Virginia Center *for* Transportation
INNOVATION
& RESEARCH

Investigation of the Safety Effects of Edge and Centerline Markings on Narrow, Low-Volume Roads

http://www.virginiadot.org/vtrc/main/online_reports/pdf/14-r3.pdf

LANCE E. DOUGALD
Research Scientist
Virginia Center for Transportation Innovation and Research

BENJAMIN H. COTTRELL, JR., P.E.
Associate Principal Research Scientist
Virginia Center for Transportation Innovation and Research

YOUNG-JUN KWEON, Ph.D., P.E.
Research Scientist
Virginia Center for Transportation Innovation and Research

IN-KYU LIM, Ph.D., P.E.
Senior Transportation Engineer
Virginia Department of Transportation

Final Report VCTIR 14-R3

VIRGINIA CENTER FOR TRANSPORTATION INNOVATION AND RESEARCH
530 Edgemont Road, Charlottesville, VA 22903-2454

www.VTRC.net

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VCTIR 14-R3	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Investigation of the Safety Effects of Edge and Centerline Markings on Narrow, Low-Volume Roads		5. Report Date: November 2013 6. Performing Organization Code:
7. Author(s): Lance E. Dougald, Benjamin H. Cottrell, Jr., P.E., Young-Jun Kweon, Ph.D., P.E., In-Kyu Lim, Ph.D., P.E.		8. Performing Organization Report No.: VCTIR 14-R3
9. Performing Organization and Address: Virginia Center for Transportation Innovation and Research 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 100982
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

Residency and regional traffic engineering staff of the Virginia Department of Transportation (VDOT) have postulated that the use of low-cost centerline and edgeline pavement markings, applied individually or in combination, can improve safety on narrow roads until higher cost, road-widening design improvements can be programmed and implemented. Mostly narrow secondary roads would fall in this category, but narrow primary roads would also be included.

The original purpose of this study was to develop a set of guidelines for VDOT traffic engineers to use when making decisions regarding the use of edgelines and centerlines on narrow, low-volume (less than or equal to 3,000 vehicles per day) roads. These guidelines were to be developed in a two-phase process, with the initiation of the second phase depending on the results of the first phase. This report describes the Phase I study, which included examining relevant literature; gathering information from other state departments of transportation; conducting a statewide inventory of edgeline and centerline markings; and performing a cross-sectional crash analysis of narrow roads identified in the inventory as (1) not having edge and centerline markings, (2) having both edge and centerline markings, (3) having edgeline markings only, and (4) having centerline markings only.

The study found that there is much variation in the practices of state departments of transportation with regard to installing pavement markings on roads 16 to 20 ft wide. In addition, the limited analysis of crash frequency, density, rate, and safety performance found no statistical difference between segments with and without centerlines and/or edgelines. Based on the results of this Phase I study, the project was limited to one phase. Therefore, a Phase II study to develop guidelines was not considered.

The study recommends that VDOT consider (1) developing a statewide process for a pavement marking inventory; (2) asking the Office of the Attorney General of Virginia for an interpretation/opinion of the term "appropriate" in House Joint Resolution No. 243 passed in the 1994 Session of the Virginia General Assembly; and (3) evaluating data from the Virginia Tech Transportation Institute's naturalistic driving study to determine if the data may be used to evaluate driver behavior on roads 16 to 20 ft wide with or without centerlines and/or edgelines.

17 Key Words: Edgelines, Centerlines, Pavement Markings, Narrow Roads, Pavement Marking Guidelines		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 34	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

INVESTIGATION OF THE SAFETY EFFECTS OF EDGE AND CENTERLINE MARKINGS ON NARROW, LOW-VOLUME ROADS

Lance E. Dougald
Research Scientist
Virginia Center for Transportation Innovation and Research

Benjamin H. Cottrell, Jr., P.E.
Associate Principal Research Scientist
Virginia Center for Transportation Innovation and Research

Young-Jun Kweon, Ph.D., P.E.
Research Scientist
Virginia Center for Transportation Innovation and Research

In-Kyu Lim, Ph.D., P.E.
Senior Transportation Engineer
Virginia Department of Transportation

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Center for Transportation Innovation and Research
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

November 2013
VCTIR 14-R3

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

ABSTRACT

Residency and regional traffic engineering staff of the Virginia Department of Transportation (VDOT) have postulated that the use of low-cost centerline and edgeline pavement markings, applied individually or in combination, can improve safety on narrow roads until higher cost, road-widening design improvements can be programmed and implemented. Mostly narrow secondary roads would fall in this category, but narrow primary roads would also be included.

The original purpose of this study was to develop a set of guidelines for VDOT traffic engineers to use when making decisions regarding the use of edgelines and centerlines on narrow, low-volume (less than or equal to 3,000 vehicles per day) roads. These guidelines were to be developed in a two-phase process, with the initiation of the second phase depending on the results of the first phase. This report describes the Phase I study, which included examining relevant literature; gathering information from other state departments of transportation; conducting a statewide inventory of edgeline and centerline markings; and performing a cross-sectional crash analysis of narrow roads identified in the inventory as (1) not having edge and centerline markings, (2) having both edge and centerline markings, (3) having edgeline markings only, and (4) having centerline markings only.

The study found that there is much variation in the practices of state departments of transportation with regard to installing pavement markings on roads 16 to 20 ft wide. In addition, the limited analysis of crash frequency, density, rate, and safety performance found no statistical difference between segments with and without centerlines and/or edgelines. Based on the results of this Phase I study, the project was limited to one phase. Therefore, a Phase II study to develop guidelines was not considered.

The study recommends that VDOT consider (1) developing a statewide process for a pavement marking inventory; (2) asking the Office of the Attorney General of Virginia for an interpretation/opinion of the term “appropriate” in House Joint Resolution No. 243 passed in the 1994 Session of the Virginia General Assembly; and (3) evaluating data from the Virginia Tech Transportation Institute’s naturalistic driving study to determine if the data may be used to evaluate driver behavior on roads 16 to 20 ft wide with or without centerlines and/or edgelines.

FINAL REPORT

INVESTIGATION OF THE SAFETY EFFECTS OF EDGE AND CENTERLINE MARKINGS ON NARROW, LOW-VOLUME ROADS

Lance E. Dougald
Research Scientist
Virginia Center for Transportation Innovation and Research

Benjamin H. Cottrell, Jr., P.E.
Associate Principal Research Scientist
Virginia Center for Transportation Innovation and Research

Young-Jun Kweon, Ph.D., P.E.
Research Scientist
Virginia Center for Transportation Innovation and Research

In-Kyu Lim, Ph.D., P.E.
Senior Transportation Engineer
Virginia Department of Transportation

INTRODUCTION

Pavement markings promote the safe use of roads by serving the important purpose of delineating the roadway and travel lanes. Roadway edge and centerline markings provide motorists with continuous information including lateral placement guidance, greater visibility of the roadway, and longer detection distances. The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) provides directives and guidance for the use of centerlines and edgelines based on roadway classification, width, and average daily traffic (ADT).

For centerlines, the directives are as follows:[1]

> Centerline markings *shall* be placed on all paved urban arterials and collectors that have a traveled width of 20 ft or more and an ADT of 6,000 vehicles per day (vpd) or greater. Centerline markings shall also be placed on all paved two-way streets or highways that have three or more traffic lanes (emphasis added).

Additional guidance is provided as follows:[1]

> Centerline markings *should* be placed on paved urban arterials and collectors that have a traveled width of 20 ft or more and an ADT of 4,000 vpd or greater. Centerline markings should also be placed on all rural arterials and collectors that have a traveled width of 18 ft or more and an ADT of 3,000 vpd or greater. Centerline markings should also be placed on other traveled ways where an engineering study indicates such a need. Engineering judgment should be used in determining whether to place centerline markings on traveled ways that are less than (16 ft) wide because of the potential for traffic encroaching on the pavement edges, traffic being affected by parked vehicles, and traffic encroaching into the opposing traffic lane (emphasis added).

For *edgelines,* the MUTCD states that the markings *shall* be placed on paved streets or highways with the following characteristics:[1]

a. freeways
b. expressways
c. rural arterials with a traveled way of 20 or more feet in width and an ADT of 6,000 vehicles per day or greater.

Further, the MUTCD states that edgeline markings *should* be placed on paved streets or highways with the following characteristics:[1]

a. rural arterials and collectors with a traveled way of 20 feet or more in width and an ADT of 3,000 vpd or greater and
b. at other paved streets and highways where an engineering study indicates a need for edgeline markings.

VDOT Pavement Marking Policy

In general, for two-lane roadways, the Virginia Department of Transportation (VDOT) currently installs centerline pavement markings on streets that have a minimum traffic count of 500 vpd and a minimum width of 18 ft. Edgelines are applied only on primary and secondary routes that do not have curb and gutter, have a minimum width of 20 ft, and have a centerline. Centerline and/or edgeline markings may be installed where an engineering study indicates a need for them. Subdivision streets are an exception to the policy and are not to be marked unless they are through traffic arteries.[2]

A problem statement submitted to the Virginia Center for Transportation Innovation and Research's (VCTIR) Traffic and Safety Research Advisory Committee (TASRAC) noted concern about safety on paved roads 16 to 20 ft wide that did not meet the design standards with respect to width and volume requirements to warrant a marked centerline or edgelines. As a result of a significant increase in housing developments and accompanying retail developments, nearby narrow roads are becoming more heavily traveled. Because these roads are not designed for such traffic volumes, there are concerns about congestion and safety. Some VDOT residency and regional traffic engineering staff have postulated that adding low-cost centerline and edgeline pavement marking installations, installed individually or in combination, would improve safety on narrow roads until such time that higher cost, road-widening design improvements could be programmed and implemented. According to one residency in the Richmond area, the request for edgelines is very high relative to the request for centerlines. Henrico County installs edgelines without centerlines; this is an option to consider.

The MUTCD[1] recommends pavement markings on all roads functionally classified as arterials or higher with daily traffic volumes of 3,000 vpd or greater. The VDOT policy[2] includes secondary roads that are mostly functionally classified as local roads. These roads also have volumes typically below 3,000 vpd. Therefore, these two standards are not directed toward the same types of roads. Nevertheless, with limited funds, the question remains as to whether or not VDOT should be marking fewer roads. There is also a need to assess the return on VDOT's investment for installing pavement markings on such roads.

PURPOSE AND SCOPE

The original purpose of this research was to develop a set of guidelines for VDOT traffic engineers to use when making decisions regarding marking edges and centerlines on narrow (a width of 16 to 20 ft) low-volume (less than or equal to 3,000 vpd) roads. These guidelines were to be developed in a two-phase process with the initiation of Phase II depending on the results of Phase I. The primary goals of Phase I were (1) to determine the safety effects of pavement markings on narrow, low-volume roads using crash analyses with cross-sectional data, and (2) if markings were effective, to identify segments that were good candidates for a before/after pilot study based on crash analyses. Phase II of the research was to examine the safety effects of longitudinal pavement markings on the pilot sites. The application of edgelines only, centerlines only, and both edgelines and centerlines would be considered. In addition, the Phase II research would compare the costs and benefits associated with the markings.

Based on the results of the Phase I research provided in this report, the scope of the project was limited to one phase. A Phase II study is not being considered.

METHODS

The following tasks were undertaken to achieve the purpose of the study.

1. Conduct a literature review.

2. Contact other state departments of transportation (DOTs) to obtain information on their pavement marking policies.

3. Develop a roadway marking inventory and a crash history database for narrow, low-volume roads in Virginia.

4. Develop a comparative crash analysis process and use it to perform a crash analysis for the roads identified in Task 3.

Literature Review

The literature review focused on recent and relevant edge and centerline marking research in the United States, in particular, studies on rural, low-volume roads and suburban roads that were formerly rural. The VDOT Research Library and relevant Transportation Research Board databases were used to identify literature related to the study.

Information Gathering From State DOTs

States that have policies that vary from the MUTCD guidelines with respect to marking narrow roads were identified via a questionnaire distributed electronically to traffic engineering staff in all 50 states. The questionnaire was also intended to gather information regarding how other states address the issue of pavement markings on narrow roads.

Development of Pavement Marking Inventory and Crash History Database for Narrow, Low-Volume Roads in Virginia

A process was developed to identify rural two-lane roadways with a width of 16 to 20 ft, their administrative road class, and their annual average daily traffic (AADT) using VDOT's Highway Traffic Records Information System (HTRIS). The regional operations maintenance manager in each of VDOT's five systems operations regions were emailed to obtain a copy of the region's pavement marking inventory of narrow, low-volume roads (i.e., roads with a width of 16 to 20 ft and a volume less than or equal to 3,000 vpd). Two of VDOT's nine districts did not have a marking inventory for these roads; one district had a paper copy of the inventory only; and the remaining six districts had an inventory in an Excel spreadsheet in varying formats. Some inventories were current; others were as much as 10 years old.

Because of these findings, the research team decided that the approach for incorporating the marking inventory data would be to identify the particular road sections that could be candidates for pavement markings. Crash histories on the inventoried road sections were obtained and added to the database. Google Earth was used to develop the marking inventory. The road sections were categorized by AADT band, pavement width, and the presence of pavement markings.

Development and Performance of Comparative Crash Analyses for Identified Narrow, Low-Volume Roads

Five years of VDOT crash data were used to conduct comparative crash analyses of the roads identified in Task 3 based on pavement width, AADT, and the presence of pavement markings.

RESULTS AND DISCUSSION

Literature Review

Use of Edgeline Markings on Rural Two-Lane Highways in Kentucky

Researchers in Kentucky performed a crash analysis of several miles of road with a width of approximately 19 ft between edgelines and found that the crash rate did not increase compared to the statewide rate for roads with lane widths of 9 and 10 ft. The percentage of single-vehicle crashes on these roads decreased compared to that for roads with similar lane widths. In addition, the study found that an edgeline with no centerline placed on a narrow, low-volume road did not result in increased crashes.[3]

In Kentucky, most rural two-lane roads with a lane width of 12 ft are arterials. Roads with a lane width of less than 9 ft are minor collectors or local roads. The highest percentage of major collectors has a lane width of 10 ft. Table 1 summarizes the study recommendations for the use of edgelines and centerlines on rural two-lane roads in Kentucky as a function of total pavement width (including paved shoulder).

In addition, the study recommended that rumble strips be placed where there is a paved shoulder and that rumble stripes (a rumble strip with a pavement marking over it) be considered. The recommendations are consistent with Kentucky's current guidelines for the use of centerline markings.

Table 1. Recommended Use of Edgelines and Centerlines for Kentucky

Pavement Width (ft)	Lane Width (ft)	Centerline?	Edgeline?	Paved Shoulder Width (ft)
28	12	Yes	Yes	2
27	12	Yes	Yes	1.5
26	11	Yes	Yes	2
25	11	Yes	Yes	1.5
24	11	Yes	Yes	1
23	10	Yes	Yes	1.5
22	10	Yes	Yes	1
21	9	Yes	Yes	1.5
20	9	Yes	Yes	1
19	8	Yes	No	1.5
18	8	Yes	No	1
17	7.5	No	Yes	1
16	7	No	Yes	1
15	6.5	No	Yes	1
14	6	No	Yes	1

Note: These recommendations are from a study by Agent and Green.[3]

Safety Impact of Edgelines on Rural Two-Lane Highways in Texas

In a study performed for the Texas DOT, crash statistics comparisons were made for highways with and without edgelines. In addition to general accident frequency analysis, varying traffic lane and shoulder widths, and roadway curvature, factors such as accident type, intersection presence, light condition, surface condition, crash-supporting factors, severity, driver age, and driver gender were considered. A before/after comparison of the effects of edgelines on rural two-lane highways found that such treatments reduced accident frequency up to 26 percent and that the highest safety impacts occur on curved segments of roadways with lane widths of 9 to 10 ft.[4]

A follow-up study investigated the impact of edgelines on driver behavior and reactions, including vehicle navigational and positioning issues, speed selection, and driver visual perception. Stationary traffic observation, test driving, and several laboratory experiments were conducted for the selected rural two-lane highways with different roadway widths before and after edgelines were installed. The edgeline treatments increased speed on average by 5 mph, or 9 percent, on both straight and curved highway segments; moved vehicles an average of 20 in toward the pavement edge during both daylight and darkness; reduced vehicle fluctuation around a trajectory center line by 20 percent; reduced drivers' mental workload; improved drivers' estimation of roadway curvature; and increased drivers' advance time of intersection identification.[5]

Effects of an Edgeline on Speed and Lateral Position: A Meta-Analysis

In this meta-analysis study, Van Driel et al.[6] evaluated the effects of an edgeline on the speed and lateral position of road users. They concluded that the effects of an edgeline on speed are related to the presence of a centerline. Further, applying only edgelines to a road that previously did not have any longitudinal pavement markings increases the speed of road users and removing previously marked centerlines and replacing them with edgelines decreases the speed. Results with respect to adding an edgeline to a road with a centerline were unclear. The study also concluded that shoulder width and road environment contribute to the effects of an edgeline on lateral position. In combination with wide shoulders or buildings and/or trees next to a road, edgelines lead to shifts of the lateral position toward the edge of the road, and in combination with narrow shoulders or open fields, edgelines lead to shifts toward the center of the road.

Impact of Pavement Edgeline on Vehicular Lateral Position on Narrow Rural Two-Lane Roadways in Louisiana[7]

The objective of this study was to determine if marking edgelines on rural narrow two-lane highways would result in any negative effect on drivers' behavior that could, in turn, decrease highway safety. The study focused on two-lane highways between 20 and 22 ft wide with an ADT between 86 and 1,855 vpd.

The major findings of the study were as follows. With edgelines, centralization of vehicles' position is more apparent during nighttime, which reduces the risk of run-off-road and head-on collisions. Edgeline markings generally cause drivers to operate their vehicle away from the road edge, irrespective of the roadway alignment. This movement could reduce run-off-road crashes (the most common type of crash on narrow two-lane highways). The analysis also found that even though the counts of centerline crossings increased at several sites during the daytime, they decreased at night when the distribution of vehicles' lateral position is more centralized. The magnitude of the impact of edgeline markings is influenced by roadway width, operating speed, time of day, frequency of heavy vehicles, pavement condition, roadway alignment, and traffic from the opposite direction. Because of the limited number of curved sections, the impact of edgelines for horizontal curves is inconclusive. Edgelines have no or little effect on the average operating speed. The before/after measurements showed that the edgeline has a positive impact on rural narrow two-lane highways in Louisiana, particularly at night. The study noted that an additional in-depth study was necessary for curve sections. Further, the qualitative safety effect in terms of number of crashes before/after edgelines should be monitored and documented as a continuation of the project.

Benefit-Cost Analysis of Lane Marking

In this study,[8] a benefit-cost analysis of edgelines, centerlines, and lane lines was presented. The analysis considered marking applied with fast-drying paint or thermoplastic, the most frequently used marking materials in the United States. The results of a literature review and telephone survey suggested striping with fast-drying paint costs $0.035/linear-foot in rural areas and $0.07/linear-foot in urban areas. Thermoplastic lines cost more than painted ones, but they can have lower life-cycle costs; in areas where snowplowing is unnecessary, the lines have a longer life. Published literature suggests that existing longitudinal pavement markings reduce crashes by 21percent and edgelines on rural two-lane highways reduce crashes by 8 percent. Applying these percentages to published aggregate crash costs by roadway type yields the safety benefits.

The analysis assumed that markings improve traffic flow from 6 A.M. to 7 P.M. on arterials, freeways, and interstate highways, increasing average speeds by 2 mph. On average, each $1 currently spent on pavement striping yields $60 in benefits. The benefit-cost ratio rises with traffic volume. The urban ratio is twice the rural ratio. The sensitivity analysis showed that the benefit-cost ratios are robust. Where striping reduces congestion, the travel time savings alone yield a positive benefit-cost ratio for striping. Most highways already have a full complement of lines; rural two-lane highways, however, sometimes lack edgelines. Edgelines on these roads would yield benefits exceeding their costs if an average of one non-intersection crash occurred annually every 15.5 mi of roadway.

Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research

One of the most important aspects of a safe and efficient roadway is the uniform application of pavement markings to delineate the roadway path and specific traffic travel lanes. Pavement markings can communicate information to road users as no other traffic control device can. They provide continuous information to road users related to roadway alignment, vehicle positioning, and other important driving-related tasks. It is estimated that in the United States alone, approximately $2 billion is spent annually on pavement markings.[9] Despite these expenditures, there is a general void in terms of a consolidated effort to quantify proven benefits of pavement markings, although many research projects have focused on specific elements of pavement markings. This study[9] was conducted to bring together many of the recent and ongoing research efforts to demonstrate a renewed perspective regarding the benefits of pavement markings and, where information is available, describe the benefits of various aspects of pavement markings. This study presents areas where conclusive findings are available and describes areas where findings are available but show inconsistent and sometimes conflicting results.

According to the study, almost all recent crash research has been geared toward adding edgelines to highways. Recent crash studies as well as those more than a half-century old have conclusively shown that adding edgelines to rural two-lane highways can reduce crashes and fatalities. Some of the findings demonstrate that these benefits can be achieved with narrow pavement widths (18 ft or less) and low AADTs (as low as 1,000 vpd). The benefits have been shown to be statistically significant in areas of all terrain types and in all locations during nighttime conditions and nighttime low-visibility conditions. In terms of vehicle speeds and lateral placements, there appears to be either no real impacts or at most only subtle impacts as a result of adding edgeline markings. This includes narrow two-lane highways and day and night conditions.[9]

Rural Road Departure Crashes: Why Is Injury Severity Correlated With Lane Markings?

This study by Kusano and Gabler[10] at Virginia Tech was conducted to determine if injury outcome is related to the presence of lane lines in road departure crashes on rural two-lane roads. Cases were extracted from a nationally representative sample of crashes, where supplemental crash reconstructions were performed as part of NCHRP Project 17-22. The dataset consisted of 851 road departure collisions that corresponded to 271,603 weighted collisions. The majority of cases (55%) occurred on two-lane roads with undivided two-way traffic. Of all paved two-lane undivided roads with two-way traffic, only 19 percent of collisions were on roads that did not have lane markings, yet these collisions accounted for a disproportionate 48 percent of seriously to fatally injured drivers.

A logistic regression found that the presence of lane marking at the side of the first lane departure decreased the odds of serious injury for the driver, adjusted for belt use and departure velocity. The finding that the presence of lane markings was correlated with injury severity in road departure crashes was unexpected. Roadside factors, such as maximum side slope and speed reduction from departure to impact, did not appear to explain the difference in injury outcome. Only 42 percent of drivers, however, were wearing their safety belt in crashes on unmarked roads compared to 67 percent of drivers on marked roads. In this sample, lane marking presence was correlated to safety belt use. This result suggests that the primary explanation for higher injury levels on unmarked roads was lower safety belt use, not the absence of lane markings.

State DOT Practices With Regard to Pavement Markings

It is important to note that many state DOTs do not own or operate the secondary road system in their state and therefore do not make decisions regarding pavement markings on narrow roads. Even with this limitation, 26 of 49 states did respond to the inquiry regarding their marking policies. In many cases, the policy included a width and/or volume criterion.

Criteria for Centerlines

Texas and Pennsylvania place centerlines on all roadways that have a traveled way of at least 16 ft. Missouri has a threshold of 18 ft, and Indiana, Montana, and Colorado have a threshold of 20 ft. North Carolina and New Hampshire use ADT as the criterion with thresholds of 100 vpd and 6,000 vpd, respectively.

The responding states that have centerline marking criteria similar to those of Virginia are Kentucky and Delaware. Kentucky requires a minimum pavement width of 18 ft (the same as Virginia) and an ADT of 300 vpd (200 vpd less than Virginia). Delaware requires a minimum pavement width of 19 ft and an ADT of 500 vpd. Delaware's ADT requirement of 500 vpd is revised from their previous requirement of 1,000 vpd. According to Delaware, the DOT has been under increasing pressure to lower its ADT criterion so that selected roads with higher traffic demands qualify for centerlines.

Criteria for Edgelines

Five responding states use the MUTCD guidance (minimum width of 20 ft and ADT of at least 3,000 vpd) as the criteria for edgelines. Four responding states reported lower width or volume thresholds, including North Carolina (minimum width 16 ft, ADT of 100 vpd), Texas (no volume requirement), Pennsylvania (ADT of 1,000 vpd), and Missouri (ADT of 400 vpd).

State DOT policies provided and reviewed through this effort typically provide edgeline marking options such as striping for roadways that do not have centerlines and for delineation to minimize unnecessary driving on paved shoulders. Conversely, options are given to exclude edgelines if the traveled way edges are delineated by curbs, parking, bicycle lanes, or other markings. The Minnesota DOT provides language that two-lane roadways "shall have pavement edgelines wherever there is poor color contrast between pavement and shoulders (especially at night), where fog conditions or unusual hazards may exist, or on approaches to piers, abutments, and retaining walls."

Additional Information From States

The state DOTs were also asked if specific safety studies had been performed relating to when and where to mark edge and centerlines. Delaware and Kentucky were the only responding states that had performed such studies. Delaware conducted numerous studies on striped road segments that considered factors such as traffic characteristics, types of crashes (crossover, run-off-the-road, etc.) and compared them to those of similarly classed roadways without striping. Results from the studies were not readily available for inclusion in this discussion.

As discussed previously, researchers in Kentucky[3] recommended installing edgelines first and then adding centerlines as the roadway gets wider. To date, Kentucky has not modified their striping policy because of concerns on how they would address a possible public "outcry" if edgelines were installed and centerlines removed on particular roadways. Kentucky's fear is that the public would feel the roadways had been narrowed.

Another area of inquiry was whether the state DOTs had experienced situations where traffic volume attributable to development on narrow rural roadways once classified as low-volume roads had increased to a level where pavement markings were/are considered a safety countermeasure. Of the states contacted, Wyoming, Delaware, and Oregon provided feedback on this issue. When this situation occurs in Wyoming, centerlines are striped. In Delaware, this issue has been one of the driving forces in two counties where roads that once handled only a few vehicles per day now handle substantially more vehicles per day. In response to this concern, as it was under significant external pressure, Delaware established a low AADT criterion for centerlines. Oregon will mark edgelines on roadways that do not meet striping warrants if there are documented safety problems that can be mitigated by edgeline installation.

Development of Pavement Marking Inventory and Crash History Database for Narrow, Low-Volume Roads in Virginia

Overview

As discussed previously, when compiling a statewide marking inventory for roads 16 to 20 ft wide, the researchers found that there was much variation in how VDOT districts maintained a pavement marking inventory in terms of software, format, data quality, and frequency of updating the inventory. Moreover, two districts did not have an inventory for these roads. Therefore, there is a need for VDOT to have a uniform, up-to-date pavement marking inventory for all VDOT-maintained roads. To address inventory limitations, a process of extracting pertinent roadway inventory from VDOT resources to develop a crash history database for narrow roads was developed.

Development of Database

VDOT maintains more than 61,000 mi of highways and stores detailed records of historical roadway information in HTRIS. HTRIS is the official repository of VDOT roadway information used for internal and external management and reporting. It is a comprehensive data management system, interrelating and consolidating relational information, and consists of 10 subsystems storing unique highway and traffic information. For the purpose of this study, 3 subsystems, i.e., Roadway Inventory (RDI), Accident (ACC), and Traffic Monitoring System (TMS), were used to form the database.

The RDI represents the VDOT highway network that consists of more than 200,000 roadway segments and provides the data maintenance functions for route identification, aliases, nodes, and links. In effect, the RDI is the backbone used by all other subsystems in HTRIS to locate events and features along individual segments. Therefore, all official roadway characteristics and events are entered and maintained in the RDI subsystem.

The ACC contains crash, vehicle, and occupant information collected on police crash report forms (Form FR300) at the scene of a crash combined with the location of crash and roadway condition information entered by VDOT's Traffic Engineering Division (TED).

The TMS contains traffic data collected by traffic count devices placed on VDOT-maintained highways throughout the state and calculates AADT, daily vehicle miles traveled, the K-factor, the single truck factor, the combination truck factor, average speed, the 85th percentile speed, the directional factor, etc. The TMS relies on the RDI and produces AADT data for use by other HTRIS components.

A set of Structure Query Language (SQL) statements, a standard programming language for retrieving Oracle databases, is used to connect the three subsystems in HTRIS and compile the data in a compatible format for data analysis. Statistical Package for the Social Sciences (SPSS) was then used to manipulate the data further to produce a statistical summary.

Ten-Step Procedure to Develop Marking Inventory and Crash Database

In order to examine the safety effectiveness of pavement markings, especially on "narrow" and "low-volume" roads, this study used 2004–2008 crash, roadway inventory, and traffic data in HTRIS. A framework for relating the processes of data manipulation among the subsystems to develop the marking inventory and crash database is shown in Figure 1.

The procedure is described as follows:

Step 1. Access the RDI subsystem from HTRIS and extract 2004–2008 historical roadway inventory data. VDOT was transitioning from one business data warehouse system to a new one when this project began. Therefore, 2009 and 2010 data were not yet incorporated into the new system. For this reason, 2008 was the most recent year for the latest available data for a 5-year period.

Step 2. Conduct rudimentary network screening to filter out roadway segments that had been added to or removed from the highway system during the 5-year analysis period. Table 2 provides the results of the screening and shows annual and consistently maintained statewide roadway mileage.

Step 3. Filter out segments defined as interstates. This screening process keeps all roads classified as primary and secondary routes.

Step 4. Add a constraint to include only segments consisting of (1) two-lane, two-way and (2) undivided facility types as cross-sectional attributers. Therefore, segments consisting of multi-lanes and other than undivided facility types are excluded in this process.

Step 5. Screen the RDI data to consider only narrow roads (pavement widths from 16 to 20 ft) that do not meet design warrants for centerline or edgeline markings.

Step 6. Combine the TMS and RDI data.

Step 7. Incorporate an AADT of less than or equal to 3,000 to meet the criterion for low-volume roads. Annual segment AADTs from 2004–2008 were extracted from the TMS subsystem in HTRIS and joined to the results of the identified segments in Step 5. About 4.2 percent (2,516.80 mi) of the total 60,066.36 mi is collected through this step. A descriptive summary of length and AADT categorized by route system and pavement width is shown in Table 3.

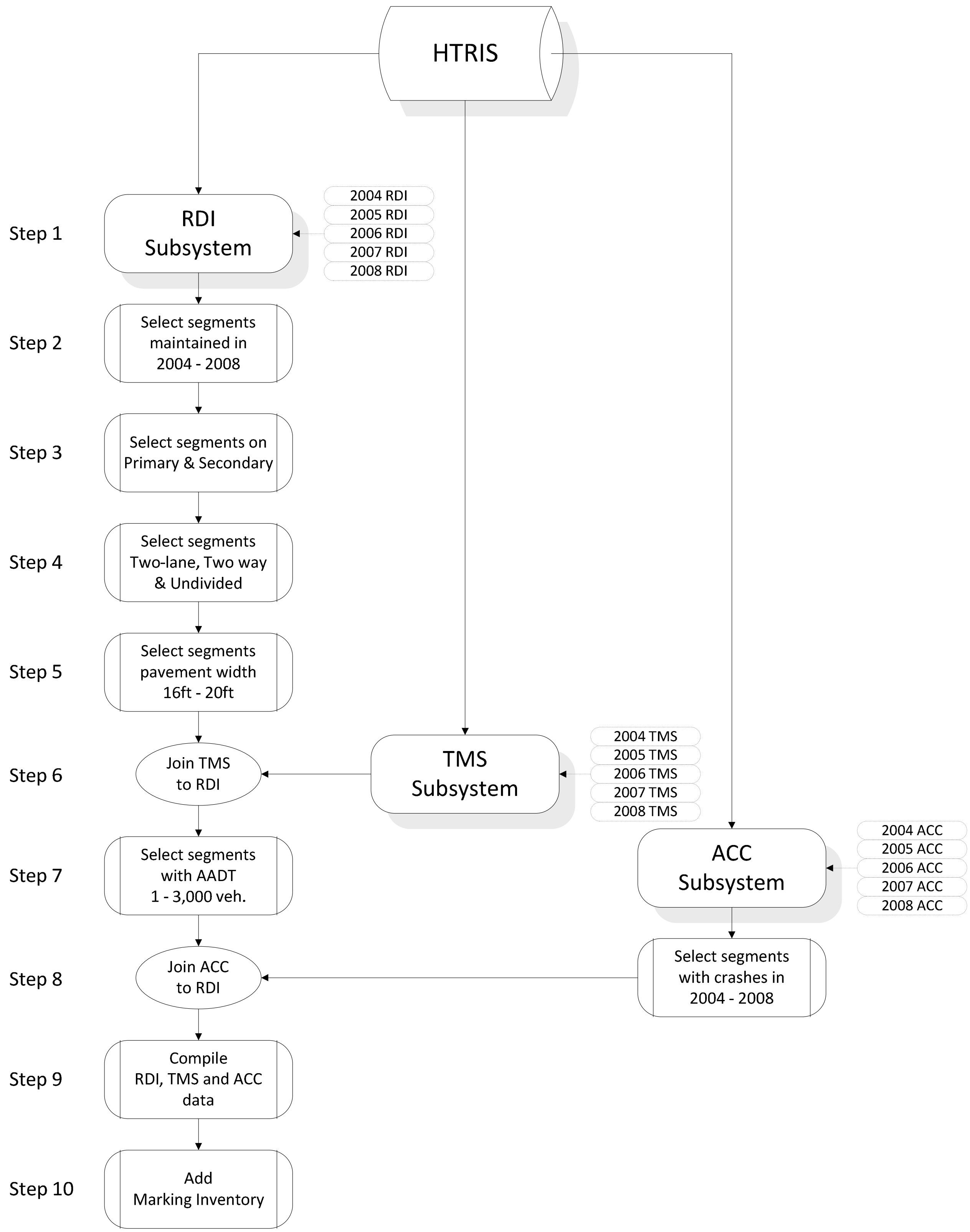

Figure 1. 10-Step Procedure for Developing Marking Inventory and Crash Database. HTRIS = Highway Traffic Records Information System; RDI = Roadway Inventory; TMS = Traffic Monitoring System; AADT = Annual Average Daily Traffic; ACC = Accident.

Table 2. 2004-2008 Annual RDI Statewide Roadway Mileage

Year	Annual Statewide Roadway Mileage	Consistently Maintained Roadway Mileage
2004	61,043.29	60,066.36
2005	61,398.19	
2006	61,722.63	
2007	61,979.72	
2008	62,187.02	

RDI = Roadway Inventory.

Table 3. Eligible Narrow and Low-Volume Segments Statewide

Number of Lanes and Facility Type	Route System	Pavement Width (ft)	Length (mi)	Annual Average Daily Traffic		
				Minimum	Maximum	Average
Two-lane and Undivided	Primary	16	20.56	167	811	449.8
		17	11.20	45	465	228.6
		18	162.09	45	2,726	1,014.1
		19	67.90	118	2,844	1,173.4
		20	1,456.11	167	2,996	1,634.9
	Secondary	16	122.50	24	2,896	586.0
		17	8.70	38	1,187	350.2
		18	350.57	4	2,907	316.4
		19	31.92	33	2,575	551.0
		20	285.25	3	2,907	342.0
Total			2,516.80	3	2,996	995.6

Step 8. Extract crash data from the ACC subsystem in HTRIS and join to the identified eligible 2,516.80 mi of narrow and low-volume segments identified in previous steps. For analyzing the safety impact of centerline and edgeline pavement markings, 2004–2008 crash data were extracted from the ACC subsystem and joined to the identified eligible 2,516.80 mi of narrow and low-volume segments (Steps 1 through 7). Intersection crashes, which occurred at or within 250 ft from the center of an intersection, were excluded in the joining process because intersection crashes were not of interest in this analysis.

Step 9. Compile the TMS and ACC data into the RDI data structure and combine yearly by categories of route system and pavement widths. Table 4 shows the initial summary of annual crash frequency categorized by route system and pavement width. During this step, it was clear

Table 4. 2004-2008 Crash Summaries by Route System and Pavement Width

Number of Lanes & Facility Type	Route System	Pavement Width (ft)	Length (mi)	Annual Crash Frequency					
				2004	2005	2006	2007	2008	Total
Two-lane & Undivided	Primary	16	20.56	11	9	16	18	12	66
		17	11.20	2	2	0	1	3	8
		18	162.09	81	111	118	126	100	536
		19	67.90	44	38	43	47	46	218
		20	1,456.11	993	1,099	1,074	1,061	955	5,182
	Secondary	16	122.50	43	61	50	56	42	252
		17	8.70	2	3	2	4	1	12
		18	350.57	45	72	70	64	76	327
		19	31.92	3	13	6	7	11	40
		20	285.25	27	30	35	31	43	166
Total			2,516.80	1,251	1,438	1,414	1,415	1,289	6,807

that the sample sizes for pavement widths of 17 and 19 ft were small compared to those for 16, 18, and 20 ft (see Table 4). Therefore, the pavement sections 17 and 19 ft wide were omitted from the analysis; the total mileage length was reduced to 2,397.08 mi.

Step 10. Obtain the pavement marking inventory data by using the KML format through ArcGIS 10. The 2,397.08 mi that consisted of 1,694 different routes were reviewed for the presence of centerlines and edgeline pavement markings using the "bird's-eye view" of each route. The segments where it was hard to distinguish the presence of the markings were recorded as having no pavement markings. Moreover, some segments included a mix of pavement marking conditions (e.g., a portion of the segment included markings whereas another portion did not). Segments with mixed marking conditions were omitted. As a result, a total of 2,033.34 mi were classified using four conditions of pavement markings:

1. segments with centerline and edgeline pavement markings
2. segments with centerline pavement markings
3. segments with edgeline markings
4. segments without pavement markings.

Because there was no practical way to validate the condition of pavement markings (site visits were not practical), an assumption was made that the conditions shown in images of pavement markings on the Google Earth maps (image dates ranged from 1998 to 2012) were the same as conditions from 2004–2008, the crash data period. Figures 2 and 3 are example screenshots of the images.

After the pavement marking inventory was added to the database, the road sections were grouped by six AADT bands and the presence of pavement markings (see Table 5). As may be seen, several groups had road sections of less than 2 mi, as indicated in bold. The six AADT bands were then reduced to two bands to increase the sample size in each group; Table 6 shows the resulting two bands. VDOT's typical practice is not to install edgelines without centerlines. This explains why the sample sizes for road sections with only edgelines are small. Table 7 shows the number and length of road sections and average crash history by AADT band, pavement width, and presence of pavement markings.

Development and Performance of Comparative Crash Analyses for Identified Narrow, Low-Volume Roads

The question to be addressed in the comparative crash analysis was as follows: Are narrow roads with pavement markings safer than those without pavement markings? This was answered by comparing the crash history of roads with no markings, centerline markings, centerline and edgeline markings, and edgeline-only markings. Because VDOT's typical practice is not to use edgeline-only markings, the sample size for this segment was small.

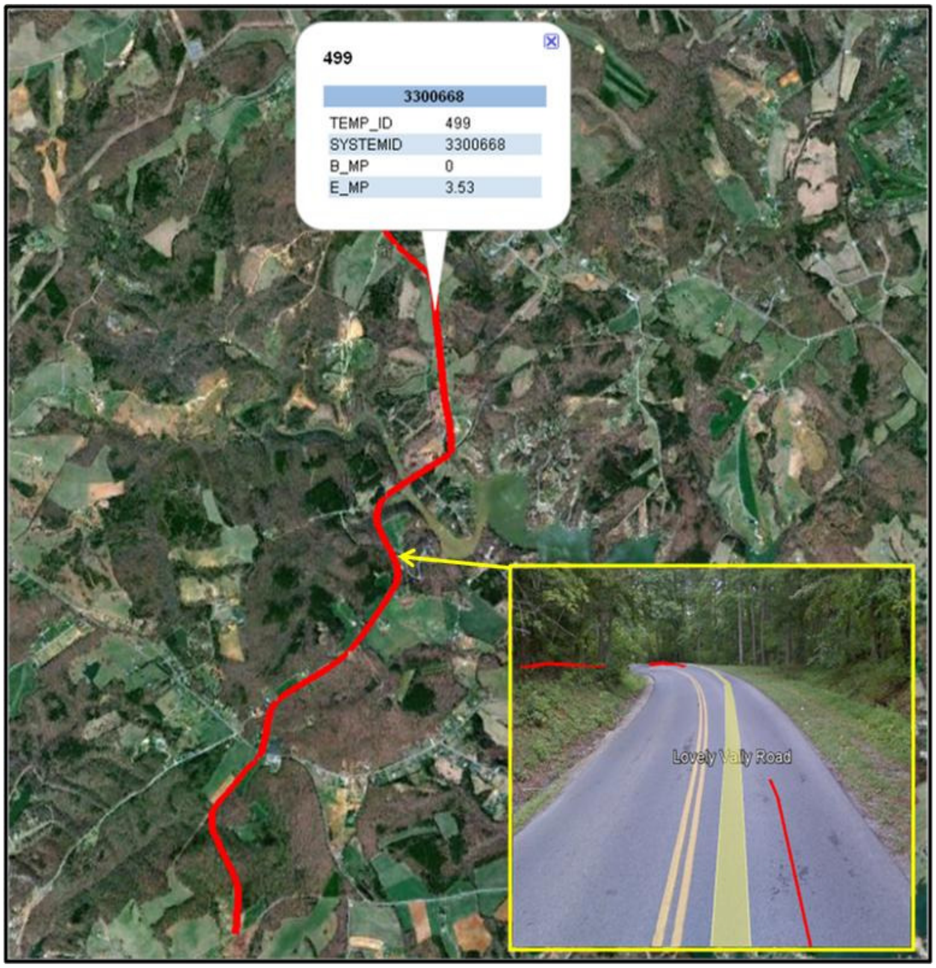

Figure 2. Sample Segment With Centerline Markings Only

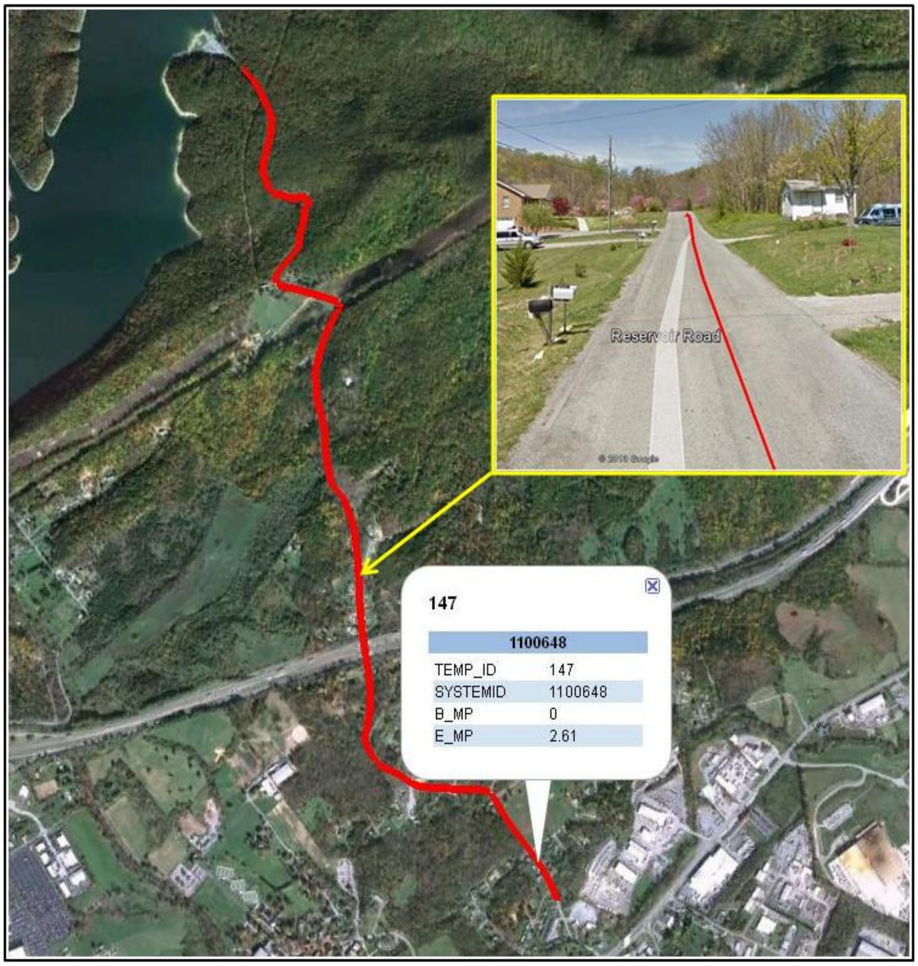

Figure 3. Sample Segment Without Pavement Markings

Table 5. Road Sections by Six AADT Bands and Presence of Pavement Markings

AADT Band	Centerline?	Edgeline?	No. of Segments	Length (mi)
1. ≤500	No	No	1910	496.41
		Yes	12	6.37
	Yes	No	27	25.35
		Yes	232	194.37
2. 501-1,000	No	No	137	33.59
		Yes	**5**	**1.84**
	Yes	No	64	38.69
		Yes	387	239.10
3. 1,001-1,500	No	No	25	4.09
		Yes	**0**	**0.00**
	Yes	No	62	25.40
		Yes	501	298.88
4. 1,501-2,000	No	**No**	**5**	**1.30**
		Yes	**1**	**1.00**
	Yes	No	40	7.89
		Yes	535	262.26
5. 2,001-2,500	No	**No**	**4**	**0.94**
		Yes	**0**	**0.00**
	Yes	No	31	10.96
		Yes	513	254.84
6. 2,501+	No	**No**	**0**	**0.00**
		Yes	**0**	**0.00**
	Yes	No	15	5.40
		Yes	291	124.66
Total			4,797	2,033.34

A notation in bold indicates road sections less than 2 miles.

Table 6. Road Sections by Two AADT Bands and Presence of Pavement Markings

AADT Band	Centerline?	Edgeline?	No. of Segments	Length (mi)
1. ≤500	No	No	1,910	496.41
		Yes	12	6.37
	Yes	No	27	25.35
		Yes	232	194.37
2. 501-3,000	No	No	171	39.92
		Yes	6	2.84
	Yes	No	212	88.34
		Yes	2,227	1,179.74
Total			4,797	2,033.34

AADT = annual average daily traffic.

Table 7. Number and Length of Road Sections and Average Crash History by Pavement Width, AADT Band, and Presence of Pavement Markings

Pavement Width (ft)	AADT Band	Centerline?	Edgeline?	No. of Segments	Length (mi)	2004-2008 Total Crashes	2004-2008 RD Crashes	Average Total Crash Density	Average RD Crash Density
16	1. ≤500	No	No	84	36.6	41	32	0.22	0.17
			Yes	4	2.82	1	1	0.07	0.07
		Yes	No	5	6.08	10	7	0.33	0.23
			Yes	13	14.67	22	20	0.30	0.27
	2. 501-3,000	No	No	34	7.22	8	7	0.22	0.19
			Yes	0	0	0	0	-	-
		Yes	No	16	12.6	45	33	0.71	0.52
			Yes	43	29.08	127	93	0.87	0.64
18	1. ≤500	No	No	708	257.88	123	101	0.10	0.08
			Yes	8	3.55	1	1	0.06	0.06
		Yes	No	16	13.82	10	10	0.14	0.14
			Yes	65	53.6	92	70	0.34	0.26
	2. 501-3,000	No	No	29	9.27	25	22	0.54	0.47
			Yes	1	1	2	0	0.40	-
		Yes	No	45	24.39	94	76	0.77	0.62
			Yes	219	99.7	410	280	0.82	0.56
20	1. ≤500	No	No	1,118	201.93	47	29	0.05	0.03
			Yes	0	0	0	0	-	-
		Yes	No	6	5.45	1	1	0.04	0.04
			Yes	154	126.1	216	171	0.34	0.27
	2. 501-3,000	No	No	108	23.43	17	11	0.15	0.09
			Yes	5	1.84	1	1	0.11	0.11
		Yes	No	151	51.35	181	104	0.70	0.41
			Yes	1,965	1,050.96	4,116	2,637	0.78	0.50
Total				4,797	2,033.34	5,590	3,707	0.55	0.36

AADT = annual average daily traffic; RD = roadway departure.

ANOVA Model

Analysis of variance (ANOVA) modeling was performed using the safety measures of 5-year crash frequency (number of crashes/5 years), crash density (number of crashes/mile/5 years), and crash rate (number of crashes/mile/vehicle/5 years). These measures are considered the dependent variables, whereas the presence of centerlines and the presence of edgelines are considered to be the predictors in the modeling process. To account for different pavement widths, individual models were developed for roadways with widths of 16, 18, and 20 ft.

Crash Comparison Without Considering Pavement Width

Crash frequency, density, and rate were calculated by the presence of centerlines and edgelines and are shown in Table 8. The segments with centerlines were found to have statistically more crashes and a higher crash density than those without centerlines; no statistical difference was found in the crash rates between the two segment groups. There was no statistical difference between the segments with and without edgelines in crash frequency, density, and rate.

Table 8. Crash Frequency, Density, and Rate by Presence of Centerlines and Edgelines

Number of Segments		**Edgelines**	
		Absent	**Present**
Centerlines	**Absent**	2081	18
	Present	239	2459
Crash Frequency (5-year crashes per segment)		**Edgelines**	
		Absent	**Present**
Centerlines	**Absent**	0.13	0.28
	Present	1.43	2.03
Crash Density (5-year crashes per 0.5 mi)		**Edgelines**	
		Absent	**Present**
Centerlines	**Absent**	0.15	0.19
	Present	1.16	1.48
Crash Rate (5-year crashes per 0.5 mi per 1,000 vehicles)		**Edgelines**	
		Absent	**Present**
Centerlines	**Absent**	0.77	0.96
	Present	1.11	1.11

Crash Comparison Considering Pavement Width

Crash frequency, density, and rate were calculated by the presence of centerlines and edgelines and by pavement width and are shown in Table 9. The segments with centerlines were found to have statistically more crashes and higher crash densities in all three pavement widths than those without centerlines; no statistical difference was found in the crash rates between the two segment groups in all three pavement widths. There was no statistical difference between segments with and without edgelines in crash frequency, density, and rate for all three pavement widths.

Table 9. Crash frequency, Density, and Rate by Presence of Centerlines and Edgelines and by Pavement Width

Number of Segments			Edgelines	
			Absent	**Present**
16 ft	**Centerlines**	**Absent**	118	4
		Present	21	56
18 ft	**Centerlines**	**Absent**	737	9
		Present	61	284
20 ft	**Centerlines**	**Absent**	1226	5
		Present	157	2119
Crash Frequency (5-year crashes per segment)			**Edgelines**	
			Absent	**Present**
16 ft	**Centerlines**	**Absent**	**0.42**	**0.25**
		Present	2.62	2.66
18 ft	**Centerlines**	**Absent**	0.20	0.33
		Present	1.70	1.77
20 ft	**Centerlines**	**Absent**	0.05	0.20
		Present	1.16	2.04
Crash Density (5-year crashes per 0.5 mi)			**Edgelines**	
			Absent	**Present**
16 ft	**Centerlines**	**Absent**	**0.49**	**0.15**
		Present	**1.64**	**1.39**
18 ft	**Centerlines**	**Absent**	0.17	0.23
		Present	1.32	1.40
20 ft	**Centerlines**	**Absent**	0.11	0.14
		Present	1.03	1.49
Crash Rate (5-year crashes per 0.5 mi per 1,000 vehicles)			**Edgelines**	
			Absent	**Present**
16 ft	**Centerlines**	**Absent**	**1.69**	**0.41**
		Present	**2.66**	**2.01**
18 ft	**Centerlines**	**Absent**	1.11	1.65
		Present	**1.58**	**1.56**
20 ft	**Centerlines**	**Absent**	**0.47**	**0.17**
		Present	0.72	1.03

Numbers in bold indicate cases where crash statistics are lower with edgelines than without edgelines.

The numbers in bold in Table 9 seem to suggest beneficial effects of the presence of centerlines and/or edgelines, and a further analysis to examine these effects was performed by separating out corresponding segments. For example, segments with 16-ft pavement widths and without centerlines were selected and split into two groups by the presence of edgelines. By comparing these two groups, pavement width and the presence of centerlines were controlled for to examine the safety effects of the presence of edgelines. Although the numbers seem to suggest beneficial effects for all examined cases, none of them was statistically significant at even a 0.2 level of significance.

Negative Binomial Model for Safety Performance Functions

Although crash frequency (number of crashes/time) is commonly used as a safety measure, it has a critical shortcoming in that it does not account for segment length or AADT. It is generally understood that there is a relationship among segment length, AADT, and crash occurrence. Crash density (number of crashes/mile/time) assumes that a longer segment is proportionally associated with a higher crash occurrence. Thus, use of crash density addresses the segment length shortcoming of crash frequency. However, traffic volume, a well-known factor associated with a crash occurrence, is still not incorporated in crash density. Crash rate (number of crashes/mile/vehicle/time) assumes that an increase in traffic volume and segment length is proportionally associated with an increase in crash occurrence. Crash rate therefore addresses the shortcomings of crash frequency and density; however, the linearity assumption (proportional relationship) of traffic volume in relation to crash frequency has been found to be invalid in many cases (e.g., safety performance functions [SPFs] of the *Highway Safety Manual).*[12]

The ANOVA model shortcomings can be addressed by employing an SPF typically estimated by the negative binomial model. An SPF was formulated using a "base condition" pavement width of 16 ft. Its effect is captured by the coefficient a, and differential effects of other pavement widths (i.e., 18 and 20 ft) are captured by b_2 and b_3. The model formulation is provided by:

$$E(Crash\ Frequency_i) = exp\begin{bmatrix} a + b_1 \times \ln(AADT_i) + b_2 \times PAVEW18_i \\ +b_3 \times PAVEW20_i + \ln(Length_i) \end{bmatrix} \qquad \text{[Eq. 1]}$$

where

i = segment index
$E(\cdot)$ = expectation
$Crash\ Frequency_i$ = number of crashes on segment i in 5 years (2004–2008)
$AADT_i$ = annual average daily traffic volume on segment i in year 2008
$PAVEW18_i$ = 1 if pavement width of segment i is 18 ft and 0 otherwise
$PAVEW20_i$ = 1 if pavement width of segment i is 20 ft and 0 otherwise
$Length_i$ = length of segment i
a, b_1, b_2, and b_3 = coefficient parameters to be estimated.

Log-transformed Length with a fixed coefficient of 1.0 and log-transformed AADT were adopted in accordance with the typical practice with regard to SPFs found in SafetyAnalyst[13] and the *Highway Safety Manual*.[12] The AADT of the most recent year in the study data (2008) was used. In general, AADTs have not varied much over the 5-year study period. Indicator variables of pavement widths being 18 and 20 ft (i.e., $PAVEW18$ and $PAVEW20$) were included in the SPF so that potential variation of safety effects by width could be controlled.

The negative binomial regression model is typically used for parameter estimation of an SPF and was adopted in this study to estimate the parameters including the four coefficients specified in Equation 1. The specification of the negative binomial regression model is written as follows:

$$Pr(Crash\ Frequency_i | AADT_i, Length_i, PAVEW18_i, PAVEW20_i)$$

$$= \frac{exp[-E(Crash\ Frequency_i) \times u_i] \times [E(Crash\ Frequency_i) \times u_i]^{Crash\ Frequency_i}}{(Crash\ Frequency_i)!} \qquad [\mathrm{Eq.\ 2}]$$

and $u_i \sim Gamma(1/k\ , 1/k)$

where

u_i = random term allowing the conditional variance to be greater than the conditional mean

k = negative binomial dispersion parameter to be estimated

$E(Crash\ Frequency_i)$ = conditional mean specified in Equation 1.

To examine the safety effects of the presence of centerlines and/or edgelines, the study data were first split into four datasets based on the presence of centerlines only, edgelines only, both markings, and no markings. The results are shown in Table 10.

The SPF for the edgelines-only dataset was not statistically significant, most likely because of its small sample size (the dataset contained only 18 segments). To visualize the difference among the four segment groups, Figure 4 was created assuming a 0.5-mi segment length. Figure 4 (*top*) shows the mean predicted crash frequency corresponding to AADTs varying from 1 to 3,000 vpd. As noted previously, the SPF of the edgelines-only group was not statistically valid although it is presented in the figure. According to the SPF curves, the segment group with only centerlines is predicted to have more crashes than the other groups at AADTs greater than about 600 vpd. The group with no lines is predicted to have fewer crashes than the group with only centerlines for the entire AADT range and for the group with both centerlines and edgelines until about 1,700 AADT.

As shown in Figure 4 *(top),* three segment groups excluding the one with only edgelines appear to be different. However, Figure 4 *(bottom)* shows the 95 percent upper limit of the mean crash predictions and reveals that the seemingly different three curves are statistically identical. This indicates that there is no statistical difference among the three segment groups in predicted crash frequencies in the entire AADT range. It should be noted that pavement width was also controlled in the SPF analysis.

Table 10. SPF Results for Four Segment Groups

Variable	**Centerline Only**		**Edgelines Only**		**Both Lines**		**No Lines**	
	Coeff.	***p*-value**	**Coeff.**	***p*-value**	**Coeff.**	***p*-value**	**Coeff.**	***p*-value**
Intercept	-4.687	<.0001	-4.965	0.091	-2.023	<.0001	-4.720	<.0001
PAVEW18	-0.457	0.108	0.437	0.718	-0.216	0.122	-0.157	0.361
PAVEW20	-0.756	0.006	-0.274	0.854	-0.297	0.020	-1.117	<.0001
lnAADT	0.913	<.0001	0.692	0.153	0.495	<.0001	0.857	<.0001
No. of Segments	239		18		2,459		2,081	

SPF = safety performance function; Coeff. = coefficient.

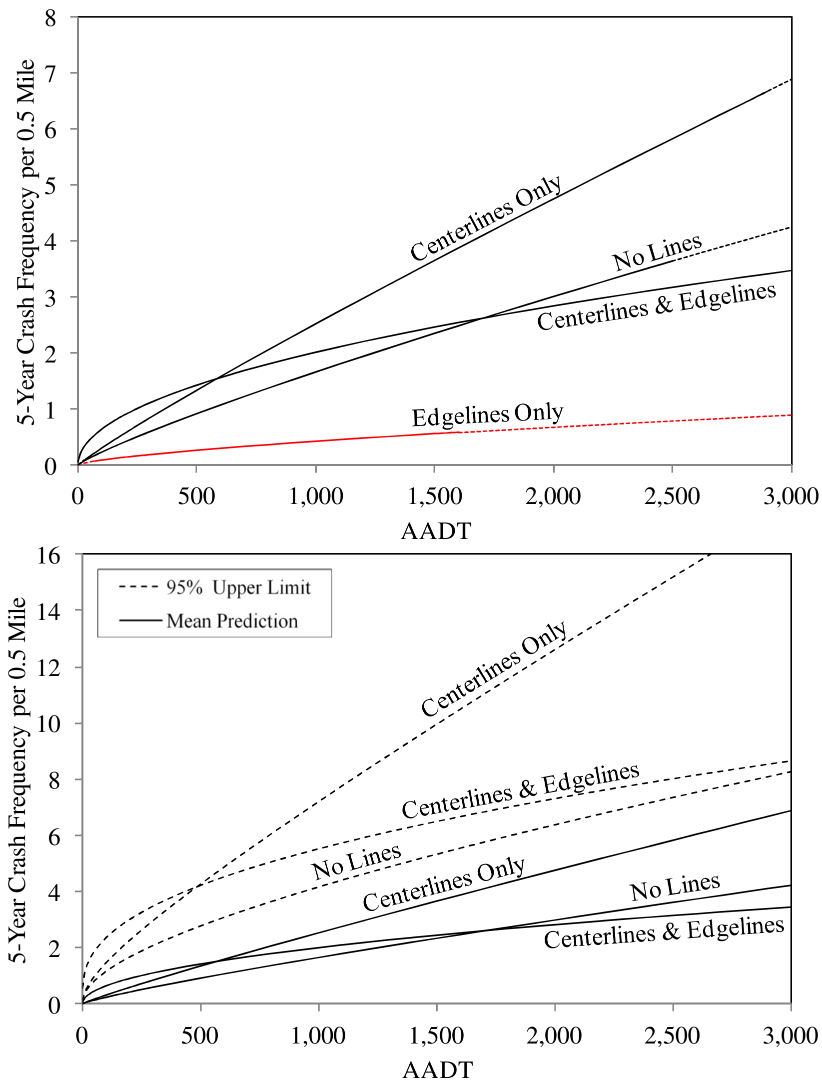

Figure 4. Safety Performance Function Results of 4 Segment Groups. *Top:* Mean Crash Predictions. The solid line indicates the range of actual AADTs, and the dotted lines indicate the range of AADTs that are not found in the data. *Bottom:* Mean Crash Predictions and 95% Confidence Limits.

The data show strong correlations among AADT, the presence of centerlines, the presence of edgelines, and the pavement width. Thus, Table 10 and Figure 4 should be interpreted with caution. For example, as AADT increases, centerlines are likely to be present. This means that the predicted crash frequency by the SPF labeled "Centerlines Only" in Table 10 and Figure 4 would be unrealistic for low AADTs because segments with low AADTs are unlikely to have centerlines. In this sense, Figure 4 is somewhat misleading because the curves were created based on the assumption that the presence of centerlines and/or edgelines is not influenced by AADT, although in reality, this is not the case.

With the datasets available for this study, the analyses found no difference among segments with or without centerlines or edgelines in terms of predicted crash frequencies while accounting for AADT, segment length, and pavement width. However, this does not indicate that centerlines and/or edgelines have no influence on traffic safety on narrow road segments. Rather, the researchers conjecture that safety improvement is attributable to the installation but there might be detrimental effects of some factors canceling out the safety improvement gained by the centerlines and/or edgelines. It might be helpful to examine what crash characteristics differ among the four segment groups.

Inference on Impact of Centerlines and Edgelines on Teen Drivers

When the age distribution of drivers involved in crashes on two-lane low-volume (AADT $\leq$ 3,000) roads was compared by the presence of centerlines and edgelines, teen drivers (age $\leq$ 19) were overrepresented in crashes on the roads without any lines compared to the roads with one or both lines (e.g., 32% were teen drivers in crashes on roads without pavement markings vs. 19 percent on roads with centerlines and edgelines); other age groups (20-34, 35-54, 55-64, 65+) showed similar proportions regardless of the presence of centerlines and/or edgelines (e.g., 30% were drivers aged 20-34 in crashes on roads without pavement markings vs. 30 percent on roads without both edge and centerlines). This might be due to either (1) different levels of use of the roads without any lines by different age groups of drivers (e.g., teen drivers are more likely to use such roads than roads with lines) or (2) different crash risk for the roads without any lines compared to roads with lines for teen drivers (e.g., teen drivers are more likely to get involved in crashes on the roads without lines than on the roads with lines).

When crash data for two-lane roads with a higher traffic volume (AADT > 3,000) were examined, the age distribution of drivers involved in crashes on these roads was similar to that of the two-lane low-volume roads. Therefore, an inference can be drawn that the degree of roadway use by drivers of different ages is similar for the types of two-lane roads this study examined, which gives credence to the second possibility, i.e., different crash risk for the roads without any lines compared to roads with lines for teen drivers. McKnight and McKnight[14] found that "cluelessness" (e.g., errors in attention, visual search, and hazard recognition) rather than "carelessness" is a contributing factor in non-fatal traffic crashes involving teen drivers based on analyses of 2,000 crashes involving teen drivers in California and Maryland. Centerlines and edgelines are intended to enhance clues for safe driving, and it might be plausible to infer that the absence of centerlines and edgelines on the two-lane low-volume roads appears to be associated with more crashes involving teen drivers, and thus centerlines and edgelines appear to be beneficial for this age group.

DISCUSSION OF VDOT PAVEMENT MARKING PERSPECTIVES

There are two perspectives within VDOT regarding the use of pavement markings on narrow roads. One perspective is to use more pavement markings on these roads when there are safety problems that may be lessened by their use. The other perspective is that VDOT is currently marking too many roads. Marking fewer roads would allow limited pavement marking funds to be used where they might be deemed a more effective return on investment. These two perspectives may be present simultaneously where there is a preference to mark particular roads and not others. This reveals the need for more guidance and flexibility in determining what roads should be marked. The language of VDOT's current policy was adopted from VDOT's *Traffic Engineering Division Memorandum TE-251: Pavement Marking Policy* (see Appendix

A), which is an inactive 1994 technical engineering memorandum. TE-251, which appears to dictate what roads should be marked based on ADT and pavement width, was issued to reflect the requirements of HJR 243 (see Appendix B). There are many other factors such as the type of road users, crash history, and road geometry (especially the presence of curves) that should be considered in determining the need for pavement markings. In HJR 243, there may be language that will permit some flexibility. It is stated that:

> the Virginia Department of Transportation be requested to revise its standards for the provision of centerline pavement markings to include all *appropriate* secondary roads having a pavement width of eighteen feet or more where official traffic counts indicate a minimum of 500 vehicles per day (emphasis added).

It is possible that the word "appropriate" may provide an opportunity to provide guidance as to what roads are marked and flexibility in determining what roads to mark and how to mark them.

LIMITATIONS

This study used a cross-sectional analysis to compare crash experiences on different roads during the same time period. A before/after study comparing the same site with and without various pavement markings using the empirical Bayes method would have been ideal. However, the before/after approach would have required additional time and effort to select and mark the roads and then a wait of 2 years or more after the marking installation before the analysis could be conducted. In addition, because of the relatively few crashes on these roads, a large number of road sections (and miles) would be required to obtain statistically valid results. Such a large sample size may not be practical. This effort did not address how drivers' behavior may be impacted by the presence of centerlines and/or edgelines. Data from the naturalistic driving study being conducted by the Virginia Tech Transportation Institute[15] may offer an opportunity for an exploratory study to investigate driver behavior on roads 16 to 20 ft wide with and without pavement markings.

CONCLUSIONS

- *There is much variation in the practices of state DOTs for installing pavement markings on roads that are 16 to 20 ft wide.*

- *Based on a limited cross-sectional analysis of crash frequency, density, and rate and SPF prediction, there appears to be no statistical difference between segments with and without centerlines and/or edgelines.*

RECOMMENDATIONS

1. *VDOT's TED should consider developing a statewide process for a pavement marking inventory.* Regional operations staff (and others as needed) should be partners in this effort. The challenges in keeping the inventory up to date should be addressed.

2. *VDOT's TED should consider asking the Office of the Attorney General of Virginia for an interpretation/opinion of the term "appropriate" in HJR 243.* If such an interpretation were to conclude that VDOT may offer guidance to determine what is appropriate, the TED should pursue the development of such guidance. The guidance should be flexible and include principles based on experience. A revised TE-251 memorandum may be the preferred means to implement this guidance.

3. *Staff of the Virginia Center for Transportation Innovation and Research should consider conducting an exploratory study to determine if the data from the naturalistic driving study being conducted by the Virginia Tech Transportation Institute[15] may be used to evaluate driver behavior on roads 16 to 20 ft wide with and without centerlines and/or edgelines.*

BENEFITS AND IMPLEMENTATION PROSPECTS

The recommendations from this report are based on ancillary findings. There is a medium chance of these recommendations being implemented, in the authors' opinion. The potential benefits are difficult to quantify.

ACKNOWLEDGMENTS

The authors thank Harry Campbell and Mark Hodges (VDOT's Traffic Engineering Division), Matthew Shiley (VDOT's Northwest Region), and Catherine McGhee of VCTIR for serving as the technical review panel and Linda Evans of VCTIR for editing the report.

REFERENCES

1. Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, D.C., 2009.

2. Virginia Department of Transportation. *Virginia Supplement to the 2009 Manual of Uniform Traffic Control Devices for Streets and Highways.* Richmond, 2011. http://www.virginiadot.org/business/resources/TED/final_MUTCD/Virginia_Supplement_Full_Document.pdf. Accessed October 9, 2013.

3. Agent, K.R., and Green, E.R. *Use of Edge Line Markings on Rural Two-Lane Highways*. KTC-08-02/SPR330-07-1I. Kentucky Transportation Center, Lexington, 2008.

4. Tsyganov, A.R., Machemehl, R.B., and Warrenchuck, N.M. *Safety Impact of Edge Lines on Rural Two-Lane Highways*. University of Texas, Austin, 2005.

5. Tsyganov, A.R., Machemehl, R.B., Warrenchuck, N.M, and Wang, Y. *Before-After Comparison of Edgeline Effects on Rural Two-Lane Highways.* University of Texas, Austin, 2006.

6. Van Driel, C.J.G., Maarseveen, M.F.A.M, and Davidse, R.J. The Effects of an Edgeline on Speed and Lateral Position: A Meta-Analysis. *Accident Analysis and Prevention*, Vol. 36, No. 4, 2004, pp. 671-682.

7. Sun, X., Park, J., and Tekell, V.O. *Impact of Edge Lines on Safety of Rural Two-Lane Highways*. Louisiana Transportation Research Center, University of Louisiana at Lafayette, 2005.

8. Miller, T.R. Benefit-Cost Analysis of Lane Marking. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 1334. Transportation Research Board of the National Academies, Washington, D.C., 1992, pp. 38-45.

9. Carlson, P.J., Park, E.S. and Andersen, C.K. Benefits of Pavement Markings: A Renewed Perspective Based on Recent and Ongoing Research. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 2107. Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 59-68.

10. Kusano, K.D., and Gabler, H.C. Rural Road Departure Crashes: Why Is Injury Severity Correlated with Lane Markings? In *TRB 91st Annual Meeting Compendium of Papers DVD*. Transportation Research Board of the National Academies, Washington, D.C., 2012.

11. Hartgen, D.T., Karanam, R.K., Fields, M.G., and Kerscher, T.A. *19th Annual Report on the Performance of State Highway Systems (1984-2008).* Policy Study 385. Reason Foundation, Los Angeles, September 2010.

12. American Association of State Highway and Transportation Officials. *Highway Safety Manual: 1st Edition*. Washington, D.C., 2010.

13. ITT Corporation. *SafetyAnalyst User's Manual*. Federal Highway Administration, Washington, D.C., 2009.

14. McKnight A.J., and McKnight A.S. Young Novice Drivers: Careless or Clueless? *Accident Analysis and Prevention*, Vol. 35, No. 6, 2003, pp. 921-925.

15. Virginia Tech Transportation Institute. 100-Car Naturalistic Driving Study. 2012. http://www.vtti.vt.edu/research/vrus/projects/100car/100car.html. Accessed July 12, 2013.

APPENDIX A

VDOT'S INACTIVE PAVEMENT MARKING POLICY AS WRITTEN IN 1994

CENTERLINE MARKINGS

1. All interstate highways shall be centerlined.

2. Centerline markings shall be applied to primary and secondary hard surfaced routes meeting all of the following criteria:
   a. Pavement width is a minimum of 18 feet.
   b. Traffic count is a minimum of 500 vehicles per day (VPD).
   c. Sections to be centerlined shall be continuous between major points. (As an example, a road may carry over 500 VPD between major points; however, the pavement width is 18 feet or more in width only on a middle portion of the section. The middle portion shall not be centerlined since it would not constitute a continuous section between major points.)

   Exception: Subdivision streets meeting the above criteria shall not be centerlined unless the street is a through traffic artery.

3. At other locations where an engineering study indicates a need for them.

EDGELINE MARKINGS

Edgeline markings shall be applied under the following criteria:

1. All interstate highways.

2. All primary and secondary routes that are not in curb and gutter, are a continuous minimum width of 20 feet between major points and that have been centerlined.

3. Sections of primary routes, not continuously edgelined, on mountain crossings, subject to frequent fog.

4. All primary and secondary hard surfaced routes not continuously edgelined shall be edgelined at narrow (3 feet or less horizontal clearance between structure and edge of pavement) and single lane structures. If road and/or bridge restrictions prevent this from being accomplished, then the procedures outlined in TE-223 shall be utilized. Exception: Subdivision streets meeting the above criteria shall not be edgelined unless the street is a through traffic artery.

5. At other locations where an engineering study indicates a need for them.

(*Source:* Virginia Department of Transportation. *Traffic Engineering Division Memorandum TE-251: Pavement Marking Policy.* Richmond, August 1994. TE-251 was last revised in part based on HJR 243 of the 1994 Virginia General Assembly.)

APPENDIX B

HOUSE JOINT RESOLUTION NO. 243

Requesting the Department of Transportation to revise its standards for highway centerlines.
Agreed to by the House of Delegates, February 10, 1994
Agreed to by the Senate, March 8, 1994

WHEREAS, the Virginia Department of Transportation is responsible for the installation and maintenance of pavement markings on all state highways; and

WHEREAS, in recent years, the Department has provided centerline pavement markings on paved secondary roads of eighteen feet or more in width where official traffic counts indicated a minimum of 750 vehicles per day; and

WHEREAS, centerline pavement markings provide positive guidance and safety benefits to motorists in rural areas and local boards of supervisors have requested these markings on other paved secondary roads; and

WHEREAS, a significant number of additional miles of secondary roads could be provided with centerline pavement markings if the standard for minimum traffic volumes is reduced to 500 vehicles per day; and

WHEREAS, the Department could accomplish the additional work to provide these centerline pavement markings with a reasonable increase in maintenance costs; now, therefore, be it

RESOLVED by the House of Delegates, the Senate concurring, That the Virginia Department of Transportation be requested to revise its standards for the provision of centerline pavement markings to include all appropriate secondary roads having a pavement width of eighteen feet or more where official traffic counts indicate a minimum of 500 vehicles per day, and proceed with the installation of such markings. The Department, in assessing its long-term commitments, be requested to review its ability to provide additional miles of centerline pavement markings in the future and gradually reduce the standard for minimum traffic volumes accordingly.