EVALUATION OF THE BUCKEYE CROSSBUCK AT PUBLIC, PASSIVE RAILROAD/HIGHWAY GRADE CROSSINGS IN OHIO

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16. Abstract

Two new crossbuck designs for use at passive Railroad/Highway Grade Crossings (RRX) were evaluated. The Standard Improved and the Buckeye crossbuck were evaluated on a state-wide basis in Ohio with respect to their potential to alter driver risk taking behavior (part I), their crash reduction potential (part II), user acceptance (part III), and with respect to their photometric performance at night (part IV). It was found that the percentage of non-compliant drivers was approximately the same for both crossbuck designs with slightly more conservative risk acceptance times obtained for the Buckeye crossbuck. Based on the last 10 years of Ohio Railroad/Highway Grade Crossings crash history the overall number of crashes at passive Railroad/Highway Grade Crossings has continued to drop. Overall, the crash numbers in part II show a statistically significant ($\alpha = 0.05$) superiority of the Buckeye crossbuck: 157 crashes for Buckeye crossbuck vs. 192 crashes for Standard Improved crossbuck (22% decrease in crashes) from 1994 until June 30th, 1999. A user acceptance survey indicated an overwhelming preference of the Buckeye Crossbuck among all surveyed user groups. The Buckeye Crossbuck provides by far the strongest visual signal among the measured crossbucks at night and during daytime. Photometric crossbuck luminance measurements conducted under automobile low-beam illumination at night indicate that due to their increased reflectorization, both the Buckeye Crossbuck and Standard Improved Crossbuck provide superior visual stimuli to an approaching driver at night. The positive effect of the Buckeye Crossbuck on crash numbers is more pronounced during daytime than during nighttime. The nighttime and daytime proportions of the crash frequencies separately still favor the Buckeye Crossbuck. The multi-faceted, fully reflectorized (micro-prismatic type VII, long distance performance LPD) shield makes a Buckeye Crossbuck the brightest and visually most powerful crossbuck design evaluated in this study. In addition, the angled shield makes the Buckeye Crossbuck less sensitive to placement in approaches that are not straight or perpendicular to the railroad tracks, and the red YIELD legend on the shield has the potential to instill into drivers, close to the Railroad/ Highway Grade Crossing, the idea that they must yield to approaching trains. It is also important to note that, especially at night, both the Standard Improved Crossbuck and the Buckeye Crossbuck designs provide an approaching driver with a reflectorized (bright) target on both sides of the tracks, which makes it possible for a driver to determine if a Railroad/ Highway Grade Crossing is occupied by a train (left crossbuck either fully or partially obstructed by railroad cars).

It is recommended to amend the national standard for crossbucks at public passive Railroad/Highway Grade Crossings in the MUTCD and to include the Buckeye crossbuck as an alternate design.

17. Key Words	18. Distribution Statement
Buckeye crossbuck, railroad crossing crashes, driver risk taking, user acceptance, photometric performance, crossing safety, near collisions, traffic violations, Railroad/Highway Grade Grossings, crossbuck, passive railroad crossings	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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Our appreciation goes to the many individuals who assisted us in developing and disseminating the user acceptance survey. Thanks to William Moroney, University of Dayton, for his insightful assistance in the development of the questionnaires, to the members of the Buckeye Sheriff Association and the Ohio State Highway Patrol, for providing a randomly sampled list of law enforcement respondents, to Bill O'Brien, Brotherhood of Locomotive Engineers B of LE), for a list of train engineers from which a random sample was drawn to represent the views of the train engineers, to the Ohio Bureau of Motor Vehicles, for programming a database script to extract a random sample of licensed motorists in selected counties along the rail lines that were studied, to Michael Smith, Xerox company, for providing a list of traveling field personnel to be included in the survey, and finally to all law enforcement officers, train engineers, school bus drivers, delivery drivers, and members of the general driving public who participated in the survey. Thanks to Tom Wall, Federal Railroad Administration (FRA) for providing the GX database, to Frances Netting, Public Utilities Commission of Ohio (PUCO) for the annual updates on the crash statistics and for the breakdown of these into different crash severity. Thanks also to Ryan Smith, graduate student, for conducting the photometric measurements of the crossbuck designs.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

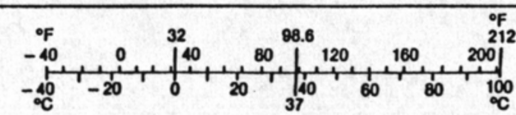
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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Prepared for

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INTRODUCTION

In the past, Ohio has ranked among the states with the highest number of crashes at passive railroad crossings. Recent crash reduction efforts by state and federal government, Ohio railroads, and Ohio Operation Lifesaver include an approach involving engineering, education, and enforcement. According to comments submitted on behalf of the Public Utilities Commission of Ohio (Docket No. FRA – 1999 –6439) to the U.S. DOT, FRA it is learned that: “over the past 10 years, the state of Ohio, with assistance from the federal government, began an ambitious program to upgrade grade crossing safety across the state. During that 10-year period, Ohio has completed in excess of 1400 light and gate projects at a cost exceeding $140 million. As a direct result of Ohio’s enhanced grade crossing safety programs, crashes and resultant fatalities have decreased more than 50% during the past 10 years. It is important to note that during that same period of time, the number of licensed drivers and registered motor vehicles in Ohio has increased to more than 7 and 11 million, respectively. Finally, the state has been able to close more than 150 public grade crossings to motor vehicles since 1990. With all of the efforts set forth above, more than 3500 public grade crossings still exist in Ohio that are protected with crossbucks only”. Two new crossbuck designs were developed by Conrail in cooperation with ODOT, to replace the Current Standard Crossbuck (see Figure 1 and Appendix) and for subsequent evaluation in a large scale state-wide field study. One of the crossbuck designs is known as the Buckeye crossbuck, named after the Conrail Buckeye railroad yard (see Figure 2 and Appendix), and the other design is referred to as the Standard Improved crossbuck (see Figure 3 and Appendix).

The field evaluation of the new crossbuck designs was conducted by Ohio University under an ODOT/FHWA contract. The research was conducted to quantify the crash reducing potential of the new crossbuck designs at passive Railroad/ Highway Grade Crossings (RRX) throughout Ohio. Driver risk taking behavior (Part I) was obtained using a before/after research approach, using train mounted video equipment. crash data for crashes at passive Railroad/Highway Grade Crossings (Part II) was used in an ongoing 10 year Railroad/Highway Grade Crossings crash analysis in Ohio. User acceptance questionnaires (Part III) were developed in order to evaluate the user acceptance and preferences of the two crossbuck designs. Extensive photometric measurements of the crossbucks (Part IV) were conducted in the field at night under automobile illumination.

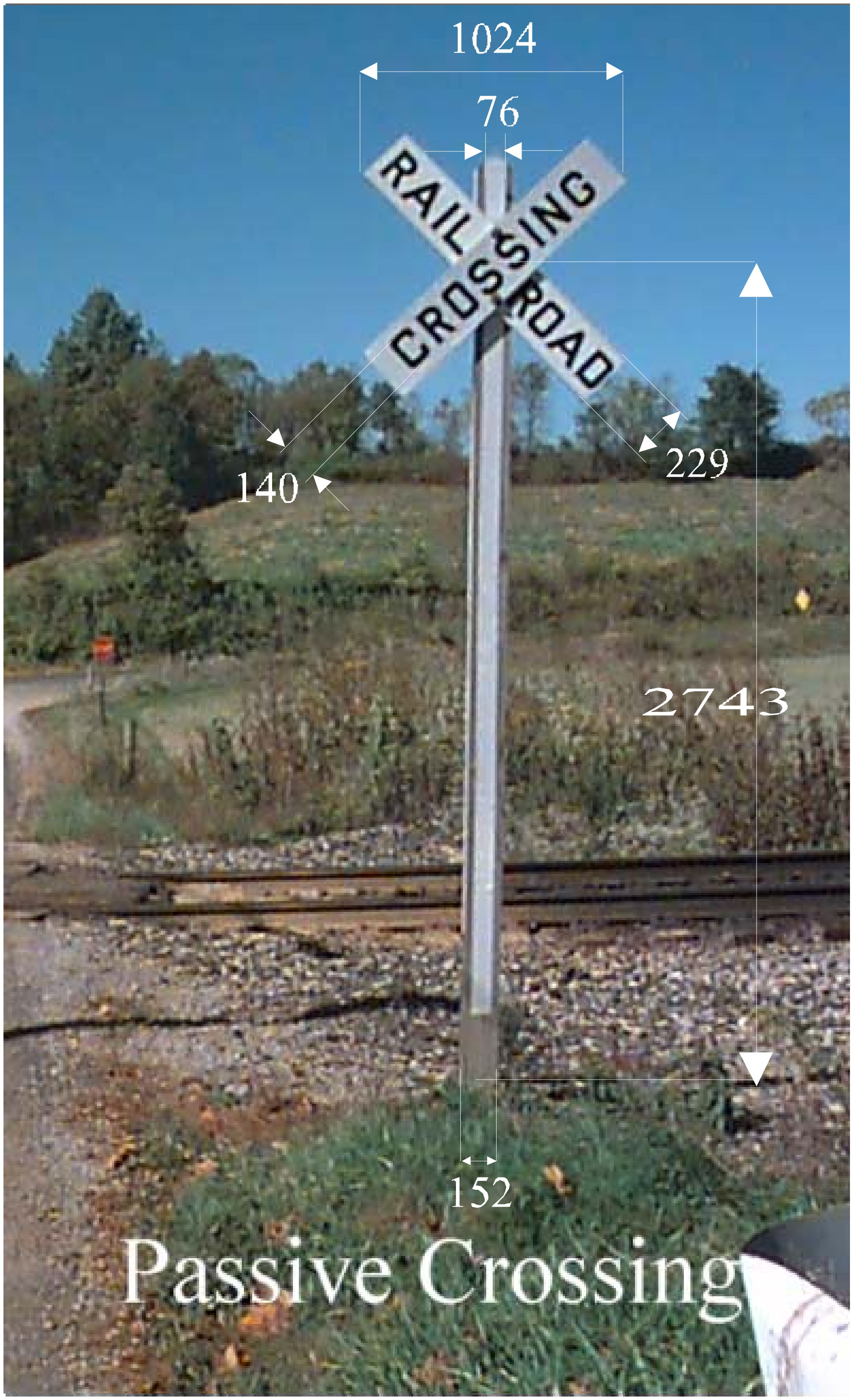
It should be noted that the research presented in this report did not consider alternative designs of advance railroad crossing warning signs or railroad crossing pavement markings. Both the advance railroad crossing warning signs and the railroad crossing pavement markings were applied according to ODOT specifications [1] during the before condition and the after condition. Every public passive Railroad/Highway Grade Crossings in Ohio was equipped either with a Buckeye crossbuck or with a Standard Improved crossbuck (Buckeye crossbucks were used for all the even Railroad/Highway Grade Crossing numbers, Standard Improved crossbucks were used for all the odd Railroad/Highway Grade Crossing numbers). In addition, the Buckeye and the Standard Improved crossbucks were also placed closer to the road edge than the Current Standard Crossbucks (see Appendix).

all values in mm

Figure 1. Current Standard Crossbuck Design

all values in mm

Figure 2. Buckeye Crossbuck Design



all values in mm

Figure 3. Standard Improved Crossbuck Design

Experimental Treatments, Current Standard Crossbuck and Two New Design Alternatives

Conrail, through the efforts of their Project 50 Labor-Management Committee under the leadership of Marty Joyce, in conjunction with ODOT has devised a modification of the standard crossbuck which is designed to improve driver recognition and awareness of the potential dangers at Railroad/Highway Grade Crossings without active warning devices. The new crossbuck concept has been shown to various Transportation Research Board (TRB) Committees, and has been demonstrated to many others from various states. The Current Standard Crossbuck (Figure 1) consisted of a non-reflectorized wooden post and extruded aluminum blades with a black Railroad/Highway Grade Crossing legend. In its latest upgrade, the blades of the Current Standard Crossbuck were usually equipped with white encapsulated retro-reflective (type III) sheeting material. The Standard-Improved crossbuck (Figure 3) which consists of a wooden post which is reflectorized on all 4 sides and aluminum blades that are reflectorized front and back with white micro-prismatic (type VII, LDP long distance performance) sheeting, represents a first level of improvement over the Current Standard Crossbuck. The Railroad/Highway Grade Crossing legend is black and the wooden post is equipped with a safety break-away hole just above the ground. The Buckeye crossbuck (Figure 2) features a shield made of 2mm (0.081") thick 6061-T6 aluminum. This aluminum shield is fully reflectorized with white micro-prismatic sheeting on both sides and consists of a 0.22m (9") wide center section showing a framed red YIELD legend and two 0.304m (12") wide side panels that are bent away 45^{o} from the approaching motorist. The side panels feature red diagonal retro-reflective stripes and specularly reflective mylar stripes, pointing down towards and emphasizing the YIELD legend. The specular mylar stripes are designed with the purpose of being most useful during nighttime as they have the potential (under certain angular conditions) to redirect a portion of the light of an oncoming train towards an approaching motorist and a portion of the light from the automobile headlights towards the approaching train, thus providing additional presence information to both the motorist and the train engineer.

REVIEW OF TECHNICAL LITERATURE

Part VIII of the [2] entitled "traffic control for rail roadway intersections" was recently amended to allow crossbuck posts to be reflectorized front and back. During the last 40 years, literally hundreds of reports, journal articles and papers have been published on the subject of Railroad/Highway Grade Crossing crashes, Railroad/Highway Grade Crossing crash countermeasures and observed driver behavior at Railroad/Highway Grade Crossings. A typical example is the FHWA Report Project No. DTFH61-88-Z-00145 by Lerner, Ratte and Walker [3]. The authors of this report review the literature on driver behavior at Railroad/Highway Grade Crossings, in support of FHWA's efforts in addressing the safety, cost and operational concerns of Rail/Highway Grade Crossings. The authors discuss the contributing factors and driver characteristics related to driver behavior at Railroad/Highway Grade Crossings and consider countermeasures which have been developed in the past to improve driver behavior and driver safety. The report elaborates on the Railroad/Highway Grade Crossing detection process from a motorist point of view. The authors state that in the case of a passive Railway/Highway Grade Crossings, the driver must first detect that there is a rail/highway crossing ahead and that it is passively rather than actively protected (e.g. by detecting the absence of gates or flashing lights). Then the presence of an approaching train must be detected and a decision regarding the course of action must be made by the driver. The looking behaviors necessary to detect the train will differ, depending on the train's location and on the alignment of the roadway with the tracks. Moreover, the driver's view of the train may be obstructed. Lerner, Ratte, and Walker indicate that the recognition process is influenced by the observer's expectations and by the physical context in which the input occurs. In particular they emphasize that a low expectancy of the presence of trains at a crossing would increase the time required to detect and recognize a train. From the near collision data presented in this report it is evident that an automobile/train encounter at a passive Railroad/Highway Grade Crossings is indeed a very improbable event, thus often leaving motorists unprepared with regard to correct action. The Lerner at al. FHWA report [3] contains an extensive list of references and a bibliography on driver behavior at rail/highway crossings. The signal detection theory implies that the higher the perceived probability of an event, the higher the likelihood that an observer will report having detected the event.

According to the Federal Railroad Administration (FRA) the US railroad system is made up of 500 railroads running on about 110,000 miles of track, and daily traveling through almost 280,000 Railroad/Highway Grade Crossings nationwide. The FRA considers reduction in railroad crashes to be its most important objective. A Railroad/Highway Grade Crossing incidentally is defined as a location where railroad tracks intersect a public or private thoroughfare, sidewalk or a pathway. A trespasser is anyone whose presence on railroad property, track, bridges, equipment and yards is not authorized by the railroad. Combined Railroad/Highway Grade crossing and trespasser deaths account for 90% of all rail related deaths. Some of the Final 1996 Federal Railroad Administration Statistics indicate:

- Every 90 minutes a train in the United States strikes a vehicle or a pedestrian.
- A motorist is 30 times more likely to die in a crash involving a train than in a collision involving another motor vehicle.

- More people die in highway-rail crashes each year than in commercial airline crashes in an average year.
- Most importantly over 50% of the crashes at public grade crossings occur where active warning devices (gates, lights, bells) exist.

The cover letter by Alan R. Schriber, Chairman, Public Utilities Commission of Ohio, in The Ohio Railroad Grade Crossing Statistics Calendar 1999, of the PUCO states that: “Ohio has continued to make progress in reducing the loss of life and property through grade crossing crashes. In the last five years, we have reduced crashes, fatalities and injuries by 40%. In the last ten years, Ohio has gone from having the second highest number of crashes and fatalities in the country to being ranked sixth in the nation for accidents and fifth for fatalities. However, no one believes our work to reduce grade crossing crashes is done. Since 1989, the Public Utilities Commission (PUCO) has worked in a partnership with the Ohio Rail Development Commission (ORDC) and the Operation Lifesaver Program to improve grade crossing engineering, public awareness, and traffic law enforcement aimed at reducing the number of rail-highway incidents. Over the last three years, ORDC and the PUCO have completed major corridor agreements resulting in 172 gate and light projects. There have been 104 additional warning device upgrades through the federal priority program. An additional 60 crossing projects were completed under the state program. One year ago, the PUCO authorized 25 grants to local highway authorities to mitigate high profile crossings. Over the last three years, Ohio has completed over 20 crossing closures usually in exchange for gate and light installations. In the spring of this year, Ohio embarked on a 10-year program to complete 40 grade separations with a combination of federal, state and railroad funds. Ohio believes that it has developed a balanced, aggressive program to mitigate high-grade crossing hazards. We have been mindful of and ever vigilant about those crossings that do come to the top of the hazard ranking while proactively addressing crossings with changing physical and operating characteristics. We believe this approach will continue to eliminate the tragic and preventable grade crossing incidents”.

On a national level according to figures published in the 1999 National Transportation Statistics Report (Bureau of Transportation Statistics, U.S. Department of Transportation p. 214) a similar downward trend is observed (1990: 698 fatalities, 2407 injuries, 5713 accidents vs. 1995: 579 fatalities, 1894 injuries, 4633 accidents vs. 1998: 431 fatalities, 1303 injuries, 3502 accidents).

Berg, Knoblauch and Heuke [4] stated, that while most highway-railroad crashes cite driver error as a factor, engineering and human factors issues may also contribute to the crash. For example, the motorist can either err in perceiving that the train is in hazardous proximity to the grade crossing or despite of having detected the train, the driver decides that adequate time is available to clear the crossing.

Korve, Wanaselja et al. [5] identified potential research areas for improving the reliability and usefulness of traffic control devices at Railroad/Highway Grade Crossings The study, which was conducted for the TRB Transit Cooperative Research Program during 1994, had the overall objective of improving the safety at grade crossings. An additional objective was to develop material for inclusion into a new light-rail highway grade crossing part of the Manual of Uniform Traffic Control Devices (MUTCD) [2]. According to [5], for all practical purposes the design, installation and use of traffic control devices at Railroad/Highway Grade Crossings, have remained unchanged since the turn of the century. Korve, Wanaselja et al. point out that devices like the regulatory railroad crossing (crossbuck) sign (R15-1), the flashing light signal, and the crossing gate (initially manually controlled) have been used virtually unchanged for years. The conditions under which these devices are expected to function on the other hand, have undergone considerable change, since the time at which the standards for the design, installation and use of these devices were adopted. Motor vehicle traffic volumes were very low back then, and other traffic control devices governing motor vehicles were virtually non-existent. The motor vehicle traffic volumes these days are much larger and the traffic control devices are also more sophisticated, not to mention the higher operating speeds of trains and shorter train headways (more train traffic). The authors point out specific issues of inconsistency and inadequacy of Railroad/Highway Grade Crossings control devices. Despite of the standard crossbuck sign being considered as a regulatory sign for motorists, neither the MUTCD nor the Uniform Vehicle Code regulates any specific action on the part of the motorist or pedestrian when a crossbuck sign is encountered. Korve, Wanaselja et al. recommend testing the motorist and pedestrian reactions to the alternative designs for the crossbuck currently used in Canada and Europe, which according to [5], command more attention besides providing better visibility for the crossing at night. It should be noted though that Korve, Wanaselja et al. do not substantiate these and other claims in their paper with statistical details. Korve, Wanaselja et al. also point out another inconsistency / inadequacy of the flashing red lights in the typical railroad flashing light assembly. These lights are considered to be a warning device to indicate when a train is approaching. The MUTCD [2] and the Uniform Vehicle Code however state that flashing red lights are regulatory (not warning) in nature and generally mean stop and proceed when safe. The authors point out that since the motorists need to be regulated more formally to stop until the train has safely cleared the crossing, this type of signal according to the MUTCD [2] and Uniform Vehicle Code, should be provided by means of a solid red circular indication, similar to a standard traffic signal. The motorists and pedestrian should be warned about the immediate approach of a train at the crossing by use of the traditional yellow caution signal to indicate that the "proceed" or "go" phase is about to be terminated.

According to Noyce and Fambro [6], the advance warning and railroad crossbuck signs do not differentiate between active and passive crossings, thereby complicating the driver's decision making task. Noyce and Fambro [6] investigated the effectiveness of a vehicle-activated strobe light and supplemental signs, as enhancements to the railroad advance warning sign, at passive Railroad/Highway Grade Crossings. The results of the research were evaluated using changes in the driver awareness of the highway- railroad crossing, as the criterion. The drivers' comprehension of the enhanced sign system was also investigated along with driver behavior on the approach to the crossing. Focus group studies prior to the actual field studies indicated that a flashing light was assumed to indicate the presence of a train and that the objective of the flashing light was to attract the driver's attention to the warning device rather than to indicate the presence of a train itself. Therefore, a supplemental sign "LOOK FOR TRAIN AT CROSSING" was installed below the crossbuck blades. The sign was thought to provide the driver with a written message consistent with the desired action at the crossing and minimized the potential of the motorist misunderstanding the meaning of the flashing strobe light. Using average perception-reaction time and an estimated sign legibility distance, a loop detector to provide vehicle activation of the strobe light, was placed approximately 170 meters upstream of the strobe light location. On activation, by the passage of a vehicle over the loop, the strobe light flashed for approximately 8 seconds. Noyce and Fambro [6] claimed that eight seconds provided sufficient time for the driver to observe the strobe light, the railroad advanced warning sign (in this case the crossbuck) and the supplemental sign. They also stated that since the purpose of the vehicle-activated strobe light was to attract the attention of the drivers, the location of the vehicle in relation to the enhancement sign system when the strobe light stopped flashing was not considered significant.

The study was carried out a rural road with an average daily traffic of 650 vehicles and up to 15 daily train crossings. The road contained two short-radius horizontal curves forming an S-curve roadway alignment approximately 50 meters west of the crossing and a crest vertical curve approximately 400 meters east of the crossing. The vertical curve limited the visibility of the crossing for eastbound drivers preventing drivers from observing the crossing until reaching the crest of the curve. Most of the drivers used the road on an almost daily basis. The effectiveness of the enhanced sign system was tested by using three surrogate methods, which Noyce and Fambro developed [6]. The first method, which involved conducting a study of the before and after speed profiles, was designed to indicate whether the objective of a more cautious approach to the highway railroad crossing was achieved. The second method involved a driver survey to evaluate the detection and comprehension of the flashing strobe light and supplemental sign. The third method involved observation of drivers' reaction to the strobe light.

The before speed study was carried out over an eight week period, by automatic traffic classifiers placed at 10, 50, 100, 150, 200, and 400 meters from the highway rail-road crossing. At each location, data was collected for up to one week. The classifier placed at 400 meters was used as the control location since it was outside the influence area of the flashing strobe light and beyond the visual range of the supplemental sign. The enhanced sign system was installed approximately four weeks after the before speed study was completed while the supplemental sign installation took place approximately four weeks prior to the after speed data collection. The vehicle-activated strobe light was operated for a two week period prior to the after study. The after study was conducted over a four week period using the same methodology as the before speed study. The results of the after speed study indicated that while the average day and night speeds in the after speed study, were somewhat lower at the 400 meter location on the west approach and near the location of the enhanced sign system, they were approximately the same at the 200 meter location. On the east approach, the average speed was slightly higher at the 400-meter location, they were lower near the location of the enhanced sign system and approximately the same at locations near the crossing. The average night speeds were lower at all locations except at the 400-meter location on the east approach where the speeds were nearly identical. A statistical comparison of the before and after speeds at each location indicated significant speed reductions at the 100, 150, and 400 meter locations on the west approach and at the 50, 150 and 200 meter locations on the east approach. Statistical comparisons of the night driving speeds found significant speed reductions on the west approach at the 100, 150 and 400 meter locations, with a non significant decrease at the 200 meter location. On the east approach the 50-meter location showed a significant decrease in average speed but at the other locations the reductions were not at a statistically significant level.

According to Tustin et al. [7] the non-recovery zone at a highway-railroad crossing is defined as the area of the approach where the amount of roadway is insufficient to avoid a collision if the stop/go decision has not already been made. The beginning of this zone coincides with the stopping sight distance point. In their study Noyce and Fambro [6] used the 100-meter location as the last speed sampling point before the vehicle entered the non-recovery zone. Average after condition speeds at the 400-meter location showed a reduction of 7% (from 51 km/h to 48 km/h) during daytime when compared to the corresponding before condition speeds. The after condition nighttime speeds showed a reduction of 13% (from 50 km/h to 43 km/h) over the corresponding before condition speeds. The variances in the after condition speed study were also lower for both day and night observations. Noyce and Fambro, therefore, claim that the enhanced sign system was effective in reducing the vehicle speeds as they entered the non-recovery zone, which in turn reduces the stopping distance requirements and has a positive effect on the safety at the crossing. It should be noted, that the study by Noyce and Fambro [6] was limited to one rural crossing, and that the results were generalized to different passive grade crossings.

Zwahlen and Schnell [8][9][10] reported on the crossbuck research conducted by Ohio University as part of an ODOT/FHWA grant. The research reported in [8][9][10][11][12] described the ongoing evaluation of the Current Standard Crossbuck (before-condition) and two new different crossbuck designs (after-condition, Buckeye crossbuck and standard improved crossbuck) in the field. Motorist behavior at passive railroad crossings (Railroad/Highway Grade Crossings) in terms of violations and near collisions were obtained on four different rail-lines in Ohio. These data were used as an additional measure of crossbuck effectiveness to corroborate the statistical analysis of crashes. The video recording system and the data analysis method are described. The time from the moment the rear end of the vehicle just cleared the Railway/Highway Grade Crossings until the train reached the Railway/Highway Grade Crossings was determined for all recorded violations and near collisions. These times were presented in cumulative distributions. The tentative results of the before [8][9] and after [10] near-collision and violation analysis indicated that if a vehicle was observed during an approach, there was a 54.48% chance that the vehicle would be non-compliant (violation) under the before-condition, and a 56.20% chance that the vehicle would be non-compliant (violation) under the after-condition. An analysis of the times needed for a train to reach the railroad grade crossing after a non-compliant (violating) vehicle cleared the tracks, indicated that both new crossbuck designs provided temporal distributions that are somewhat shifted towards longer times (about 25 seconds) when compared with the temporal distribution obtained with the Current Standard Crossbuck (median value 20 seconds). In other words, violating drivers in the after condition cross the Railroad/Highway Grade Crossing when the train arrival times are longer compared to the shorter arrival times in the before condition. This temporal shift towards longer times may be indicative of the higher conspicuity and “warning-power” of the new crossbuck designs, even during daytime. A seven year summary (1989-1996) of crashes at passive Railway/Highway Grade Crossings in Ohio is given in [8][9].

William J Kemper [13] conducted laboratory studies to evaluate the effects of modifications to the railroad pavement marking symbol and to the crossbuck. These studies, which consisted of 40 slide identifications by 40 test subjects (20 male and 20 female of various ages, were conducted in a laboratory (11’ by 16’) with the walls and ceilings painted black. The slides were a mixture of highway signs and markings. Six of the slides were concerned with different types of railroad pavement X markings and eight slides were concerned with different types of crossbucks. Eight different types of crossbucks were used in the study. One slide showed a distant shot of a regular crossbuck while the others had variations in the color of the border (black or red). The majority of the subjects identified the X markings as ‘some type of crossing’ ‘no parking’ or ‘no stopping’. Only one subject (out of 40) identified the marking as ’stop for railroad crossing’. Another subject stated that the markings indicated ‘crossroad ahead’. Kemper concluded that the pavement X marking was not well recognized. Also the size of the pavement X marking did not seem to make any difference in recognition, as most of the subjects did not notice the difference unless it was pointed out to them. The crossbuck was found to be identified mainly by its shape. Up to 80% of the subjects recognized it without the words ‘railroad crossing’. Also 85% of the subjects preferred the crossbuck with a black border while none preferred the standard crossbuck without any border. Kemper suggests actual field studies to further evaluate the benefits of the black border crossbuck.

Nancy Bridwell, Elizabeth Alicandri, Doug Fischer, and Esther Kloeppel [14], carried out a similar laboratory evaluation of seven different types of passive railroad crossbuck signs. They used recognition distance, conspicuity and comprehension as measures of effectiveness for comparison of the crossbuck signs. The study was conducted using 84 subjects having no vision deficiencies. The results indicated that there were no differences between the signs for recognition distance. The MUTCD standard crossbuck (R15-1) on a barber-striped pole, as well as the one with the standard yield sign (R1-2) mounted below had the highest conspicuity. The modified Canadian crossbuck with the “Conrail” yield sign mounted below also did well on this count. The MUTCD standard crossbuck (R15-1) and the Canadian crossbuck showed the worst conspicuity. For each of the seven signs, two types of comprehension, the meaning of the sign, and the action to be taken on seeing it were examined. The best response was obtained for the Standard yield sign (R1-2) with a regulatory plaque below reading “TO TRAINS” and for the Standard Yield (R15-1 and R1-2). The worst responses were for the MUTCD Standard (R15-1) and the Canadian Crossbuck. Since the standard crossbuck performed worse than the more advanced designs, the authors suggested a change from the current standard. Another suggestion was that the “Canadian” crossbuck could be safely omitted from future investigations, as it was the only sign found to perform worse than the standard crossbuck on the measures of effectiveness used in [14].

Lerner and Ratte [3] stated that while the responsibility of the motorist in a vehicle-train collision cannot be denied, there are at least 14 important human factors issues that contribute to driver error in decision making at Railroad/Highway Grade Crossings. These include ambiguity in the information presented to the motorist on the approach to the railroad crossing; credibility of the information presented (false signal or long warning times). Other factors relate to a driver’s expectancy of the train traffic and the crossing itself (active v/s passive). Costs of compliance (delay and annoyance) are also important issues, besides temporal constraints due to limited sight distance, vehicle speeds etc.

The subject of driver behavior at railroad crossings was also studied by Abraham, Datta and Datta [15]. They stated that violations of traffic control device messages at railroad crossings involve motorists who may have had their expectancy violated, who may have incorrectly assessed the risk associated with a specific situation, or who may have disobeyed the message deliberately. The study was carried out at 37 randomly selected railroad crossing sites in the state of Michigan. The field data collection activities were performed over a period of 18 months, for a total of 126 days and for an average of 2.5 hours per day. The study included crossings by 272 trains and 1271 observed violations. These observations were conducted during daylight and fair weather conditions. Abraham, Datta and Datta concluded that motorists approaching a multi-track crossing from a multi-lane approach commit more violations and that such sites were also found to have a higher number of crashes. On the basis of their field observations they stated that at multi-lane/multi-track sites the motorists find enough room to drive around the gates. They also point out that even though the single track single lane railroad crossings had an equally high number of violations, the number of crashes at such crossings were lower. This is attributed to the fact that motorists at such crossings have a better chance of safely clearing the intersection. It was also found that drivers in the age group of 25and 40 years committed more violations as compared to any other age group. Abraham, Datta and Datta further concluded that a study of the driver violations at rail-highway crossings could be an important indicator of the relative hazard of a Railroad/Highway Grade Crossings.

PART I, DRIVER RISK TAKING AT SELECTED PASSIVE HIGHWAY GRADE CROSSINGS IN OHIO

Method

The Railroad/Highway Grade Crossings research conducted by Ohio University used unobtrusively obtained near collisions and violations at passive Railroad/Highway Grade Crossings as a proxy measure of crossbuck effectiveness to corroborate the findings of the ongoing crash data analysis (part III). During an approach to a Railroad/Highway Grade Crossing every approaching train has to blow the whistle from the time the whistle post (located about 1600 ft in advance of the Railroad/Highway Grade Crossings) is reached until the front of the engine clears the railroad crossing (Railroad/Highway Grade Crossings). Vehicles that traverse the Railway/Highway Grade Crossings in the presence of an approaching train, despite the warning provided by the train whistle are in violation of Ohio traffic laws. The temporal closeness of the violation event was determined from the video record. For a detailed account of the violation terminology the reader should refer to [10]. In most cases there were no vehicles present at the passive Railroad/Highway Grade Crossings. If vehicles were present, they were categorized into compliant vehicles (vehicles that yield to the approaching train blowing the whistle) and non-compliant vehicles (vehicles that drove over the Railroad/Highway Grade Crossing although the approaching train was blowing its whistle). Sometimes there were multiple compliant vehicles present at the passive Railroad/Highway Grade Crossings.

Motorist near-collision and violation video data was collected along four selected rail corridors during 1995 under the before-condition (Current Standard Crossbuck, Figure 1). A total of 3,833 passive railroad crossing approaches were recorded under both the before and the after condition. The video taping runs were repeated along the exact same rail corridors under the after condition during late 1996 and early 1997. Half of the Current Standard Crossbucks in Ohio were replaced with the Buckeye crossbuck (Figure 2, all even crossing numbers) and the other half was replaced with the Standard Improved crossbuck (Figure 3, all odd crossing numbers) prior to the after condition. It should be noted, that Conrail had already replaced all of their Current Standard Crossbucks in Ohio with either the Standard-improved or the Buckeye Crossbuck between May and October 1993. Therefore, no Conrail lines could be included in the before/after near-collision/violation study. As an initial step in the analysis, the Railroad/Highway Grade Crossings crash analysis was performed separately for Conrail and for all other railroad companies in Ohio.

The violation/near-collision video data was collected (mostly during daytime) with a specially designed train borne video capturing system using state of the art Hi-8 industrial grade cameras and global positioning system (GPS) satellite technology. A connectivity diagram of the train borne video system can be found in [10]. An outboard video camera encased in an aluminum box was installed on the nose of the selected train engine. The GPS and the video equipment could be controlled from a knee-board.

Results of Driver Risk Taking Study

The video data records of the before-condition and the after-condition were carefully reviewed and categorized into compliant vehicles (vehicles that yield to the approaching train blowing its whistle) and non-compliant vehicles (vehicles that drove over the Railroad/Highway Grade Crossing although the approaching train was blowing its whistle). If vehicles were observed during a train approach to a passive Railroad/Highway Grade Crossings they were either categorized as being compliant vehicles (vehicles waiting at the passive Railroad/Highway Grade Crossings for the train to pass) or non-compliant vehicles (vehicles that drove over the Railroad/Highway Grade Crossing although the approaching train was blowing the whistle).. A near-collision was arbitrarily defined as a non-compliant vehicle clearing the tracks only within a time of less than 2 seconds prior to the arrival of the train at the passive Railroad/Highway Grade Crossings. A violation was categorized if a non-compliant vehicle cleared the tracks within a time of equal or more than 2 seconds prior to the arrival of the train at the passive Railroad/Highway Grade Crossings when the train whistle was blown.

A total of 3,833 approaches to passive Railroad/Highway Grade Crossings were recorded along the four selected rail corridors (total before and after). The classification process described above has provided observation frequencies for the "no vehicles" category, the "compliant vehicles" category, and the "violations" category. No near-collisions (time to Railroad/Highway Grade Crossings < 2 sec) were found among the 3,833 observations.

Overall for the before-condition, it was found that in the majority of the observations (87.57% or 1986 out of 2,268 observations) there were no vehicles in the proximity of the Railroad/Highway Grade Crossings during the train approach. A total of 301 vehicles (compliant and non-compliant) were observed during 282 of the 2,268 before-condition approaches (12.43%). Of these 301 vehicles there were 137 compliant vehicles (45.51% of all observed vehicles) and 164 non-compliant vehicles (54.48% of all observed vehicles).

Similar results were found under the after condition [12][16]. Again, most of the time (90.29% or 1,413 out of 1,565 observations) no vehicles were observed during the Railway/Highway Grade Crossings approaches. A total of 155 vehicles (compliant and non-compliant) were observed during 152 of the 1,565 after-condition approaches (9.71%). Of these 155 vehicles there were 68 compliant vehicles (43.87% of all observed vehicles) and 87 non-compliant vehicles (56.13% of all observed vehicles). Based on the before and after condition near-collision/violation frequencies alone, it seems that the new crossbuck devices (after condition) do not provide for a violator behavior that is substantially safer from the violator behavior that was observed under the before condition (Current Standard Crossbuck).

Table 1 illustrates separately for the Buckeye crossbuck and the Standard Improved crossbuck the observation frequency and percentage for events with compliance, events with single violations and events with no vehicles during train approach to the passive Railroad/Highway Grade Crossings under the after-condition. According to the breakdown listed in these two tables, it appears that the Buckeye crossbuck provided for slightly fewer violations than the Standard Improved crossbuck. In other words, it is possible that the Buckeye crossbuck may have a slightly higher potential than the Standard Improved crossbuck, in convincing a driver not to drive over the Railroad/Highway Grade Crossing although the approaching train was blowing its whistle.

Table 1. Observation Frequency and Percentages Classified According to the Type of Crossbuck for Events with Compliance, Events with Single Violations, and Events with No Vehicles Present During Train Approach to the Passive Railroad/Highway Grade Crossings (After Condition-Standard Improved and Buckeye Crossbuck).

a. Frequencies

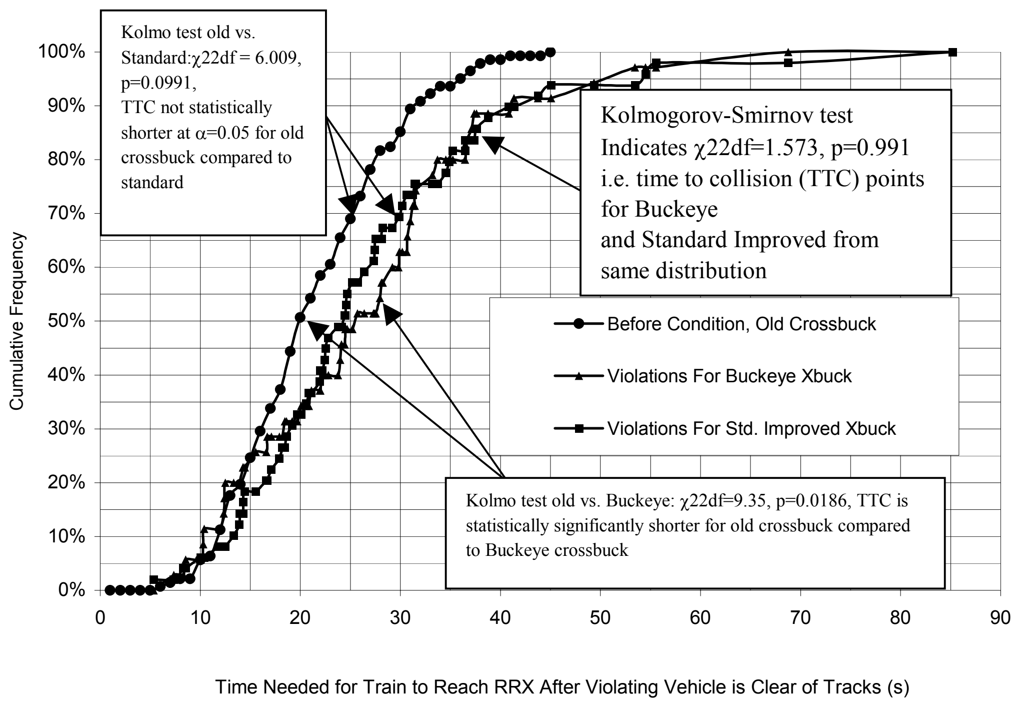
Railroad Companies	No vehicles present during RRX approach	Compliant Category																								Total
		Left Side						Right Side						Left and Right Side												
		One Vehicle present during RRX approach		Two vehicles present during RRX approach		Three vehicles present during RRX approach		One Vehicle waiting at RRX		Two vehicles waiting at RRX		Three vehicles waiting at RRX		One and one vehicle waiting at RRX		One and two vehicles waiting at RRX		One and three vehicles waiting at RRX		Total of Compliant Category		Non Compliant		Compliant + Non Compliant		
		SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	
Wheeling & Lake Erie	337	9	4	0	0	0	0	3	7	0	1	0	0	1	0	0	0	0	0	13	12	12	8	25	20	382
R. J. Corman	257	12	2	0	0	0	0	7	5	0	0	0	0	1	0	0	0	0	0	20	7	30	15	50	22	329
Norfolk Southern	652	3	2	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	4	7	10	12	14	19	685
CSXT	167	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	169
Total Observ.	1413	24	8	0	0	0	0	12	18	0	1	0	0	2	0	0	0	0	0	38	27	52	35	90	62	1565
Total Vehicles	0	24	8	0	0	0	0	12	18	0	2	0	0	4	0	0	0	0	0	40	28	52	35	92	63	

b. Percentages

Railroad Companies	No vehicles present during RRX approach	Compliant Category																								Total
		Left Side						Right Side						Left and Right Side												
		One Vehicle present during RRX		Two vehicles present during RRX		Three vehicles present during RRX		One Vehicle waiting at RRX		Two vehicles waiting at RRX		Three vehicles waiting at RRX		One and one vehicle waiting at RRX		One and two vehicles waiting at RRX		One and three vehicles waiting at RRX		Total of Compliant Category		Non Compliant		Compliant + Non Compliant		
		SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	SI	B	
Wheeling & Lake Erie	88.22	2.36	1.05	0.00	0.00	0.00	0.00	0.79	1.83	0.00	0.26	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	3.40	3.14	3.14	2.09	6.54	5.24	100
R. J. Corman	78.12	3.65	0.61	0.00	0.00	0.00	0.00	2.13	1.52	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	6.08	2.13	9.12	4.56	15.2	6.69	100
Norfolk Southern	95.18	0.44	0.29	0.00	0.00	0.00	0.00	0.15	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	1.02	1.46	1.75	2.04	2.77	100
CSXT	98.82	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.59	0.00	0.00	0.59	0.59	100
Total Observat	90.29	1.53	0.51	0.00	0.00	0.00	0.00	0.77	1.15	0.00	0.06	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	2.43	1.73	3.32	2.24	5.75	3.96	100
Total Vehicles	0.00	26.1	12.7	0.0	0.0	0.0	0.0	13.0	28.6	0.0	3.2	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	43.5	44.4	56.5	55.6	100	100	

Note: SI = Standard Improved crossbuck, B = Buckeye crossbuck. Percentages in last row (gray) were computed based on total number of vehicles per crossbuck type i.e. 100% on Standard Improved crossbuck means 92 vehicles, 100% on Buckeye crossbuck means 63 vehicles

The video records were further analyzed with regard to the time it took the train to reach the passive Railroad/Highway Grade Crossings after the non-compliant (violating) vehicle cleared the tracks (temporal closeness of the violation). It was assumed that the train speed distributions were about the same during the before and after conditions. Figure 4 illustrates this temporal closeness of 164 violations observed at passive Railroad/Highway Grade Crossings equipped with the Current Standard Crossbuck (before condition), 52 violations observed at passive Railroad/Highway Grade Crossings equipped with the Standard Improved crossbuck (after-condition), and 35 violations observed at sites with the Buckeye crossbuck (after-condition). Figure 4 shows quite clearly that both the Buckeye crossbuck and the Standard Improved crossbuck provided almost identical temporal distributions with a median time around 25 seconds. A Kolmogorov-Smirnov test [17] (χ^2_{2df} =1.573, p=0.991) between the Buckeye crossbuck and the Standard improved crossbuck did not show any statistically significant shift in the temporal distribution. A comparison between the Current Standard Crossbuck and the Standard improved crossbuck with a Kolmogorov-Smirnov test (χ^2_{2df} =6.009, p=0.0991) also did not indicate a statistically significant shift in the temporal distribution. However, a comparison between the Current Standard Crossbuck and the Buckeye crossbuck, using a Kolmogorov-Smirnov test (χ^2_{2df}=9.35, p=0.0186) indicated a statistically significant shift of the temporal distribution towards longer times under the Buckeye crossbuck condition. Both new crossbuck designs also provide temporal distributions that are somewhat shifted towards longer times (about 25 seconds) when compared with the temporal distribution obtained with the Current Standard Crossbuck (median value 20 seconds). As indicated earlier this temporal shift towards longer times may be indicative of the higher conspicuity of the new crossbuck designs during daytime. It should be noted that the cumulative time curves shown in Figure 4 converge for shorter times. This convergence seems to indicate that reckless violators who choose to drive over the Railroad/Highway Grade Crossing although the approaching train was blowing its whistle and was relatively close-in mask out any stimuli provided by Railroad/Highway Grade Crossing warning devices. Again, as discussed earlier, longer times for trains to reach the Railroad/Highway Grade Crossing after a violating vehicle is clear of the tracks indicate that drivers when violating the law prefer longer train arrival times under the after condition. Longer train arrival times indicate that violating drivers want more assurance that they can cross the rails successfully! That shift to longer train arrival times makes violating drivers more cautious in the after condition.



Note: 165 violations observed at sites equipped with the Current Standard Crossbuck (before condition), 52 violations observed at sites equipped with the Standard Improved crossbuck (after-condition), and 35 violations observed at sites equipped with the Buckeye crossbuck (after-condition).

Figure 4. Cumulative Frequency [%] as a Function of Time Needed for Train to Reach Public Passive Railroad/Highway Grade Crossings After Non-Compliant (Violating) Vehicle Is Clear of Tracks

PART II, CRASH HISTORY AT HIGHWAY GRADE CROSSINGS IN OHIO

Data regarding crashes at Railroad/Highway Grade Crossings in Ohio was obtained from the Public Utilities Commission of Ohio (PUCO) and from the Federal Railroad Administration (FRA) in electronic format. A relational database was designed using the Microsoft^{TM} Access database design tool. Another database (GX) containing traffic data and geometrical data for each public passive Railroad/Highway Grade Crossings in Ohio was obtained through the Federal Railroad Administration (FRA). The two databases were joined using the Railroad/Highway Grade Crossings number as a link. Queries could be run on the crash table of the resulting relational database and geometrical information and traffic related information could be gained from the GX table. Queries were designed to gather the crash data at public passive Railroad/Highway Grade Crossings.

Results of Crash Analysis

Table 2a shows the ten year crash summary at active and passive, public Ohio Railroad/Highway Grade Crossings during dusk, daytime, dawn, and nighttime. Also shown in this table are the numbers of public passive and active railroad crossings in Ohio for each year from 1989 to 1999. These crossing numbers were provided by the Federal Railroad Administration (FRA), and show a considerable decrease in the number of public passive railroad crossings from 1989 to 1999 in Ohio (1553 fewer public passive railroad crossings), while for the same time an increase in active railroad crossings of 404 is observed.

Data for active Railroad/Highway Grade Crossings and dawn/dusk crash data was not further analyzed. The fact that Conrail installed the Buckeye and Standard Improved Crossbuck during 1993, while all other railroad companies performed the upgrade in the period between December, 1995 and March, 1996 suggested as a first step a separate analysis of the crash data for “Conrail” and for “All railroad companies except Conrail”. Conrail used the Current Standard Crossbuck during the years 1989 (first year for which data was made available to the authors) until and including 1992. All other railroad companies used the Current Standard Crossbuck during the years 1989 until and including 1995. During the year 1993, a mixture of all three crossbuck designs (Current Standard Crossbuck, Buckeye crossbuck and Standard Improved crossbuck) were present at public passive Conrail Railway/Highway Grade Crossings in Ohio. The Standard Improved and Buckeye crossbucks (state-wide mixture of 50% each, Standard Improved on Railroad/Highway Grade Crossings with odd numbers, Buckeye crossbucks on Railroad/Highway Grade Crossings with even numbers) were present at the public passive Conrail Railroad/Highway Grade Crossings from 1994 to date. During the period from December 1995 to March 1996, a mixture of all three crossbuck designs were present at all railroad companies other than Conrail. The Buckeye and the Standard Improved crossbucks were installed at all non-Conrail rail lines in Ohio during the time from December 1995 to March, 1996 (state-wide mixture of 50% each, Standard Improved on Railroad/Highway Grade Crossings with odd numbers, Buckeye crossbucks on Railroad/Highway Grade Crossings with even numbers). Table 2a clearly shows that overall the number of Railroad/Highway Grade Crossing crashes in Ohio has been declining over the past 10 years.

Table 2. Ten Year Crash Summary, Number of Daytime Crashes and Number of Nighttime Crashes

a. Ten Year Crash Summary at Ohio Public Railroad/Highway Grade Crossings (Public Active and Passive) and Railroad/Highway Grade Crossing Numbers provided by FRA

Note: 1999 data only for January through June 30th

Phase	Year	Dawn		Day		Dusk		Night		Total			RRX Numbers in OH, as provided by FRA	
		Active	Passive	Active	Passive	Active	Passive	Active	Passive	Active	Passive	Act, Pass	Passive	Active
Old XB	1989	8	10	73	110	5	9	90	93	176	222	398	4638	2899
	1990	3	6	56	100	3	14	65	62	127	182	309	4585	2931
	1991	5	10	47	100	2	8	59	80	113	198	311	4567	2931
	1992	2	6	53	92	3	7	52	56	110	161	271	4015	2946
Mix Old and New	1993	7	7	37	94	3	3	51	54	98	158	256	3904	2996
	1994	1	7	38	69	4	8	44	49	87	133	220	3719	2994
	1995	1	5	40	89	5	1	44	39	90	134	224	3524	3027
New XB*	1996	1	4	35	54	4	9	42	28	82	95	177	3187	3202
	1997	2	0	36	66	1	4	35	29	74	99	173	3172	3212
	1998	2	1	32	47	1	3	30	25	65	76	141	3134	3243
	1999	0	2	15	27	0	1	13	8	28	38	66	3085	3303
	Total	32	58	462	848	31	67	525	523	1050	1496	2546		

* Note: Still a few old crossbucks, January through March of 1996

b. Daytime and Nighttime Crash Frequency at Public Passive Railroad/Highway Grade Crossings Equipped with Either the Standard Improved Crossbuck or the Buckeye Crossbuck in Ohio

Note: 1999 data only for January through June 30th, na means data not available

YEAR	DAY				NIGHT			
	CONRAIL		OTHERS		CONRAIL		OTHERS	
	SI	B	SI	B	SI	B	SI	B
1994	10	15	na	na	9	3	na	na
1995	11	19	na	na	3	3	na	na
1996	13	11	21	9	6	3	6	6
1997	13	9	24	20	4	1	11	13
1998	6	2	26	13	6	7	7	5
<July, 1999	4	2	8	12	1	1	3	3
Total	57	58	79	54	29	18	27	27
	Ratio is not Statistically significant $\alpha = 0.05$ $N_{RRX,C} = 475$, Z-value = -0.10, P-value = 0.921		Ratio is Statistically significant at $\alpha = 0.05$ $N_{RRX,O} = 1097$, Z-value = 2.24, P-value = 0.025		Ratio is not Statistically significant at $\alpha = 0.05$ $N_{RRX,C} = 475$, Z-value=1.65, P-value=0.099		Ratio is identical $N_{RRX,O} = 1097$	
	Ratio for all railroads, daytime SI/B is not statistically significant at $\alpha = 0.05$, $N_{RRX,C+O} = 1572$, Z-value = 1.59, P-value = 0.112, however in favor of Buckeye crossbuck				Ratio for all railroads, nighttime SI/B is not statistically significant at $\alpha = 0.05$, $N_{RRX,C+O} = 1572$, Z-value=1.11, P-value=0.266, slightly in favor of Buckeye crossbuck			
	Ratio for all railroads, daytime and nighttime combined, SI/B is statistically significant at $\alpha = 0.05$, $N_{RRX,C+O} = 1572$, Z-value= 1.99, P-value=0.047, in favor of Buckeye crossbuck							
	α=0.05, $Z_{0.975}$=1.96							

It should be noted that nationwide annual train mile data, data on the number of vehicles, and annual vehicle mile data [18] suggest a nationwide increase in traffic and exposure over recent years. For example, over the past 10 years the number of licensed drivers and registered motor vehicles in Ohio has increased from about 7 to more than 8.4 and from about 9 to more than 11.5 million, respectively. A downward public passive Railroad/Highway Grade Crossings crash trend is observed in spite of increased exposure. This reduction in crashes may be indicative of the effectiveness of the new crossbuck designs at public passive Railroad/Highway Grade Crossings, but may also be explained in part by the increased public awareness due to programs such as operation lifesaver, or the elimination/conversion of many of the most dangerous public passive Railroad/Highway Grade Crossings to active Railroad/Highway Grade Crossings. Figure 5a shows the cumulative crash frequency as a function of the year at public passive Railroad/Highway Grade Crossings in Ohio during daytime. The crash data from 1989 to 1992 was removed as the Buckeye and Standard Improved crossbucks were available only from 1993 onwards. It can be seen that the Standard Improved crossbuck at public passive Conrail Railroad/Highway Grade Crossings shows a better performance with regard to the number of daytime crashes than the Buckeye crossbuck at public passive Conrail Railroad/Highway Grade Crossings The observed crash frequency at public passive non-Conrail Railroad/Highway Grade Crossings is lower for the Buckeye crossbuck than for the Standard Improved crossbuck. Both the data for the Conrail company and for all other companies exhibit approximately the same slope, indicating a similar crash rate, assuming a relatively stable train frequency and relatively constant ADTs (average daily traffic) during recent years.

The hypothesis $P_1 = P_2$, P_1 and P_2 two independent proportions, has been tested [17] with the following proportion-pairs using the Minitab statistical software:

Proportions using daytime crashes only:

- $P_1 = \frac{N_{Crashes,SI,C,Daytime}}{N_{RRX,C}}$ $P_2 = \frac{N_{Crashes,B,C,Daytime}}{N_{RRX,C}}$
- $P_1 = \frac{N_{Crashes,SI,O,Daytime}}{N_{RRX,O}}$ $P_2 = \frac{N_{Crashes,B,O,Daytime}}{N_{RRX,O}}$
- $P_1 = \frac{N_{Crashes,SI,C+O,Daytime}}{N_{RRX,C+O}}$ $P_2 = \frac{N_{Crashes,B,C+O,Daytime}}{N_{RRX,C+O}}$

Proportions using nighttime crashes only:

- $P_1 = \frac{N_{Crashes,SI,C,Nighttime}}{N_{RRX,C}}$ $P_2 = \frac{N_{Crashes,B,C,Nighttime}}{N_{RRX,C}}$
- $P_1 = \frac{N_{Crashes,SI,O,Nighttime}}{N_{RRX,O}}$ $P_2 = \frac{N_{Crashes,B,O,Nighttime}}{N_{RRX,O}}$
- $P_1 = \frac{N_{Crashes,SI,C+O,Nighttime}}{N_{RRX,C+O}}$ $P_2 = \frac{N_{Crashes,B,C+O,Nighttime}}{N_{RRX,C+O}}$

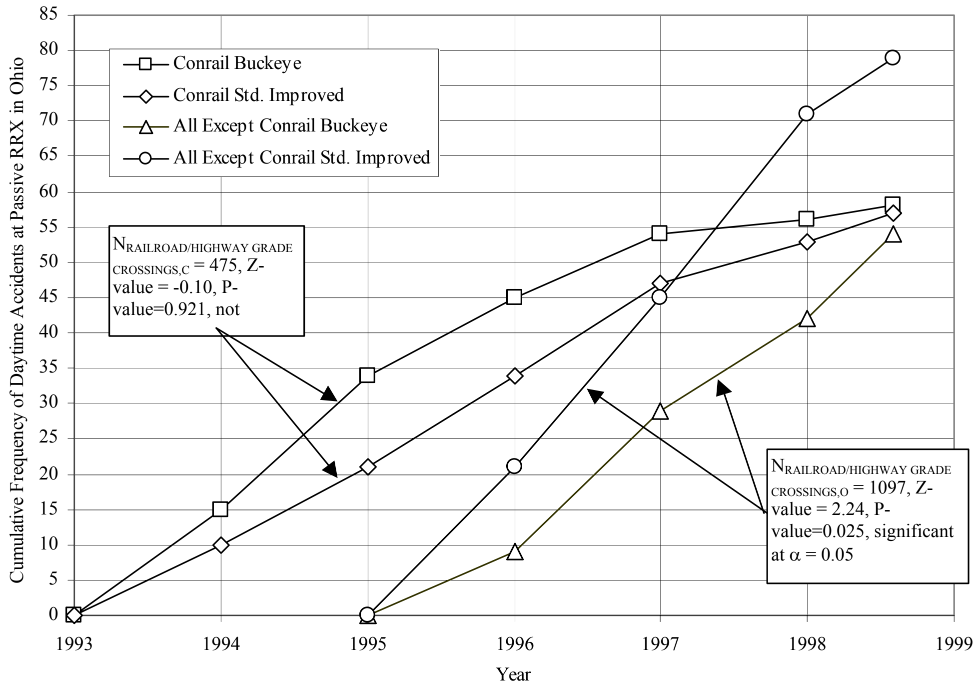
Proportions using both, day- and nighttime crashes:

- $P_1 = \frac{N_{Crashes,SI,C+O,Daytime+Nighttime}}{N_{RRX,C+O}}$ $P_2 = \frac{N_{Crashes,B,C+O,Daytime+Nighttime}}{N_{RRX,C+O}}$

$N_{Crashes,SI}$ denotes the cumulative number of crashes at passive public Railroad/Highway Grade Crossings equipped with the Standard Improved crossbuck, and $N_{Crashes,B}$ denotes the cumulative number of crashes at passive public Railroad/Highway Grade Crossings equipped with the Buckeye crossbuck. The additional subscripts $_{C}$, $_{O}$, and $_{C+O}$ refer to the Conrail-only, the other railroad companies-only, and the combined (all railroad companies, including Conrail) cumulative number of crashes, respectively. The additional subscripts $_{Daytime}$, $_{Nighttime}$, and $_{Daytime+Nighttime}$ indicate that just the daytime, just the nighttime, or the combined daytime/nighttime cumulative crash data is used, respectively. $N_{RRX,C}$ refers to the average number of Conrail passive public Railroad/Highway Grade Crossings from 1996 to 1999, $N_{RRX,O}$ refers to the average number of non-Conrail (other railroad companies) passive public Railroad/Highway Grade Crossings during the same period of time, and $N_{RRX,C+O}$ refers to the total average number of passive public Railroad/Highway Grade Crossings (Conrail and non-Conrail together) from 1996 to 1999. Approximately, 30.23% of all passive public Railroad/Highway Grade Crossings in Ohio are Conrail-operated and 69.77% are operated by other railroad companies than Conrail. When assuming an average number of public passive Railroad/Highway Grade Crossings between 1996 and 1999 of 3145, there are about 950 Conrail-operated Railroad/Highway Grade Crossings (one half of them, 475, are Buckeye crossbuck equipped, and the other half of them, again 475, are Standard Improved crossbuck equipped), and about 2194 Railroad/Highway Grade Crossings operated by others (1097 are Buckeye crossbuck equipped, and also 1097 are Standard Improved crossbuck equipped).

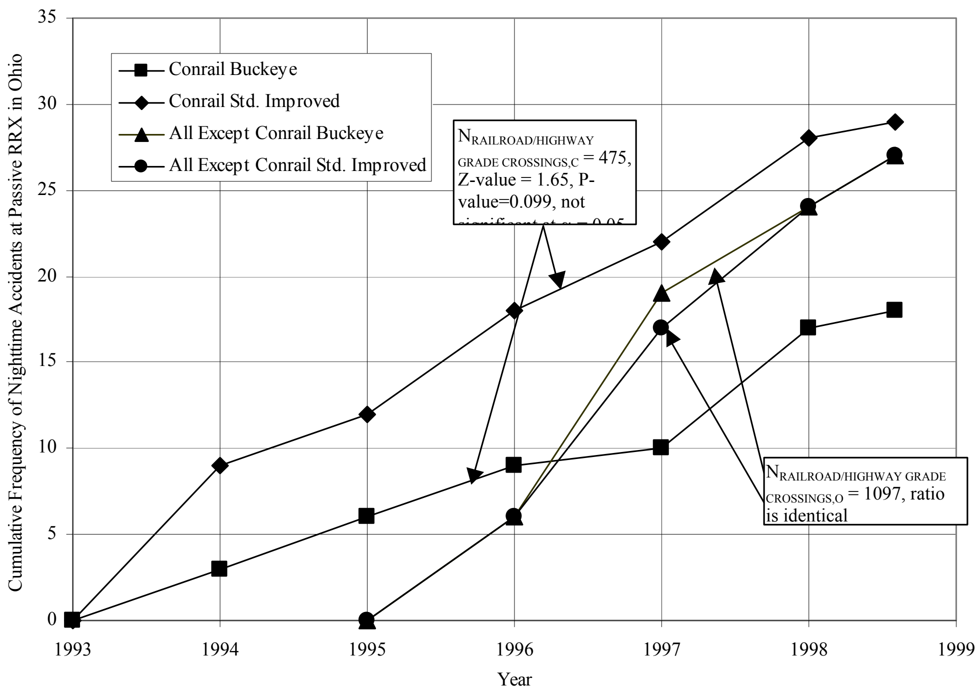
As indicated in Table 2b and Figure 5a,b, there was no statistically significant (α=0.05) evidence for Conrail Railroad/Highway Grade Crossings that the proportions P_1 and P_2 were different during daytime. For all other Railroad/Highway Grade Crossings the difference between the two proportions during daytime was statistically significant (α=0.05) in favor of the Buckeye crossbuck. No statistically significant (α=0.05) effect of the crossbuck design on the number of crashes per Railroad/Highway Grade Crossing was found during nighttime, indicating that from a statistical point of view both crossbuck devices perform about equally well at night. While not being statistically significant (α=0.05), the nighttime proportions of crash frequencies for Conrail Railroad/Highway Grade Crossings are in favor of the Buckeye crossbuck. The difference in the daytime proportions of crash frequencies for all Railroad/Highway Grade Crossings (Conrail operated and non-Conrail operated together) is not statistically significant ($p \leq 0.112$), but the ratios are in favor of the Buckeye crossbuck. No statistical significance ($p \leq 0.266$) in the difference of the proportions was found for the combination of Conrail operated Railroad/Highway Grade Crossings and non-Conrail operated Railroad/Highway Grade Crossings together during nighttime. Again, while not being statistically significant, the nighttime proportions of crash frequencies for Conrail Railroad/Highway Grade Crossings and non-Conrail Railroad/Highway Grade Crossings combined, favor the Buckeye crossbuck. The difference in the proportions of crash frequencies for the combination of daytime and nighttime and the combination of Conrail Railroad/Highway Grade Crossings and non-Conrail Railroad/Highway Grade Crossings was statistically significant ($p \leq 0.047$) in favor of the Buckeye crossbuck (157 total crashes for the Buckeye crossbuck and 192 crashes for the Standard Improved crossbuck from 1994 until June 30th, 1999).

It should be noted, that each and every public passive Railroad/Highway Grade Crossings in Ohio was included in this crash analysis and that all those Railroad/Highway Grade Crossings were equipped with either the Buckeye crossbuck or the Standard Improved crossbuck. The Buckeye crossbucks and the Standard Improved crossbucks were evenly matched in terms of their numbers (totally matched population).



Note: 1999 data only for January through June 30th, 1999

a. Daytime.



Note: 1999 data only for January through June 30th, 1999

b. Nighttime.

Figure 5. Cumulative Frequency as a Function of Year at Public Passive Highway/Rail Grade Crossings (Conrail and All Except Conrail) in Ohio During Daytime and Nighttime

PART III, USER ACCEPTANCE SURVEY OF NEW CROSSBUCK DESIGNS

A set of user acceptance questionnaires was developed with the help of William F. Moroney of the University of Dayton, to determine the subjective preference of the three crossbuck designs being evaluated as part of this project. User acceptance questionnaires were sent out to respondents in Ohio in order to provide subjective data to corroborate the tentative findings of the crash statistics, the near collision/violation measurements, and the photometric measurements. Multiple choice questionnaires were mailed out to the general driving public, school bus drivers, delivery drivers, law enforcement officers, and train engineers. The survey pursued a number of goals:

1. Determine if road users perceive passive Railroad/Highway Grade Crossings as a hazard.
2. Determine self reported driving behavior at passive Railroad/Highway Grade Crossings.
3. Determine which one of the three crossbuck designs is preferred by the surveyed user groups.

Of the 340 questionnaires sent to the general public, 111 were returned (32%). Of the 200 questionnaires sent to school bus drivers, 35 were returned (17.5%). Of the 105 questionnaires sent out to delivery drivers, 36 were returned (34%). Of the 209 questionnaires sent to law enforcement officers, 152 were returned (72%). And, of the 155 sent to train engineers, 40 were returned (25%). The questionnaire allowed respondents to make a selection from multiple choices. Some questions were restricted to one selection, while others could have more than one selection. All questions provided space for comments.

Method

Survey participants were randomly sampled from the licensed Ohio driver population. The sample population was then separated into four categories as follows:

1. General public
2. School bus drivers
3. Delivery drivers
4. Law enforcement officials.

A list of 34,000 randomly selected potential participants in the general public category was obtained from the Bureau of Motor Vehicles for the following 34 Ohio counties where railroads operate:

Montgomery, Preble, Butler, Warren, Greene, Clinton, Clermont, Hamilton, Delaware, Licking, Fairfield, Franklin, Pickaway, Madison, Marion, Summit, Cuyahoga, Medina, Portage, Stark, Wayne, Tuscawaras, Carroll, Columbia, Wood, Lucas, Fulton, Henry, Putnam, Hancock, Wyandot, Seneca, Sandusky, and Ottawa.

From the 34,000 general driving public names a total of 7,832 participants were selected in a first randomization step. This new list was then randomized again, and 340 names were finally chosen for participation in the general survey. The Bureau of Motor Vehicles also provided a list of 22,714 school bus drivers. From this list, 200 names were randomly chosen as participants. A Xerox district manager was very helpful in obtaining a list of about 200 employees who provide service within the targeted counties of Ohio. A total of 100 names were randomly selected as participants. Another group of professional drivers considered in the survey included gas company meter readers. From available contacts, 5 participants were gained.

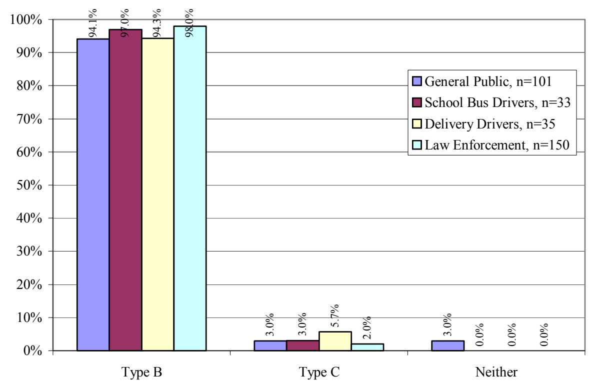
The law enforcement category consisted of sheriff's deputies and Ohio highway patrol officers. A request for assistance was sent to the headquarters of the Ohio State Highway Patrol and to the Buckeye Sheriff's Association. The Buckeye Sheriff Association distributed a letter to each target county, requesting them to send a list of law enforcement official names to the Human Factors and Ergonomics Laboratory. Sheriff offices which did not respond were contacted by phone to request assistance. In some cases, responses were not sent because the original request was received just before a new Sheriff was elected and the request was either lost or forgotten. In other cases the request for a list of names was met with skepticism. Of the 203 Sheriff and deputy names that were acquired, 57 were randomly selected as participants. A list of 153 highway patrol officers was obtained from the Ohio State Highway Patrol. All of these officers were selected as participants.

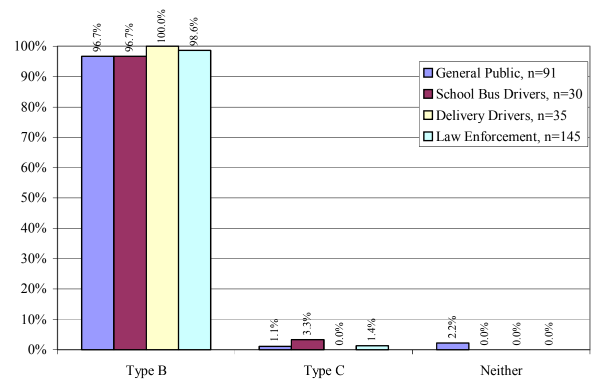
The train engineer population was split into Conrail engineers and all others. Conrail engineers were singled out because the standard improved and the Buckeye crossbucks were installed along Conrail lines earlier than any other lines. Thus, Conrail engineers were assumed to have more exposure to the new crossbucks. Special thanks is due to William T. O'Brien of the Brotherhood of Locomotive Engineers for providing a list of Ohio based train engineers.

Questionnaires were sent to all participants along with a postage-paid business reply envelope. The questionnaire had attached a cover letter that gave some background information about the survey and some instructions on how to fill out the questionnaire. Also attached was a full color page displaying the Current Standard Crossbuck, the standard improved crossbuck, and the Buckeye crossbucks during daytime. This page was included so that respondents could make reference to the full color pictures when evaluating the different designs without having to print the whole questionnaire in color. The driving public questionnaire had 9 questions, some with multiple parts. The train engineer questionnaire had 12 questions, some with multiple parts. A computerized questionnaire response entry system was developed to aid in compiling the results of the questionnaire.

Results of User Acceptance Survey

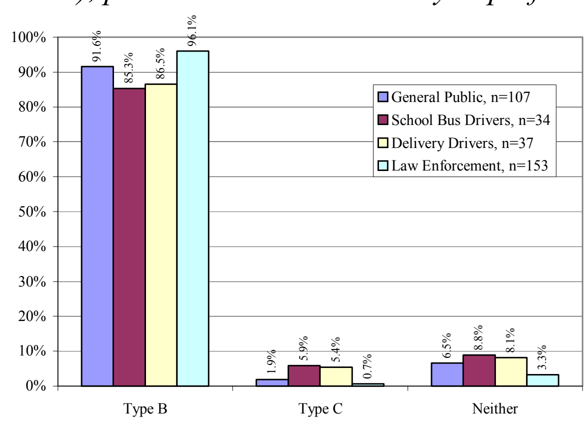
The questionnaire contained a rather large number of questions. Only the major responses pertaining to decisions to be made between the Buckeye crossbuck (type B) and the Standard Improved crossbuck (type C) are provided in this report. Details of this analysis are stored in the Human Factors and Ergonomics Laboratory at Ohio University and are available upon request. Figure 6 and Figure 7 clearly demonstrate the overwhelming user preference for the Buckeye crossbuck (type B) over the Standard Improved crossbuck (type C). The Buckeye crossbuck appears to be by far the most preferred device for all user groups included in the survey. Users seem to like the idea of providing a more salient visual signal by using an additional bent shield with stripes.



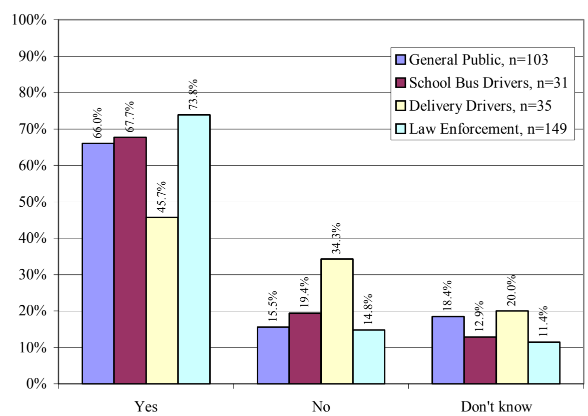


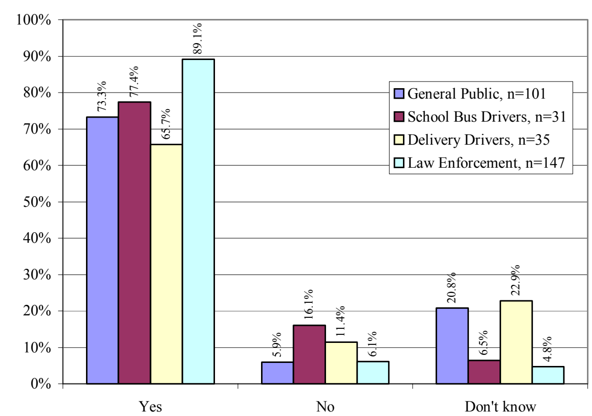
During Daytime During Nighttime

Question 3a and 4a of the "general public questionnaire": *"Of the two crossbucks (type B = Buckeye and C = Std Improved), please select the one that you prefer during daytime/nighttime."*



Question 5 of the "general public questionnaire": *"Considering both daytime and nighttime driving in Ohio, which one of the two crossbuck designs (type B = Buckeye and C = Std Improved) should be installed at passive Railroad/Highway Grade Crossings on a statewide basis in the future to warn drivers about a passive railroad/highway crossing?"*

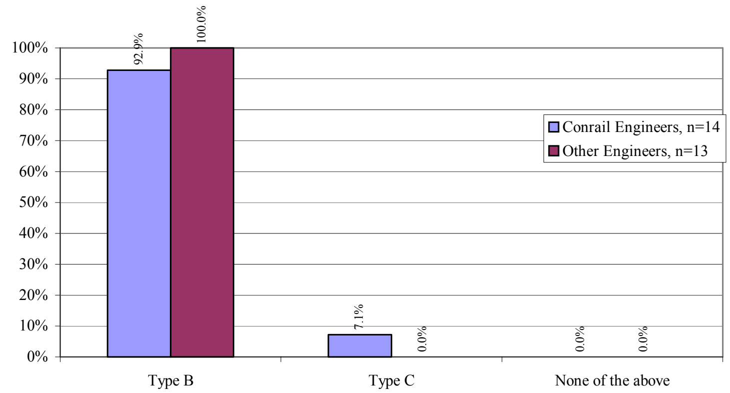




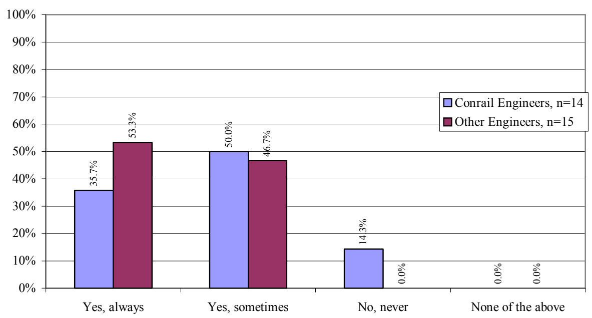
During Daytime During Nighttime

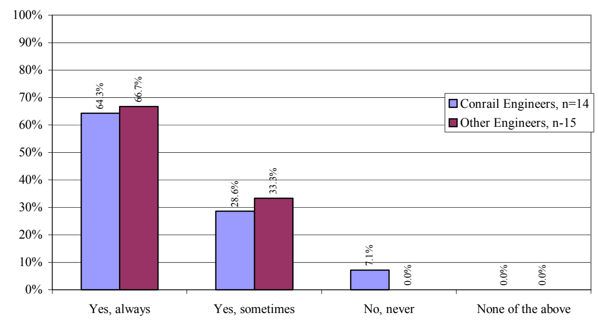
Question 8a and 9a of the "general public questionnaire": *"Does the reflectorized crossbuck on the opposite side of the tracks help you from a driving safety point of view when approaching a passive railroad/highway grade crossing in Ohio during daytime/nighttime?"*

Figure 6. Excerpts of the "General Public Questionnaire" Responses



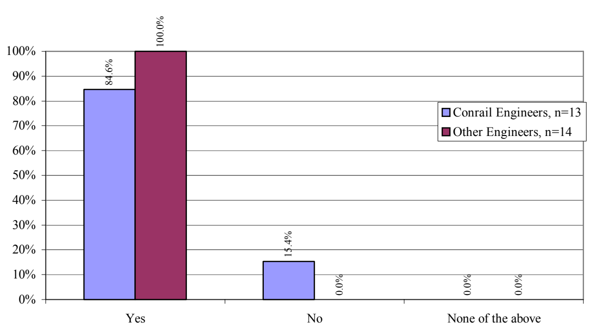
Question 3 of the “train engineer questionnaire”: *“Based on your daytime and nighttime experience as a train engineer in Ohio, which one of the two crossbuck designs (type B = Buckeye and C = Std Improved) should be installed at passive Railroad/Highway Grade Crossings on a statewide basis in the future to warn drivers about a passive railroad/highway grade crossing?”*

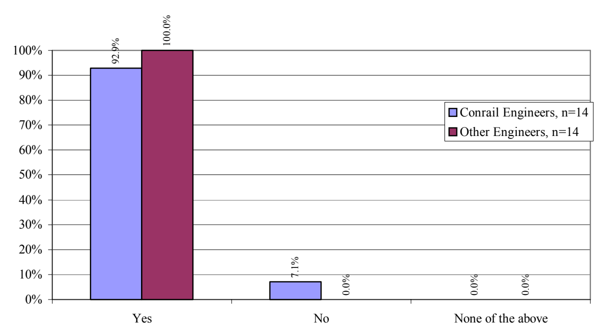




During Daytime During Nighttime

Question 4a and 5a of the “train engineer questionnaire”: *“Both crossbuck type B (Buckeye) and crossbuck type C (Std Improved) have posts equipped with white reflective tape on all four sides. Do the white crossbuck posts facing the train help you to determine the exact location of the crossing ahead during daytime/nighttime?”*





During Daytime During Nighttime

Question 6 and 7 of the “train engineer questionnaire”: *“Does the shield which is installed on crossbuck type B (Buckeye) help you as a train engineer to better see a passive railroad/highway grade crossing during daytime/nighttime?”*

Figure 7. Excerpts of the “Train Engineer Questionnaire” Responses

PART IV, NIGHTTIME PHOTOMETRIC EVALUATION OF OLD AND NEW CROSSBUCK DESIGNS

Luminances at various locations on the three crossbuck designs (see Figure 1 to Figure 3) and surround luminances were measured in the field at night under automobile low-beam illumination. Surround luminances are luminances of the background behind and adjacent to the crossbuck. The measurements were conducted in the field in order to maintain a 1:1 scale arrangement of a typical approach to a rural two-lane public passive Railroad/Highway Grade Crossings.

Method

The measurements were conducted on the old unused Ohio University airport runway which is about 23m wide and 500m long, runs east to west, and is located on the outskirts of the city of Athens, Ohio. The measurements were taken in the Eastbound direction, which provided a background that fairly closely resembled the conditions a single vehicle would encounter in a rural two-lane road driving situation. A headlamp rig was constructed to simplify aiming of the headlamp beams and the photometric equipment. No windshield was present in the measurement setup. The photometric attenuation due to the windshield transmission (T=0.72) was accounted for when the data was analyzed. The headlamps were commercially available GE H6054 sealed-beams that were operated at 13.3VDC at the lamp terminals. A stabilized DC power supply ensured accurate lamp voltage throughout the measurements. The crossbuck designs were placed along the simulated 6.71m-wide (22ft) rural two-lane road with a lateral separation of the post centerline from the edge of the roadway pavement of about 1.27m (4.17ft), and with a longitudinal separation of the post centerline from the centerline of the simulated railroad track of about 3.89m (12.75ft). According to the Appendix and [1], the distance between the post centerline and the edge of the roadway pavement must be between 1.22m (4ft) and 1.83m (6ft) in rural situations for the Buckeye and Standard Improved crossbuck, and at least 3.66m (12ft) in rural situations for the Current Standard Crossbuck. In urban situations, this distance must be between 0.30m (1ft) and 0.61m (2ft). The distance between the post centerline and the centerline of the railroad track must be between 3.20m (10.5ft) and 4.57m (15ft). It can be seen that the used setup complies with the ODOT crossbuck placement specifications for the evaluation study (see Appendix).

Results of the Photometric Evaluation

The measurement location of the crossbuck luminances reported in this report are shown in Figure 8, Figure 9, and Figure 10 for the Current Standard Crossbuck, Standard Improved crossbuck, and the Buckeye crossbuck, respectively. The corresponding luminances [cd/m^2] are shown in Table 3 and Table 4 for the front (right side) and the back (left side), respectively. The reader is reminded that the Current Standard Crossbuck was equipped with encapsulated lens (type III) sheeting material (front of blades only), and both the Standard Improved crossbuck as well as the Buckeye crossbuck were equipped with micro-prismatic (type VII, long distance performance, LDP) sheeting material (front and back of blades, post on all 4 sides, front and back of shield of Buckeye crossbuck).

The micro-prismatic type VII materials individually outperformed the encapsulated lens type III materials at 91.44m (300 ft) but not necessarily at 45.72m (150 ft). From a driver safety point of view it is the author’s opinion that the higher luminances of the micro-prismatic type VII (LDP) material at longer distances are more relevant and advantageous. The real visual advantage of the Standard Improved crossbuck over the Current Standard Crossbuck at night lies in the bright reflectorized post, part of which is closer to the hot spot of the automobile low-beam headlamps. From a visual impact point of view and for distances in excess of 91.44m (300 ft), the individual reflectorized parts of the Buckeye crossbuck provides the strongest luminous signal back at a driver’s eye, for each one of the vertical crossbuck rotations and distances considered in this measurement series. Because of the angled shield of the Buckeye Crossbuck there is almost always a reflectorized facet that provides a visual signal to the approaching driver.

Front Corresponds to Right Shoulder Location

Back Corresponds to Left Shoulder Location

Note: Images shown at daytime for illustration purposes only.

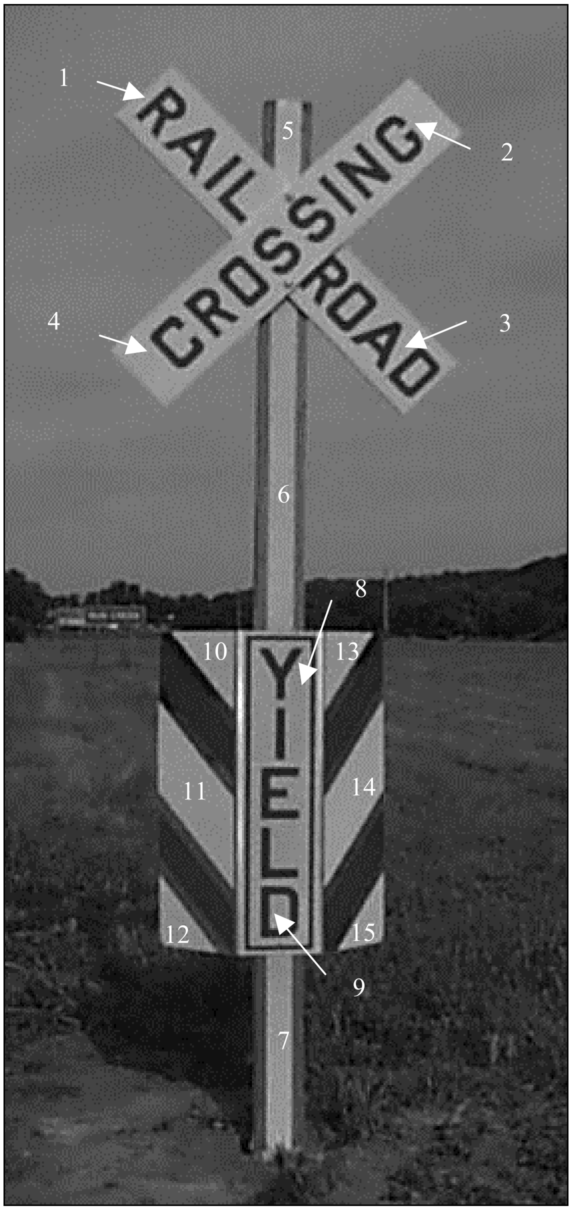
Figure 8. Current Standard Crossbuck Luminance Measurement Point Legend

Front Corresponds to Right Shoulder Location

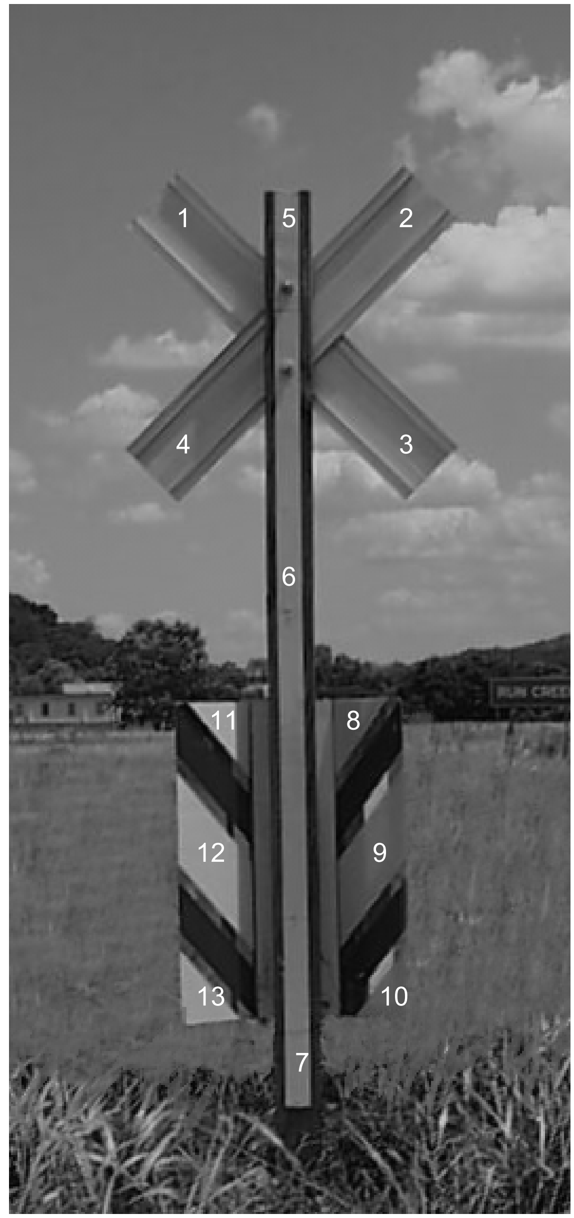
Back Corresponds to Left Shoulder Location

Note: Images shown at daytime for illustration purposes only.

Figure 9. Standard Improved Crossbuck Luminance Measurement Point Legend



Front Corresponds to Right Shoulder Location



Back Corresponds to Left Shoulder Location

Note: Images shown at daytime for illustration purposes only.

Figure 10. Buckeye Improved Crossbuck Luminance Measurement Point Legend

Table 3. Measured Crossbuck Luminances at Points Indicated in Figure 8 to Figure 10, Right Road Shoulder Mounted Crossbuck, Front Side

			Luminance at Point [cd/m^2]														
Distance	Crossbuck	Angle	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
45.72m	Old	0	5.978	4.785	13.15	6.773	1.19	0.795	0.795								
		15	5.183	3.983	5.978	6.773	1.193	0.795	0.398								
		45	3.983	3.188	3.983	5.183	1.52	0.398	0.795								
	Standard	0	5.978	6.375	8.37	7.568	4.785	10.358	47.82								
		15	4.785	4.785	7.568	7.17	4.785	7.17	48.22								
		45	1.455	1.228	1.193	0.795	2.393	3.186	23.51								
	Buckeye	0	2.393	3.983	8.768	5.58	5.58	6.375	59.78	23.91	47.82	15.54	26.69	38.66	15.54	25.5	33.47
		15	6.375	3.983	9.96	6.773	4.785	7.17	49.01	26.7	43.83	7.973	21.52	32.28	21.12	27.1	33.47
		45	0.192	0.192	0.188	0.26	0.178	0.545	6.178	9.165	37.06	22.31	54.99	51.01			
91.44m	Old	0	12.75	9.563	16.34	15.14	0.031	0.066	0.214								
		15	13.54	9.96	17.39	15.14	0.047	0.07	0.214								
		45	11.71	9.165	13.15	14.35	0.026	0.039	0.162								
	Standard	0	29.49	23.51	33.47	46.48	31.88	45.03	56.18								
		15	30.68	22.31	33.47	31.88	31.08	47.42	70.13								
		45	3.585	3.585	3.188	5.183	13.95	22.31	35.06								
	Buckeye	0	11.16	36.66	62.16	38.25	39.45	42.64	65.35	60.57	72.92	21.92	24.71	33.08	24.71	31.88	37.06
		15	11.56	34.67	48.22	36.66	34.67	42.64	79.7	56.18	74.11	26.7	31.08	33.47	22.71	29.89	31.08
		45	5.183	3.585	7.17	5.183	23.12	26.7	49.01	20.33	37.46	44.23	54.99	56.99			

Table 4. Measured Crossbuck Luminances at Points Indicated in Figure 8 to Figure 10, Left Road Shoulder Mounted Crossbuck, Back Side

			Luminance at Point [cd/m^2]												
Distance	Crossbuck	Angle	1	2	3	4	5	6	7	8	9	10	11	12	13
45.72m	Old	0	0.018	0.012	0.02	0.016	0.006	0.009	0.02						
		15	0.056	0.031	0.09	0.044	0.006	0.009	0.028						
		45	0.007	0.005	0.008	0.006	0.005	0.007	0.024						
	Standard	0	2.393	3.188	5.183	5.183	4.38	4.785	17.14						
		15	3.188	3.188	4.38	5.978	3.983	5.183	10.76						
		45	2.79	1.995	3.188	1.995	1.193	3.585	6.375						
	Buckeye	0	1.635	2.723	11.97	3.81	2.723	17.96	59.31	32.1	76.18	74	37	58.22	71.28
		15	3.983	3.585	3.983	5.58	3.983	8.37	12.66	5.98	12.35	14.35	6.375	8.768	12.66
		45	2.79	3.585	2.79	4.38	2.392	6.375	14.75	12.35	17.14	21.52			
91.44m	Old	0	0.015	0.019	0.032	0.019	0.001	0.008	0.014						
		15	0.022	0.016	0.027	0.018	0.009	0.005	0.015						
		45	0.006	0.003	0.004	0.007	0.004	0.009	0.012						
	Standard	0	13.55	16.34	11.96	14.35	19.13	29.09	29.89						
		15	14.35	13.95	14.75	16.34	17.93	25.9	29.49						
		45	7.568	5.98	6.773	5.58	8.37	13.55	15.54						
	Buckeye	0	11.56	14.35	12.35	13.95	10.76	20.33	39.05	13.55	14.35	11.56	11.16	13.15	19.13
		15	11.56	14.35	13.96	13.15	10.76	24.31	35.06	10.36	11.96	16.73	9.96	12.75	19.13
		45	7.568	5.98	6.773	5.58	8.37	13.55	15.54	18.64	22.71	29.28			

The luminance measurements (part IV of this study) seem to indicate that the high location (2.74m) of the blades is not favorable for the micro-prismatic type VII sheeting materials at relatively short distances. The center of the Buckeye shield, on the other hand, is located about 1m (3.2 ft) above the ground and thus provides for a much higher light return than the blades. The multi-facetted, fully reflectorized (micro-prismatic, type VII, long distance performance LDP) shield makes the Buckeye crossbuck the brightest and visually most powerful crossbuck design evaluated in this study. In addition, the angled shield makes the Buckeye crossbuck less sensitive to placement in approaches that are not straight or perpendicular to the railroad tracks, and the red YIELD legend on the shield has the potential to instill into drivers close to the Railroad/Highway Grade Crossing the idea that they must yield to approaching trains. It is also important to notice that especially at night, both new crossbuck designs provide an approaching driver with a reflectorized (bright) target on both sides of the tracks, which makes it possible for a driver to determine if a Railroad/Highway Grade Crossing is occupied by a train (left crossbuck either fully or partially obstructed by railroad cars).

DISC USSION, CONCLUSIONS, AND RECOMMENDATIONS

This study consisted of four parts. Part I investigated, unobtrusively, the driver risk taking behavior at public passive Railroad/Highway Grade Crossings, where a train was approaching, as a function of crossbuck design. Part II consisted of a state-wide ten-year crash analysis at public passive Railroad/Highway Grade Crossings for the Current Standard Crossbuck, the new Standard Improved crossbuck, and the new Buckeye crossbuck. Part III was a user-acceptance survey, and Part IV was a nighttime photometric evaluation. For a decision-maker, making counter measure deployment decisions, it seems that parts II and III are the most important points and clearly favor the Buckeye crossbuck. The results from parts I and IV also favor the Buckeye crossbuck.

Data gathered in part I of this study (driver risk taking behavior and violations at public passive Railroad/Highway Grade Crossings in Ohio, daytime only) generally indicates that when a train was approaching, if a vehicle was observed during the approach to the Railroad/Highway Grade Crossings, there was a 54.48% chance that the vehicle would be non-compliant (violation) under the before-condition (Current Standard Crossbuck), and a 56.13% chance that the vehicle would be non-compliant (violation) under the after-condition (Standard Improved and Buckeye crossbuck). Such driver behavior would seem to indicate that perhaps more aggressive and continuous enforcement of the traffic laws at public passive Railroad/Highway Grade Crossings and more driver education may be needed. It was also found that none of the observed driver violations was closer than 5 seconds, indicating that most drivers are somewhat aware of the danger an approaching train poses, and generally do not attempt to drive over the Railroad/Highway Grade Crossing when the approaching train blowing the whistle, is too close. Both new crossbuck designs provided temporal distributions that were slightly shifted towards longer risk acceptance times (median value around 25 seconds) when compared with the temporal distribution obtained with the Current Standard Crossbuck (median value about 20 seconds). This temporal shift towards longer risk acceptance times may be indicative of the somewhat higher daytime conspicuity and “warning-power” of the new crossbuck designs (especially for the Buckeye crossbuck). The time differences in favor of the Buckeye crossbuck when compared to the Current Standard Crossbuck, are statistically significant ($p \leq 0.0186$).

The Railroad/Highway Grade Crossings crash analysis (part II of this study) from 1989 to June 30, 1999, seems to indicate a rather strong downward trend in terms of crash frequency at Railway/Highway Grade Crossings in Ohio in spite of possible nationwide indications of increasing exposure (increased train miles, number of automobiles, drivers, and automobile traffic). The crossing numbers provided by the Federal Railroad Administration (FRA) in Table 2a (for 1989 to 1999) show a considerable decrease in the number of public passive warned railroad crossings (1553 fewer public passive warned railroad crossings), while for the same time an impressive increase in active warned railroad crossings is observed (in excess of 1400 light and gate crossings according to PUCO). Overall (day and night combined, Conrail and the other railroad companies combined), the cumulative crash numbers in part II show a statistically significant superiority ($p \leq 0.047$) of the Buckeye crossbuck (157 crashes for Buckeye crossbuck vs. 192 crashes for Standard Improved crossbuck from 1994 until June 30, 1999, a

22.3% decrease in the number of overall crashes for the Buckeye crossbuck when compared against the Standard Improved crossbuck). The positive effect of the Buckeye crossbuck on crash numbers is more pronounced during daytime than during nighttime. While individually not being statistically significant, both the nighttime and daytime proportions of crash frequencies also favor the Buckeye crossbuck.

Initially, it was thought that the crash numbers at public passive Railroad/Highway Grade Crossings in Ohio should be looked at separately for Conrail (due to earlier installation of the crossbuck) and separately for the group of all other railroad companies in Ohio. Further, in addition to railroad company separation, it was initially thought that the crash numbers should be analyzed separately for daytime and for nighttime, since both new crossbuck designs were vastly superior to the Current Standard Crossbuck in terms of their retro-reflective performance. Dusk and dawn data was excluded due to the small number of crashes. Initially, it was also expected that, especially the nighttime conspicuity of the Buckeye crossbuck design (because of the shield) would show a larger crash reduction potential when compared to the Standard Improved crossbuck. It appears, however, that the shield of the Buckeye Crossbuck in combination with the retro-reflectorized post and blades provides a strong visual signal, even during daytime. The obtained statistical results for the four separate conditions (Conrail day/night, all other railroad companies day/night) show that only the daytime condition for non-Conrail railroad companies (which accounts for approximately 70% of all public passive Railroad/Highway Grade Crossings in Ohio) resulted in a statistically significant difference in the crash numbers between the Buckeye crossbuck and the Standard Improved crossbuck. This statistical significance was in favor of the Buckeye crossbuck with a $p \leq 0.025$. It should be noted, that the sample sizes for each of these four conditions (crashes are for the most part very low probability events) are relatively small, especially during night, and for the less represented Conrail company. The only statistically significant difference when using the four separate conditions, is found for the condition representing the largest sample size (non-Conrail railroad companies, daytime).

In a perfect world with no variability or noise within the crash generation process, one would have expected that all four conditions would have shown a similar statistical superiority in terms of crash numbers of the Buckeye crossbuck. As mentioned before, this was actually observed under the non-Conrail daytime condition. Unfortunately, we live in an imperfect world, and the cumulative crash number differences observed between the Standard Improved crossbuck and the Buckeye crossbuck under the three statistically non-significant conditions range from –1 to 11 in favor of the Buckeye crossbuck. When combining the four conditions, first into two conditions by lumping all railroad companies together, and then into one overall condition, by lumping day and night together, we see a remarkable crash reduction effect in favor of the Buckeye crossbuck. While not being statistically significant by itself, the condition for all railroad companies (Conrail and non-Conrail) combined during daytime is in favor of the Buckeye crossbuck ($p \leq 0.112$). The most interesting situation is the one where all conditions are combined. The resulting overall proportion of the numbers of crashes is statistically significant (α=0.05) in favor of the Buckeye crossbuck ($p \leq 0.047$). Based on the crash analysis and statistical comparison of the Buckeye crossbuck and the Standard Improved crossbuck conducted in this study, there is a strong, statistically significant effect favoring the Buckeye crossbuck when looking at the combined crash data for the Buckeye crossbuck and the Standard Improved crossbuck.

The user acceptance survey (part III of this study) shows an overwhelming preference of the Buckeye crossbuck over the Standard Improved crossbuck. The majority of the road users perceive the additional area of the shield, with its vertical "YIELD" legend, as useful in warning an approaching driver about the presence of a public passive Railway/Highway Grade Crossing. The road users clearly indicate that the Buckeye crossbuck should be adopted as a warning device at public passive Railroad/Highway Grade Crossings.

The fact that all four sides of the post and both sides of the blades (and both sides of the shield of the Buckeye crossbuck) of the new crossbuck designs are fully reflectorized, would seem to be of great advantage to a nighttime motorist who is approaching a public passive Railroad/Highway Grade Crossing that is already occupied with a passing or standing train. A passing or standing train would most likely (except for the gaps between the railroad cars) obstruct the left crossbuck post and therefore provide an approaching driver with a clue indicating that the crossing is occupied by a train. The gaps between the railroad cars would allow the left crossbuck to flash up for an instant resulting in a unique, possibly even dynamic signal under the moving train condition. Especially for the left side reflectorized crossbuck (relatively low illumination from low beam headlamps as the hottest point is located approximately 2 degrees to the bottom and 2 degrees to the right) micro-prismatic sheeting material appears to be highly desirable. In addition, post reflectorization of all 4 sides provides train engineers, especially at night, with superior knowledge of exactly where a Railroad/Highway Grade Crossing is located ahead, which was evaluated as a very positive feature in the train engineer survey.

Based on the research results the authors of this report recommend to amend the national standard for crossbucks at passive Railroad/Highway Grade Crossings in the MUTCD and to include the Buckeye crossbuck as an alternate design.

There are a few modifications to the design of the Buckeye crossbuck the authors of this report would like to discuss which one may want to consider in the future to make the Buckeye crossbuck even a better and more cost effective traffic control device.

1. It is the opinion of the authors of this report that the sheeting material of choice for the whole Buckeye crossbuck should be a micro-prismatic sheeting material with a high angularity (type VII, VIP, instead of type VII, LDP).
2. It is the opinion of the authors of this report that from a legibility point of view one could use either the red or black "RAILROAD CROSSING" legend on the blades and the number of tracks plate (if more than one track). A black legend would slightly increase the luminance contrast, which would very slightly increase the legibility distance and would comply better with established population stereotypes. On the other hand, a red legend will provide a color contrast, which could make up at least partially for the loss of some of the luminance contrast compared to a black legend. The unique shape of the crossbuck due to the use of the blades, is probably the most important visual stimulus for a driver approaching a public passive Railway/Highway Grade Crossings. The RAILROAD CROSSING legend color on the blades is most likely of little importance for driver comprehension and compliance.

3. It is the opinion of the authors of this report that one could omit the specular (mirror) Mylar stripes on the shield and that this would be of very little practical consequence from a visibility and safety point of view.

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APPENDIX

ODOT Dimensions and Specifications for the Buckeye Crossbuck and the Standard Improved Crossbuck Used in this Evaluation

NOTES

Highway Crossing Sign for use where automatic signal protection is not required.

Location
The sign shall be erected on the right hand side of the roadway on each approach to the crossing. The centerline of the post shall be placed not less than 10'6" or more than 15'0" from the centerline of the track and not less than 4'0" or more than 6'0" from the centerline of the post to the edge of the roadway surface, excluding aprons. In urban areas a clearance of 2'0" is recommended as a working minimum from the face of the curb, a clearance of 1'0" from the face of the curb where sidewalk width is limited. Where unusual conditions demand, variations determined by good judgement should provide the best possible combination of view and safety clearances attainable. The height should be 9'0" above the roadway level to the center of the crossbuck, but may be varied to suit local conditions. At locations where the Inventory Number is odd, Crossbuck and Number of Track signs shall be black with no YIELD SIGN installed. Where the Inventory Number is even, Crossbuck and Number of Track signs shall be red with YIELD SIGN installed.

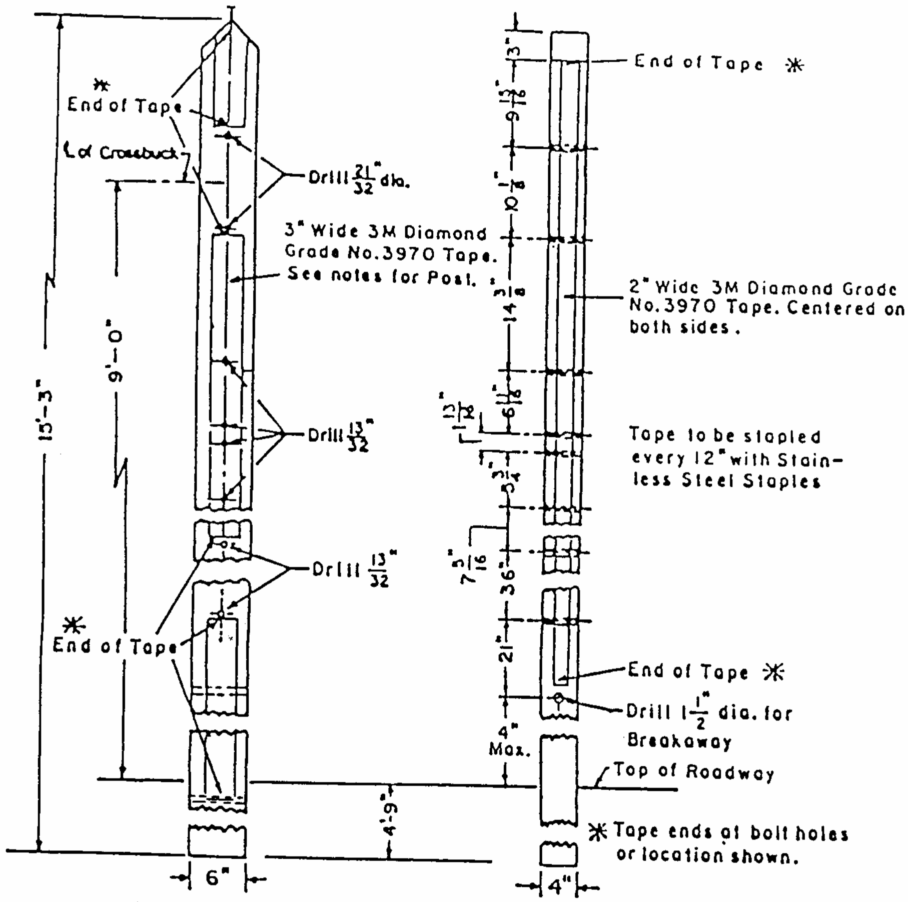
Crossbuck
The blade shall be 6063-T6 extruded aluminum. The face of the blades shall be covered with No. 3970 Silver, Diamond Grade, Scotchlite sheeting with No. 882 red or No. 805 black letters as appropriate for location. The Diamond Grade sheeting may be applied to the crossbuck blade with the directional arrow in line with the length of the blade. A 2" wide strip of No. 3970 Diamond Grade, Scotchlite is required on the back of each blade. The reflective strip should be centered and run the length of the blade.

Number of Tracks Sign
The sign is to be used where there are two or more tracks. The number displayed on the sign shall be the total number of tracks crossed, including sidings. Normally where the distance between tracks, measured along the highway, exceeds 100 feet, an additional crossing sign should be erected unless local conditions require otherwise. The sign shall be .081", 6061-T6 aluminum sheet. The face of the signs shall be covered with No. 3970 Diamond Grade, Scotchlite sheeting with No. 882 red or No. 805 black letters as appropriate for the location.

Yield Sign
The sign shall be .081", 6061-T6 aluminum sheet. The front of the sign shall be covered with No. 3970 Diamond Grade, Scotchlite sheeting with No. 882 red letters and stripes, and No. 5400 chrome stripes. The back of the sign shall have No. 3970 Diamond Grade, Scotchlite with No. 882 red and No. 5400 chrome stripes on the 12" bent sections of the sign only. The 9" center section of the back of the sign shall be blank.

Specifications
The letters and numerals of the Crossbuck, number of tracks sign and yield sign are to be per current U.S. DOT Series D and E.

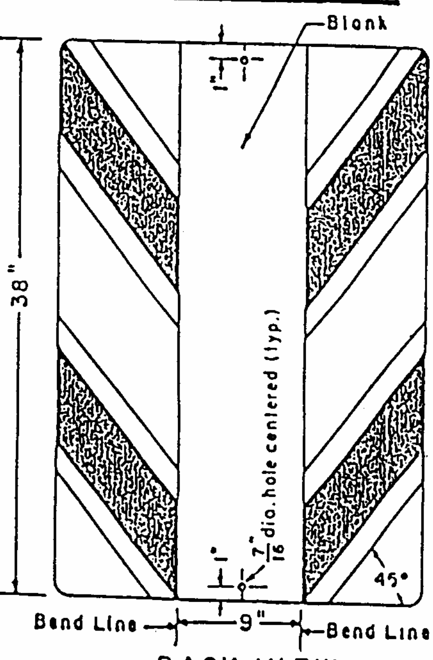
AAR/DOT Inventory Number
AAR/DOT Inventory Number tag should be installed on the back of the post at 6'0" above ground level. The Inventory Number tag should be 80 gauge aluminum sheeting measuring 4" by 9". The face of the Inventory Number tag shall be covered with Engineering Grade Reflective sheeting. The letters and numbers shall be No. 805 black. The Inventory Number tag shall be fastened with four coated nails.



FRONT VIEW

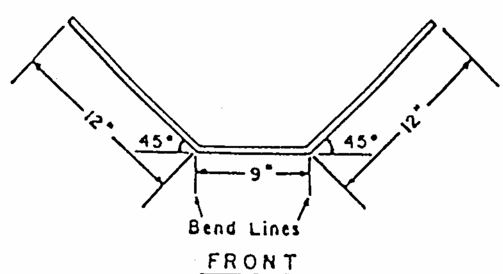
SIDE VIEW

ABRAMS POST

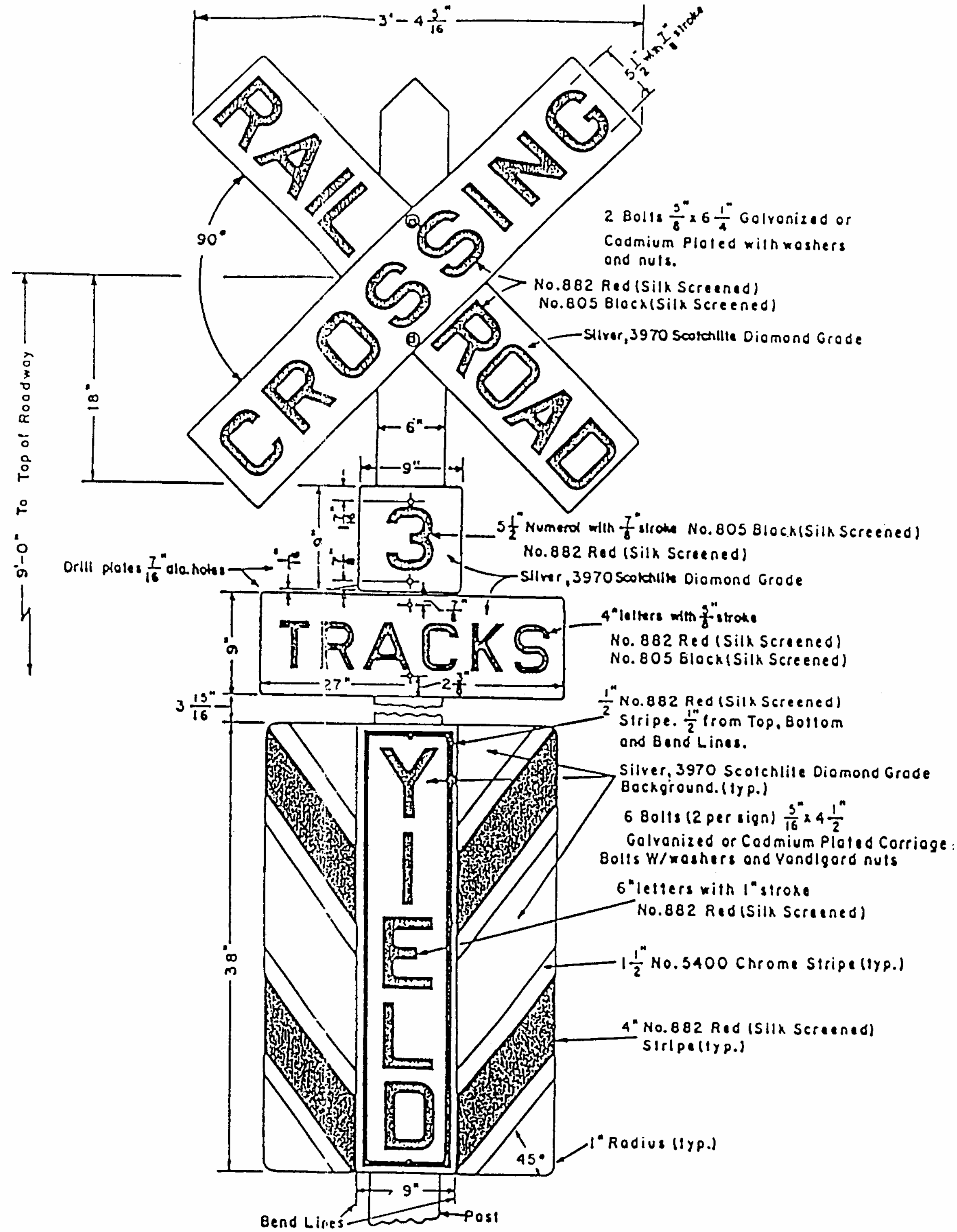


BACK VIEW

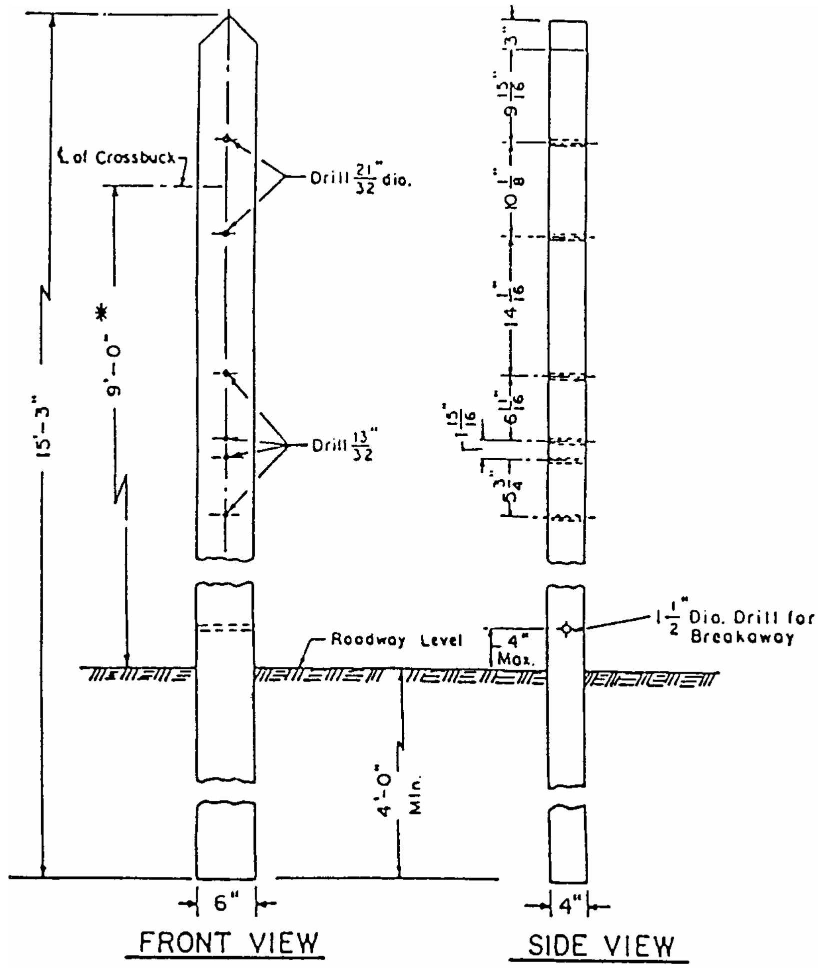
Post
The post shall be No. 2 Common Southern Pine with CCA pressure treatment in accordance with AWPA section C-2 for soil and fresh water use of southern pine. All holes are to be drilled prior to the post being treated. A 3" strip of reflective material on the back of the post to be applied from 4" above top of rail to top of post. A 3" strip of reflective material on the front of the post to be applied in three sections as shown on the plan. A 2" strip of reflective material on the side of the post to be applied from top of post to top of breakaway hole as shown.



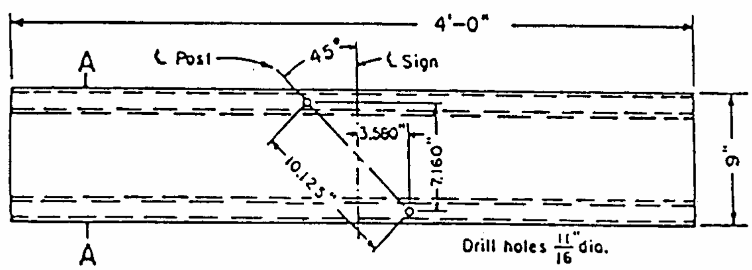
TOP VIEW


3'– 4 5/16"
5 1/2" with 7/8" stroke
RAIL
ROAD
CROSSING
90°
2 Bolts 5/8" x 6 1/4" Galvanized or Cadmium Plated with washers and nuts.
No.882 Red (Silk Screened)
No.805 Black (Silk Screened)
Silver, 3970 Scotchlite Diamond Grade
18"
9'-0" To Top of Roadway
6"
9"
3
5 1/2" Numeral with 7/8" stroke No.805 Black (Silk Screened)
No.882 Red (Silk Screened)
Silver, 3970 Scotchlite Diamond Grade
Drill plates 7/16" dia. holes
TRACKS
4" letters with 5/8" stroke
No. 882 Red (Silk Screened)
No. 805 Black (Silk Screened)
9"
27"
2 3/8"
3 15/16"
1/2" No.882 Red (Silk Screened) Stripe. 1/2" from Top, Bottom and Bend Lines.
Silver, 3970 Scotchlite Diamond Grade Background. (typ.)
6 Bolts (2 per sign) 5/16" x 4 1/2" Galvanized or Cadmium Plated Carriage Bolts W/washers and Vandlgard nuts
YIELD
6" letters with 1" stroke
No.882 Red (Silk Screened)
1 1/2" No.5400 Chrome Stripe (typ.)
4" No.882 Red (Silk Screened) Stripe (typ.)
38"
45°
1" Radius (typ.)
9"
Bend Lines
Post

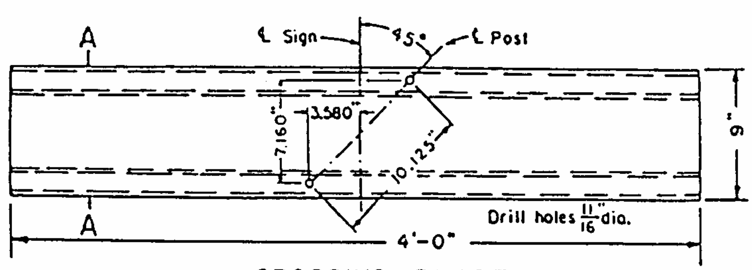
FRONT VIEW



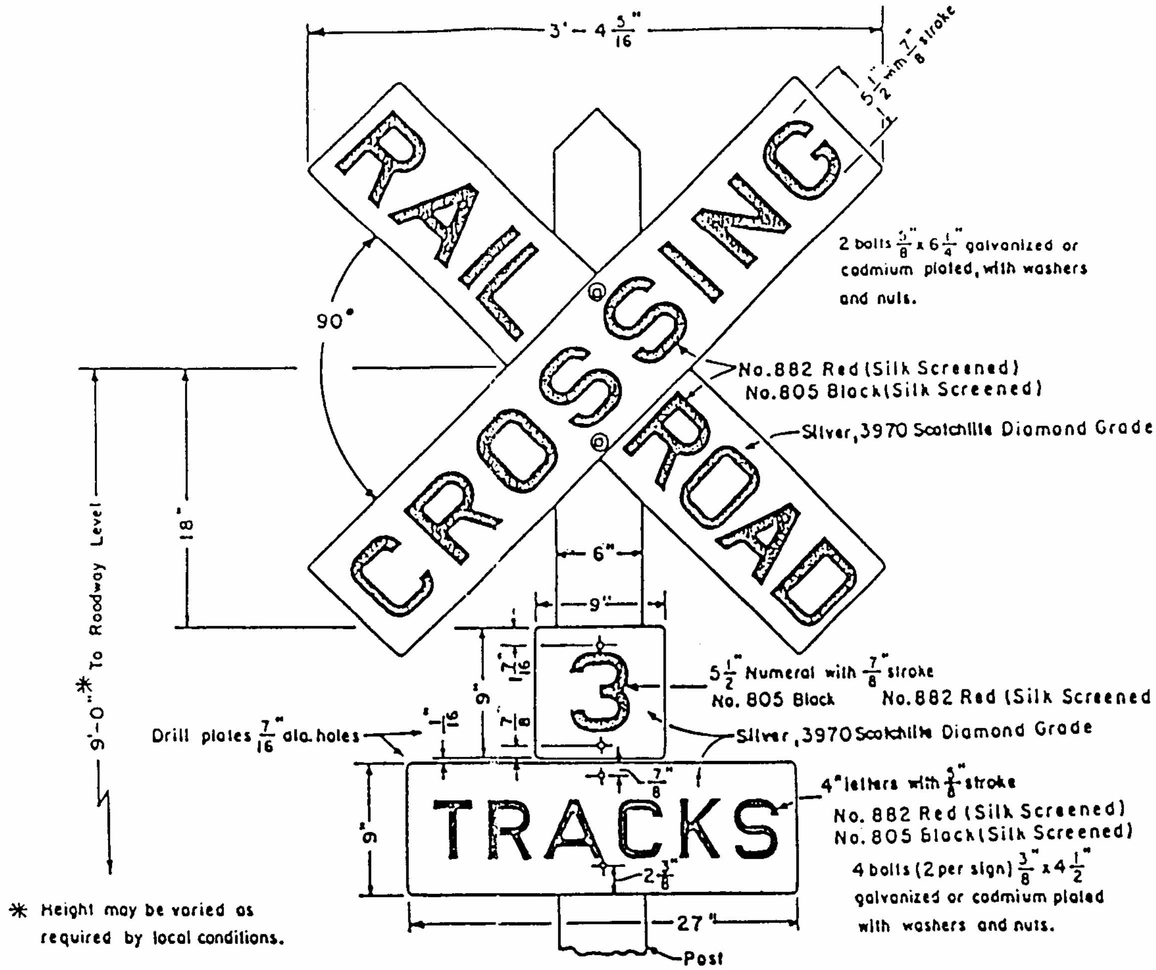
POST



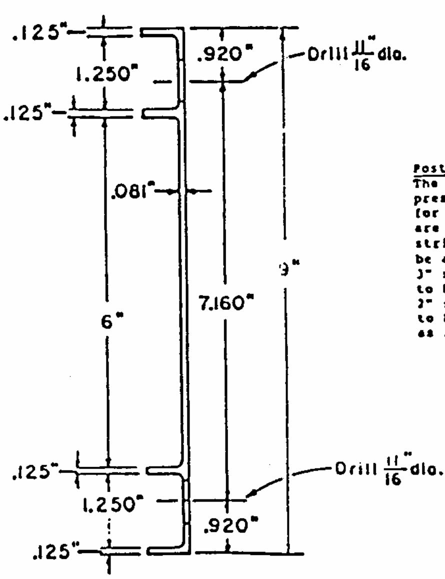
RAILROAD BLADE



CROSSING BLADE



CROSSING SIGN ASSEMBLY



Post
The post shall be No. 2 Common Southern Pine with CCA, pressure treatment in accordance with AWPA section C-2 for soil and fresh water use of southern pine. All holes are to be drilled prior to the post being treated. A 3" strip of reflective material on the back of the post to be applied from 4" above top of rail to top of post. A 3" strip of reflective material on the front of the post to be applied in three sections as shown on the plan. A 3" strip of reflective material on the side of the post to be applied from top of post to top of breakaway hole as shown.

SECTION A-A

Figure WS-9, Revision 12 (September 7, 1982), of the Ohio Manual of Uniform Traffic Control Devices for Streets and Highways [1], 1972, Representing the Dimensions and the Placement for the Current Standard Crossbuck

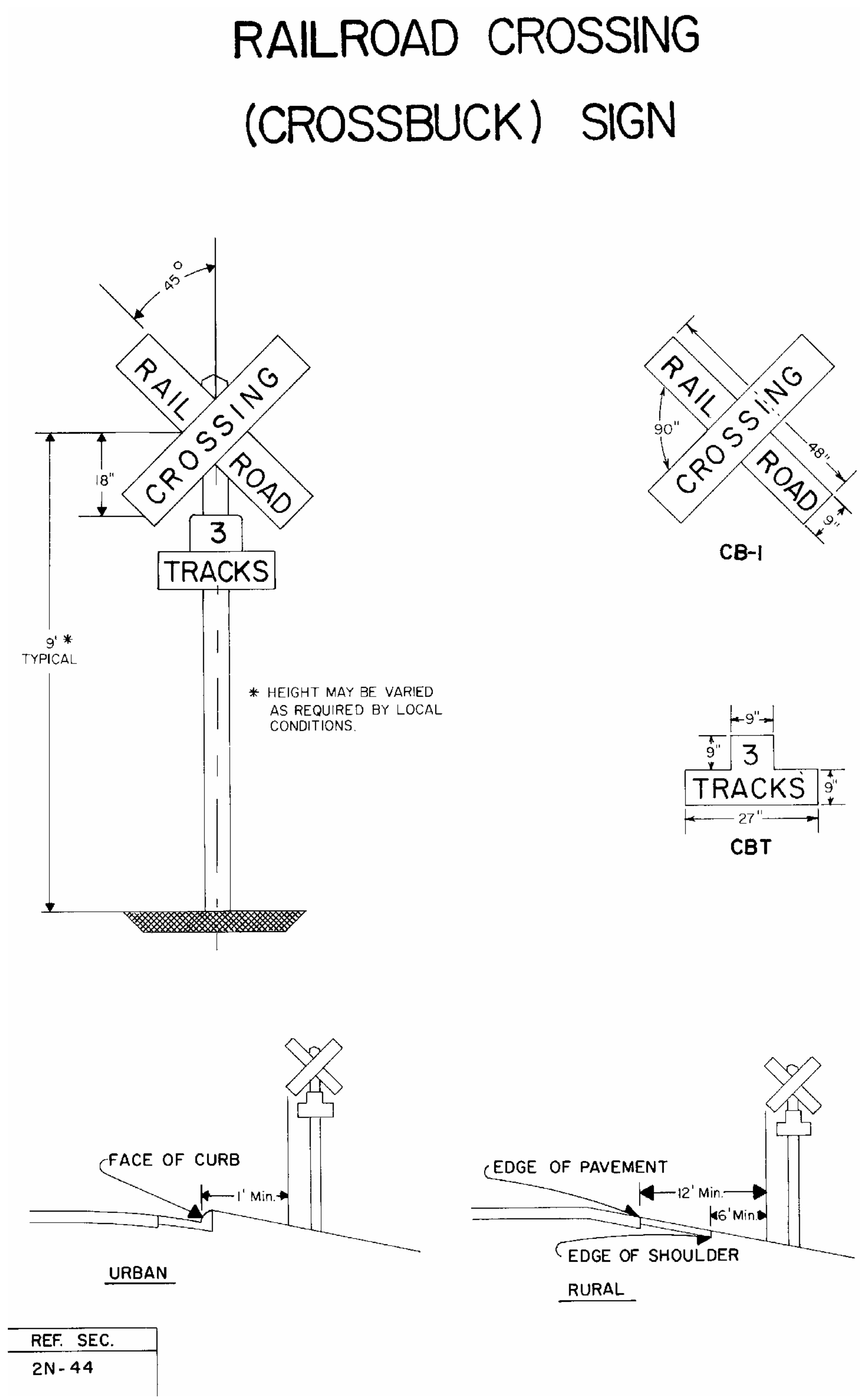


Figure RS-5, Revision 20 (January 1, 1997), of the Ohio Manual of Uniform Traffic Control Devices for Streets and Highways [1], 1972, Indicating the Absence of Special Lateral Placement Requirements for Crossbucks