visibility safety apparel and headwear. Test methods are provided in the standard to help ensure that a minimum level of visibility is maintained when items are subjected to ongoing care procedures.

Purpose. Conspicuity is enhanced by high contrast between the clothing and/or headwear and the ambient background against which it is seen. This standard provides performance requirements of conspicuous materials to be used in high-visibility items and specifies minimum areas and placement of the materials.

The standard specifies minimum amounts of retroreflective materials, colors and placement of materials for items used to enhance the visibility and safety of workers. Performance Class guidelines are identified with corresponding recommendations for selection based on worker risk hazards, such as complex backgrounds, vehicular traffic and speeds encountered.

Types, Classes and Colors. Finished items are specified as either apparel or headwear. Apparel includes, but is not limited to, clothing such as vests, jackets, trousers, etc. Headwear includes, but is not limited to, items such as ball caps and knit caps.

Three Performance Classes are specified in terms of minimum area of the materials to be incorporated. A documented hazard analysis should be performed to determine the appropriate Performance Class required.

Performance Class 3: While the type of garment and the size of the wearer dictate the area of clothing, it is the intention of this standard for Performance Class 3 to offer greater visibility to the wearer in both complex backgrounds and through a full range of body movements. Additionally, visibility is enhanced beyond Performance Class 2 by the enhancement of the background and reflective materials to the arms and/or legs. Regardless of the area of materials used, a sleeveless garment or vest alone shall not be considered Performance Class 3.

Performance Class 2: Performance Class 2 provides superior visibility for wearers by the additional coverage of the torso, and is more conspicuous than Performance Class 1.

Performance Class 1: Performance Class 1 provides the minimum amount of required material to differentiate the wearer from the work environment.

Performance Class E Apparel: Waistband trousers and shorts may be classified as Performance Class 3, which shall be the designation for this ensemble accessory meeting all minimum requirements for retroreflective and background materials, except for minimum area and placement required for Performance Class 3, 2 or 1. Performance Class E trousers shall have a minimum of 0.30 m^2 (465 in^2) of background material and 0.07 m^2 (108 in^2) of retroreflective material. Retroreflective material for trousers shall encircle each leg. Retroreflective material shall not be placed less than 50 mm (1.97 in) above the bottom of the trouser leg. When such Performance Class E trousers are worn with a Performance Class 2 or 3 garment, the overall classification for the ensemble shall be classified as a Performance Class 3 ensemble. Performance Class E shorts shall have a minimum of 0.30 m^2 (465 in^2) of background material and 0.07 m^2 (108 in^2) of retroreflective material. For shorts, the retroreflective material shall encircle each leg. When such Performance Class E shorts are worn with a Performance Class 2 or 3 garment, the overall classification for the ensemble shall be classified as a Performance Class 3 ensemble.

Headwear is considered an important accessory and complements the overall visibility of the wearer. High-visibility headwear enhances visibility to the head of a moving worker in daylight and helps to define the shape of the human form during nighttime exposure.

Each Performance Class shall have the minimum area of materials incorporated in the garment according to the table below. Garments shall incorporate the minimum area of background and retroreflective materials or combined-performance material. The areas required are not intended to create a secondary hazard by specifying garments that could get caught in equipment or machinery. Care should be taken to ensure proper fit for all size wearers.

The photometric performance of Level 2 retroreflective material is intended to provide greater contrast and visibility over wider viewing angles of safety apparel when seen in headlights through darkness. When greater conspicuity is required, the higher performance level of retroreflective material should be used.

Minimum Areas of Visible Material

	Performance Class 3	**Performance Class 2**	**Performance Class 1**	**Performance Class E**	**Headwear**
Background material	0.80 m^2 (1,240 in^2)	0.50 m^2 (775 in^2)	0.14 m^2 (217 in^2)	0.30 m^2 (465 in^2)	0.05 m^2 (78 in^2)
Retroreflective or combined-performance material with background material	0.20 m^2 (310 in^2)	0.13 m^2 (201 in^2)	0.10 m^2 (155 in^2)	0.07 m^2 (108 in^2)	0.0065 m^2 (10 in^2)
Photometric performance	Level 2 or 1	Level 2 or 1	Level 2 or 1	Level 2 or 1	Level 2
Combined-performance material used without background material			0.20 m^2 (310 in^2)		0.05 m^2 (78 in^2)
Photometric performance			Level 2 or 1		Level 2 or 1

Design: Garment Requirements. Each Performance Class shall have the minimum areas of material incorporated into the garment in accordance with the above table.

Minimum Widths of Retroreflective or Combined-Performance Materials. Configurations of retroreflective bands or patterns, such as logos, design icons or identification text, may contribute to the minimum area requirements specified in the preceding table. For Performance Class 3, the retroreflective or combined-performance materials incorporated into the garment shall not be less than 50 mm (1.97 in) wide. For Performance Class 2, the retroreflective or combined-performance materials incorporated into the garment shall not be less than 35 mm (1.38 in) wide. For Performance Class 1, where retroreflective material is used in conjunction with specified background material, the bands of retroreflective material incorporated into the garment shall not be less than 25 mm (0.98 in) wide.

When utilized, these retroreflective or combined-performance materials shall be distributed within an area of "non-compliant" background materials in such a manner that a minimum of 50% of the contiguous area making up the bands or patterns be comprised of combined-performance or retroreflective materials meeting the specifications of the tables below. If the Performance Class 1 garment is constructed with "non-compliant" background material, the bands of combined-performance material incorporated into the garment shall not be less than 50 mm (1.97 in) wide.

Minimum coefficient of retroreflection in cd/(lx*m2) for Level 2 retroreflective or combined-performance material

Observation angle	Entrance angle			
	5^o	20^o	30^o	40^o
12’	330	290	180	65
20’	250	200	170	60
1^o	25	15	12	10
$1^o30’$	10	7	5	4

Minimum coefficient of retroreflection in cd/(lx*m2) for Level 1 retroreflective or combined-performance material

Observation angle	Entrance angle			
	5^o	20^o	30^o	40^o
12’	250	220	135	50
20’	120	100	75	30
1^o	19	11	9	7
$1^o30’$	7	5	3	3

NOTE: The observation angle is that formed by the headlight, the retroreflective material, and the observer. The entrance angle is that formed by the headlight, the retroreflective material, and the reflector's axis.

Spacing Between Multiple Bands. Whenever multiple bands are placed on the garment, the minimum distance between bands of retroreflective or combined-performance material shall be at least equal to the width of the band.

Distance from Bottom Edge of Garment. Whenever horizontal retroreflective or combined-performance materials are placed near the bottom edge of a jacket, vest, or poncho, the material shall not be placed less than 50 mm (1.97 in) above the bottom edge of the garment.

Placement of Materials on Full-Length Sleeves. *Encircling the Arm*: Whenever horizontal retroreflective or combined-performance materials are placed on full-length sleeves of coveralls and jackets, the material shall encircle the arm. *Placement of Upper and Lower Bands*: If upper bands are utilized on the full-length sleeves, the bands shall encircle the upper part of the sleeves between the elbow and the shoulder. When lower bands are utilized, the bottom edge of the retroreflective or combined-performance material shall not be less than 50 mm (1.97 in) from the bottom of the sleeve.

Gaps to Enable Fastening. Gaps in retroreflective, combined-performance, and background materials to enable fastening shall not be more than 50 mm (1.97 in) horizontally.

Contiguous 360^o Visibility. Performance Class 1, 2 or 3 garments, such as vests, waistcoats, jackets, ponchos, coveralls, and bib overalls, shall have contiguous areas of retroreflective or combined-performance materials encircling the torso and placed in such a manner to provide 360^o visibility of the wearer.

Placement of Materials on Legs. *Encircling the Leg*: Coveralls and bib overalls shall have contiguous areas of retroreflective or combined-performance materials encircling each leg in such a manner to provide 360^o visibility of the wearer. *Distance from Bottom of Legs*: Retroreflective or combined-performance materials on the legs shall be placed 50 mm (1.97 in) or more above the bottom edge of the leg.

Designation of Performance Class E. Performance Class E garments are not intended to be worn without a Performance Class 2 or 3 garment. Performance Class E garments shall have a minimum of 0.30 m^2 (465 in^2) of background material and 0.07 m^2 (108 in^2) of retroreflective material placed 50 mm (1.97 in) or more above the bottom edge of the leg.

Requirements for Background and Combined-Performance Retroreflective Materials: Color. *Background Material (prior to exposure tests)*: The chromaticity shall lie within one of the areas defined in the following table and the total luminance factor (Y expressed as a percentage) shall exceed the corresponding minimum in the following table, when measured in accord with procedures defined in ASTM E1164-02 *Colorimetry – Standard Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation*.

Requirements for Background and Combined-Performance Retroreflective Materials: Color. *Combined-Performance Material (prior to exposure tests)*: The chromaticity shall lie within one of the areas defined in the following table and the total luminance factor (Y expressed as a percentage) shall exceed the corresponding minimum in the following table, when measured in accord with procedures defined in ASTM E1164-02 *Colorimetry – Standard Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation*. (*The chromaticity coordinate system is shown in Figure 1*).

Color, background material

Color	Chromaticity coordinates		Minimum total luminance factor
	X	Y	Y(%)
Fluorescent yellow-green	0.387 0.356 0.398 0.460	0.610 0.494 0.452 0.540	76
Fluorescent orange-red	0.610 0.544 0.579 0.655	0.390 0.376 0.341 0.344	40
Fluorescent red	0.655 0.579 0.606 0.690	0.344 0.341 0.314 0.310	25

Color, combined-performance material

Color	Chromaticity coordinates		Minimum total luminance factor
	X	Y	Y(%)
Fluorescent yellow-green	0.387 0.356 0.398 0.460	0.610 0.494 0.452 0.540	70
Fluorescent orange-red	0.610 0.535 0.570 0.655	0.390 0.375 0.340 0.344	40
Fluorescent red	0.655 0.570 0.595 0.690	0.344 0.340 0.315 0.310	25

The mean value of the total luminance factor of retroreflective material shall comply with the requirements of the preceding tables when measured at each rotation angle of 0^{o} and 90^{o}. The chromaticity of combined-performance material shall comply with the requirements of the preceding tables when measured at the two rotation angles defined previously.

Suggested Performance Class Guidelines. *Performance Class 1 (or 2 under certain conditions)*: Workers directing drivers to parking or service locations, roadside right-of-way or sidewalk maintenance workers, and delivery vehicle drivers. *Performance Class 2 (or 1 or 3 under certain conditions)*: Roadway construction workers, utility workers, survey crews, railway workers, school crossing guards, parking and toll gate personnel, emergency response personnel, law enforcement personnel, and accident site investigators. *Performance Class 2 or 3*: Roadway construction personnel, utility workers, survey crews, emergency response personnel, and flagging crews.

Other components of ANSI/ISEA 107-2004 consider apparel design configurations, the colorfastness of materials, resistance to water penetration, mechanical properties such as bursting strength, testing methods, and other aspects of high-visibility clothing.

Australian/ New Zealand Standard

A joint Australian/ New Zealand standard entitled *High Visibility Safety Garments* was published in September 1999 as AS/NZS 4602: 1999. The standard defines three classes of garments, as follows:

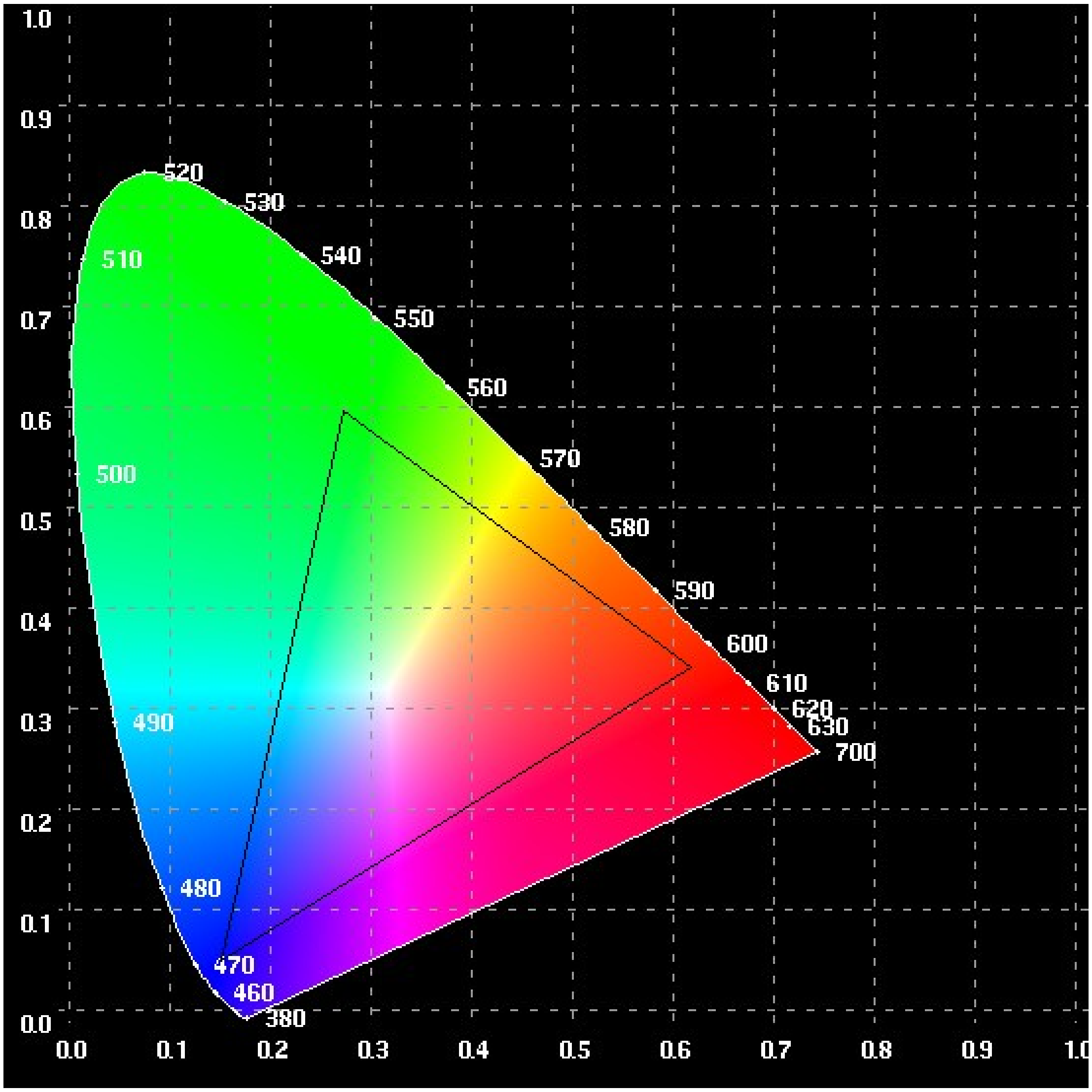

Figure 1. CIE Chromaticity Chart – *polygon units are wavelengths; axis units pertain to a relative scale (www.cs.bham.ac.uk/~mer/colour/cie.html).*

- Class D – outdoor daytime use only, comprising fluorescent or other non-retroreflective high visibility material.
- Class N – nighttime use only, comprising retroreflective elements on an unspecified background.
- Class D/N – both day and night use, comprising retroreflective elements on a fluorescent or other non-retroreflective high visibility background material.

Fluorescent materials are either red-orange or yellow. A minimum visible area of 0.4 m^2 of material is required (there is no distinction by performance class, as in the ANSI/ISEA standard). Any openings in the material, other than arm and neck holes, shall not be more than 50 mm wide. Retroreflective materials on Class N and D/N garments are to be applied in strips not less than 50 mm wide according to specified patterns. In Australia, it is acceptable to use two 25 mm strips set not more than 25 mm apart, in place of 50 mm wide strips (in New Zealand, the 50 mm strips must be used).

Whereas the ANSI/ISEA standard offers *example* garment and retroreflective strip designs, the AS/NZS standard features configuration *requirements*, with a few alternatives. For example, Class N garments must feature (a) a strip over each shoulder of minimum length 400 mm plus a complete horizontal hoop at approximately waist level, with the strips either vertical or crossed on the back, or (b) a hoop of retroreflective material around each arm between the elbow and shoulder. Item (b) is intended for Class D/N garments in hot climates in which over-the-shoulder strips have been shown to cause excessive heat-related discomfort. Horizontal hoops in segmented form may be used as an alternative to continuous strips, with each segment comprised of a rectangle measured 50 mm minimum horizontally, and with a gap between segments not exceeding 12 mm.

Class D garments are recommended for workers whose tasks require them to be within or close to the path of oncoming traffic, such as traffic controllers or emergency road situations. Class N garments are intended to be worn at night where the wearer can be observed by retroreflected light, such as from vehicle headlights. The color of daytime use garments should be selected for the greatest *contrast* with the prevailing background of the work area. For example, yellow may stand out best in urban areas, whereas red or orange may be better in rural situations. For added safety, workers should wear light-colored clothing on areas of the person not covered by a high visibility garment.

Specifications regarding chromaticity, photometrics, colorfastness, and other aspects of colorimetry are provided in a separate standard, AS/NZS 1906.4: 1997, *Retroreflective Materials and Devices for Road Traffic Control Purposes – High Visibility Materials for Safety Garments*.

Canadian Standards Association

The Canadian Standards Association published CSA Z96, *High-Visibility Safety Apparel*, in September 2002. The standards were based on ANSI/ISEA 107-1999, the predecessor to ANSI/ISEA 107-2004. The CSA standard is, therefore, similar to the American one, with the following exceptions:

Back Configuration. Stripes/bands shall be laid out in the following distinctive standardized pattern: (a) a symmetric "X" on the back extending from the shoulders to the waist; (b) two vertical stripes on the front extending over the shoulders and down to the waist; and (c) a waist-level horizontal stripe extending around the back to the bottom of the vertical stripes on the front. (ANSI/ISEA 107-2004 offers *example* garment designs, some of which feature the "X" on the back, but the designs are not standardized).

Body Coverage. CSA Z96 uses high-visibility material areas similar to those provided in ANSI/ISEA 107-2004. A critical difference, however, is that the CSA refers to *body coverage* rather than *minimum areas* of coverage. Hence, with the CSA, the coverage areas are well-defined.

Flame- or Flash-Resistant Garments. The CSA makes reference to flame- and flash-resistant (FR) apparel, whereas ANSI/ISEA 107-2004 does not mention these. Background materials for FR garments can be "bright" rather than fluorescent; hence, the photometric requirements are different (lower) than those specified for fluorescent garments.

Photometric Requirements of Class 3 Apparel. CSA Z96 specifies that Class 3 garments meet Level 2 photometric requirements, whereas ANSI/ISEA 107-2004 allows Class 3 garments to meet the requirements of Level 1 *or* 2.

European Norm

The author did not obtain a copy of EN 471: 2003, *High-Visibility Warning Clothing for Professional Use*, the European (norm) standard for high-visibility apparel. The AS/NZS standard, however, is based on EN 471, with a few changes "to be more reflective of conditions in Australia and New Zealand."

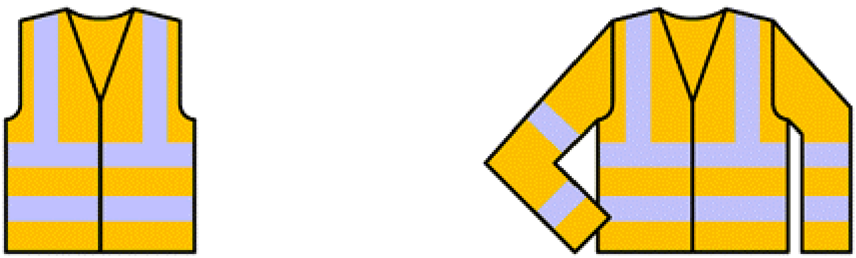

Figure 2. **Euro Class 2 & 3 High Visibility Apparel** (*EN 471: 2003*; *http://solutions.3m.com/wps/portal*)

2.3 Recommended Practices

MUTCD

The 2003 edition of the *Manual on Uniform Traffic Control Devices* states under the category of Temporary Traffic Control: Pedestrian and Worker Safety – Guidance (Chapter 6, Section D):

> Worker Safety apparel – all workers exposed to the risks of moving roadway traffic or construction equipment should wear high-visibility safety apparel meeting the requirements of ISEA "American National Standard for High-Visibility Safety Apparel," or equivalent revisions, and labeled as ANSI 107-1999 standard performance for Class 1, 2 or 3 risk exposure. A competent person designated by the employer to be responsible for the worker safety plan within the activity area of the job site should make the selection of appropriate class of garment.

The *MUTCD* also has a Standard and Guidance for **high-visibility safety apparel for flaggers**, as follows (Chapter 6, Section E):

> Standard: For daytime and nighttime activity, flaggers shall wear safety apparel meeting the requirements of ISEA "American National Standard for High-Visibility Apparel" and labeled as meeting the ANSI 107-1999 standard performance for Class 2 risk exposure. The apparel background (outer) material color shall be either **fluorescent orange-red** or **fluorescent yellow-green** as defined in the standard. The retroreflective material shall be either **orange, yellow, white, silver, yellow-green**, **or a fluorescent version of these colors**, and shall be **visible at a minimum distance of 300 m (1,000 ft)**. The retroreflective safety apparel shall be designed to clearly identify the wearer as a person.
>
> Guidance: For nighttime activity, safety apparel meeting the requirements of ISEA "American National Standard for High-Visibility Apparel" and labeled as meeting the ANSI 107-1999 standard performance for Class 3 risk exposure should be considered for flagger wear (instead of the Class 2 safety apparel in the Standard above). When uniformed law enforcement officers are used, high-visibility safety apparel as described in this Section should be worn by the law enforcement officer.

OSHA

The Occupational Safety and Health Administration posted a remark regarding the use of high-visibility safety apparel by construction workers, as follows:

> Other than the use of flaggers, Subpart G (*of the MUTCD*) does not address the circumstances in which it is necessary to provide warning garments to protect against the hazard posed by traffic. However, under Section 5(a)(1) of the Occupational Safety and Health Act, employers are required to furnish to their employees. . . . "employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees . . . ." It is well recognized in the construction industry that construction workers in highway/road construction work zones need to be protected from traffic. The MUTCD reflects industry practice with respect to identifying the types of situations where these workers need high-visibility warning garments. In such cases, Section 5(a)(1) requires the use of such garments.

ATSSA

The American Traffic Safety Services Association (ATSSA) published a brochure entitled *Choosing the Best High-Visibility Apparel in a Variety of Roadway Scenarios* in 2005 (www.atssa.com/resources). The brochure's guidance is based on ANSI/ISEA 107, but with wording oriented toward applications. The following garment classifications are offered:

- Class 1 – For workers in occupations that permit full and undivided attention to approaching traffic; when backgrounds are not complex; when workers on foot are separated from traffic; and, when vehicles are moving at speeds not exceeding 25 mph.
- Class 2 – For workers who require greater visibility under inclement weather conditions; when backgrounds are not complex; and, when tasks divert attention from approaching vehicle traffic.
- Class 3 – For workers on foot and vehicle operators whose high task loads place them in danger; when the weather must be conspicuous through the full range of body motions at a minimum of 390 m (1,280 ft); and, when the wearer must be identified as a person.

2.4 State DOT Practices, Policies and Requirements

A web (Google) survey of the high-visibility apparel practices of the State DOTs was conducted between October and December 2005. The results are summarized in Table 3. The deepest "repository" of data was found at www.flagger.com, a website devoted to flaggers (in highway work, in addition to other disciplines). The FHWA's "Work Zone Best Practices" website was also an important resource. In a few cases, an individual State DOT's website was consulted. The findings from the survey were as follows:

- About 37 States have practices, policies and-or requirements for high-visibility safety apparel for highway workers.
- A total of 18 States (including Utah) have policies or requirements for headwear *only*.
- Policies, practices and-or requirements apply to flaggers, DOT employees, and-or contractors – in several States, the policies-practices-requirements differ between the three groups.
- Headwear (hardhat) colors being used (number using – some States approved of several colors):

Fluorescent orange (4)	*White (6)*	*Yellow-green (2)*
Orange (12)	*Yellow (9)*	

- Vest colors (number using – some States approved of several colors):

Fluorescent orange-red (4)	*Lime green (1)*	*Yellow-green (2)*
Fluorescent red (1)	*Orange (6)*	*Yellow-green + orange (2)*
Fluorescent yellow-green (3)	*Yellow (1)*	

The following text summarizes additional, specific findings from a few selected States:

Illinois

The Illinois DOT funded a study on flagger visibility. One finding was that 32% of truck drivers had problems seeing flaggers. The general comment was that the standard orange mesh flagger vest had a tendency to blend into the bright orange of the traffic control devices and reflective sheeting in the backgrounds of work areas (Schoenherr 2003).

Iowa

In a telephone conversation during December 2005, Dan Sprengler of the Iowa DOT noted that requirements for high-visibility apparel were being "loosened." He explained that *all* flaggers were required, and would continue to be required, to wear Class 2 apparel as designated by ANSI/ISEA 107-2004; further, *all highway workers*, regardless of their affiliation, were and would continue to be required to wear Class 2 apparel *at night*. Otherwise, however, the DOT would no longer have any high-visibility clothing requirements for contractors. Formerly, contractors were required to wear full-range, bio-motion, reflective materials on the limbs of their clothing. The new "relaxed" requirements had not been processed as of the conversation. Also, Dan emphasized that the new specifications did not necessarily apply to DOT employees.

Table 3. High-Visibility Apparel Practices of State DOTs

State	Format	Application	Apparel	Reference
Alabama	Requirement	Flaggers	Orange vest & orange hardhat	www.flagger.com
Alaska	Requirement	Flaggers Workers within project limits Flaggers at all times; workers at night	Fluorescent orange hardhat Fluorescent red-orange vest, jacket or coverall top during the daytime (Class 2) Fluorescent red-orange pants or coverall bottoms (Class 3)	www.flagger.com www.dot.state.ak.us/stwddes/dcspubs/assets/pdf/directives/120303att_e07m109.pdf
Arizona	Requirement	Flaggers	Orange vest & yellow hardhat	www.flagger.com
Arkansas	Requirement	Dot employees	Class 2 apparel (ANSI/ISEA 107-1999)	www.ahtd.state.ar.us/EquipPro/2005/06November%5CBids%5CM-05-046P.pdf
California	Practice/ policy Requirement	Nighttime work Flaggers	Reflectorized full-body suit Retroreflective clothing must have $\geq$ 1 horizontal strip around torso; white hardhat	FHWA Work Zone Best Practices MUTCD 2003 California Supplement www.flagger.com
Colorado	Requirement	Flaggers	Fluorescent orange hardhat	www.flagger.com
Connecticut	Requirement	Flaggers	Orange hardhat "if worn"	www.flagger.com
Delaware	Requirement	Flaggers	No information	www.flagger.com
Florida	Requirement[1]	Workers within 15 ft of roadway Flaggers	ANSI/ISEA 107-1999 or ANSI/ISEA 107-2004 Class 2 apparel (Class 3 may be substituted) Background: Fluorescent orange-red or fluorescent yellow-green Retroreflection: Orange, yellow, white, silver, yellow-green or fluorescent version of these Daytime: Class 2 (orange vest & hardhat, color not specified); Nighttime: Class 3	Cheryl Adams memo, "Transition from Safety Vest to High-Visibility Safety Apparel;" www.flagger.com
Georgia	Requirement	Flaggers	Orange hardhat	www.flagger.com
Hawaii	Requirement	Flaggers	Yellow hardhat	www.flagger.com
Idaho	Requirement	Flaggers	DOT workers: orange vest Contractors: orange, yellow or yellow-green vest & orange, yellow or yellow-green hardhat	www.flagger.com
Illinois	Requirement	Flaggers DOT employees	MUTCD (compliance by 12/22/2006) Bicolor vest: 60% fluorescent yellow-green & 40% fluorescent orange stripe with reflective material	www.dot.state.il.us/blr/manuals/infocirculars/cl2005-02.pdf www.dot.state.il.us/blr/spring2003.pdf

Indiana	No information	--	--	--
Iowa	Practice/ policy	DOT employees	Fluorescent yellow-green & orange vest	FHWA Work Zone Best Practices
Kansas	Unknown	--	--	--
Kentucky	Requirement	Flaggers	Workers: orange hardhat; Supers: white hardhat	www.flagger.com
Louisiana	Requirement	Flaggers	Lime green with silver & orange stripes vest; orange hardhat (supervisors: white hardhat)	www.flagger.com
Maine	Requirement	Flaggers	ANSI/ISEA 107-1999 Class 2 *Identical to MUTCD 2003 Section 6E.02*	www.maine.gov/mdot/contractor-consultant-information/flagger
Maryland	Unknown	--	--	--
Massachusetts	Unknown	--	--	--
Michigan	Requirement	Flaggers	Yellow hardhat	www.flagger.com
Minnesota	Requirement	Night work Flaggers	Full-length high-visibility reflective clothing Vest & hardhat required, colors not specified	FHWA Work Zone Best Practices www.flagger.com
Mississippi	Requirement	Flaggers	Fluorescent orange hardhat	www.flagger.com
Missouri	No information	--	--	--
Montana	Requirement	Flaggers	Fluorescent orange hardhat	www.flagger.com
Nebraska	Requirement	Flaggers	Orange softcap or orange hardhat	www.flagger.com
Nevada	No information	--	--	--
New Hampshire	No information	--	--	--
New Jersey	Requirement	Flaggers	Orange hardhat	www.flagger.com
New Mexico	Requirement	Flaggers	Yellow hardhat	www.flagger.com
New York	Requirement	DOT employees	"High-visibility apparel" (orange) → reflectorized orange vest & orange hardhat	NYSDOT Safety Bulletin 6/18/03 www.flagger.com
North Carolina	No information	--	--	--
North Dakota	No information	--	--	--
Ohio	No information	--	--	--
Oklahoma	Requirement	Flaggers	Yellow hardhat	www.flagger.com
Oregon	Requirement	Flaggers	Yellow, white or orange hardhat	www.flagger.com
Pennsylvania	Practice/ policy	DOT workers	Fluorescent yellow-green & orange vest	FHWA Work Zone Best Practices
Rhode Island	No information	--	--	--
South Carolina	Requirement	Flaggers	Yellow hardhat	www.flagger.com
South Dakota	No information	--	--	--
Tennessee	Requirement	Flaggers	Orange hardhat	www.flagger.com
Texas	Requirement	Flaggers	Vest (color not specified) & white hardhat	www.flagger.com
Utah	Requirement	Flaggers	Orange hardhat	www.flagger.com
Vermont	No information	--	--	--

Virginia	Requirement[2]	DOT workers	ANSI 107-1999 Class 3 garments: Background: fluorescent orange-red or fluorescent yellow-green Retroreflection: orange, yellow, white, silver, yellow-green or fluorescent versions of these	Virginia Work Area Protection Manual
Washington	Requirement	Flaggers	ANSI/ISEA 107-1999: Daytime – 775 in^2 of background (fluorescent yellow-green, fluorescent orange-red or fluorescent red), 201 in^2 of retroreflective material, & hard hat (white, yellow, orange, red or yellow-green) Nighttime – Class 2 garment as above, or white overalls or Class 2 coveralls with retroreflective bands on legs, & hard hat with $\geq$ 12 in^2 of retroreflective material	Washington Administrative Code www.leg.wa.gov/WAC/index.cfm
West Virginia	Requirement	Flaggers	Yellow or white hardhat	www.flagger.com
Wisconsin	No information	--	--	--
Wyoming	Requirement	Flaggers	Yellow-green vest & yellow-green hardhat	www.flagger.com

1 Effective July 1, 2006.
2 Effective January 1, 2007.

A later conversation with Barb Mallon of the Iowa DOT confirmed the latter statement. She noted that all DOT workers were required to wear Class 2 apparel during the day; in addition, flaggers were required to wear softcaps. The apparel (vests) were “strong” yellow-green (not fluorescent) with orange reflective stripes. At night, all DOT workers, including flaggers, were required to wear Class 3 apparel, including pants (which would actually be Class E apparel).

Louisiana

Louisiana was the first State to adopt the ANSI/ISEA 107-1999 high-visibility apparel standards. In 2000, the Louisiana DOTD purchased lime-green safety vests for their employees (Pearson 2001). Numerous other States have followed suit.

Minnesota

Minnesota was the first State to test a variety of high-visibility apparel colors, and to work toward establishing a relevant policy. In a 1990 study, the Minnesota DOT displayed four mannequins in fluorescent jumpsuits at the State Fair. Fair attendees were asked to choose the most visible mannequin. The colors and the number selecting each were:

1. Fluorescent yellow 5,796
2. Fluorescent green 2,706
3. Fluorescent orange 2,231
4. Fluorescent pink 2,017

Fluorescent yellow was clearly the most visible color of the four. Developments since the DOT study in research elsewhere have identified certain color combinations, such as yellow-green or lime yellow, as potentially more visible than plain yellow. The study was presumably conducted during the daytime (Blauer 2005).

Washington

Dave Hammerker of the Washington DOT (telephone conversation, November 2005) noted that his State was one of the few in the U.S. with laws regarding high-visibility apparel in work zones. The Washington Administrative Code contains specific requirements for flaggers (but not for all highway workers); flaggers are required to wear Class 2 ANSI/ISEA apparel with a hardhat. Washington was using orange vests with lime-yellow reflectorized material. Dave explained that the Washington DOT trucks were lime colored, and that the State was, in general, "very green." Hence, the orange vests were conspicuous against the green backgrounds.

Discussion

Several other informational elements relevant to this study were obtained from the conversations with Barb Mallon (Iowa DOT) and Dave Hammerker (Washington DOT). Dave mentioned that the use of high-visibility apparel was widespread (i.e, nationwide), but that there was little commonality in the colors being used. For example, he mentioned that Caltrans was using lime yellow apparel, in part because the Caltrans trucks were a deep orange color. He also mentioned that the biggest obstacle to standards and implementation of PPE (personal protective equipment) was a lack of data on high-visibility apparel's role in preventing work zone incidents. Barb's statements concurred with those of Dave. She went further, though, in emphasizing that there was little commonality, not only in colors, but also in designs and configurations. She pointed out that the Texas DOT, for example, was using a longhorn steer design on the backs of their safety vests (suggesting that such a design would be unique to Texas). Barb also noted that most States were "on board" with high-visibility apparel and the ANSI/ISEA standards. She also explained that the National Organization of Safety Officers (NOSO) was serving as a forum for the exchange of information and ideas among State DOTs. (According to Barb, UDOT was inactive in NOSO as of the writing of this report, after being active in years past. Also, NOSO's informational exchanges were not accessible to the general public, but were the exclusive domain of DOT safety officers). Barb also made the following useful observations:

- The choice of safety apparel colors depends on the anticipated backgrounds.
- Strong yellow-green is more visible than orange, regardless of the season.
- The International Safety Equipment Association (ISEA) has supported a number of high-visibility apparel studies, but these have, in general, been performed by vendors. Their findings are, therefore, somewhat suspect (i.e., slanted and biased).
- There have been very few independent studies of high-visibility safety apparel.
- There is currently a great deal of latitude in high-visibility apparel. The ANSI/ISEA standards specify coverage areas, but there are color alternatives, several clothing types, and no guidance on shapes or configurations.
- The choice of apparel is not scientific – in Iowa, for example, the typical process is for vendors to send samples; a group of employees observe the clothing and give their opinions.
- Because of the costs, it is not practical to buy new vests each year, or to have different sets of vests for different seasons.
- The high-visibility apparel market is very competitive, and there have been several useful innovations. These include breathable fabrics, and a flexible, reflective tape developed by 3M. She has seen the costs of safety vests drop from about $35 to $11 each over the past several years.
- The procedure that seems to work, for now, in Iowa (and probably elsewhere), is to use a set of safety vests until they wear out, then look for what is new on the market.

2.5 Contractor Practices

Dave Hulvorsen of Granite Construction, in a telephone conversation (November 16, 2005), stated that his organization's workers were using a Class 2 or 3 **lime green reflective vest**. He said that the selection was based in part on the ANSI/ISEA standards; the choice was also based on the supposition that some drivers had difficulty in seeing orange, particularly those who are color-blind. He also noted that traffic signs were "moving to lime green." He indicated that the vest maker was Reflexite. (A visit to www.reflexiteamericas.com revealed that Reflexite makes retroreflective trim, tape and patches; another company makes the vest).

Jorge of the Staker and Parsons Companies (telephone conversation, December 20, 2005) stated that his employees wore high-visibility vests according to “UDOT criteria.” He noted that UDOT construction contracts required vests, hardhats, steel-toed shoes and safety glasses. As of the date of the conversation, Staker/Parsons was using **orange vests with yellow striping**; each vest featured the company logo. Jorge was not sure about the relationship between insurance and high-visibility garments. He was almost certain, however, that insurance premiums were not attached to the use of high-visibility apparel. He offered that his company’s safety *record* was the basis of insurance costs, implying that there was no direct connection to high-visibility safety apparel.

2.6 Insurance Provider Requirements

Jerry Peterson of the Farmers Insurance Group (telephone conversation, December 2005), explained that insurers consider two types of claims in dealing with contractors: liability and worker’s compensation. He was doubtful that high-visibility clothing would ever be an issue in an incident; that is, the causes and factors would most likely involve other things. In worker’s compensation cases, for example, safety clothing issues, if any, would involve items such as safety glasses, gloves, and steel-toed shoes; the visibility of clothing would rarely be considered. Jerry admitted that Farmers did not like to take on the risks associated with workers exposed to motor vehicles, placing such activities in “Category 5,” the highest of five classes of insured groups.

CHAPTER 3. Applications and Users of High-Visibility Apparel

Three general categories of highway workers are of concern: construction workers, maintenance workers, and flaggers. These three groups may be further classified as either State DOT workers or private contractors. The clothing needs of each of the six groups vary. There is little formal documentation on this topic, but there are some generally accepted practices. Construction workers are associated with an off-road construction site, surrounded by heavy equipment and materials, and wearing hardhats and other personal protective equipment. Construction projects may last for months or even years. Maintenance workers, as described by Fontaine (not dated), may frequently be involved in on-road or roadside projects that last for no more than a few days, and often for less than one day. Maintenance workers may, in many cases, be more exposed to through traffic than construction workers. Flaggers generally work on the fringes of construction and maintenance projects. Their exposure to through traffic, as well as entering and exiting construction vehicles, will generally be greater than that of other highway workers. Many States have more stringent requirements for flagger apparel than for that of other highway workers.

Construction workers are often employed by private contractors, rather than by government agencies. In Iowa, the DOT was in the process of relieving contractors of any high-visibility safety apparel requirements. The DOT's approach was to make the contractors accountable to their insurance providers on this, thereby relieving the State of the associated enforcement, penalties and liabilities. Maintenance workers, by comparison, are usually State or local DOT employees. Many States have high-visibility apparel requirements for DOT workers, as shown in Table 3. It is probable that in many cases these workers would be involved primarily in maintenance projects.

There are no definitive garment types for given work environments, but several organizations offer suggestions. Some of these were listed earlier, such as those found in ANSI/ISEA 107-2004, and those described by the ATSSA. While the ANSI/ISEA 107-2004 standards are widely accepted, there is some confusion regarding the performance class designations. That is, Classes 1, 2 and 3 pertain moreso to minimum areas of coverage of fluorescent and background material than to any specific applications. There is, for example, a Class E garment that can be categorized as a Class 2 or 3 garment, depending on whether or not it is combined with a(n upper body) Class 2 or 3 garment. A simplified scheme, with specific indications as to what distinguishes the garments, and how they are to be used, would be useful. The ATSSA has attempted to do this, as described in section 2.3 above. The Australian/New Zealand system, which features just three garment classes – daytime, nighttime, and day-night – is probably too simple. The daytime versus nighttime distinction, however, should be embedded into a set of garment use recommendations.

CHAPTER 4. High-Visibility Garment Care and Management

4.1 Availability

As mentioned previously, the high-visibility safety apparel market was highly competitive as of the preparation of this report. There were numerous suppliers, and DOTs were able to procure contracts for bulk quantities of specific garment designs through competitive bid processes. The 31 high-visibility safety apparel suppliers that were compiled in the 2005 *ISEA Buyer's Guide* are listed in Table 4.

Table 4. High-Visibility Apparel Suppliers in the U.S.

Supplier	Accessories	Coveralls Jumpsuits	Harnesses	Headwear	Jackets Outerwear	Pants	Vests
3M Personal Safety Products www.3m.com	●						
Allsafe Services & Materials www.jpisafety.com				●	●	●	●
Ansell Healthcare www.ansellpro.com		●					●
Avery Denison www.reflectives.averydennison.com	●						
Blauer Manufacturing www.blauer.com					●	●	●
Buckingham Manufacturing www.buckinghammfg.com			●				
Bullard www.bullard.com				●			
Carolina Safety Sport Int'l www.cssport.com	●			●	●	●	●
DQE www.dqeready.com							●
Erb Industries www.e-erb.com				●			●
Ergodyne www.ergodyne.com	●			●	●	●	●
FSI North America www.fsinorth.com							●
Global Protection www.protectivesuits.com		●			●	●	●
Hanes Industries www.hanesindustries.com							●
I. Spiewak & Sons www.spiewak.com		●		●	●	●	●
Iron Horse Safety Specialists www.reflectivefabric.com	●			●	●	●	●
Kishigo, M.L. Mfg.	●	●	●	●	●	●	●

www.mlkishigo.com							
Logistical Services Int'l	●	●	●	●	●	●	●
Magid Glove & Safety Mfg. www.magidglove.com	●	●	●	●	●	●	●
MCR Safety www.mcrsafety.com		●			●	●	●
MSA www.MSAnet.com			●				●
MTS Safety Products www.mts-safety.com	●		●	●	●	●	●
NASCO Industries www.nascoinc.com		●			●	●	
North Safety Products www.northsafety.com	●		●	●			●
Occunomix International www.occunomix.com	●				●	●	●
OK-1 Manufacturing www.ok-1safety.com						●	●
Orion Safety Systems www.orion-safety.com	●	●	●	●	●	●	●
Reflexite Americas www.reflexiteamericas.com	●		●				●
Safe Reflections www.safereflections.com	●	●			●	●	●
Twitchell www.twitchellcorp.com	●						●
Vizcon www.viz-con.com	●			●		●	●

NOTE: Accessories include reflectorized armbands, headbands, and trim.

The list of suppliers in Table 4 is by no means exhaustive, but is indicative of the extensive market. The most active and aggressive vendors will provide free samples of their products to potential buyers, thereby enabling DOTs to stay abreast of the latest fabrics and expected performance levels.

4.2 Durability

The durability of high-visibility apparel is a multidimensional concern. There are, in general, two components to each high-visibility garment: retroreflective material and background material. Background materials are either fluorescent or brightly-colored ("strong"). There are also combined-performance materials that are both retroreflective and fluorescent. The materials, fabrics and dimensions of performance differ for each of these. ANSI/ISEA 107-2004 addresses most of these concerns through criteria and testing procedures for the following durability parameters:

Background materials: colorfastness		Procedure
• Bleaching	Grade $\geq$ 4.0 on Gray Scale for Color Change	AATCC 61-2001
• Crocking	Grade $\geq$ 3.0 on Gray Scale for Staining	AATCC 8-2001
• Dry-cleaning	Grade $\geq$ 4.0 on Gray Scale for Color Change	AATCC 132-1998
• Exposure	Chromaticity coordinates must be met after Xenon arc lamp test	ANSI/ISEA 107-2004 ISO 105-B02:1994
• Hot-pressing	Grade $\geq$ 4.0 on Gray Scale for Color Change Grade $\geq$ 3.0 on Gray Scale for Staining	AATCC 133-1999
• Laundering	Grade $\geq$ 4.0 on Gray Scale for Color Change Grade $\geq$ 3.0 on Gray Scale for Staining	AATCC 61-2001 (at 105° F)
• Perspiration	Grade $\geq$ 4.0 on Gray Scale for Color Change Grade $\geq$ 3.0 on Gray Scale for Staining	AATCC 15-2002
• Water	Grade $\geq$ 3.0 on Gray Scale for Color Change Grade $\geq$ 3.0 on Gray Scale for Staining	AATCC 107-2002

Background materials: dimensional stability		Specifications
• Length	Change of $\leq \pm$4% for woven fabrics Change of $\leq \pm$7% for knitted fabrics	ASTM D1776 AATCC 135-2000
• Width	Change of $\leq \pm$2% for woven fabrics Change of $\leq \pm$5% for knitted fabrics	AATCC 158-1995 AATCC 96-1999

Background materials: mechanical properties		
• Bursting strength	$\geq$ 267 N (60 lb)	ASTM D3787-01
• Tear resistance	$\geq$ 13 N (1,326 gm)	ASTM D1424-96

Background materials: water interaction

• Water penetration resistance	AATCC 35-2000
	AATCC 127-1998
• Water repellency	AATCC 22-2001
• Water vapor permeability (breathability)	ASTM E96-00

The colorfastness requirements also apply to combined-performance materials. There are also color requirements for background and combined-performance materials, as described in section 2.2. Hypochlorite is the key chemical in bleaching. AATCC is the American Association of Textile Chemists and Colorists. The lists above refer to several of the AATCC test procedures. The Gray Scale for Color Change is a 9-grade scale, in which a 5 indicates no change in color between the original and tested specimens, and a 1 indicates that most of the color in the tested specimen was lost. The Gray Scale for Staining is similar, except that a 5 indicates virtually no staining of the test specimen, while a 1 indicates that the test specimen has poor colorfastness. Crocking refers to the transfer of color from a fabric onto a white test fabric. Crocking tests are performed under dry and wet conditions. Materials are exposed to a Xenon arc lamp for a set period, until pertinent blue scale control standard numbers are reached (the "blue scale" refers to a set of specially-prepared blue-dyed wool cloths that are used to evaluate lightfastness). Minimum chromaticity coordinates must be met or exceeded following the lamp exposure. ISO is the International Organization for Standardization. ASTM is the American Society for Testing and Materials. Standards for water interaction are not listed above, but are as follows. Water penetration is to be less than or equal to 1 gm of water after a 2 min spray at a pressure head of 2 ft. Water repellency is to be at least 90 originally (small drops on the fabric surface) and at least 70 at five launderings (wetting on half of the surface, with some penetration through the cloth). Fabrics are to be "breathable" with a water vapor transmission of at least 600 gm/m^2/24 hr upright, and at least 3,600 gm/m^2/24 hr inverted.

Retroreflective materials: exposure	Extent of Testing	Procedure
• Abrasion	9 kPa for 5,000 cycles	EN 530:1994
• Dry-cleaning	As stated on care label	ISO 3175:1998
• Flexing	7,500 cycles	ISO 7854:1997

•	Folding at cold temperatures	At –20 ± 1°C for 2 hours	ISO 4675:1990
•	Influence of rainfall	284 mm/hr for 2 min	ANSI/ISEA 107-2004
•	Temperature variation	12 hr at 50 ± 2°C, then 20 hr at –30 ± 2°C	ANSI/ISEA 107-2004
•	Washing	5 washing cycles	ISO 6330:2000

Following each of the seven preceding types of exposure, the material is to retain retroreflectivity of at least 100 cd/(lx*m^2) at either a 0° or 90° rotation angle, and at least 75 cd/(lx*m^2) at the other rotation angle, at an observation angle of 12' and an entrance angle of 5°. Note that these coefficients of retroreflection are substantially lower than those listed in section 2.2, which pertain to materials *prior to* test exposure. The exposure requirements also apply to combined-performance materials.

Zeigler (2001) emphasized the importance of proper fit in protective apparel, noting that OSHA *requires* that PPE be properly sized. He suggested that proper fit would be a key factor in the durability of a garment. Fit parameters include comfort, flexibility and range of motion. The author noted that ASTM F-1154 and ANSI/ISEA 101-1996 each contain a set of bending and stretching exercises that a wearer should perform to determine if a garment fits properly, and if it will restrict work procedures.

Because of the special knowledge involved in fabric construction, fiber content, pigmentation and materials, high-visibility apparel durability testing will probably be beyond the scope of most transportation agencies. Some agencies may choose to do some appearance tests on sample garments, and others may elect to collect data on appearance over time. Regarding the latter, it is important for agencies to keep track of their clothing investments, given that bulk purchases of high-visibility apparel can cost tens of thousands of dollars. Further, it is important that agencies not allow their high-visibility garments to deteriorate below ANSI/ISEA standards before replacement. Garment manufacturers should be able to provide information about the care, performance and durability of their products. An agency can request this information as part of a contract with a clothing supplier.

4.3 Contrast and Configuration Changes

Fontaine (not dated) described a study funded by the Texas DOT on the conspicuity of five different vests against eight different backgrounds. The results are listed in Table 5. The luminance contrast ratio, representing the luminance of the foreground object (vest) divided by the luminance of the background object (various), was used as the measure of performance. Details regarding lighting, ambient conditions, and other potentially influential factors were not provided.

Table 5. **Conspicuity of Colored Vests, Variable Backgrounds** (*Texas DOT study*)

Garment	Lane Closure	Sky	Asphalt	Concrete	Foliage	Work Zone	White Truck	Yellow Loader
Fluores. orange mesh vest	2.00	0.88	1.54	0.90	1.99	1.14	0.67	2.24
Fluores. yellow-green mesh vest I	3.21	1.42	2.33	1.68	3.56	1.61	0.28	3.64
Fluores. yellow-green mesh vest II	1.89	0.83	1.32	0.84	2.16	1.19	0.71	1.94
Fluores. yellow-green solid vest	4.30	1.90	3.06	2.46	4.76	2.19	1.51	4.75
Fluores. yellow-green solid jacket	4.61	2.04	2.64	1.97	4.07	1.97	1.41	4.70

NOTE: The numbers are luminance contrast ratios (cd/m^2 of foreground to cd/m^2 of background), where cd=candelas.

"Lane closure" and "work zone," presumably, pertain to the presence of standard orange signs and cones in the background. No information was provided on the color of the foliage or the sky in the test. The results were surprisingly consistent: the fluorescent yellow-green solid vest had the highest luminance contrast ratio against six of the eight backgrounds. For the other two backgrounds, the fluorescent yellow-green solid jacket was the champion. All of the contrast ratios were at their lowest with the white truck as the background. Some concern was expressed over user comfort in hot weather with the solid garments. In such cases, the garment with the third-highest luminance contrast ratios against seven of eight backgrounds, the fluorescent yellow-green mesh vest I, would be preferable. No other formal studies of contrast were identified in the literature search. It is evident that additional studies are needed, particularly of alternative colors, backgrounds and lighting conditions.

Although there is a dearth of studies on contrast, some conclusions can be drawn from the Texas DOT research. First, it is evident that a single color or garment may be more visible against several backgrounds than any other color or garment. Hence, it may be possible to use the same color or garment in numerous situations, rather than having to stock multiple garments.

The use of multiple garments may actually be expensive and impractical. Second, the Texas study suggests the bases for further studies of contrast, such as different foliage colors, different sky colors, and other environmental settings.

CHAPTER 5. Lighting Considerations

The nighttime visibility of apparel is influenced not only by the amount of retroreflectivity, but also by the amount of lighting provided. Highway workers will generally be viewed under three types of lighting: motor vehicle headlamps, overhead streetlights, and temporary portable lighting. Streetlights are generally insufficient for focal vision, which observers use to detect and recognize objects. Similarly, normal low-beam headlamps enable detection and recognition only at short sight distances; in many cases, drivers overestimate the sight distance relative to their ability to stop. Peripheral vision is not supported by headlamps, often leaving streetlights as the only source of lighting on the periphery. Green (no date) remarked that ambient vision, which is used to detect large shapes on the periphery, does not require much lighting. The detection of an object as a pedestrian, however, relies on focal vision. Green estimated that, as a rule of thumb, drivers who are not expecting to see a pedestrian will not detect one at a distance greater than about 100 ft (~30 m). Drivers begin to exceed this stopping sight distance at speeds of 35 mph (~60 km/h). Portable lighting can be a critical asset to a work zone, therefore, given the inadequacy of headlights and streetlights.

The relationship between nighttime visibility, clothing, retroreflectivity and lighting is still being understood. Green, for example, noted that motor vehicle headlamps aim toward the road, directly in front of the vehicle. Pedestrians, therefore, are illuminated close to the ground. The pedestrian’s legs and the road receive the same amount of light; detection, therefore, relies on the difference in reflectance between the pedestrian’s legs and the road. A retroreflective trouser leg might show up well against a dark asphalt road, but not necessarily a lighter-colored concrete road. In many cases, then, drivers detect pedestrians by the contrast between their upper bodies and the background. The background will typically be dark behind the upper body, since the headlamps aim low. As long as the pedestrian is wearing bright or retroreflective clothing, he or she should be detected. A bright light in the background might actually interfere with detection. In fact, with a bright background, a pedestrian may be more detectable by wearing dark clothing, thereby creating a negative contrast. Green warned, however, that a pedestrian would appear only as a silhouette in negative contrast, and would only be distinguished by form or motion cues.

The research on nighttime pedestrian visibility is limited, and the solutions to detection and recognition problems are unclear. It is evident that most of the findings, and the existing high-visibility apparel standards, have assumed that the observer sees the pedestrian or worker head-on under normal headlamp illumination. Muttart (2000), for example, found that a retroreflective, fluorescent red-orange vest was more quickly detected at night than retroreflective, fluorescent lime, retroreflective white, and non-retroreflective, fluorescent yellow vests. Muttart also found that 25% of the test subjects (ages 17 to 70) were unable to detect a pedestrian who was not wearing a vest. In many cases, however, workers would be in the periphery of a driver's vision, thereby negating many of Muttart's and others' findings and standards. Zwahlen and Schnell's (1997) study on peripheral vision concentrated on daytime conspicuity. Their finding that conspicuity heavily depends on target size, however, is probably applicable to nighttime situations. That is, color and retroreflectivity are of lesser importance than the size of the object being retroreflected or illuminated. These findings suggest that Class E apparel (trousers) may be essential at night. Also, it may be worthwhile to investigate the use of wider retroreflective strips, or, possibly, innovative retroreflective shapes.

CHAPTER 6. Development of Suggested Practice and Policy Considerations

6.1 Discussion

This chapter presents some considerations for a set of practices or policies on high-visibility safety apparel. The suggestions represent a synthesis and composite of the material presented in Chapters 1-5 of this report. It is recognized that there are no federal mandates on high-visibility apparel, nor has there been extensive scientific research on the subject. Further, there are only a few commonalities in State DOT practices, although the commonalities are widespread. The information in this chapter is, therefore, fairly subjective, and should be interpreted as a discussion piece, rather than as definitive guidance. First, in reference to one of the research articles on this subject, Langham and Moberly (2003) emphasized that poor pedestrian conspicuity, excessive vehicle speed, driving under the influence, and inadequate visual search all contribute to pedestrian-vehicle collisions. Increasing pedestrian conspicuity, therefore, constitutes just one method of increasing highway safety. The authors noted that *conspicuity*, rather than *visibility*, is a primary concern in pedestrian safety. That is, conspicuity is defined as "the size of a background area within which a target can be detected during a single, brief presentation," while visibility is defined as "the ease of detection when the observer is aware of the target's location." The authors provided a candid report on the shortcomings of pedestrian conspicuity research, and how inconsistency in experimental approaches may have led to conclusions of limited usefulness. For example, the authors found that nearly all pedestrian conspicuity experiments were conducted at night, despite the concurrent need for daytime studies. Nonetheless, the authors identified a common ground in the studies that they reviewed, making the following recommendations:

- Pedestrians should make use of retroreflective clothing.
- Pedestrians should wear retroreflector configurations that outline the shape of the human body.
- Pedestrians should be warned that they are not as conspicuous as they may believe.
- Many drivers travel at speeds that do not allow them to stop in time for an unexpected obstacle, particularly at night.

- Driver expectancy for pedestrians may be increased by additional warning signage.
- Roadway lighting should be increased in areas where pedestrians are at risk.

Langham and Moberly warned that experimental evaluations of pedestrian conspicuity may not correspond to conspicuity in actual situations. The authors describe two types of conspicuity: search and attention. Most research had explored search conspicuity, with drivers looking for randomly placed pedestrians in simulated settings. Attention conspicuity, in which drivers are completely unaware of the potential presence of pedestrians, let alone their random placement, had not been extensively examined.

6.2 Appearance

Colors (Daytime)

The majority of States have adopted at least some, if not all of the ANSI/ISEA 107-2004 standards on high-visibility apparel. Nolan (2003) predicted that these (actually, the earlier ANSI/ISEA 107-1999) standards would become the basis for a set of federal mandates "within the next five years," so it will be interesting to see if the forecast is accurate. Based on the research and the state of the practice, the "top two" daytime colors seem to be fluorescent orange-red and fluorescent yellow-green. Between these two, it is not clear which is "better;" for example, orange is associated with color blindness, as may be red, but their combination was, in at least one study, better detected than all other color combinations. Fluorescent yellow-green has been widely adopted for use in traffic signs, confirming its acceptance as a high-visibility color. At least one researcher suggested, and two States are using, a **combination of fluorescent yellow-green and fluorescent red-orange** (or just orange). In the Illinois DOT's case, the garment was bicolored, with 60% of the area devoted to fluorescent yellow-green, and 40% devoted to fluorescent orange stripes that featured retroreflective strips on the stripe edges. The bicolored approach may help to distinguish the worker from construction signs, cones and barricades, as well as from standard traffic signs. Further, as the background behind the worker varies, at least one of the colors may be visible at all times, with the exception of an all-white background. Figure 3 below shows the Illinois DOT high-visibility apparel. Mr. Koehler is wearing Class E trousers. Mr. Jenkins is wearing a Class 3 vest. Messrs. Kulavic and Koehler are wearing Class 2 vests.

From left to right: Mark Jenkins (District One), Tom Kulavic (District Six), Geno Koehler (Day Labor)

Figure 3. **Illinois DOT High-Visibility Safety Garments**
(http://www.transportation.org/community/quality/portal.nsf/b400882cb254934286256aba0076a1be/151e58ff1b68e46286256c1e00615fd3/$FILE/02Fall.pdf)

Retroreflection (Nighttime)

At night, retroreflective materials on the garments are essential. Marsh and Tyrrell (1998) found that the color of retroreflective material was relatively inconsequential; retroreflective power was the critical factor in brightness and detectability. Consequently, ANSI/ISEA 107-2004 does not provide any specifications on retroreflective material colors for nighttime use. Retroreflective material colors *are* important for daytime use, however, such as in a combined-performance garment. **Retroreflective colors** either in or approved for use by State DOTs include **orange, silver, white, yellow and yellow-green**.

Garment Types

The general consensus among practitioners is that **Class 2 apparel** is the minimally acceptable class for highway workers. Some States require **Class 3 apparel at night**; for **flaggers**, some States are requiring **Class 3 apparel at all times**. The use of Class E apparel (i.e., retroreflectorized trousers) is not consistent, although some States seemed to be treating this class as Class 3. Some problems were evident in accommodating workers during high temperatures, during which some of the full-length apparel, as well as some of the retroreflective strips, might prove uncomfortable. At least one State was allowing its workers to wear retroreflectorized T-shirts during the summer. There is very little science in the garment types and classes, so it is difficult to make suggestions. For example, there are no data on the safety of Class 3 garments versus Class 2 garments, nor on the effectiveness of garment types such as T-shirts, vests and trousers. There is conflicting research on the effectiveness of biomotion markings on garments. That is, it is not clear if retroreflective strips along the arms and legs are any more visibility enhancing than encircling or torso markings. Further experimentation is needed. In the absence of this, the most sensible approach may be to use modified Class 2 or 3 apparel **when temperatures are high**, such as **mesh vests for Class 2** (with the requirement that the worker wear **brightly-colored background clothing**). Although not addressed among current practices, the usage of **retroreflective strips around the ankles** to obtain ground level illumination from headlamps at night might be considered.

Shapes and Configurations of Retroreflective Material

Recognizing that there is only limited guidance on garment types and classes, there is even less guidance on shapes and configurations. So et al. (2002) claimed to have developed a model that would predict the optimal shape of retroreflection, but there is little information on the applicability of their product. The CSA seems to have taken a logical step with vests, in that over-the-shoulder retroreflective strips must extend from a retroreflective waistband on the torso to the waist on the back, in the process making an "X." This enables the observer to distinguish between the front side and back side of the worker, possibly helping the observer to recognize the configuration as a person from a distance. There are numerous other potential configurations, however, that have not been tested. For example, would a large, retroreflective "U" on the torso or back enhance the visibility of a UDOT worker? Also, the discussion in Chapter 5 of this report suggests that large targets would have increased visibility peripherally, particularly at night. Further study of shapes and configurations is needed.

6.3 Applications

Users

Chapter 3 of this report refers to three classes of highway worker: flaggers, DOT employees, and contractors. There may be a trend toward relaxing daytime high-visibility apparel requirements for contractors, thereby allowing them to develop their own procedures, in conjunction with their insurers. The consensus among DOTs appears to be that flaggers are in high-risk positions, and should be outfitted with the most visible apparel (Class 3) at all times. DOT employees are given some flexibility, with Class 2 apparel during the daytime and Class 3 apparel at night. It may be most economical for an agency to use a combined-performance garment that can be worn during the day and at night. Construction and maintenance workers should be outfitted with high-visibility safety apparel. The primary difference may be in the headwear: maintenance workers might wear softcaps only, while construction workers would be expected to wear hardhats. In either case, the headwear should be highly visible, according to the recommendations of ANSI/ISEA 107-2004.

Backgrounds and Contrast

There has been only limited research on backgrounds and contrast, and the effects on the visibility of the foreground. One State argued that fluorescent yellow-green was visible against all backgrounds, while another cautioned that green foliage would make fluorescent orange or orange-red more visible. According to Texas DOT research, fluorescent yellow-green was more visible than fluorescent orange against eight different backgrounds. Only one fluorescent orange garment type was tested, however – a mesh vest – whereas four different fluorescent yellow-green garment types were tested. Further study is needed; in the absence of additional information, a bicolored garment may be the most sensible approach.

Driver Expectancy and Familiarity

It is clear from the literature that drivers who expect to see pedestrians are more likely to detect and recognize them than drivers who are "unalerted." Driver expectancy can be enhanced through associations with elements of the highway environment. For example, the color red is commonly associated with stop signs and fire trucks, school buses are yellow, and orange is associated with construction signs and cones. A high-visibility apparel color, therefore, could become familiar to drivers as one that highway workers are *expected* to be wearing. Similar relationships could be developed with patterns, shapes or garment types. For example, stop signs are octagonal, school zone signs are pentagonal, and railroad crossing warning signs are circular. It is not clear if fluorescent yellow-green is the critical color for highway workers, since it is also associated with school zone and pedestrian signing. Fluorescent orange-red or a bicolor arrangement may potentially be more associative with construction and maintenance work. Further research is needed on these aspects of coloration, as well as on patterns and shapes.

6.4 Garment Care and Management

Availability

As indicated in Table 4, there is a large number of high-visibility garment suppliers in the U.S. Because there is a competitive market, an agency should be able to specify its garment needs, including customized designs, as part of a competitive bidding process. An example contract between the Michigan DOT and a vendor of high-visibility safety vests can be found at http://www.michigan.gov/localgov/0,1607,7-194-32568_32745-123683--,00.html. In this case, the contract was originally for $25,000, but was extended and increased to $75,000. Note that the product specifications were given in detail.

Durability

The ANSI/ISEA 107-2004 standards include a thorough set of test procedures and criteria that garments must pass. An agency can ensure that the purchased garments are of the highest quality by requiring that their suppliers meet all of the ANSI standards. The standards, however, say little about the durability of high-visibility safety apparel. That is, the relationship between all of the tests that a garment must pass and its expected performance in the field is difficult to determine. An agency should establish a mechanism for measuring the deterioration of its high-visibility clothing. The two greatest concerns are, most likely, loss of color and loss of retroreflectivity. Informal evaluation procedures might involve periodic inspections of garments by agency personnel. With normal wear and use, agencies should probably establish an expected garment duration period of two to three years.

6.5 Proposed Safety Vest Design

Based on the findings of the research, and from exchanges between the technical advisory council (TAC) members, along with the PI, a retroreflective safety vest design was drafted. The design concerns included color, configuration, shape, size and retroreflectivity. Other design issues included contrast, driver expectancy and familiarity, and user needs. The vest was designed for both daytime and nighttime conditions; hence, both fluorescence and retroreflection were featured. The proposed vest is shown in Figure 4. The design features similar front and back colors and patterns. The arrangement partitions the vest into four sectors on the front and the back, with two sectors on each side of the vertical centerline. Looking at the front of the vest, on the left side of the centerline, the top sector is lime green and the bottom sector is red orange; on the right side, the top is red orange and the bottom is lime green. The selected colors, which include those that are most visible to motorists based on past studies, would be fluorescent. The design vest is further enhanced by a retroreflective yellow “X” that crisscrosses in the front and back. The “X” ends just above the waist level, where it borders a retroreflective yellow band that encircles the vest. To enhance the vest’s contrast against light-colored backgrounds, black strips border the yellow “X” as well as the waist band. Through a competitive bidding process, it should be possible to negotiate a contract with a vendor that would manufacture the vest. Vendors and potential contractors might provide prototypes for no charge. The selected supplier would be required to design the garment to ANSI/ISEA 107-2004 specifications. For example, minimum coverage areas of retroreflective striping would be required. Prototypes would give UDOT an opportunity to view the garment in test conditions before committing to a large purchase. A subsequent study to evaluate the durability and safety performances of the proposed vest is suggested.

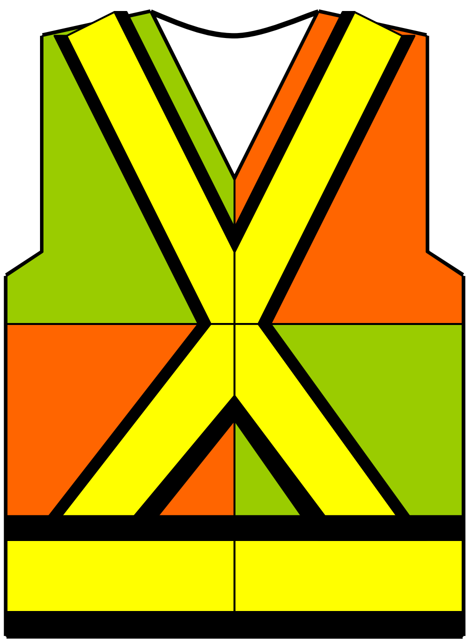

Figure 4. Proposed UDOT Highway Safety Vest (*similar pattern and colors on the back – not to scale*)

CHAPTER 7. References

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