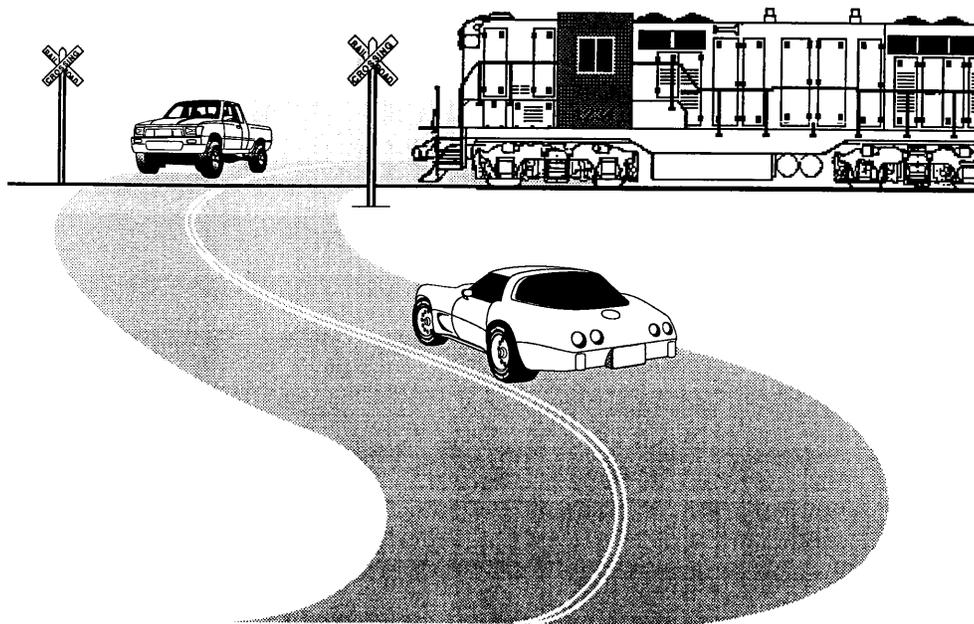


FINAL REPORT

INVESTIGATION OF RETROREFLECTIVE SIGN MATERIALS AT PASSIVE RAILROAD CROSSINGS



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VIRGINIA TRANSPORTATION RESEARCH COUNCIL

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**(The opinions, findings, and conclusions expressed in this
report are those of the author and not necessarily
those of the sponsoring agencies.)**

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The goal of this study was to determine the best configuration of retroreflective material on Railroad Crossing (crossbuck) signs and posts for improving the visibility and safety of passive highway-railroad grade crossings at night. The material costs of upgrading existing crossbucks with the retroreflectorized crossbuck systems were also explored.

Five configurations for marking crossbucks and posts were developed and installed at five passive grade crossings on the Virginia Southern Railroad line between Fort Mitchell and Green Bay, Virginia. At each crossing, photographs of each approach were taken at night using only the low beams and high beams of a vehicle for illumination. To supplement the photographs, researchers videotaped driving through the crossings at night. Each location was driven through twice, once with low beams and once with high beams. Researchers also videotaped a train traveling through each crossing.

The photographs and videotape were used as the media for a subjective analysis of which of the five systems was most visible at night. The subjective analysis consisted of one-on-one interviews with 19 individuals watching the videotapes of the systems and answering a questionnaire survey.

Although the sample size was limited by the time constraints of the study, results indicated that the double-sided crossbuck with retroreflective material along the full length of both sides of both posts was preferred. If used throughout the Commonwealth, this system will improve: 1) the visibility of the crossing; 2) the uniformity with which passive crossings are marked; 3) the driver's depth perception of the crossing; and 4) the driver's ability to detect a train in the crossing.

FINAL REPORT

INVESTIGATION OF RETROREFLECTIVE SIGN MATERIALS AT PASSIVE RAILROAD CROSSINGS

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INTRODUCTION AND PROBLEM STATEMENT

There are approximately 181,953 highway-railroad grade crossings in the United States.¹ The Commonwealth of Virginia currently has 2,234 at-grade crossings, accounting for 1.23% of the national figure. Of the crossings in Virginia, 57 percent are considered "active" and 43 percent "passive." Active crossings warn of the approach or presence of a train by train-activated control devices (flashing lights and/or gates). Passive crossings do not have a train-activated warning system. Whether the crossing is active or passive, a Railroad Crossing (Crossbuck) sign (R15-1 in the Manual on Uniform Traffic Control Devices) is required for each roadway approach to at-grade crossings.²

In 1988 and 1989, the Minnesota Department of Transportation (Mn/DOT) held 14 forums on transportation safety.³ A recurring theme at these forums was the public's demand for a stronger state program to improve the safety of highway-railroad grade crossings. Mn/DOT subsequently developed such a program. Mn/DOT and other states have increased the visibility and safety of passive grade crossings efficiently and inexpensively by using retroreflective materials on the posts and backs of crossbucks. However, the configuration of the materials varies from state to state. For example, Mn/DOT marks a 4 foot (1.22 meter) section on the back of the crossbuck posts while the Ohio DOT marks the entire length of the post on all four sides.

Considering the public demand for increased safety at highway-railroad grade crossings, the Commonwealth of Virginia should identify the best configuration of retroreflective material for crossbucks and posts and apply it uniformly throughout the Commonwealth as an efficient, low-cost way to improve the visibility and safety of these crossings at night.

PURPOSE AND SCOPE

The goal of this study was to identify the best configuration of retroreflective material for railroad crossbucks and posts, for improving the visibility and safety of passive at-grade

crossings at night. The retroreflective material used in this study was a new 3M sheeting, Visual Impact Performance (VIP™). VIP™ is essentially an improved version of Diamond Grade™ sheeting with increased visibility as one gets closer to the sign. This study also explored the material costs of upgrading existing crossbucks with a new retroreflectorized crossbuck system, district-wide and statewide.

METHODOLOGY

Literature Review

The literature on retroreflective materials for highway-railroad grade crossings was reviewed after a computerized literature search. Other states experimenting with or using retroreflective materials for upgrading passive grade crossings were solicited by telephone for information about their current practices and specifications, and the results of upgrading crossings with these materials.

Development of Alternative Marking Configurations

After reviewing the literature and practices reported by other states, five marking configurations for passive highway-railroad grade crossings were developed (Figures 1-5). These configurations, or systems, are based on markings used in other states, modified in some cases by research findings. The characteristics and location of each system are noted in the figures.

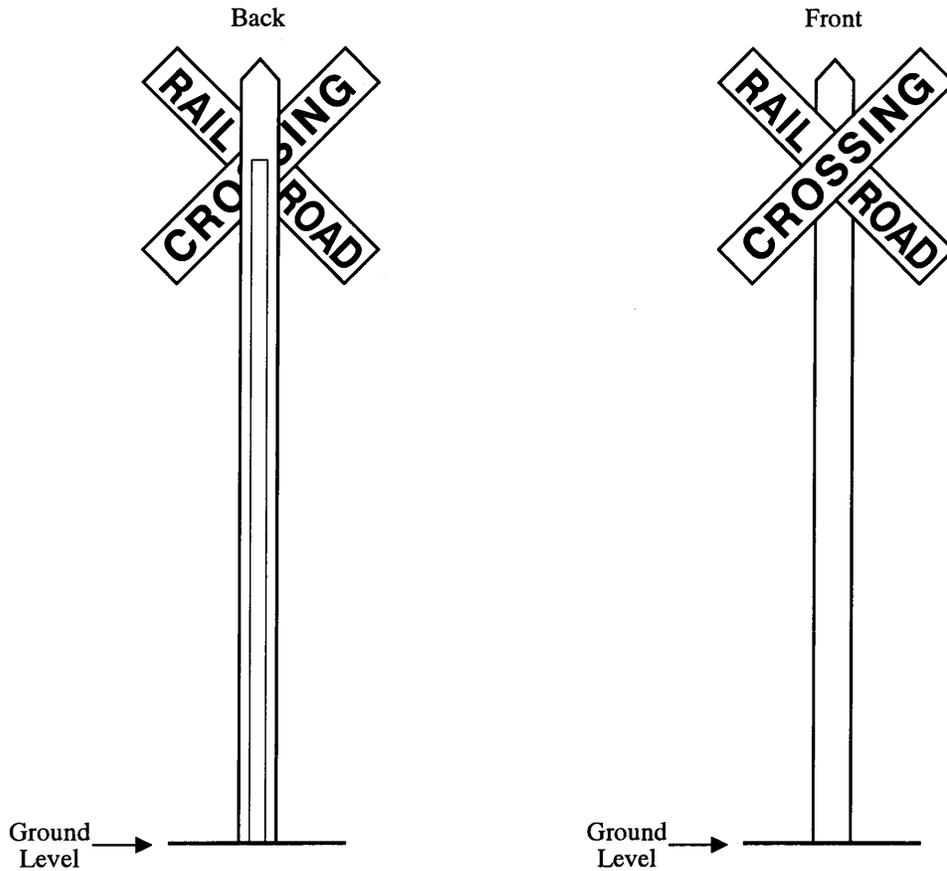
Site Selection and Installation of Alternative Marking Configurations

The study examined five passive grade crossings along the Virginia Southern Railroad line between Fort Mitchell and Green Bay, Virginia. The Virginia Southern Railroad was selected because one of the five systems was already installed at one of their crossings and because they were interested in testing additional systems at crossings on their line. Sites were selected on four criteria: 1) adequate roadway sight distance, 2) the absence of external light sources, such as home security lights or street lights, 3) relatively flat approach grades, and 4) the angle at which the railroad tracks and roadway intersected, a 90-degree crossing was preferred.

The five systems were installed in one day by Virginia Southern Railroad's Road Master, a representative from the Virginia Department of Transportation's Traffic Engineering Division, and the researcher. Where new retroreflectorized crossbucks were to be evaluated, the existing crossbucks were simply removed and replaced with the new ones. The retroreflective tape applied to the crossbuck posts had an adhesive pressure sensitive backing, which was reinforced by stapling, using one staple approximately every 4 inches (10 cm).

Figure 1

System No. 1



System No. 1 Characteristics

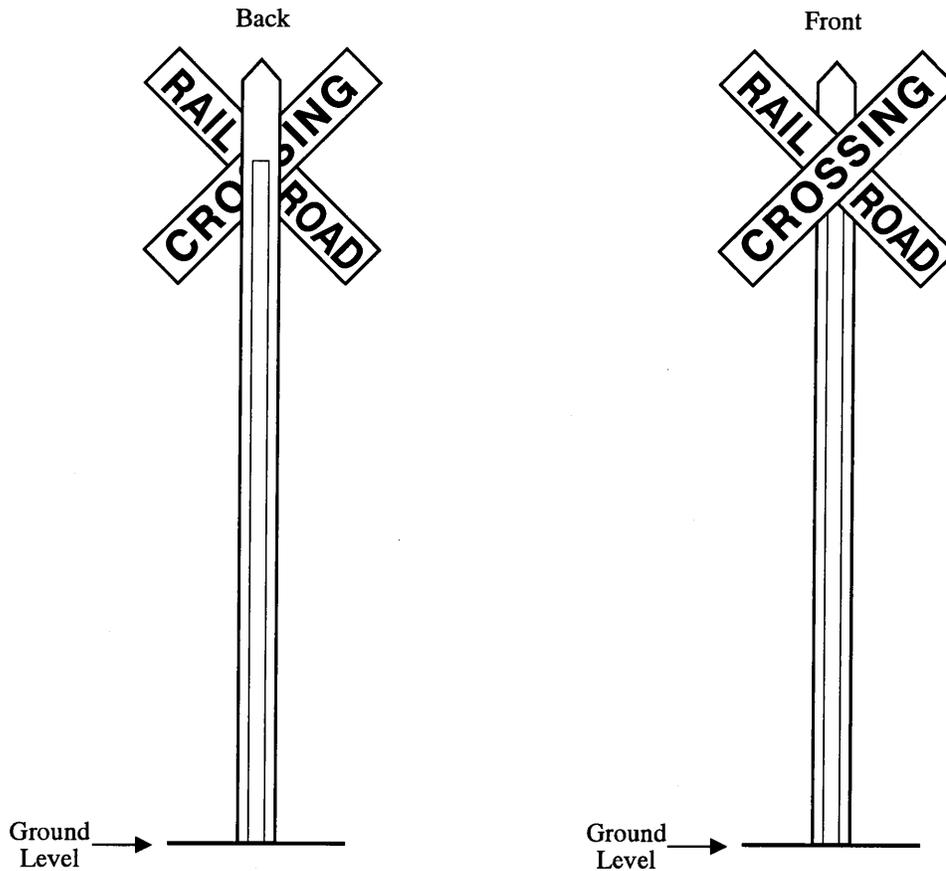
- Double-sided crossbucks with VIP™ sheeting
- 2 inch wide VIP™ sheeting installed on backside of post
- VIP™ sheeting is applied to post at or near ground level, to center of crossbuck mounting

Location Installed

- State Route 701 in Lunenburg County
- DOT-AAR No. 715-148J

Figure 2

System No. 2



System No. 2 Characteristics

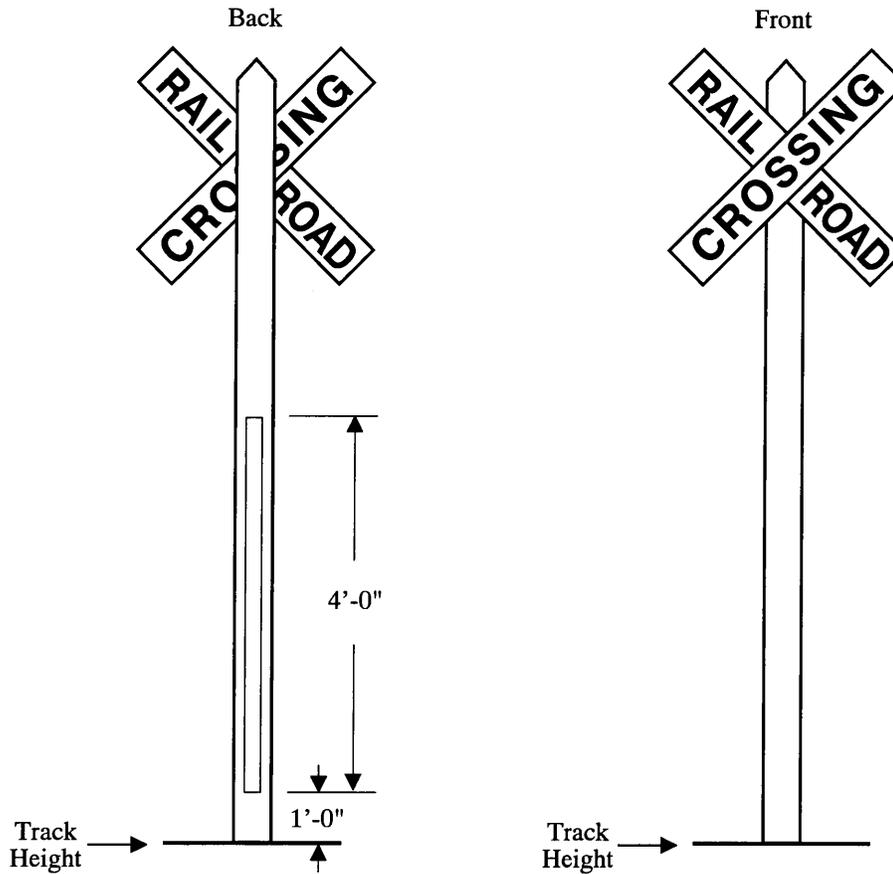
- Double-sided crossbucks with VIP™ sheeting
- 2 inch wide VIP™ sheeting installed on frontside and backside of post
- VIP™ sheeting is applied to post at or near ground level, to center of crossbuck mounting

Location Installed

- State Route 623 in Charlotte County
- DOT-AAR No. 714-112X

Figure 3

**System No. 3
(Minnesota System)**



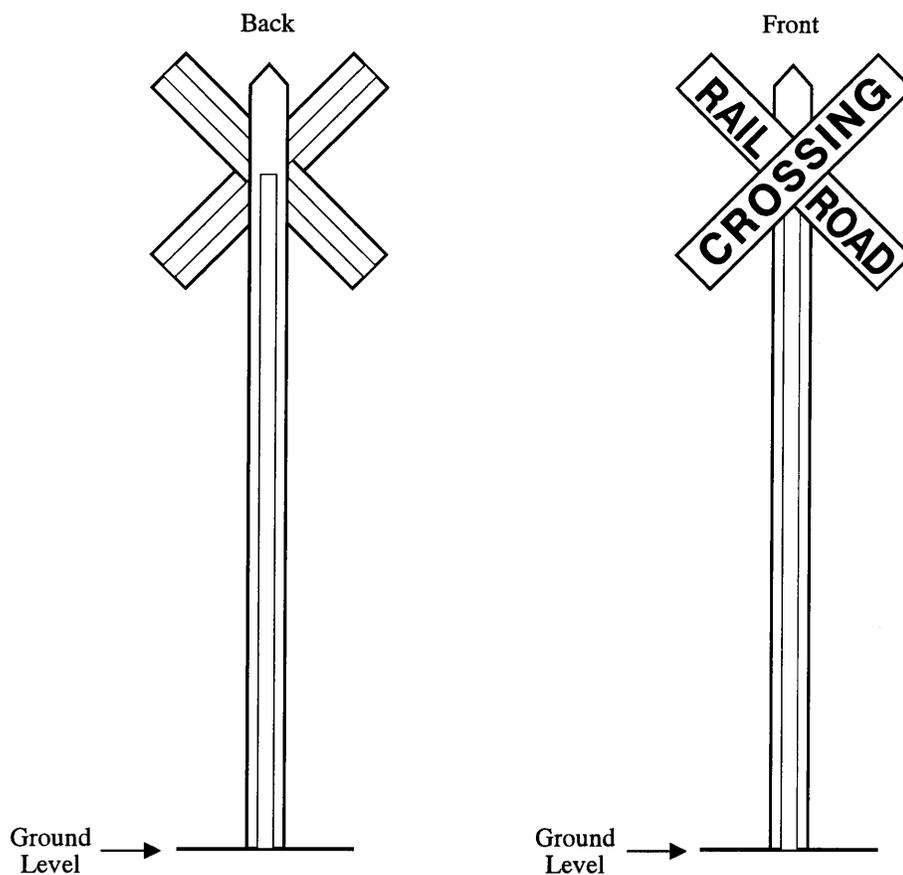
System No. 3 Characteristics

- Double-sided crossbucks with VIP™ sheeting
- 2 inch wide by 4 feet long VIP™ sheeting installed on backside of post
- VIP™ sheeting is applied to post 1'-0" above a line parallel to the top of the track and intersecting the post.

Location Installed

- State Route 704 in Prince Edward County
- DOT-AAR No. 715-150K

Figure 4
System No. 4



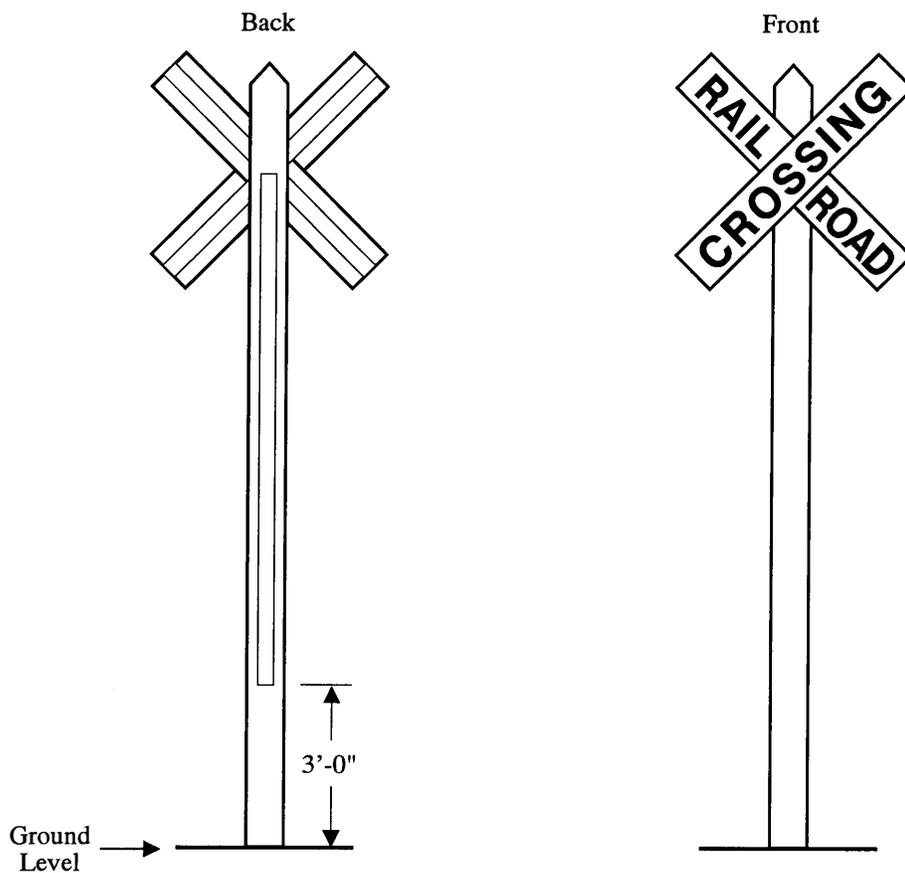
System No. 4 Characteristics

- Existing standard crossbucks
- 2 inch wide VIP™ sheeting installed on frontside and backside of post
- VIP™ sheeting is applied to post at or near ground level, to center of crossbuck mounting
- 2 inch wide VIP™ sheeting installed to back of crossbuck blades

Location Installed

- State Route 673 in Prince Edward County
- DOT-AAR No. 715-157H

Figure 5
System No. 5



System No. 5 Characteristics

- Existing standard crossbucks
- 2 inch wide Diamond Grade™ sheeting installed on backside of post
- Diamond Grade™ sheeting is applied to post 3'-0" above ground level
- 2 inch wide Diamond Grade™ sheeting installed to back of crossbuck blades

Location Installed

- State Route 685 in Lunenburg County
- DOT-AAR No. 715-147C

Data Collection

Night photographs were taken of each approach to the five crossings using only the low and high beams from a vehicle for illumination (Appendix A, Figures 6-10). The researchers also videotaped driving through the crossings at night. Each location was driven through twice, once with low beams and once with high beams. The researchers videotaped a train traveling through each crossing, using only the high beams of a vehicle for illumination. The photographs and the videotape were then used as the media for a subjective analysis.

The material costs for each system were determined using cost figures from three manufacturers. The 3M Company supplied the costs for the VIP™ sheeting, the Power Parts Sign Company supplied the costs for the punched aluminum crossbuck blanks, and Vulcan Aluminum provided the costs for the aluminum strips placed on the crossbuck posts.

Data Analysis

To determine which system was the most visible at night, 19 individuals were interviewed one-on-one. Each interview began with a brief overview of the project, followed by slides depicting the five systems as they were installed, which allowed the interviewer to point out the subtle differences in the marking configurations of each system. Subjects then viewed a videotape of the drive-throughs and answered a series of questions about the crossing treatments on an interview questionnaire.

The videotape was divided into five sections, one for each crossing. Each section depicted: 1) driving through the crossing at night using low beams, 2) the same drive using high beams, and 3) a train traveling through the crossing at night illuminated by high beams. The interviewees were asked to rate the visibility of various components of the crossing on a scale of 1 to 5, with 1 being poor and 5 being very good. This rating was conducted for the low beam drive-through, then for the high beam drive-through, and finally for the train traversing the crossing. The format of watching a section of videotape and then rating the visibility of the crossing components was repeated for each crossing. When the interviewees had seen the whole videotape and answered the questions, they were asked to rank the crossings from best to worst. They were also encouraged to comment on any aspect of the crossing treatments throughout the interview. All responses were put into a spreadsheet to calculate a final rating for each system and a final overall ranking of all the systems.

The material costs of each crossing treatment were also tabulated on a spreadsheet to compare the systems on a district and statewide level.

RESULTS AND DISCUSSION

Literature Review

Several states, including Minnesota, Ohio, Kansas, and Vermont, have experimented with and used low-cost retroreflective warning signs to improve safety at passive highway-railroad grade crossings. Mn/DOT recently replaced 66 percent of the crossbucks at their 5,200 public at-grade crossings with the latest back-to-back design.⁴ In this configuration, one blade is placed on the front of the post with the word "CROSSING" lettered on the front and the word "RAILROAD" lettered on the back. The second blade is placed on the back of the post with the word "RAILROAD" on the front and the word "CROSSING" on the back. Essentially the front side of one blade is the reverse of the other. Minnesota reflectorizes a portion of the back of the posts with a 4 foot by 2 inch (1.22 m by 5.08 cm) strip of Diamond Grade™ sheeting, placed 1 foot (0.30 m) above a line parallel to the top of the track and intersecting the post (Figure 3).⁵ This was the brightest prismatic sheeting on the market when Minnesota's program began. Mn/DOT stated that reflectorizing the crossbucks and the back of the posts with Diamond Grade™ sheeting was effective because

It enables vehicles approaching from the opposite direction to perceive a train in the crossing during darkness. Headlights reflect on the backside of the crossbuck on the far side of the track between railroad cars. The resulting flickering reflection alerts the driver that a moving train is ahead (p. 21).⁵

The Ohio Department of Transportation (ODOT) uses Diamond Grade™ sheeting on the front of the crossbucks and a 2 inch (5.08 cm) wide strip of Diamond Grade™ tape on the back of each blade. ODOT also reflectorizes the full length of all four sides of the post with Diamond Grade™ tape. Ohio officials say that this treatment increases driver awareness of dark rural crossings. Preliminary results of the Ohio treatment indicate, however, that approaching drivers seeing the new crossbucks think it is a lighted crossing.⁶

In September 1993, Kansas State University (KSU) published a report, *Highway-Rail Crossing Safety Demonstrations*, on five low-cost, passive warning systems tried on state highways in Kansas.⁷ One of the systems used double-sided crossbucks with Diamond Grade™ sheeting on both sides of the support posts. In subjective tests, the use of high-performance retroreflective tape on crossbuck posts in this manner had a "very high impact to the approaching driver. On a level roadway at night in a dark, rural area, the reflectorized posts have a high visual impact at about 2,000 feet (600 meters) or more."¹ During the study, KSU researchers noted that when the crossbucks were illuminated but the posts did not have retroreflective material on them, the crossbucks "appear to float in the sky."¹ When high-performance tape was installed on the full length of the post, approaching motorists were able to "tie-in" the position of the post and the crossbuck relative to the roadway.

Another phenomenon noted by KSU researchers was the "goal post" effect, where both sides of the support posts are reflectorized so the approaching motorist can see two reflectorized posts. This allows motorists to estimate their distance from the crossing as well as the width of the crossing. Also, reflectorizing the back of the crossbucks and both sides of the posts results in a "flicker effect" when a train moves through the crossing at night. The automobile headlights shine between the moving cars of the train and illuminate the crossbuck posts.⁸ This flicker effect alerts the approaching driver that a train is in the crossing.

The KSU study recommended that double-sided crossbucks become standard, and that high-performance retroreflective material be used on both sides of the crossbuck and the full length of both sides of both posts, as a minimum.

The Vermont Railroad Company (VRC) also studied low-cost measures to improve safety at highway-railroad grade crossings. VRC installed retroreflective test devices at three crossings in Vermont. The study concluded that the most promising devices were multiple retroreflectorized panels installed in all four quadrants of the crossing, coupled with retroreflectorized material placed on the back of crossbucks.^{9,10}

Site Selection

Since this study used a small branch line (the Virginia Southern Railroad line between Fort Mitchell and Green Bay, Virginia) as the test bed for the alternative marking systems, the number of highway-railroad grade crossings that met all the criteria was limited. All of the study sites had relatively flat approach grades and no external light sources. Roadway sight distance varied between locations, from 264 feet (80.5 meters) to 917 feet (279.5 meters). More importantly, four of five sites had crossing angles of 75 degrees or better. Table 1 depicts the characteristics of the study sites.

Data Analysis

The analysis of data was divided into: 1) a subjective analysis and 2) a cost analysis. The subjective analysis determined which of the five systems was the most visible at night. The cost analysis explored the cost of upgrading the public, passive highway-railroad grade crossings in each district and statewide.

Subjective Analysis

Nineteen individuals from VDOT's Traffic Engineering Division (VDOT - TED), the Virginia Department of Rail and Public Transportation (VDRPT), and the Virginia Transportation Research Council (VTRC), watched the videotape of the five crossing treatments and were then interviewed.

TABLE 1
SITE CHARACTERISTICS

System No.	Crossing & Location	Estimated AADT	Roadway Sight Distance (ft)	Posted Highway Speed (mph)	Train Count D/N	Train Speed (mph)	Crossing Angle
System 1	715-148J Lunenburg	158	917	55	2D 2N	5 - 25	30
System 2	714-112X Charlotte	225	634	55	2D 2N	5 - 25	85
System 3	715-150K Prince Edward	212	264	55	2D 2N	5 - 25	90
System 4	715-157H Prince Edward	200	269	55	2D 2N	5 - 25	90
System 5	715-147C Lunenburg	395	730	55	2D 2N	5 - 25	75

Photographs of the crossings appear in Appendix A. The subjects first rated the visibility of the near-side crossbucks, those on the right-hand side of the road. The crossbucks with the new VIP™ sheeting received higher visibility ratings than the existing crossbucks, for both low beam and high beam situations. System 2 received the highest ratings for both conditions. Under low beam conditions, Systems 1, 2, and 3 were rated higher than the existing crossbucks by 34 to 140 percent. On high beam, Systems 1, 2, and 3 had higher visibility ratings than the existing crossbucks by 5 to 68 percent. This was expected since the existing crossbucks had Engineering Grade sheeting and had been in service for some time.

Interviewees were then asked to rate the visibility of the far-side crossbuck, on the left-hand side of the road. Under low beam conditions, only System 2 had a higher visibility rating than System 5, in which retroreflective tape was placed on the backs of the existing crossbuck blades. However, System 5 was rated 2.4 times more visible than System 4 even though both systems had the same configuration of material. If System 5 was not included in the evaluation, Systems 1, 2, and 3 would have received higher ratings than the modified existing crossbucks. For the high beam condition, Systems 1 and 2 (with the new VIP™ sheeting) had higher visibility ratings than the modified existing crossbucks by 6 to 77 percent. It is possible that System 3's crossbucks were rated lower because of the shorter approach to the crossing.

Subjects were asked whether the near-side crossbuck appeared to "float in the sky." Most subjects thought that the systems with no retroreflective material on the front of the crossbuck post (Systems 1, 3, and 5) did appear to float in the sky, under low beam and high beam conditions. Most respondents said that the crossbucks in Systems 2 and 4, which had retroreflective material installed the full length of the front of the post, did not appear to float.

The subjects rated the visibility of the near-side crossbuck post in Systems 1, 3, and 5 as very poor for low beam and very poor to poor for high beam. System 4 received a visibility rating of good for both low beam and high beam, and System 2 was rated very good. Again, Systems 1, 3, and 5 had no retroreflective material on the front of the post.

Far-side crossbuck posts with retroreflective material installed the full length of the post were rated good to very good on low beam. Although System 5 did not have the material installed the full length of the post, its visibility ratings were consistent with those systems that did. Systems 1, 2, 4, and 5 were all rated as being very good under high beam conditions. System 3, the Minnesota System, was rated fair for both low beam and high beam conditions, primarily due to the non-contiguous method of marking the post.

Interviewees were also asked if they could determine where the railroad tracks crossed the roadway by using the crossbucks and posts as reference points. The subjects could accurately determine where the tracks crossed the roadway with Systems 2 and 4, in which the near-side crossbuck post had retroreflective material installed the full length of the post. Respondents could not definitely tell where the tracks crossed the roadway for the three other systems.

Interviewees were asked if they could detect a strobe-like effect from the vehicle headlights shining between the railroad cars onto the back of the retroreflectorized crossbuck and post. At all but one crossing, respondents detected the strobe-like effect. System 1 was located at a skewed crossing with no line of sight through the railroad cars. The respondents were unable to detect a "true" strobe-like effect at this crossing, but 79 percent of them said they noticed part of the reflectorized post at the wheels and undercarriage of the railroad cars.

The interviewees were asked to rate the visibility of the overall systems on low beam and high beam, taking into consideration both approaches to the crossing, the crossbucks on both sides of the road, and the posts on both sides of the road. On low beam, Systems 3 and 5 were rated as poor, Systems 1 and 4 were rated as fair, and System 2 was rated as very good. On high beams, Systems 3, 4, and 5 were rated as fair, System 1 was rated as good, and System 2 remained very good.

Finally, all of the respondents were asked to rank the five systems from best to worst. All 19 respondents chose System 2 as the best system. System 1 was ranked as the second best followed by System 4, System 3, and System 5. Respondents ranked System 3 higher than System 5 because System 3's double-sided crossbucks provided added visibility.

Additional Respondent Comment

Comments during the interviews provided insight into what motorists perceive when they approach passive crossings. Most interviewees could see the new double-sided crossbucks at a distance, but found it difficult to judge how far away the crossing actually was when the posts were not marked. This was largely due to the new crossbuck's brightness, which the respondents said made it appear to float in the sky when the posts were not reflectorized. Several individuals said that they were unable to see the existing crossbucks until they were nearly in the crossing. One individual said that he did not see the existing near-side crossbuck, and thought the reflectorized back of the far-side crossbuck was on the near side. This person felt that he probably would have stopped on the tracks to look for the train.

Most of the respondent's comments concerned the reflectorization of the support posts. They felt that marking the full length of the front and back of the posts does two things: 1) the tape visually stabilizes the crossbuck and ties the sign to the ground, providing a valuable reference point, and 2) it makes part of the post visible below the undercarriage of moving railroad cars when a train is in the crossing. Having some portion of the post be visible is very important at skewed crossings, where the line of sight through the railroad cars is blocked. The full strobe effect is lost, but there is still some flickering to alert motorists to the presence of a moving train.

Several individuals found Minnesota's method of marking the back of the post confusing. One said that we should have "either marked the whole thing or nothing at all." Others said there was no apparent connection between the crossbuck and post and the sign appeared to float, making it hard to tell if the post was for the crossbuck or something else. Another respondent thought the lack of continuity in the markings reduced the strobe effect significantly. Had the entire length of the back of the post been marked, the strobe effect would have been much stronger.

Respondents also thought the visibility of the entire crossing suffered when the back of the far-side crossbuck post was marked and the front of the near-side post was not. Others said that when the full length of both sides of the posts was marked, the crossing was "highly visible and it really jumps out at you." Some respondents also said that marking the full length of both sides of the posts helped them accurately determine where the tracks crossed the roadway and how wide the crossing was. Others said that having both sides of the crossbucks and posts marked gave them something to expect. Uniformity in how passive crossings are marked is important here, since the disappearance of the far-side crossbuck and post would alert expectant motorists that a train is in the crossing.

A few respondents mentioned the strobe effect. Some felt the strobe effect would have been better had the speed of the train been greater. The faster the train, the more intense the resulting strobe effect; the slower the train, the weaker the effect.

Cost Analysis

The costs of upgrading Virginia's public, passive highway-railroad grade crossings with any of the five systems were investigated. The costs were generated by making the following assumptions:

- Using a standard Railroad Crossing Sign (R15-1) with dimensions 48 x 9 inches (1.22 m by 22.86 cm) for each blade.
- Mounting the crossbuck 9 feet (2.74 m) from ground level.
- Configuring each site with 2 crossbucks (4 blades).
- Using VIP™ retroreflective sheeting on the crossbucks.
- Using 2 inch (5.08 cm) wide retroreflective sheeting on the support posts.
- Placing aluminum strips on the posts with the following dimensions: 0.040 inches (1.02 mm) thick, 3 inches (7.62 cm) wide, and 9 feet (2.74 m) long.

Aluminum strips were not installed on the posts at the five study sites due to the time limitations of the evaluation. However, aluminum strips should be installed as a secure mounting surface for the retroreflective tape, in compliance with manufacturers' specifications.

The cost calculations here are only for materials, and do not include labor costs for installation. The individual railroad companies will be responsible for installing these systems and the labor costs will likely vary among railroad companies.

As expected, systems with double-sided crossbucks (Systems 1, 2, and 3) are 2.8 to 7.9 times more costly than those systems that used the existing single-sided crossbucks. Tables 2 through 6 (Appendix B) depict the anticipated material costs broken down by district for Systems 1 through 5, respectively. The majority of the costs for Systems 1, 2, and 3, 82 to 95 percent, are for the double-sided crossbucks which include the new aluminum sign blanks and the retroreflective sheeting. Systems 4 and 5 were the cheapest to implement since the only materials required were the aluminum strips for the posts and the retroreflective tape.

CONCLUSIONS

1. Double-sided crossbucks are more visible than the existing crossbucks.
2. Marking only a portion of the back of the crossbuck post with retroreflective material confuses motorists.
3. If retroreflective material is not installed the full length of the both sides of the posts, the crossbucks appear to "float in the sky," which prevents motorists from accurately determining where the tracks cross the roadway.

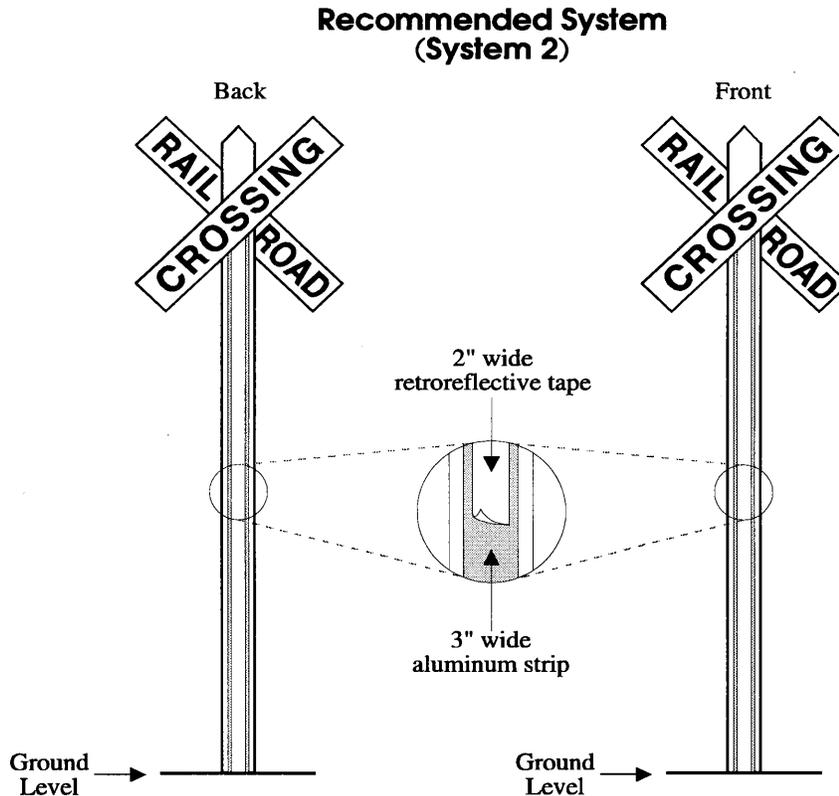
4. Using double-sided crossbucks and marking the full length of both sides of both posts increases: 1) the visibility of the crossing; 2) the uniformity in which passive crossings are marked; 3) driver depth perception of the crossing; and 4) driver ability to detect a train in the crossing.
5. At unskewed crossings, a strobe effect helps motorists determine whether the crossing is active when the vehicle headlights shining between the railroad cars are reflected from the back of the far-side crossbuck and post.
6. At skewed crossings, if retroreflective material is installed the full length of the far-side post a limited strobe effect at the wheels and undercarriage of the rail cars warns motorists that a moving train is in the crossing.
7. The strobe effect is a function of train speed. The faster the train, the greater the effect; the slower the movement, the weaker the effect.
8. Most of the material cost of upgrading Virginia's passive crossings to System 1, 2, or 3 is for the punched aluminum sign blanks, not the retroreflective material.
9. The material costs of upgrading all of the public, passive grade crossings in Virginia to System 2 would be \$205,458.49. In the researcher's opinion, the safety benefits far outweigh the costs.

RECOMMENDATION

To increase the uniformity, visibility, and safety of the Commonwealth's public, passive highway-railroad grade crossings, the Virginia Department of Rail and Public Transportation in cooperation with the Virginia Department of Transportation should consider:

- Upgrading all public, passive grade crossings to System 2, consisting of highly retroreflective double-sided crossbucks, 0.040 inches (1.02 mm) thick, 3 inches (7.62 cm) wide, with 9 foot (2.74 m) aluminum strips applied to the front and back of the posts, and highly retroreflective 2 inch (5.08 cm) wide tape applied to the aluminum strips on both sides of each post (Figures 11, 12).

Figure 11



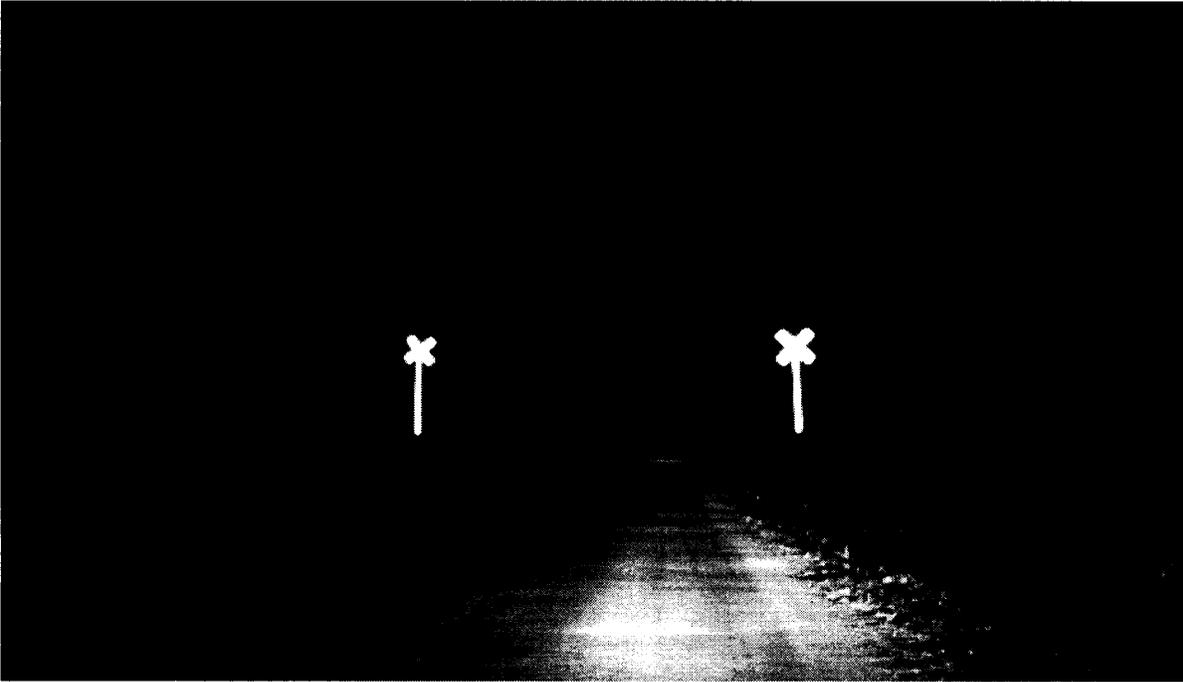


Figure 12. System 2 at night under low-beam conditions.

- Remaining abreast of new technologies, to use these technologies to further enhance the safety and visibility of public, passive highway-railroad grade crossings.

ACKNOWLEDGMENTS

We thank J. P. Leigh of 3M for donating the double-sided crossbucks and retroreflective tape; Ted Proctor and Mary Lyn Jernigan of the Virginia Southern Railroad for allowing these systems to be tested on their line; John Streat of the Virginia Southern Railroad for installing the materials; Steve Blackwell, Lewis Woodson, and Jeff Hughes for collecting the night-time data; Randy Combs for providing the graphics in the final report; Gary Mawyer for report editing; and M. A. Perfater, B. H. Cottrell, Jr, C. W. Lynn, J. D. Austin, and E. N. Stitzer for reviewing the final report.

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APPENDIX A

NIGHT PHOTOGRAPHS OF THE APPROACHES TO THE CROSSINGS



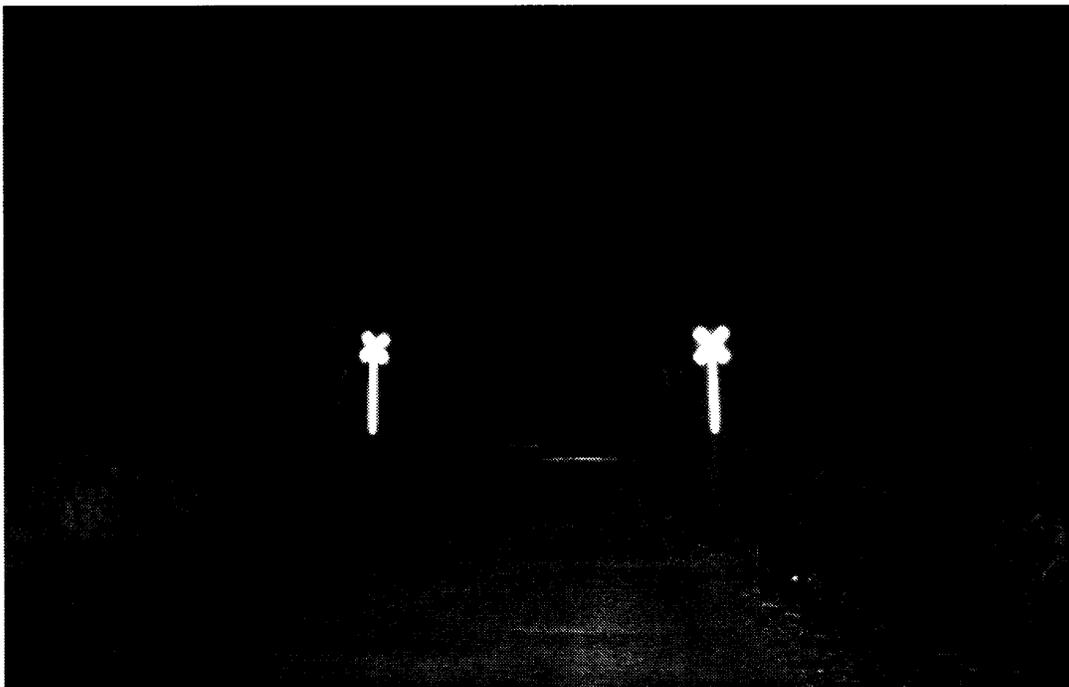
Photograph 6a- System 1, Northbound, Low Beam, 200 feet (61 meters).



Photograph 6a- System 1, Northbound, High Beam, 200 feet (61 meters).



Photograph 7a- System 2, Eastbound, Low Beam, 200 feet (61 meters).



Photograph 7b- System 2, Eastbound, High Beam, 200 feet (61 meters).



Photograph 8a- System 3, Northbound, Low Beam, 130 feet (40 meters).



Photograph 8b- System 3, Northbound, High Beam, 130 feet (40 meters).



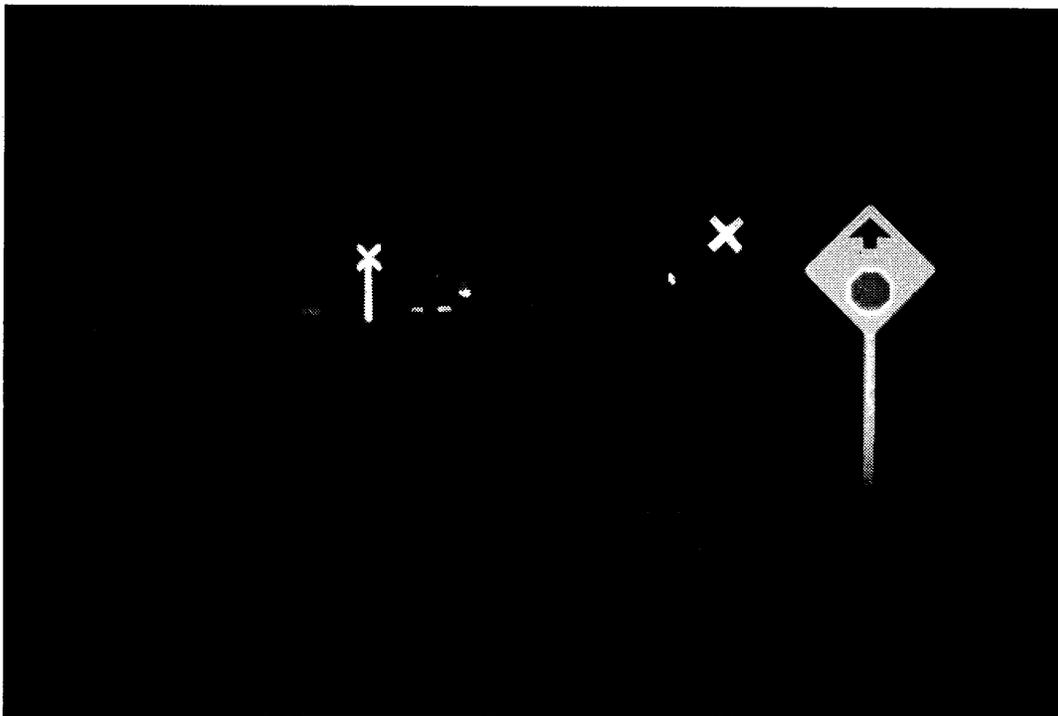
Photograph 9a- System 4, Southbound, Low Beam, 150 feet (46 meters).



Photograph 9b- System 4, Southbound, High Beam, 150 feet (46 meters).



Photograph 10a- System 5, Northbound, Low Beam, 200 feet (61 meters).



Photograph 10b- System 5, Northbound, High Beam, 200 feet (61 meters).

APPENDIX B

COST ANALYSIS FOR CROSSBUCK AND POST UPGRADE

Table 2
SYSTEM No. 1

District	No. of Passive Crossings	No. of Assemblies	Cost per Crossbuck	Total Crossbuck Cost	Sheeting Req. per Post (sq.ft.)	Sheeting Unit Cost (\$/sq.ft.)	Aluminum Req. per Post (sq.ft.)	Aluminum Cost (\$/sq.ft.)	Sheeting & Aluminum Cost/Assembly	Sheeting & Al. Cost per Crossing	Total Sheeting & Al. Cost	Total Cost of System
Bristol	146	292	\$87.50	\$25,550.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$2,735.31	\$28,285.31
Culpeper	36	72	\$87.50	\$6,300.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$674.46	\$6,974.46
Fredericksburg	22	44	\$87.50	\$3,850.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$412.17	\$4,262.17
Lynchburg	108	216	\$87.50	\$18,900.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$2,023.38	\$20,923.38
NOVA	15	30	\$87.50	\$2,625.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$281.03	\$2,906.03
Richmond	146	292	\$87.50	\$25,550.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$2,735.31	\$28,285.31
Salem	100	200	\$87.50	\$17,500.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$1,873.50	\$19,373.50
Staunton	194	388	\$87.50	\$33,950.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$3,634.59	\$37,584.59
Suffolk	200	400	\$87.50	\$35,000.00	1.5	\$4.25	2.25	\$1.33	\$9.37	\$18.74	\$3,747.00	\$38,747.00
TOTAL	967	1934		\$169,225.00							\$18,116.75	\$187,341.75

Note: An "assembly" has been defined for the purpose of this study as the crossbuck, post, aluminum strip, and retroreflective material installed to the post and/or crossbuck. In most situations there needs to be two (2) assemblies per crossing.

Table 3
SYSTEM No. 2

District	No. of Passive Crossings	No. of Assemblies	Cost per Crossbuck	Total Crossbuck Cost	Sheeting Req. per Post (sq.ft.)	Sheeting Unit Cost (\$/sq.ft.)	Aluminum Req. per Post (sq.ft.)	Aluminum Cost (\$/sq.ft.)	Sheeting & Aluminum Cost/Assembly	Sheeting & Al. Cost per Crossing	Total Sheeting & Al. Cost	Total Cost of System
Bristol	146	292	\$87.50	\$25,550.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$5,470.62	\$31,020.62
Culpeper	36	72	\$87.50	\$6,300.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$1,348.92	\$7,648.92
Fredericksburg	22	44	\$87.50	\$3,850.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$824.34	\$4,674.34
Lynchburg	108	216	\$87.50	\$18,900.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$4,046.76	\$22,946.76
NOVA	15	30	\$87.50	\$2,625.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$562.05	\$3,187.05
Richmond	146	292	\$87.50	\$25,550.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$5,470.62	\$31,020.62
Salem	100	200	\$87.50	\$17,500.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$3,747.00	\$21,247.00
Staunton	194	388	\$87.50	\$33,950.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$7,269.18	\$41,219.18
Suffolk	200	400	\$87.50	\$35,000.00	3.00	\$4.25	4.50	\$1.33	\$18.74	\$37.47	\$7,494.00	\$42,494.00
TOTAL	967	1934		\$169,225.00							\$36,233.49	\$205,458.49

Note: An "assembly" has been defined for the purpose of this study as the crossbuck, post, aluminum strip, and retroreflective material installed to the post and/or crossbuck. In most situations there needs to be two (2) assemblies per crossing.

Table 4
SYSTEM No. 3 (Minnesota System)

District	No. of Passive Crossings	No. of Assemblies	Cost per Crossback	Total Crossback Cost	Sheeting Req. per Post (sq.ft.)	Sheeting Cost (\$/sq.ft.)	Sheeting Unit Cost (\$/sq.ft.)	Aluminum Req. per Post (sq.ft.)	Aluminum Cost (\$/sq.ft.)	Sheeting & Aluminum Cost/Assembly	Sheeting Cost per Crossing	Total Sheeting & Al. Cost	Total Cost of System
Bristol	146	292	\$87.50	\$25,550.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$1,219.83	\$26,769.83
Culpeper	36	72	\$87.50	\$6,300.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$300.78	\$6,600.78
Fredericksburg	22	44	\$87.50	\$3,850.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$183.81	\$4,033.81
Lynchburg	108	216	\$87.50	\$18,900.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$902.34	\$19,802.34
NOVA	15	30	\$87.50	\$2,625.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$125.33	\$2,750.33
Richmond	146	292	\$87.50	\$25,550.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$1,219.83	\$26,769.83
Salem	100	200	\$87.50	\$17,500.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$835.50	\$18,335.50
Stanton	194	388	\$87.50	\$33,950.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$1,620.87	\$35,570.87
Suffolk	200	400	\$87.50	\$35,000.00	0.67	\$4.25	\$4.25	1.00	\$1.33	\$4.18	\$8.36	\$1,671.00	\$36,671.00
TOTAL	967	1934		\$169,225.00								\$8,079.29	\$177,304.29

Note: An "assembly" has been defined for the purpose of this study as the crossback, post, aluminum strip, and retroreflective material installed to the post and/or crossback. In most situations there needs to be two (2) assemblies per crossing.

Table 5
SYSTEM No. 4

District	No. of Passive Crossings	No. of Assemblies	Cost per Crossback	Total Crossback Cost	Sheeting Req. per Post (sq.ft.)	Sheeting Cost (\$/sq.ft.)	Sheeting Unit Cost (\$/sq.ft.)	Aluminum Req. per Post (sq.ft.)	Aluminum Cost (\$/sq.ft.)	Sheeting & Aluminum Cost/Assembly	Sheeting Cost per Crossing	Total Sheeting & Al. Cost	Total Cost of System
Bristol	146	292	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$7,121.15	\$7,121.15
Culpeper	36	72	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$1,755.90	\$1,755.90
Fredericksburg	22	44	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$1,073.05	\$1,073.05
Lynchburg	108	216	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$5,267.70	\$5,267.70
NOVA	15	30	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$731.63	\$731.63
Richmond	146	292	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$7,121.15	\$7,121.15
Salem	100	200	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$4,877.50	\$4,877.50
Stanton	194	388	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$9,462.35	\$9,462.35
Suffolk	200	400	existing	existing	4.33	\$4.25	\$4.25	4.50	\$1.33	\$24.39	\$48.78	\$9,755.00	\$9,755.00
TOTAL	967	1934										\$47,165.43	\$47,165.43

Note: An "assembly" has been defined for the purpose of this study as the crossback, post, aluminum strip, and retroreflective material installed to the post and/or crossback. In most situations there needs to be two (2) assemblies per crossing.

Table 6

SYSTEM No. 5

District	No. of Passive Crossings	No. of Assemblies	Cost per Crossbuck	Total Crossbuck Cost	Sheeting Req. per Post (sq.ft.)	Sheeting Unit Cost (\$/sq.ft.)	Aluminum Req. per Post (sq.ft.)	Aluminum Cost (\$/sq.ft.)	Sheeting & Aluminum Cost/Assembly	Sheeting & Al. Cost per Crossing	Total Sheeting & Al. Cost	Total Cost of System
Bristol	146	292	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$3,474.07	\$3,474.07
Culpeper	36	72	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$856.62	\$856.62
Fredericksburg	22	44	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$523.49	\$523.49
Lynchburg	108	216	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$2,569.86	\$2,569.86
NOVA	15	30	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$356.93	\$356.93
Richmond	146	292	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$3,474.07	\$3,474.07
Salem	100	200	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$2,379.50	\$2,379.50
Staunton	194	388	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$4,616.23	\$4,616.23
Suffolk	200	400	existing	existing	2.33	\$4.25	1.50	\$1.33	\$11.90	\$23.80	\$4,759.00	\$4,759.00
TOTAL	967	1934									\$23,009.77	\$23,009.77

Note: An "assembly" has been defined for the purpose of this study as the crossbuck, post, aluminum strip, and retroreflective material installed to the post and/or crossbuck. In most situations there needs to be two (2) assemblies per crossing.