TRANSPORTATION RESEARCH DIGEST

APRIL 2009

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

TO: TRANSPORTATION PROFESSIONALS, MANAGERS, & POLICY MAKERS

FROM: ARIZONA TRANSPORTATION INSTITUTE

The volume of information on transportation issues, policies, technologies, and related topics is huge. Not even the most well-read professional can keep up with everything that might be useful to know. The *Transportation Research Digest* series is designed to expedite the transmission of information by condensing and summarizing significant documents. Busy professionals or managers may quickly obtain the gist of new developments and determine whether they need to see the full document.

The *Transportation Research Digest* is not meant to present definitive resolutions of scientific or policy controversies, but contributions to the pursuit of knowledge and the debate of issues. The intent is to be comprehensive rather than conclusive on the multitude of issues and topics of concern to those working in the field of transportation. Readers are encouraged to obtain the original document summarized in the *Transportation Research Digest* and subject the content to their own judgment.

Transportation professionals who would like to recommend documents to be summarized or submit summaries to be considered for inclusion in this publication are invited to do so. To recommend a document please send a copy (or information indicating how a copy can be obtained) of the research report to be summarized. To be considered, the report must meet the following requirements: (1) it is transportation related, (2) it is no more than two years old, (3) there is enough information in the report to warrant a two page summary. To write a summary, insure that the document being summarized meets the above requirements. The summary should be submitted in an electronic format. This summary should be in the 500 to 800 word range and may include tables and/or simple graphics—all of which must fit within the *Transportation Research Digest's* two-page format. Submissions are subject to editing for clarity and length. We do not guarantee that all submissions will be published.

If you would like to obtain the full report upon which a *Transportation Research Digest* summary is based you have several options. Check your local university library. You may want to contact the publisher using the contact information appearing in the *Transportation Research Digest*. Some of the documents are free for the asking. Others can be purchased.

There is a database listing of all the previously published *Transportation Research Digests* that we have on file (back to 1984). Copies of the list or of portions of the list selected by topic or mode can be provided on request. You may also access the database via the internet at

Transportation Research Digests from December 1995 to November 2003 are available on request.

A "Topic" code in the Table of Contents will help readers more quickly identify items of interest. The topic codes are explained in the table below.

Code	Topic	Code	Topic
ADM	Administration	PLAN	Planning
AIRP	Airports	PRIV	Privatization
AVIA	Aviation	RAIL	Railroads
BIKE	Bicycles	RDSD	Roadside
CON	Construction	ROW	Right-of-Way
ECON	Economics	SAFE	Safety
ENV	Environment	STR	Structures
FIN	Finance	TECH	Technology
INOV	Innovations	TOLL	Toll Roads
MAIN	Maintenance	TRAN	Transit
MISC	Miscellaneous	TRF	Traffic
MVD	Motor Vehicle Dept	TRK	Trucking
PAVE	Pavement	VEH	Vehicles

Requests or inquiries may be made via e-mail (jsemmens@cox.net).

Thank you.

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

TABLE OF CONTENTS

SAFE/ drivers	***The Impact of the Sanctioning Process on Driver Safety*** by Robert J. Vance, Michael S. Renz,Barbara T. Harder, John P. Hausknecht, Vance & Renz, LLC 606 Wayland Place, State College, P A 16803 (Pennsylvania Department of Transportation, Bureau of Planning and Research, Commonwealth Keystone Building, 400 North Street, 6 Floor, Harrisburg, PA 17120-0064; ftp://ftp.dot.state.pa.us/public/pdf/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Reducing%20Fatalities/The%20Impact%20of%20the%20Sanctioning%20Process%20on%20Driver%20Safety.pdf) (May 2008). Recommendations for improving the driver sanction program's effectiveness are made.	15-16
SAFE/ intersect	***Low-Cost Safety Measures at Signalized Intersections*** by Kenneth R. Agent, Kentucky Transportation Center, College of Engineering, University of Kentucky, Lexington 40506-0281 (Kentucky Transportation Cabinet, State Office Building, Frankfort, Kentucky 40602; http://www.ktc.uky.edu/Reports/KTC_08_11_SPR_316_06_1F.pdf) (May 2008). The low cost of most of the evaluated countermeasures, when compared to the reduction in crashes, would result in a high benefit cost ratio.	17-18
STR/ bridge	***Assessing the Needs for Intermediate Diaphragms in Prestressed Concrete Bridges*** by Steve Cai, and R. Richard Avent, Department of Civil Engineering, Louisiana State University, Baton Rouge, Louisiana 70803 (Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808; http://www.ltrc.lsu.edu/pdf/2008/FR_420.pdf) (May 2008). RC IDs provided the greatest protection to exterior girders undergoing impact.	19-20
TRAN/ signal priority	***Comprehensive Evaluation of Transit Signal Priority System Impacts Using Field Observed Traffic Data*** by Yinhai Wang, Mark Hallenbeck, Jianyang Zheng, Guohui Zhang, Jonathan Corey, and Xiaolei Ma, Transportation Northwest Regional Center X (TransNow), Box 352700, 129 More Hall, University of Washington, Seattle, WA 98195-2700 (Research Office, Washington State Department of Transportation, Transportation Building, MS 47372, Olympia, Washington 98504-7372; Project Manager: Kathy Lindquist, 360-705-7976) (Jun 2008). For all passengers who used the two test corridors, the average person delay decreased by 0.1 second in the Phase One test and 0.02 second in the Phase Two test.	21-22
TRAN/ FIN	***Transportation Policy: Getting the Facts Straight*** by Wendell Cox and Ronald D. Utt (Heritage Foundation, 214 Massachusetts Ave NE, Washington DC 20002-4999; http://www.heritage.org/Research/SmartGrowth/wm2148.cfm; ph 202.546.4400) (Dec 3, 2008). The share of federal spending on transit vastly exceeds its passenger market share.	23-24
TRF/ signs	***Evaluation of Chevron Markings on Freeway-to-Freeway Connector Ramps in Texas*** by A.P. Voigt, S.P. Kuchangi, Texas Transportation Institute, Texas A&M University System, College Station, Texas 77843-3135 (Texas Department of Transportation, Research and Technology Implementation Office P.O. Box 5080, Austin, Texas 78763-5080; 979.845.1734; http://tti.tamu.edu/documents/0-4813-2.pdf) (Apr 2008). The magnitude of the decrease in overall mean speed is about 0.14 mph to 0.45 mph.	25-26

TRANSPORTATION RESEARCH DIGEST
ARIZONA TRANSPORTATION INSTITUTE
e-mail jsemmens@cox.net

APRIL 2009

Evaluation of Pavement Marking Performance by Eric R. Green, Kenneth R. Agent, Kentucky Transportation Center, College of Engineering, University of Kentucky, Lexington 40506-0281 (Kentucky Transportation Cabinet, State Office Building, Frankfort, Kentucky 40602; http://www.ktc.uky.edu/Reports/KTC_08_21_SPR_330_07_2I.pdf) (Jun 2008)

Highlights
- Striped lines can still produce passing retroreflectivity levels even after two years.
- Higher amounts of beads per gallon slightly raise the initial retroreflectivity levels.
- Lines with the highest amounts of beads per gallon tend to lower the retroreflectivity levels after one year.

The primary objective of the investigation was to evaluate the useful life of pavement markings. The evaluation also led to a methodology to determine what roadways should be restriped each year in Kentucky.

A total of 480 locations were selected across the state with 40 in each highway district. Thirty locations were selected that had been painted one year before data collection and 10 locations that had been painted two years prior to data collection. The one-year data were not available for all districts. Up to three lines were collected at each site. The time frame was based on the line that was randomly selected for each site; therefore the time since painted may not be accurate for all lines. It was assumed that each line was painted in the same year.

The data clearly show that striped lines can still produce passing retroreflectivity levels even after two years. White lines maintain levels above bonus after one year and above passing after two years. Yellow lines maintain levels near the passing limit after one year and just under passing after two years. Sixty percent of all lines striped had passing levels after one year and nearly half of all lines striped had passing levels after two years. The levels maintained show that is not necessary to restripe many roads annually.

The data collected indicated that retroreflectivity of striped lines are not directly affected by roadway characteristics such as lane width, shoulder width and number of lanes. ADT did not have a measurable effect on retroreflectivity, likely due to higher ADT roads typically having wider lanes. Truck percentage seemed to have little effect on retroreflectivity. Patterns were noted for two-lane rural roads; however, the sample sizes were too small to be significant. Region and district have the largest effect on failure rate. The eastern areas of the state typically have a high percentage of curvy and narrow roads with high truck percentages.

Higher amounts of beads per gallon slightly raise the initial retroreflectivity levels; however bonus levels are achieved at the lowest beads per gallon levels for yellow centerlines. Additionally, lines with the highest amounts of beads per gallon tend to lower the retroreflectivity levels after one year. For white edgelines the maximum retroreflectivity levels were achieved at about seven pounds of beads per gallon. More or fewer beads tend to lower the average retroreflectivity levels (initial readings and one year later).

Studies of others show that retroreflectivity levels less than current passing levels can provide adequate visibility. Furthermore, some research of others indicates that the same levels could be used for yellow and white lines. Retroreflectivity ranging from 70 to 170 have been found to provide adequate visibility in various studies.

Recommendations

1. Minimum levels of retroreflectivity should be set for determining what roads to restripe annually. These values should be lower than the passing/bonus thresholds used in the QC/QA program. It is recommended that yellow lines should be above 100 mcd/m^2/lux and white lines should be above 150 mcd/m^2/lux. These values are based on the findings in this report and research conducted on older drivers and crash data.

2. Retroreflectivity measurements should be collected and used to determine which roads should be painted each year. The current Maintenance Rating Program (MRP) can be used to facilitate this process.

a. Data should be collected at 300 randomly selected locations in each district.

b. The sites should be the same locations used in the MRP.

c. This data should be reported to the MRP such that redundant data are not collected.

d. If possible the data should be collected in February.

e. Roadways with retroreflectivity under the minimums levels should be restriped.

3. An inventory of striped roads should be maintained to allow a determination of when specific roadway sections were last restriped.

4. The effect of the amount of beads per gallon on retroreflectivity should be studied further; however it seems fewer beads could be used.

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

Pavement Markings State-of-the-Practice Study by Philip M. Garvey, Stephen J. Damin and Martin T. Pietrucha, Thomas D. Larson Pennsylvania Transportation Institute, Pennsylvania State University, 201 Transportation Research Building, University Park, PA 16802-4710 (Pennsylvania Department of Transportation, Bureau of Planning and Research, Commonwealth Keystone Building, 400 North Street, 6 Floor, Harrisburg, PA 17120-0064; ftp://ftp.dot.state.pa.us/public/pdf/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Reducing%20Fatalities/PSU%20008%20Final%20Report.pdf) (Feb 2008)

Highlights

- Only a minority of states have a minimum retroreflectivity requirement for wet nighttime pavement markings.
- About half of the DOTs would not apply pavement markings when temperatures are below 15˚F.

The goal of this project was to improve Pennsylvania's pavement marking program by identifying pavement marking practices in states with characteristics similar to Pennsylvania's. This was accomplished through a brief literature and state DOT website review and a formal survey of 19 states. Two critical issues were of particular interest to PennDOT: marking for wet weather conditions and the application of markings in cold weather. The findings from the literature review and the survey for those two topics are summarized below.

Wet Weather Pavement Marking Practices

The literature and website survey revealed that the following materials and practices were being used to improve wet nighttime pavement marking visibility:

- Pavement markings on rumble strips;
- Wet night reflectance tape, also known as structured tape (e.g., 3M's A-20 and A-21 products);
- Larger glass beads;
- Double drop beads (large and small bead diameter);
- Increased number of beads (bead density);
- Increased use of retroreflective raised pavement markers;
- Inlay tape and epoxy; and
- "Rainline" thermoplastic (profile thermoplastic road marking specifically made for wet night visibility).

When asked in the survey if the state agencies had a minimum retroreflectivity requirement for wet nighttime pavement markings, 16 states said they did not. Connecticut said it does, but it is the same as the state's dry requirement (250 for white and 175 for yellow markings). Virginia plans to establish 200 for white and 100 for yellow, and West Virginia uses 200 for white and 150 for yellow markings under recovery conditions and 100 for white and 75 for yellow under continuous wet conditions.

When asked if they use any special products or procedures to ensure wet night pavement marking visibility, 8 states said they did not while 11 states did. The products and procedures are similar to those found in the literature and website review and include:

- Raised pavement markings (often specified as "snowplowable"),

- Wet reflective tape (e.g., 3M 780 tape, 3M 380WR),
- Pavement markings in shoulder rumbles (i.e., rumble stripes),
- Wet reflective polyurea,
- Larger glass beads,
- 3M all-weather paint, and
- Profiled lane lines.

Cold Weather Pavement Marking Practices

The literature and website survey resulted in few specific findings related to pavement marking materials and practices for late season or cold weather application. The main exception was MN, which has five approved cold-weather epoxy marking materials and two approved paint materials. The following materials are currently under evaluation:

- MN and OH: Ennis cold weather waterborne paint 985251 (White) and 985252 (Yellow).
- VT: Franklin Paint Company, Inc. "Cold Weather Waterborne Traffic Paint with XSR." (XSR is an acrylic resin.)

When asked in the survey what products or procedures would they use if they had to apply markings during late season/cold weather conditions (e.g., under 15˚F), 10 states said they would not stripe in such cold weather. Of the nine that said they would, the responses were as follows:

- Temporary raised pavement markers, Waterborne paint,
- Regular dry (solvent-based) paint,
- Epoxy,
- Acetone paint,
- Applied hot spray thermoplastic,
- Polyurea, and
- Preformed thermoplastic.

TRANSPORTATION RESEARCH DIGEST
ARIZONA TRANSPORTATION INSTITUTE
e-mail jsemmens@cox.net

APRIL 2009

Effect of Drainage in Unbound Aggregate Bases on Flexible Pavement Performance by Mingjiang Tao and Murad Y. Abu-Farsakh, (Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808; http://www.ltrc.lsu.edu/pdf/2009/fr_429.pdf) (May 2008)

Highlights
- There is a narrow range of variation between the optimum-coarse and the optimum-fine aggregate gradations that would provide a stable and drainable pavement base layer.
- The additional handling required to achieve this optimum is estimated to cost $18.50 per cubic yard (or ≈25%) over the current bid prices.

A laboratory testing program was conducted to optimize the gradation of Mexican limestone aggregate material to satisfy both permeability and stability criteria needed for use as a drainable base in pavement structures. Based on this study, the following conclusions can be drawn:

All gradations except LA II-fine achieved the permeability criterion recommended by FHWA, which is 0.35 cm/sec. (1,000 ft/day).

The LA II-coarse and optimum-coarse gradations achieved higher shear strength and resilient modulus values; while the NJ-medium and LA II-fine had lower strength and modulus. The optimum-fine gradation had intermediate strength and stiffness values. This finding suggests that neither a very uniform gradation nor one with excessive fines content will perform well as a pavement base material.

Overall, the Mexican limestone base material has gained strength when compacted at optimum moisture contents and maximum dry density. However, it experiences strain-softening behavior, post-peak shear strength, in which the shear stress decreases with the strain increase until reaching the residual shear strength.

The results of the tube section tests showed that the LA II-fine gradation of Mexican limestone has a relatively high dielectric value (an indication of free moisture content absorption under capillarity suction) and, thus, can be considered as a poor base in terms of water susceptibility. The rest of the gradations are considered in general marginal bases. This result suggests that, the more fines the gradation has, the larger the DV is and, thus, the higher the water susceptibility, which can adversely affect the performance of the Mexican limestone base layer. The results of another research study showed that the strength, stiffness, and permanent deformation of Mexican limestone base material are very sensitive to the moisture content.

There is a strong correlation between the optimum moisture content determined from the Standard Proctor test and the maximum dielectric values [$DV = 11.4 \ln(W_{opt}) - 8.7$], with a coefficient of determination R2 = 0.87. Such correlation provides a quick approach to predict water susceptibility of unbound aggregates as pavement base materials.

The results of repeated loading triaxial tests showed that coarser gradations (optimum-coarse, LA II-coarse, New Jersey–medium) had much smaller permanent deformation and strain rate compared to finer gradations (optimum-fine, LA II-fine). However, the optimum-fine gradation had less permanent and strain rate, hence, an improved structural stability compared to LA II-fine gradation.

Different performance rankings were obtained for the aforementioned gradations, based on the results of different structural stability tests and the permeability requirement. However, more weight should be given to laboratory tests that are directly related to the long-term performance of the Mexican limestone base layer, e.g., resilient modulus for structural stability, permanent deformation for pavement rutting distress, and the hydraulic conductivity for base drainability. Accordingly, the optimum-course gradation will be ranked A and LA II-fine gradation will be ranked E. The reader should realize that these rankings are based merely on laboratory tests that need to be validated and/or correlated with field test data.

Good correlations exist between the DCPI and resilient modulus and between the unsoaked CBR and permanent strain. However, no significant correlations exist between the DCPI and unsoaked CBRs, between the DCPI and permanent strain, and between the resilient modulus and permanent strain.

The results indicate that there is a narrow range of variation between the optimum-coarse and the optimum-fine aggregate gradations that would provide a stable and drainable pavement base layer with improved performance as compared to LA class II gradations. This narrow acceptable drainable range might be difficult to achieve in the field. Achieving this gradation in the field would require running a pug-mill on the site and a spreader (paving machine) to lay the material. This additional handling by the material suppliers and the contractor, is estimated to cost \$18.50 per cubic yard (or ≈25%) over the current bid prices.

Recommendations

Based on the results of this research study, it is recommended that DOTD consider using the proposed optimum gradation range if an unbound drainable base is used. In this situation, the field test sections should be built to verify/validate the results of this study. Since the range of gradation between optimum-coarse and optimum-fine that satisfy the permeability and stability requirements is narrow and might be difficult to achieve in the field, a pug-mill is needed to run on the site and a spreader to lay the material. This will be associated with an estimated extra cost of \$18.50 per cubic yard (or ≈25%) over the current average cost.

The laboratory test results indicated that the finer the Mexican limestone gradation is, the higher its water susceptibility and the weaker the base material is in terms of strength, stiffness, and permanent deformation. Therefore, it is recommended that DOTD consider tightening the specification of fine gradation side by moving toward the coarse side to achieve a better long-term performance.

With respect to the issue of drainable base, DOTD should consider stabilized open-graded aggregates with very high permeability. To ensure its long-term stability, geogrids, asphalt or cement can be used to stabilize the open-graded base material. A research project is therefore needed to evaluate the most efficient method for stabilizing the open-graded, drainable base material, and to study the strength, stiffness, and permanent deformation of open-graded stabilized specimens.

TRANSPORTATION RESEARCH DIGEST
ARIZONA TRANSPORTATION INSTITUTE
e-mail jsemmens@cox.net

APRIL 2009

Evaluation of Median Barrier Safety Issues by Kenneth R. Agent, Jerry G. Pigman, Kentucky Transportation Center, College of Engineering, University of Kentucky, Lexington 40506-0281 (Kentucky Transportation Cabinet, State Office Building, Frankfort, Kentucky 40602; http://www.ktc.uky.edu/Reports/KTC_08_14_SPR_329_06_1F.pdf) (Jun 2008)

Highlights

- The successful performance of cable barrier, along with the ability to repair damage with no disruption of traffic, warrants expanded use of this type of median barrier.

The objective of this study was to evaluate the effectiveness of the Brifen TL-4 and Trinity CASS median cable barrier systems in preventing cross-median collisions on sections of I-64, I-71, and I-265 (Brifen system) and I-265 (Trinity system) in Jefferson County and on KY 4 (Brifen system) in Fayette County.

An effort was made to identify crashes which involved a vehicle crossing a median. Using specific logic to identify this type of crash, 392 crashes were identified for the five-year period of 2001 through 2005. Using crash and mileage data resulted in an average of 0.28 crossover crashes per mile in the five years and an average of 0.05 fatal crossover crashes per mile. Using a statistical test, critical numbers of 0.35 cross-median crashes per mile per year for crashes of any severity and 0.20 fatal crashes involving cross-median crashes per mile per year were recommended as guidelines for median barrier applications.

The study involved an evaluation of 325 crashes with a police reports obtained for 185 of the crashes. The large majority of the crashes where a police report was not located involved a minor impact where the vehicle probably continued with no report. The number of damaged posts ranged from one to 70 with an average of about six posts. A tractor trailer was involved in the crash where 70 posts were damaged. Only 29 of the 325 crashes (8.9 percent) resulted in a reported injury related to the impact with the cable system with no fatalities.

There were 61 crashes in which the vehicle crossed the median before contacting the cable system; therefore, these crashes would likely have resulted in a vehicle encroaching into the opposing lane. There were 96 additional crashes in which the vehicle collided with the cable system when it was positioned adjacent to the travel lane and an analysis of the crash (including variables such as the impact angle) indicated that the vehicle had a substantial probability of crossing the median into the opposing lane. This is an indication that in the approximate 21 month time period of the study (less for the KY 4 installation) the cable system prevented up to 157 encroachments into the opposing lanes. On these high volume and high speed roadways, an encroachment into the opposing lane has the possibility of resulting in a crash with a severe or fatal injury.

The cable system was found to successfully redirect the vehicles. A wide range of types of vehicles hit the cable at consistently high speeds. In only three crashes (0.9 percent) did a vehicle continue through the cable system and into the opposing travel lanes.

Recommendations

The successful performance of cable barrier warrants expanded use of this type of median barrier. The cable barrier was found to prevent median crossovers (on high speed roadways) and the damage to the cable system could be repaired relatively easily with no major disruption to traffic. Future installations should include the mow strip used in the Lexington installation to provide additional post stability and reduce maintenance.

It is recommended that guidelines for median barrier applications developed by the Kentucky Transportation Cabinet in March 2006 (updated in April 2008) be implemented. A copy is included as Appendix A. In order for the guidelines to be more representative of Kentucky crash data (developed as part of this research), it is recommended that the following crash criteria should be used in the guidelines.

.

- 0.35 cross-median crashes (of any severity) per mile per year
- 0.25 injury or fatal crashes involving cross-median crashes per mile per year
- 0.20 fatal crashes involving cross-median crashes per mile per year

It should be noted that, due to the small number of this type of crash, these critical numbers may not be met. An analysis of crash data in Kentucky should be used to identify locations where this type of median barrier would be most cost effective. This would involve determining the locations which have had the highest concentration of median crossover crashes.

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

The Impact of the Sanctioning Process on Driver Safety by Robert J. Vance, Michael S. Renz,Barbara T. Harder, John P. Hausknecht, Vance & Renz, LLC 606 Wayland Place State College, P A 16803 (Pennsylvania Department of Transportation, Bureau of Planning and Research, Commonwealth Keystone Building, 400 North Street, 6 Floor, Harrisburg, PA 17120-0064; ftp://ftp.dot.state.pa.us/public/pdf/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Reducing%20Fatalities/The%20Impact%20of%20the%20Sanctioning%20Process%20on%20Driver%20Safety.pdf) (May 2008)

Highlights

- Recommendations for improving the driver sanction program's effectiveness are made.

The Pennsylvania Department of Transportation's Bureau of Driver Licensing administers a driver sanctioning system to help improve driving habits and to ensure safe driving. Improvements to this system should be evidence-based. Driver records, which the Bureau maintains for every licensed Pennsylvania driver (as well as unlicensed drivers who are convicted of violations), contain histories of points incurred for each moving violation and sanctions imposed when point totals reach six or more. These records were analyzed to test the effectiveness of sanctions and, together with observations of Pennsylvania's sanctioning system in action, interviews with stakeholders, a review of relevant research, and review of best practices of other states, informed a set of recommendations for system improvements to foster a safer motoring environment for all who travel Pennsylvania's roadways.

Recommendations

A. Sanctions and the Sanctioning Process

A1: Type II Hearing within 3 Years after Licensure: Drivers who trigger a Type II Hearing (i.e., who reach six [6] points for a second time) within three (3) years after initial licensure should receive a 30-day suspension.

A2: Six Points within First 18 Months after Licensure: Drivers who accumulate six or more points within their first 18 months after initial licensure should incur a Special Point Examination and a Departmental Hearing. The outcome of this hearing should be biased toward a suspension of at least 30 days. The hearing should immediately follow the Special Point Examination.

A3: Six Points within First 18 Months after Licensure for Young Drivers: Young drivers (16 - 17 years old) who accumulate six or more points should incur a Special Point Examination and a Departmental Hearing. The outcome of this hearing should be a suspension of at least 90 days. The hearing should immediately follow the Special Point Examination. Enforce Section 1503(c3), Jr License of the Vehicle Code.

A4: The Special Point Examination

A4a. Review and update the contents of the Special Point Examination: Review and revise for clarity items on the Special Point Examination. Expand the content coverage of items on the Special Point Examination to test knowledge of violations, points, and sanctions, in conjunction with expansion of content coverage of the *Special Point Examination Driver's Handbook* (see Recommendation A4b).

A4b. Review and update the contents of the Special Point Examination Driver's Handbook: The Special Point Examination Driver's Handbook focuses on DUI and suspensions in Part 1. The safe driving section, Part 2, doesn't have any wording on the sanctions that may accompany unsafe driving, it really only focuses on how to avoid an accident. What is missing is information on what to expect if the driver doesn't change behavior -- more points, hearings, etc. Material that addresses points, sanctions, and the likelihood that past bad driving patterns will lead to further sanctions should be included. Understanding of this material should be assessed with questions added to the Special Point Examination.

B. Violations and Points

Bl. Violation-free Drivers: Acknowledge drivers whose driving records remain violation-free. -In the current system, there is no positive reinforcement for drivers who maintain violation-free driving records. There is only the absence of punishment that comes with sanctions. PennDOT should occasionally compliment violation-free drivers and remind them of the importance of safe driving, perhaps in license renewal letters. This would both reinforce safer driving practices and subtly remind drivers that PennDOT keeps records.

B2. Points and Sanction System Details: Make details of the points and sanction system more readily available to learners, drivers, and especially violators. Revise the Special Point Examination and Driver's Handbook (Publication 248) as follows:

B2a. Add the point system details to the Driver's Handbook. Express in an easy to understand format. Include in Part 1 of the Handbook, not as an appendix.

B2b. Include questions in the Sample Test Items (Part 1): Regarding point values for specific violations and other relevant violation/sanction issues.

B2c. Include questions on the Special Point Examination: That determine working knowledge of the point system and sanctions for violations.

B2d. Add narrative to the Driver's Handbook: Perhaps in the form of short scenarios that describe common situations seen that lead to points, special exams, hearings and license revocation. See Appendix D for examples and illustrations.

B2e. Add information to the Driver's Handbook. Part 1: Regarding sanctions for non-driving offenses that exacerbate the impact of driving behavior violations.

B2f. Add an additional reference to the Pennsvlvania Point Svstem Fact Sheet in Chapter 6 of the Pennsylvania Driver's Manual (Publication 95).

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

Low-Cost Safety Measures at Signalized Intersections by Kenneth R. Agent, Kentucky Transportation Center, College of Engineering, University of Kentucky, Lexington 40506-0281 (Kentucky Transportation Cabinet, State Office Building, Frankfort, Kentucky 40602; http://www.ktc.uky.edu/Reports/KTC_08_11_SPR_316_06_1F.pdf) (May 2008)

Highlights

- The low cost of most of the evaluated countermeasures, when compared to the reduction in crashes, would result in a high benefit cost ratio.

The objectives of this study were to: a) identify intersections with a high number of crashes involving a driver disregarding the traffic signal, b) identify types of low-cost safety measures which may be used as a countermeasure for red-light running, and c) evaluate the effectiveness of the installation of some of these countermeasures at a sample of intersections.

The following procedures were followed to achieve the objectives of the study:

1) a literature review was conducted to determine the types of low-cost countermeasures which have been used at signalized intersections,
2) low-cost countermeasures to test were identified (using information from the literature review and from traffic engineers across the state),
3) the CRASH data base was used to identity signalized intersections which have had a high number and rate of crashes (an emphasis was placed on locations where "disregard traffic control" was listed as a contributing factor),
4) the identified countermeasures were installed at selected intersections and e) the effectiveness of the countermeasures was evaluated (using before and after crash data) with a limited amount of conflict data.

The available before and after crash data show the benefit of the various low-cost safety countermeasures to reduce the number of crashes at intersections, specifically angle crashes. A small amount of conflict data support the crash data. The low cost of most of the evaluated countermeasures, when compared to the reduction in crashes, would result in a high benefit cost ratio. Examples of the types of low cost countermeasures included in the evaluation are: double red indications, retro-reflective backplates, and adding signal heads so there is one signal head per lane. The public response to the countermeasures, as reported by traffic engineers, has been positive with requests for additional installations.

Given the severity of the angle collisions resulting from a driver disregarding a traffic signal, the installation of relatively low-cost safety countermeasures are warranted at intersections where this type of crash has occurred or conditions exist which may result in this type of crash. The type of crash analysis described in this report should be used to identify intersections where these countermeasures have the highest potential for reducing crashes. The countermeasures identified should be considered at these intersections with the intersection characteristics and specific crash history used to select the specific countermeasure to implement at a given intersection.

Conclusions

The before and after crash data show the benefit obtained from the various low-cost safety countermeasures in reducing the number of crashes at intersections, especially angle crashes. The limited amount of conflict data support the crash data. The low cost of most of the evaluated countermeasures, when compared to the reduction in crashes, would result in a high benefit cost ratio. The public response to the countermeasures, as reported by traffic engineers, has been positive with requests for additional installations.

Recommendations

Given the severity of the angle collisions resulting from a driver disregarding a traffic signal, the installation of relatively low-cost safety countermeasures is warranted at intersections where this type of crash has occurred or conditions exist which may result in this type of crash. The crash analysis described in this report should be used to identify intersections where these countermeasures have the highest potential for reducing crashes. The countermeasures identified should be considered at these intersections with the intersection characteristics and specific crash history used to select the specific countermeasure to implement at a given intersection.

TRANSPORTATION RESEARCH DIGEST
ARIZONA TRANSPORTATION INSTITUTE
e-mail jsemmens@cox.net

APRIL 2009

Assessing the Needs for Intermediate Diaphragms in Prestressed Concrete Bridges by Steve Cai, and R. Richard Avent, Department of Civil Engineering, Louisiana State University, Baton Rouge, Louisiana 70803 (Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808; http://www.ltrc.lsu.edu/pdf/2008/FR_420.pdf) (May 2008)

Highlights
- The ID decreases the load distribution factor for interior girders and increases the load distribution factor for exterior girders.
- RC IDs provided the greatest protection to exterior girders undergoing impact.

The research team examined and reviewed the state-of-the-art technology and current practices from many sources regarding intermediate diaphragms (IDs). Current Louisiana practice was investigated through a survey sent to all nine LADOTD districts, a review of the Louisiana Bridge Design Manual and other technical literature, and direct interaction with experienced bridge engineers. Bridges that were of interest for this study were selected for visiting and field inspection. Much information was acquired from these field trips to various bridge locations.

A refined scope of work was developed through a work plan. The parametric study was conducted successfully, and important parameters were identified to understand how each one influences the ID performance on the load distribution factor. From the initial parametric study, it was concluded that the ID influence on bridge performance was mainly a function of span length, skew, diaphragm stiffness, and location of diaphragms, and was found to be relatively independent of continuity, girder spacing, and number of spans.

Through further analysis of the identified parameters, the effect of IDs on load distribution was quantified. The current AASHTO design codes do not include information about quantifying the ID performance in load distribution. A systematic parametric study was carried out using a wide range of values for possible parameters which were representative of the current prestressed concrete girder bridges existing in Louisiana. From the results obtained through this parametric study, formulas were developed to determine the diaphragm effect on load distribution for both interior and exterior girders.

Using the correction factors developed to account for the influence of IDs, a more rational load distribution factor could be obtained. The formula developed for an increase in load distribution due to the ID effect on exterior girders gains importance, as no rational formula is available for determining this increment in LDF due to IDs.

From the results obtained in the parametric study and the formulae developed, it could be concluded that the ID decreases the load distribution factor for interior girders and increases the load distribution factor for exterior girders. The IDs increased the deflection marginally for exterior girders and decreased the deflection for interior girders. The deflections were observed to be within permissible limits, both with and without IDs, thereby indicating that deflection is not an important criterion influencing the decision to eliminate reinforced concrete (RC) IDs or replace them using steel IDs.

Researchers proposed steel diaphragm configurations for different bridge configurations that could perform similarly to RC diaphragms. A study was done on the relative performance of RC IDs and steel IDs during the process of deck construction. The alternate steel diaphragms were proposed based on the minimum target stiffness as a proportion of the absolute diaphragm stiffness contributed by the existing RC ID. These steel IDs were found to provide stability near that produced by RC IDs during the deck construction. Therefore, if the reinforced concrete diaphragms were provided only for the purpose of providing girder stability during construction, then this could be served by providing steel diaphragms.

Reinforced concrete IDs and steel IDs under lateral impact loading were investigated, keeping in view the possible collision caused in the prestressed concrete bridges due to over-height trucks passing under them. Through these studies, various issues relating to ID effectiveness were covered to assess the need for reinforced concrete intermediate diaphragms, and alternate ID configurations were proposed.

Results obtained from the impact tests carried out on the bridge with different ID configurations indicated that RC IDs provided the greatest protection to exterior girders undergoing impact, when the impact occurred at the ID location. When the impact took place at a location away from the ID, it was observed that the ID configuration did not significantly influence the bridge performance. The researchers concluded that the IDs could not be counted on for their ability to protect girders if the IDs were not right above the traffic lanes. In cases where there is no traffic passing under the bridge, steel IDs could be used as well if their only purpose is to provide stability.

Based on the nonlinear finite element analysis, the ultimate strength calculated according to the current AASHTO LRFD code is very conservative. This means the strength of the bridge is underestimated when the actual strength is almost double that predicted by the code. Therefore, generally speaking, the ultimate strength of prestressed concrete bridges should have no problem, even without IDs, if the code specified capacity is satisfied.

Detailed descriptions of the field testing were presented. Strains, deflections, and acoustic signals were acquired. Preliminary analysis showed that when 30% diaphragm stiffness was considered, it resulted in a better match with experimental observations than when the full stiffness was used.

When considering rigid connections between the IDs and the girders, the maximum effects of IDs on load distribution was up to 15%, except for BT beams that can be as high as 26%. However, this could be a fictitious number since the real connection is much weaker. Previous literature suggests the IDs contribute about 30% of their stiffness. This conclusion was confirmed based on the observation of the present experimental results. Therefore, the maximum effect of ID effect on load distribution is at a level of 5% for most beams and 10% for BT beams.

TRANSPORTATION RESEARCH DIGEST
ARIZONA TRANSPORTATION INSTITUTE
e-mail jsemmens@cox.net

APRIL 2009

Comprehensive Evaluation of Transit Signal Priority System Impacts Using Field Observed Traffic Data by Yinhai Wang, Mark Hallenbeck, Jianyang Zheng, Guohui Zhang, Jonathan Corey, and Xiaolei Ma, Transportation Northwest Regional Center X (TransNow), Box 352700, 129 More Hall, University of Washington, Seattle, WA 98195-2700 (Research Office, Washington State Department of Transportation, Transportation Building, MS 47372, Olympia, Washington 98504-7372; Project Manager: Kathy Lindquist, 360-705-7976) (Jun 2008)

Highlights

- The SS-RTSP system provided remarkable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross-streets.
- For all passengers who used the two test corridors, the average person delay decreased by 0.1 second in the Phase One test and 0.02 second in the Phase Two test.
- The average number of granted TSP trips per day per intersection was only 16.96 in the Phase One test and 14.40 in the Phase Two test.

Transit signal priority (TSP) is an operational strategy that facilitates the movements of in-service transit vehicles through signalized intersections. To improve the level of service for Community Transit (CT) buses, the South Snohomish Regional Transit Signal Priority (SS-RTSP) project was launched. To understand the overall benefit of this project, the SS-RTSP system was tested and evaluated after the hardware and software had been installed on the 164th Street SW corridor (Phase One) and the SR 99 corridor (Phase Two) in Snohomish County. This comprehensive evaluation was based on a large number of field-observed traffic data and real-world traffic control settings. These data included 11,448 hours of traffic video tapes and over 3.74 GB of raw traffic data in addition to the video data. They were collected by nine traffic control/operation systems within six transportation agencies.

This study quantitatively evaluated the impacts of the SS-RTSP system on both transit and local traffic operations on the basis of field-observed data. Simulation models were also built and calibrated to compute measures of effectiveness that could not be obtained from field-observed data. The evaluation results showed that the SS-RTSP system provided remarkable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross-streets. The overall impact of the SS-RTSP system on local traffic at each entire intersection was not statistically significant at the p=0.05 level.

With the SS-RTSP system, transit vehicles can be operated more reliably. The measure of effectiveness (MOE) of Transit Time Match indicated improvements in transit vehicle adherence to their schedules by 1 minute and 34 seconds, or about 16.3% in the Phase One test, and 15 seconds, or about 6%, in the Phase Two test.

In the Phase One test, the mean eastbound corridor travel time of transit vehicles was 6.7 seconds, or 4.9%, shorter for granted trips than the average corridor travel time without TSP. Similarly, the average saved transit corridor travel time was 54 seconds, or 4.93%, in the Phase Two test. Because of the saved transit travel time, the SS-RTSP system decreased overall personal delays. For all passengers who used the two test corridors, the average person delay decreased by 0.1 second in the Phase One test and 0.02 second in the Phase Two test, although these observations were not statistically significant at the p=0.05 level. Although such a delay decrease is trivial on a personal basis, it can be converted to an overall saved delay of 56,227 person-hours per year for peak-hour only travel along the two test corridors.

Simulation experiments showed that the impacts of the SS-RTSP system on local traffic delay at an entire intersection sometimes increased and sometimes decreased. Paired t-tests on average vehicle delay and number of vehicle stops did not find any significant impacts from the SS-RTSP system at the p=0.05 level. The SS-RTSP system's impacts on cross-street traffic was also analyzed. Test data showed slight changes in vehicle delay, queue length, and signal cycle failure frequency on cross-streets. However, the t tests indicated that these changes were not significant at the p=0.05 level after the TSP implementation.

To improve the performance of the current SS-RTSP system, more transit vehicles could be enabled for TSP eligibility. The average number of granted TSP trips per day per intersection was only 16.96 in the Phase One test and 14.40 in the Phase Two test. Given that the negative impacts of the SS-RTSP system on local traffic were not statistically significant, more transit trips could be given proper TSP treatment, and the frequency of TSP requests could be increased to generate more benefits from the SS-RTSP system.

Simulation-based investigations of TSP system operations and optimization were conducted. The SR 99 corridor was selected as the test site, and three practical semi-actuated signal control plans were applied to examine TSP system performance. The simulation-based research findings indicated that to achieve the best operation efficiency, the compatibility between TSP control schemes and signal control coordination should be strengthened to minimize transit disruption to signal coordination. TSP systems must be fully tested under different coordinated control plans prior to implementation.

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

Transportation Policy: Getting the Facts Straight by Wendell Cox and Ronald D. Utt (Heritage Foundation, 214 Massachusetts Ave NE, Washington DC 20002-4999; ph 202.546.4400; http://www.heritage.org/Research/SmartGrowth/wm2148.cfm) (Dec 3, 2008)

Highlights

- The share of federal spending on transit vastly exceeds its passenger market share.
- Despite many years of massive government spending on transit, it has experienced serious market share losses.
- Only 63% of the federal fuel taxes paid by motorists are spent on roads.

Many environmental groups, business trade associations, and state and local governments anticipate that new Democratic leadership in Washington next year will lead to major changes in federal surface transportation policy. With the current highway authorization law (SAFETEA-LU) set to expire in September 2009, many of these organizations are recommending a substantial increase in federal transportation spending and expect that it will be funded by an equally substantial increase in the federal fuel tax (now set at 18.3 cents per gallon of gasoline).

At the same time, many environmental groups, labor unions, consultants, and construction companies are urging the federal government to redirect federal transportation policy toward 19th century transportation options by shifting federal resources from highways and autos to transit and trains, as well as hiking and biking, in the belief that these latter modes--while slower and more costly--are more fuel efficient and environmentally friendly. With an opportunity to receive greater subsidies, the transit and train lobbies have moved aggressively to influence Congress and the media, and many in Congress are already promising to push for these changes.

But as the facts reveal, such a shift would cost vast sums of money, yield little or no transportation benefits, and undermine our economic well being by limiting mobility and raising the cost of travel.

Despite claims of underfunding, the share of federal spending on transit vastly exceeds its passenger market share. Whereas about 20% of federal surface transportation spending is devoted to transit, only 1.9% of all urban passenger travel and 4.9% of all commuters use transit.

Despite many years of massive government spending on transit--a total of $1 trillion (inflation adjusted) since 1970--transit has experienced serious market share losses. In 1970, 8.5% of commuters used transit, but 4.9% did in 2007.

Although carpooling receives very little government financial support, in 2007 more commuters carpooled (10.4%) than used transit (4.9%). Where modest government investments have been made in carpooling, the results have been impressive: In the Washington, D.C., suburb of Prince William County, Virginia, where a dedicated HOV lane is supported by remote commuter parking lots and a well-organized driver/rider system, 17.6% of commuters carpool, compared to the 4.7% that use transit.

The share of "commuters" who work at home--an employment option that also receives little federal encouragement--reached 4.1% in 2007 compared to 4.9% for transit. At current trends, the share of the job market that works at home will exceed that of transit by 2012.

U.S. transit ridership is concentrated in just a few metropolitan areas. In 2007, 74% of U.S. transit ridership took place in just seven metropolitan areas: New York; Philadelphia; Washington, D.C.; Boston; Chicago; San Francisco; and Los Angeles. In the Portland, Oregon, metropolitan area, which has made massive investments in a light rail system and transit-oriented development, only 5.5% of commuters in the area used transit in 2007, well below the pre-light-rail (1980) share of 8.4%.

Despite exaggerated claims that Americans are turning to transit, more than half of the much-heralded increase in transit ridership is concentrated in a single metropolitan area: Of the 10.8% increase in nationwide transit ridership that occurred between 2005 and 2007, 60% of that increase occurred in the New York City urbanized area.

Transit advocates recently claimed that high gas prices have encouraged motorists to abandon their cars in favor of transit, but a detailed analysis of recent trends reveals that only 3% of the reduction in auto use shifted to transit by early 2008. The other 97% of the reduction in vehicle miles traveled in automobiles was absorbed by carpools, working at home, less auto use, walking, and more efficient auto use (combining trips, for example). This estimate closely tracks recent polling results on changing travel patterns, which found that 4% of commuters used transit instead of driving, 9% shifted to carpools, and 66% combined multiple trips into a single trip.

Passenger rail advocates have made similar claims (and complaints) for Amtrak, but the record does not support them. Despite claims of rising ridership, Amtrak still serves less than 1% of the intercity travel market. A 15% increase of a miniscule share of the market is still a miniscule share of the market. Indeed, despite ridership gains, so far this year Amtrak trains are only 51.6% full, compared to more than 80% for commercial airlines.

Amtrak's complaints of being underfunded are also exaggerated. Although it accounts for only about one-half of 1% of the intercity passenger market, it will receive 2.5% of the federal surface transportation spending in FY 2008, nearly five times its market share. Of all of the modes of travel, Amtrak riders receive far and away the highest per passenger federal subsidy. According to a 2004 U.S. Department of Transportation study, Amtrak passengers received a federal subsidy of $210.31 per passenger per thousand miles, compared to $4.66 for intercity buses and $6.18 for commercial airlines. Automobiles earn a "profit" for the federal government since only about 63% of the federal fuel taxes paid by motorists are spent on roads; most of the rest is spent on transit.

Claims that Amtrak subsidies are justified because trains save on energy are also not supported by the facts. According to an earlier U.S. Department of Energy analysis of per passenger per mile BTU use by alternative travel modes, intercity buses are nearly three times more fuel efficient than passenger rail (Amtrak). In effect, America could achieve significant savings in energy and reduce greenhouse gas emissions if it shut down Amtrak and transferred all passengers to buses.

Congress may soon be embarking upon a massive spending program that is without precedent. And while the purposes of such a package will be both to stimulate the economy and "lay the groundwork for long-term economic growth," as President-elect Obama promised, the facts presented above suggest that money devoted to technologically obsolete transportation schemes that the public does not use will undermine both of these goals, and America will be a poorer place because of it.

TRANSPORTATION RESEARCH DIGEST

ARIZONA TRANSPORTATION INSTITUTE

e-mail jsemmens@cox.net

APRIL 2009

Evaluation of Chevron Markings on Freeway-to-Freeway Connector Ramps in Texas by A.P. Voigt, S.P. Kuchangi, Texas Transportation Institute, Texas A&M University System, College Station, Texas 77843-3135 (Texas Department of Transportation, Research and Technology Implementation Office P.O. Box 5080, Austin, Texas 78763-5080; 979.845.1734; http://tti.tamu.edu/documents/0-4813-2.pdf) (Apr 2008)

Highlights

- Comparison of mean speeds for all vehicle classes indicates a slight decrease in speeds after the installation of chevrons at the start and mid of the curve.
- The magnitude of the decrease in overall mean speed is about 0.14 mph to 0.45 mph.

This project looked at the effectiveness of the converging chevron pavement marking in reducing speeds on a freeway-to-freeway connector ramp. A converging chevron pavement marking pattern was installed on Ramp K at the interchange of US 54 and I-10 in El Paso, Texas. This ramp connects US 54 westbound to I-10 westbound. To evaluate the impact of the pavement marking pattern, per-vehicle speed and classification data were collected during three discrete time periods (before, early-after, and late-after deployment of the markings) at four locations on the project ramp (two locations upstream of the curve, at the start of the freeway-to-freeway connector curve, and at the middle of the connector curve).

Findings

The project facility has a posted advisory speed of 30 mph on the curve, which requires motorists to reduce from 60 mph to 30 mph as they enter the curve. General statistics computed on all three datasets (before, early-after, and late-after) indicate that mean speed of the motorists at upstream location was about 60-63 mph, mean speeds at the start of the curve and middle of the curve ranged between 47 to 48 mph. This indicates that on average motorists reduce their speed by about 12 to 16 mph as they traverse from the upstream location to the start or mid of the curve. This trend is observed in all study periods—before, early-after and late-after, and is in contrast to the 30 mph reduction recommended by the curve advisory speed of 30 mph (considering the upstream speed limit signing of 60 mph).

A general observation of deceleration characteristics by vehicle class indicates that heavy trucks decelerate more than passenger vehicles as motorists travel from upstream, through the chevron marking treatment, to the start of the curve in all time-periods (before, early-after and late-after periods). However, between the start of the curve and the middle of the curve there were varied observations, most notably in the late-after period when all vehicles seemed to accelerate between start of the curve and middle of the curve.

Although motorists decreased their speeds on an average by 12 to 16 mph in all time periods on approach to the connector curve, the speeds of motorists driving 15 mph above the posted advisory speed did decrease after the installation of chevron pavement markings at the start of the connector curve.

The effectiveness of chevron pavement markings on speed reduction was obtained from the before-after analysis. In this analysis, mean speeds were compared between the following study periods at each location on the freeway-to-freeway connector curve:

- before and early-after,
- before and late-after, and
- early-after and late-after.

Comparison of mean speeds for all vehicle classes from the before to early-after periods indicates a slight decrease in speeds after the installation of chevrons at the start and mid of the curve. However, the magnitude of the decrease in overall mean speed is about 0.14 mph to 0.45 mph. Although the magnitude is small, the effect of chevrons in decreasing the speeds was found to be statistically significant at a 95% confidence level. This indicates that chevron markings were effective in reducing overall mean speed on freeway-to-freeway connectors.

In the before and early-after comparison by vehicle classification, heavy vehicles had a higher reduction in mean speeds when compared to passenger vehicles at the start of the curve. This result is promising as trucks are more prone to speed-related incidents on freeway-to-freeway connector ramps. However, there was no significant difference in speeds from before to early-after period upstream of the curve. Hence, the converging chevron pattern that was installed between the upstream section and the start of the curve seems to have influenced motorists' perception to reduce speeds.

The before and early-after comparison segregated by daytime and nighttime conditions indicated that the reduction in mean speed after installation of chevron was slightly greater during nighttime conditions than daylight conditions. This could have resulted from the visual effect of pavement marking being more prominent with high retroreflectivity.

A comparison of mean speeds between the before and late-after periods indicates that there was a reduction in speed at upstream of the curve and at the start of the curve. However, at the middle of the curve, a significant increase in speeds was observed. A noticeable difference in the late-after period was that reduction in speed due to chevron marking installation was observed at the upstream section itself, whereas in the early-after period the speed reduction was observed only from the start of the curve. A possible reason for this could be that motorists become cognizant of the chevron markings over time and reduce their speeds even before they drive through the converging chevron markings.

Also, in the late-after period, all vehicle categories showed significant reduction in speed at the upstream and start of the curve, with heavy trucks being the most affected by the chevron markings to reduce speeds. Moreover, the magnitude of reduction in mean speeds from before to late-after was much greater than the reduction in speeds from before to early-after. This indicates that the effectiveness of chevron markings did not degrade over time.

However, the before to late-after comparison of mean speeds at the middle of the curve showed a significant increase for all vehicle classes. The observed increase in speeds at the middle of the curve could be due to motorists slowing more before the curve, but then judging the upcoming curve and accelerating through. For this particular freeway-to-freeway connector curve, motorists have much better sight distance by the time they reach the start of the connector curve, which could encourage some acceleration.