



## **Christine E. Carrigan, P.E., Ph.D.**



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### **SUMMARY**

*Award winning roadway safety thought leader. Has conducted numerous research projects involving road safety. Widely published in peer reviewed literature. National and international speaker on roadway safety. Serves on key national committees dealing with roadway safety and engineering ethics. Hands-on experience designing a wide variety of highway and intersection improvements. Registered professional engineer in more than fifteen states. PhD in Civil Engineering with a focus on highway safety from Worcester Polytechnic Institute.*

### **DETAILED BIOGRAPHICAL SKETCH**

Dr. Carrigan has been active in transportation engineering for more than 25 years. She received her undergraduate degree in Civil Engineering from Worcester Polytechnic Institute in 1997 and began her career in civil engineering as a highway designer joining a Massachusetts consulting firm. Dr. Carrigan later joined the Massachusetts Highway Department then later a second highway design consulting firm. She was responsible, during these engagements, for the design of highway geometric improvements; the design of highway reconstruction and maintenance projects; the design of signalized and unsignalized intersections and interchanges; the preparation of temporary traffic control plans; construction and maintenance inspection; and preparation of contract documents. Dr. Carrigan has a wide variety of highway design, construction, and maintenance experience.

Dr. Carrigan gained close to ten years of practical design and construction experience before earning a Master of Science degree in 2008 and a PhD in 2010 from Worcester Polytechnic Institute in Civil Engineering with a focus on roadside and highway safety.

Dr. Carrigan formed a research consulting business with two partners in 2010 and has subsequently been almost exclusively focused on roadside and highway safety research. Dr. Carrigan has or is currently conducting research funded by the National Academy of Science's National Cooperative Highway Research Program (NCHRP), the Federal Highway Administration (FHWA), and a variety of other government and industry sponsors.

Dr. Carrigan has developed design guidance for inclusion in publications such as the AASHTO Roadside Design Guide and the AASHTO LRFD Bridge Specification. She has developed models for quantifying crash frequency and severity for inclusion in

the AASHTO Highway Safety Manual. Dr. Carrigan co-authored NCHRP Report 892 providing guidance for shielding bridge piers and NCHRP WO Document 307 which provides guidance for the selection of bridge rails. She co-authored NCHRP WO Document 319 which updated the cost-benefit procedures and software available within the AASHTO Roadside Design Guide. She documented the FHWA study on the in-service performance of terminals. Dr. Carrigan is the lead author of NCHRP Report 996 on the selection and placement of median and roadside barriers. She is a co-author of NCHRP Report 972 which updated the guidance available through the AASHTO Roadside Design Guide. Dr. Carrigan is the lead author of NCHRP Report 1010 which provides guidance for evaluating the field performance of roadside hardware and also the lead author on NCHRP WO Document 407 for gathering data elements to evaluate the field performance of roadside hardware. Dr. Carrigan is currently the principal investigator for an NCHRP project which will define acceptable field performance guidelines for roadside hardware. She is also the principal investigator for an NCHRP project which will develop new crash testing procedures and the associated evaluation criteria for a future update to the AASHTO Manual for Assessing Safety Hardware (MASH).

Dr. Carrigan is a member of the National Society Professional Engineers Board of Ethical Review. She is a member of the Transportation Research Board Committee on Roadside Design. She is the chair of the In-Service Performance Evaluation (ISPE) subcommittee. Dr. Carrigan is a registered professional engineer the States of Arizona, Connecticut, Florida, Hawaii, Illinois, Indiana, Maine, Massachusetts, Mississippi, New York, New Mexico, North Carolina, Ohio, South Carolina, Texas, Washington, and West Virginia.

## **PROFESSIONAL FOCUS**

In-service performance evaluations of roadside hardware, probability concepts in highway safety; development and use of crash-based and encroachment-based models in highway and roadside safety; risk and cost effectiveness analysis of design alternatives; design and evaluation of geometric and roadside improvements; and development of roadside design guidance.

## **EDUCATION**

- Ph.D in Civil Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts (2010).
- MS in Civil Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts (2008).
- BS in Civil Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts (1997).

## **HONORS**

- AFB20 Best Paper Award, *Using Risk Analysis to Minimize Adverse Consequences in Non-Standard Designs* by Malcolm H. Ray and Christine E. Carrigan (2015)
- AFB20 Volunteer of the Year (2014)
- Schroff Participation Grant from the ASEE/Engineering Design Graphics Division (2009)
- International Road Federation Student Essay Competition runner-up, Silvestri, C. and Conron, C. E., *Proposed Policy for Highway Design and Maintenance for the Reduction of Tree Crashes* (2008)
- Autodesk University Scholarship Recipient (2007 & 2008)
- Massachusetts Highway Department Pride in Performance Award (2000)

## **PROFESSIONAL ENGINEER REGISTRATION**

- Arizona #64906
- Connecticut # PEN.0032781
- Florida #91763
- Hawaii # PE-20463-0
- Illinois #062.072241
- Indiana # PE12200715
- Maine #13379
- Massachusetts #49330
- Mississippi #29254
- New Mexico #27581
- New York #106054-01
- North Carolina #052285
- Ohio #82166
- South Carolina #33916
- Texas, #135720
- Washington State #55350
- West Virginia #25369

## **CERTIFICATION**

- Local Project Administrator

## **SERVICE**

- National Society of Professional Engineers (Board of Ethical Review, September 12, 2024-June 30, 2027)
- Maine Society of Professional Engineers (Past President, May 2023-June 2024)
- Maine Society of Professional Engineers (President, May 2022-May 2023)
- Maine Society of Professional Engineers (President Elect, May 2021-May 2022)
- Transportation Research Board, Subcommittee AKD20(3) In-Service Performance Evaluation (Chair, November 2020 - Present).
- Transportation Research Board, Roadside Safety Committee AFB20 (Member, April 15, 2019-April 14, 2025). Renamed AKD20 in April, 2020.
- Lake Anasagunticook Association, Board Member (Director, 2019 – June 2022)
- Maine Society of Professional Engineers, Board of Directors (Director, May 2019 – May 2021)
- NCHRP 20-05/Topic 50-04, “Utility Pole Safety and Hazard Evaluation Approaches” (Panel Member, 2018-2019).
- Transportation Research Board, Standing Committee on Utilities, Committee AFB70, (Utility Task Group, 2014 – 2018).

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

- Transportation Research Board, Roadside Safety Committee AFB20 (Friend, 2009 – April 15, 2019).
- Transportation Research Board, Highway Safety Performance Committee ANB25 (Friend, 2013 – present).
- Transportation Research Board, Geometric Design Committee AFB10 (Member, 2012-April 14, 2022). Renamed AKD10 in April, 2020.

## **CURRENT PROFESSIONAL MEMBERSHIPS**

- American Society of Civil Engineers
- Institute of Transportation Engineers
- National Society of Professional Engineers
- Maine Society of Professional Engineers

## **EXPERIENCE**

**2010-Present: Partner, RoadSafe LLC, Canton, Maine:** Perform research, consulting, and litigation support in the areas of roadside and highway safety. Conduct in-service performance evaluations (ISPEs) of safety features. Apply probability concepts in roadside and highway safety for the reduction of run-off-road crash frequency and severity. Develop and use crash-based and encroachment-based models for risk and cost effectiveness analysis of design alternatives. Develop design and assessment guidance for incorporation into transportation agency design, construction, and maintenance manuals. Design and evaluate highway and roadside improvements. Assist municipalities in the design, construction, and administration of road projects.

**2024-Present: Selectman, Town of Canton, Maine:** The executive power and duties of the town are vested in the board of selectmen. Responsibilities of the board include the protection of life and property, the protection of voting rights and ballots, the maintenance of public ways, snow removal, and civil defense.

**2007-2010: Adjunct Instructor of Civil and Environmental Engineering at the Worcester Polytechnic Institute, Worcester, MA:** Taught classes in the areas of transportation engineering, computer aided engineering, and construction management.

- 2001-2005:** **Project Engineer at Vanasse, Hangen, Brustlin, Inc., Springfield and Watertown, MA:** Designed highway improvement and signalization projects in rural, suburban, and urban areas, balancing the conflicting requirements of established design standards and limitations of available land. Prepared permit documents for new interchange construction. Conducted public meetings and hearings to inform the citizens of proposed roadway improvements and gain their feedback. Coordinated improvement project schedules with impacted groups, including municipalities, utility companies, and regulatory agencies. Trained staff on the use of computer aid design and drafting tools for improved performance of design tasks and plan production.
- 1998-2001:** **Civil Engineer at the Massachusetts Highway Department, Worcester, MA:** Designed signalized and unsignalized intersection reconstruction projects to improve traffic flow utilizing available traffic analysis software, including HCS, Syncro, and SimTraf. Developed conceptual designs for new interstate interchanges and new regional roadways. Conducted project reviews of consultant designs for adherence to design standards. Prepared construction bid documents. Prepared design plans using computer aiding drafting tools such as AutoCAD and Land Development Desktop. Prepared environmental regulatory agency filings. Conducted construction inspections of private contractors to assure compliance with the contract documents. Conducted public presentations utilizing digital and non-digital media to inform citizens of proposed roadway improvements and gain their feedback.
- 1997-1998:** **Project Engineer at Earth Tech, Inc, Concord, MA:** Prepared timing and lane configuration plans for traffic signal improvement projects. Prepared traffic signal warrant analysis. Conducted roundabout and traffic signal capacity analysis. Prepared cost estimates. Prepared design plans using computer aiding drafting tools such as AutoCAD and Softdesk.

## **PUBLICATIONS**

### **Books and Monographs**

1. **C.E. Carrigan and C.A. Plaxico, “Guide for Bridge Curb/Rail and Approach Treatment for Extremely Low Volume Roads,”** FHWA-FLH-23-003a, February 9, 2023 <https://highways.dot.gov/sites/fhwa.dot.gov/files/bridge-curb-railing-approach-treatment-final-guide.pdf>

2. **C.E. Carrigan** and E.M. Ray, “**Data Collection Practices for Use with In-Service Performance Evaluations,**” National Cooperative Highway Research Program NCHRP Web-Only Document 407, National Academy of Sciences, Washington, D.C., 2024 <https://doi.org/10.17226/27911>
3. M.H. Ray, **C.E. Carrigan** and E.M. Ray “**Development of Safety Performance-Based Guidelines for the Roadside Design Guide,**” National Cooperative Highway Research Program Report 972, National Academy of Sciences, Washington, D.C., 2022 <https://doi.org/10.17226/26763>
4. **C.E. Carrigan** and M.H. Ray, “**In-Service Performance Evaluation: Guidelines for the Assembly and Analysis of Data,**” National Cooperative Highway Research Program Report 1010, National Academy of Sciences, Washington, D.C., 2022 <https://doi.org/10.17226/26751>
5. **C.E. Carrigan**, M.H. Ray, E. Ray, A.M. Ray “**Multi-State In-Service Performance Evaluations of Roadside Safety Hardware,**” National Cooperative Highway Research Program NCHRP Web-Only Document 332, National Academy of Sciences, Washington, D.C., 2022. <https://doi.org/10.17226/26749>
6. **C.E. Carrigan** and M.H. Ray, “**Selection and Placement Guidelines for Test Levels 2 through 5 Median Barriers,**” National Cooperative Highway Research Program Report 996, National Academy of Sciences, Washington, D.C., 2022
7. **C.E. Carrigan** and M.H. Ray, “**Consideration of Roadside Features in the Highway Safety Manual,**” National Cooperative Highway Research Program NCHRP Web-Only Document 325, National Academy of Sciences, Washington, D.C., 2022. <https://doi.org/10.17226/26571>
8. M. H. Ray, **C. E. Carrigan**, C. A. Plaxico, S-P Miaou, T. O. Johnson, “**Roadside Safety Analysis Program (RSAP) Update,**” National Cooperative Highway Research Program Web-Only Document 319, National Academy of Sciences, Washington, D.C. 2022. <https://doi.org/10.17226/26521>.
9. C.A. Plaxico, M.H. Ray, **C.E. Carrigan**, T.O. Johnson, A.M. **Ray**, “**Criteria for Restoration of Longitudinal Barriers, Phase II,**” National Cooperative Highway Research Program Web-Only Document 304, National Academy of Sciences, Washington, D.C. <http://www.trb.org/main/blurbs/182506.aspx>, 2021.
10. M.H. Ray and **C.E. Carrigan**, “**Roadside Hardware Replacement Analysis User’s Guide,**” National Cooperative Highway Research Program Web-Only Document 292, National Academy of Sciences, Washington, D.C. <http://www.trb.org/main/blurbs/181809.aspx>, 2021.

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

11. M.H. Ray, **C.E. Carrigan** and C.A. Plaxico, “**Guidelines for Shielding Bridge Piers**,” National Cooperative Highway Research Program Report 892, National Academy of Sciences, Washington, D.C., 2018.
12. M. H. Ray and **C. E. Carrigan**, “**Recommended Guidelines for the Selection of Test Levels 2 through 5 Bridge Railings**,” National Cooperative Highway Research Program Web-Only Document 307, National Academy of Sciences, Washington, D.C., [https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_wod\\_307.pdf](https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_wod_307.pdf), 2015.
13. M. H. Ray, C. A. Plaxico and **C.E. Carrigan**, “**Roadside Safety Analysis Program (RSAP) User’s Manual**,” National Cooperative Highway Research Program Web-Only Document 319 Appendix A, [https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_wod\\_319User.pdf](https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_wod_319User.pdf), October 25, 2012.
14. M. H. Ray, C. A. Plaxico and **C.E. Carrigan**, “**Roadside Safety Analysis Program (RSAP) Engineer’s Manual**,” National Cooperative Highway Research Program Web-Only Document 319 Appendix B, [https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_wod\\_319Engineer.pdf](https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_wod_319Engineer.pdf), October 25, 2012.
15. M. H. Ray, C. A. Plaxico and **C.E. Carrigan**, “**Roadside Safety Analysis Program (RSAP) Programmer’s Manual**,” National Cooperative Highway Research Program Web-Only Document 319 Appendix C, [https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_wod\\_319Programmer.pdf](https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_wod_319Programmer.pdf), October 25, 2012.

### Technical Reports

16. **C.E. Carrigan** and C.A. Plaxico, “**Bridge Curb/Railing and Approach Treatment for Extremely Low Volume Roads**,” FHWA Publication Number: FHWA-FLH-23-003b, December 2022.
17. **C.E. Carrigan**, C.A. Plaxico, E. Ray, and A.M. Ray, “**In-Service Performance Evaluation (ISPE) of New England Transportation Consortium (NETC) Steel Bridge Railings**,” Roadsafe LLC, 2022
18. **C.E. Carrigan**, M.H. Ray, E. Ray, and A.M. Ray, “**Proposed Alternative Procedures for Assessing Compliance with the Washington State Department of Transportation Control Zone Policies**,” Roadsafe LLC, 2018.

19. **C.E. Carrigan** and M.H. Ray, “**Development of a Strategic Plan for the AASHTO SCOD Technical Committee on Roadside Safety (TCRS)**,” American Association of State Highway and Transportation Official, <http://sp.design.transportation.org/Documents/TC%20Roadside%20Safety/TCRS%20Strategic%20Plan%202015.pdf>, 2015.
20. **C.E. Carrigan** and M.H. Ray, “**Comprehensive Roadside Design Guide Strategic Plan**,” American Association of State Highway and Transportation Official, <http://sp.design.transportation.org/Documents/TC%20Roadside%20Safety/TCRS%20Strategic%20Plan%202015%20-%20Chapter%203%20attachment%20-%20RDG.pdf>, 2015.
21. **C.E. Carrigan**, M.H. Ray, and C.A. Plaxico, “**Instrumental MASH Strategic Plan**,” American Association of State Highway and Transportation Official, <http://sp.design.transportation.org/Documents/TC%20Roadside%20Safety/TCRS%20Strategic%20Plan%202015%20-%20Chapter%204%20attachment%20-%20MASH.pdf>, 2015.
22. **C.E. Carrigan** and M.H. Ray, “**Evidence-based Roadside Engineering Strategic Plan**,” American Association of State Highway and Transportation Official, <http://sp.design.transportation.org/Documents/TC%20Roadside%20Safety/TCRS%20Strategic%20Plan%202015%20-%20Chapter%205%20attachment%20-%20Evidence%20based%20roadside.pdf>, 2015.

#### **Refereed Papers**

23. **C.E. Carrigan** and M.H. Ray, “**Application of Historic and Emerging Median Barrier Guidance to Median Design**,” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2024
24. **C.E. Carrigan**, M.H. Ray, and E.M. Ray, “**A Case Study of Applying the Forgiving Roadside Concept to Detention Ponds in an Urban Environment**,” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2024
25. E.M. Ray, **C.E. Carrigan**, C.A. Plaxico, “**Demonstrating Crashworthiness of Bridge Railings in Maine**,” Transportation Research Record, Journal of the Transportation Research Board, Washington, D.C., July 27, 2024. Available online: <https://journals.sagepub.com/doi/10.1177/03611981241255600>
26. M.H. Ray and **C.E. Carrigan**, “**Six Decades of Roadside Encroachment Modeling**,” Transportation Research Record, Journal of the Transportation Research Board, Washington, D.C., June 24, 2022. Available online: <https://journals.sagepub.com/doi/10.1177/03611981221101026>

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

Page | 8

27. **C.E. Carrigan** and M.H. Ray, “**Developing Selection Tables for MASH Test Levels 2 through 5 Median Barriers,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2022.
28. **C.E. Carrigan** and M.H. Ray, “**A Synthesis of Encroachment Adjustment Factors to Support Keeping Vehicles on the Road,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2022.
29. C. E. Carrigan and M. H. Ray, “**Modeling the Maximum Lateral Extent of Encroachment and Probability of Passenger-Vehicle Rollover on Slopes,**” Transportation Research Record No. 2673(1) pages 173-181, Journal of the Transportation Research Board, Washington, D.C., January 2, 2019. Available online: <https://doi.org/10.1177/0361198118821313>
30. **C.E. Carrigan** and M.H. Ray, “**In-Service Performance Evaluation of Longitudinal Barrier to Study Occupant Risk,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2019.
31. **C.E. Carrigan**, E M. Ray, and M.H. Ray, “**Proposed Methodology for Quantifying Roadside Tree Crash Risk,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2019.
32. **C.E. Carrigan** and M.H. Ray, “**A Model of the Probability of a Cross-Median Crash when a Vehicle Fully Crosses the Median,**” Transportation Research Record: Journal of the Transportation Research Board, Washington, D.C., April 11, 2018. Available online: <http://journals.sagepub.com/doi/10.1177/0361198118758310>
33. **C.E. Carrigan** and M.H. Ray, “**Consideration of Placement Criteria for Utility Poles to Minimize Crash Risk,**” Transportation Research Circular Number E-C220 on pages 185-195, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
34. M.H. Ray, **C.E. Carrigan**, and C.A. Plaxico, “**Heavy Vehicle Encroachment Trajectories,**” Transportation Research Circular Number E-C220 on pages 820-830, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
35. **C.E. Carrigan** and N.M. Sheikh, “**Proposed Modification Factors for Roadside Slopes,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2017.

36. **C.E. Carrigan** and M.H. Ray, “**Assessment of the MASH Heavy Vehicles for Field Relevancy,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2017.
37. **C.E. Carrigan**, M.H. Ray, and A.M. Ray “**Evaluating the Performance of Roadside Hardware,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2017.
38. **C.E. Carrigan** and M.H. Ray “**A New Approach to Run-off-Road Crash Prediction,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2017.
39. **C.E. Carrigan**, T.O. Johnson, and M.H. Ray, “**Tree Planting and Clearing Guidance with Consideration of Minimized Crash Risk,**” Transportation Research Record: Journal of the Transportation Research Board, No. 2588 on pages 110–115, Washington, D.C., 2016.
40. **C.E. Carrigan** and M.H. Ray, “**Practitioner’s Guide to the Analysis of In-Service Performance Evaluation Data,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2016.
41. M.H. Ray and **C.E. Carrigan**, “**Using Risk Analysis to Minimize Adverse Consequences in Non-Standard Designs,**” Transportation Research Record: Journal of the Transportation Research Board, No. 2521 on pages 109–114, Washington, D.C., 2015.
42. **C.E. Carrigan** and M.H. Ray, “**Proposed Horizontal Curve and Vertical Grade Encroachment Adjustment Factors,**” Transportation Research Record: Journal of the Transportation Research Board, No. 2521 on pages 94–100, Washington, D.C., 2015.
43. **C.E. Carrigan** and M.H. Ray, “**Proposed Heavy Vehicle Encroachment Adjustment Factor,**” Transportation Research Record: Journal of the Transportation Research Board, No. 2521 on pages 101–108, Washington, D.C., 2015.
44. M.H. Ray and **C.E. Carrigan**, “**A Review of Bus Run-off-Road Crashes,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2015.
45. **C.E. Carrigan**, M.H. Ray, T.O. Johnson, and A.M. Ray, “**Run-off-road Crash Prediction Models for Each Edge of Undivided and Divided Roadways,**” Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2015.

46. **C.E. Carrigan, M.H. Ray and T.O. Johnson, “Understanding Heavy Vehicle Encroachment Frequency,”** Transportation Research Record 2437, Transportation Research Board, Washington, D.C., pages 20-26, Washington, D.C., 2014.
47. M.H. Ray, **C.E. Carrigan,** and C.A. Plaxico, **“Developing Selection Tables for Bridge Railing,”** Transportation Research Record 2437, Transportation Research Board, Washington, D.C., pages 10-19, 2014.
48. M.H. Ray, **C.E. Carrigan,** and C.A. Plaxico, **“Method for Modeling Crash Severity with Observable Crash Data,”** Transportation Research Record 2437: Journal of the Transportation Research Board, pages 1-9, Washington, D.C., 2014.
49. M.H. Ray and **C.E. Carrigan,** **“Methodology for Systematically Comparing Longitudinal Barrier Performance,”** Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2014
50. M.H. Ray, **C.E. Carrigan,** and C.A. Plaxico, **“Estimating Crash Costs in the Updated Roadside Safety Analysis Program,”** Transportation Research Board Annual Meeting Compendium of Papers, Transportation Research Board, Washington, D.C., 2012.
51. M.H. Ray, C. Silvestri, **C.E. Conron,** M. Mongiardini, **“Experience with Cable Median Barriers in United States: Design Standards, Policies and Performance,”** Journal of Transportation, American Society of Civil Engineers, October 2009.

#### **Conference Proceedings**

52. **C. E. Carrigan** and M. H. Ray, **“In-Service Performance Evaluation of Longitudinal Barrier to Study Occupant Risk,”** ASCE International Conference on Transportation & Development 2020, <https://doi.org/10.1061/9780784483145.004> August 31, 2020.
53. **C. E. Carrigan** and M. H. Ray, **“Probability of a Vehicle Traveling Thru a Longitudinal Barrier: Penetrations, Rollovers, Vaults,”** ASCE International Conference on Transportation & Development 2020, <https://doi.org/10.1061/9780784483145.003>, August 31, 2020.
54. **C. E. Carrigan** and M. H. Ray, **“Modeling the Probability of a Collision Given the Lateral Offset and Size of a Narrow-Fixed Object,”** ASCE International Conference on Transportation & Development 2020, <https://doi.org/10.1061/9780784483145.002>, August 31, 2020.

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

55. **C.E. Carrigan M.H. Ray, and C.A. Plaxico “Assessment of Existing Barrier Warrants for Roadside Slopes,”** ASCE International Conference on Transportation & Development, <https://doi.org/10.1061/9780784481530.016> Pittsburgh, Pennsylvania, July 15-18, 2018.
56. **M.H. Ray and C.E. Carrigan, “Meta-Analysis of the Risk of Fatal and Incapacitating Injury in Tangent W-Beam Guardrail Terminal Collisions,”** ASCE International Conference on Transportation & Development, <https://doi.org/10.1061/9780784481530.014> Pittsburgh, Pennsylvania, July 15-18, 2018.
57. **C.E. Carrigan and M.H. Ray, “Assessing the Field Performance of W-beam Terminals in Washington,”** ASCE International Conference on Transportation & Development, <https://doi.org/10.1061/9780784481530.015> Pittsburgh, Pennsylvania, July 15-18, 2018.
58. **C.E. Carrigan, and M.H. Ray, “Consideration of Roadside Features in the Highway Safety Manual,”** Transportation Research Circular Number E-C220 on page 421, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
59. **C.E. Carrigan, and M.H. Ray, “Benchmarking the Risks of Roadside Hazards,”** Transportation Research Circular Number E-C220 on page 497, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
60. **C.E. Carrigan, and M.H. Ray, “Selection and Placement Guidelines for Test Level 2 through Test Level 5 Median Barriers,”** Transportation Research Circular Number E-C220 on page 609, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
61. **M.H. Ray and C.E. Carrigan, “Guidelines for Shielding Bridge Piers,”** Transportation Research Circular Number E-C220 on page 629, Transportation Research Board, Washington, D.C., 2017. Available online: <http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf>
62. **C.E. Carrigan, M.H. Ray and C.A. Plaxico, “Influence of Geometric Design on Roadside Encroachments,”** 4<sup>th</sup> Urban Street Symposium, Chicago, IL, 2012.
63. **C.E. Carrigan, M.H. Ray, and C.A. Plaxico, “Modeling Urban and Suburban Run Off Road Crashes: A Comparison of the RSAP and the Highway Safety Manual,”** 4<sup>th</sup> Urban Street Symposium, Chicago, IL, 2012.

64. **C.E. Carrigan** and M.H. Ray, “**Incorporating Measurable Outcomes into the Highway Design Process: A Case Study to Demonstrate Highway Safety Improvements,**” In Urban Transport XVII, Proceedings of the Urban Transport and Environment in the 21<sup>st</sup> Century Conference, Pisa, Italy, WIT Press, 2011.
65. **C.E. Carrigan** and M.H. Ray, “**A Proposed Performance-Based Highway Design Process: Incorporating Safety Considerations,**” In Urban Transport XVII, Proceedings of the Urban Transport and Environment in the 21<sup>st</sup> Century Conference, Pisa, Italy, WIT Press, 2011.
66. **C.E. Conron** and M.H. Ray, “**Incorporating Crash Costs into Highway Cost Analysis,**” American Association of State Highway and Transportation Officials, National Value Engineering Conference Proceedings, September 2009.
67. **C.E. Conron**, C. Silvestri, M.H. Ray, “**A Policy Recommendation for the Reduction of Tree Crashes,**” Transportation Research Forum 50<sup>th</sup> Annual Forum Conference Proceedings, March, 2009.
68. **C.E. Conron**, “**A Systematic Approach to Applying Seasonal Load Restrictions,**” Transportation Research Forum 50<sup>th</sup> Annual Forum Conference Proceedings, March, 2009.
69. **C.E. Conron**, C. Silvestri, A. Gagne, M.H. Ray, “**Using Public Information and Graphics Software in Graduate Highway Safety Research at Worcester Polytechnic Institute,**” American Society for Engineering Education, Engineering Design Graphics Division, 63rd Annual Midyear Meeting Conference Proceedings, January 2009.
70. **C.E. Conron**, J.A. Bergendahl, “**Bringing Graphics and Design to First Year Engineering Students,**” American Society for Engineering Education, Engineering Design Graphics Division, 63rd Annual Midyear Meeting Conference Proceedings, January 2009.
71. G.F. Salazar, **C.E. Conron**, “**Introduction of Object-Oriented Software into Civil Engineering Curriculum through Undergraduate Projects at WPI,**” American Society for Engineering Education, Engineering Design Graphics Division, 63rd Annual Midyear Meeting Conference Proceedings, January 2009.
72. M.H. Ray, C. Silvestri, **C.E. Conron**, R.B. Albin, “**Assessment of Fatality Risk in Collisions with Cable Median Barriers in the State of Washington,**” Risk Analysis VI: Simulation and Hazard Mitigation, WIT Press, 2008.

## Trade Publications

73. M.H. Ray, **C.E. Carrigan**, C.A. Plaxico, “**Roadside Safety Analysis Program, Version 3: Upgrading a Tool for Roadside Safety Design,**” TR News, page 12-13, October 2012.
74. C. Silvestri and **C.E. Conron**, “**Proposed Policy for Highway Design and Maintenance for the Reduction of Tree Crashes,**” IRF Examiner, January 2009.

## INVITED PRESENTATIONS

1. **C.E. Carrigan**, “**Multi-State ISPE of Longitudinal Barriers,**” 2024 AKD20(03) Meeting at the TRB Annual Meeting, Washington D.C., January 6, 2025.
2. **C.E. Carrigan**, “**Guidelines for Bridge Pier Protection,**” 2023 TRB AKD20 and AASHTO TCRS Joint Meeting, Atlanta, Georgia, August 1, 2023.
3. **C.E. Carrigan**, “**Development of Safety Performance Guidelines for the Roadside Design Guide,**” 2023 TRB AKD20 and AASHTO TCRS Joint Meeting, Atlanta, Georgia, July 31, 2023.
4. **C.E. Carrigan**, “**Summary of Ongoing and Recently Completed Roadside Safety Research,**” 2022 Joint Meeting of the AASHTO Committee on Design, Kansas City, Missouri, August 12, 2022.
5. **C.E. Carrigan**, “**Status of In-Service Performance Evaluation (ISPE) of Roadside Safety Features,**” 2020 American Traffic Safety Services Association, New England Chapter Meeting.
6. **C.E. Carrigan**, “**History of In-Service Performance Evaluations (ISPEs),**” 2020 Joint Meeting of the TRB AKD20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Virtual Meeting, August 11, 2020.
7. **C.E. Carrigan**, “**Update on NCHRP 22-33, Multi-State In-Service Performance Evaluations of Roadside Safety Hardware,**” 2020 Joint Meeting of the TRB AKD20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Virtual Meeting, August 11, 2020.
8. **C.E. Carrigan**, “**In-service Performance Evaluation (ISPE), Best Practices and Obstacles**” FHWA ISPE Peer Exchange, Sacramento, California, November 19-20, 2019.
9. **C.E. Carrigan**, “**In-service Performance Evaluation (ISPE), Data Analysis and Evaluation**” FHWA ISPE Peer Exchange, Sacramento, California, November 19-20, 2019.

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

10. **C.E. Carrigan, “In-service Performance Evaluation of Roadside Safety Devices-Why, When, and How?”** Panel Discussion, 49<sup>th</sup> Annual ATSSA Traffic Expo, Tampa, Florida, February 8-12, 2019.
11. **C.E. Carrigan, “In-service Performance Evaluation (ISPE), the Good, the Bad, the Ugly”** FHWA ISPE Peer Exchange, Tampa, Florida, August 28 - 29, 2018.
12. **C.E. Carrigan, “In-service Performance Evaluation (ISPE), Data Analysis and Evaluation”** FHWA ISPE Peer Exchange, Tampa, Florida, August 28 - 29, 2018.
13. **C.E. Carrigan, “Update on NCHRP 22-31, Selection and Placement of TL2 – TL5 Median Barrier,”** 2018 AASHTO Technical Committee on Roadside Safety (TCRS), Austin, Texas, July 11-13, 2018.
14. **C.E. Carrigan, “Update on NCHRP 22-33, Multi-State In-Service Performance Evaluations,”** 2018 AASHTO Technical Committee on Roadside Safety (TCRS), Austin, Texas, July 11-13, 2018.
15. **C.E. Carrigan, “Tracing the Evolution of Slope Guidance”** 2018 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Austin, Texas, July 8-11, 2018.
16. **C.E. Carrigan, “Progress on ISPEs and How to Use Them”** 2018 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Austin, Texas, July 8-11, 2018.
17. **C.E. Carrigan and M.H. Ray “Pending Updates to AASHTO Publications,”** Maine Section ASCE Annual Technical Seminar, Auburn, Maine, March 22, 2018.
18. **C.E. Carrigan “In-Field Evaluation of MASH Hardware,”** 2016 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Baltimore, Maryland, June 22, 2016.
19. **C.E. Carrigan and M.H. Ray “Leveraging New Software to Quantify the Crash Risk of Roadside Hazards,”** 2016 WTS Annual Conference, Austin, Texas, May 18-20, 2016.
20. **C.E. Carrigan and M.H. Ray “Roadside Safety Analysis Program (RSAPv3),”** 2016 ITE Northeastern District Annual Meeting, Portsmouth, New Hampshire, May 11, 2016.
21. **C.E. Carrigan and M.H. Ray “In-Service Performance Evaluations (ISPEs) of W-beam Terminals,”** Maine Section ASCE Annual Technical Seminar, Lewiston, Maine, May 24, 2016.

22. **C.E. Carrigan, “TCRS Strategic Plan for RDG”** 2015 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Chicago, Illinois, July 12-15, 2015.
23. **C.E. Carrigan, “Consideration of Roadside Features in HSM (17-54)”** 2015 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), Chicago Illinois, July 12-15, 2015.
24. **C.E. Carrigan, “Discussion of TCRS Strategic Plan Development”** AASHTO Technical Committee on Roadside Safety (TCRS) Business Meeting, Chicago, Illinois, July 15, 2015.
25. **C.E. Carrigan, “To Tree or Not to Tree — Strategies for Answering a Roadside Question”** Workshop SMW15-005 of the 2015 Transportation Research Board Annual Meeting, Washington, D.C., 2015.
26. M.H. Ray, **C.E. Carrigan, Plaxico, C.A., “Using the Roadside Safety Analysis Program, Part 1: Tutorial”** Workshop 117 of the 2014 Transportation Research Board Annual Meeting, Washington, D.C., 2014.
27. M.H. Ray, **C.E. Carrigan, C.A. Plaxico, “Using the Roadside Safety Analysis Program, Part 2: Workshop”** Workshop 176 of the 2014 Transportation Research Board Annual Meeting, Washington, D.C., 2014.
28. **C.E. Carrigan, “Summary of NCHRP 17-54”** AASHTO Technical Committee on Roadside Safety (TCRS) Business Meeting, Portland, Maine, July 17, 2014.
29. **C.E. Carrigan, “Summary of NCHRP 12-90”** AASHTO Technical Committee on Roadside Safety (TCRS) Business Meeting, Portland, Maine, July 17, 2014.
30. **C.E. Carrigan, “Summary of NCHRP 22-12(03)”** AASHTO Technical Committee on Roadside Safety (TCRS) Business Meeting, Portland, Maine, July 17, 2014.
31. **C.E. Carrigan, “Discussion of TCRS Strategic Plan Development”** AASHTO Technical Committee on Roadside Safety (TCRS) Business Meeting, Portland, Maine, July 17, 2014.
32. **C.E. Carrigan, “SPF’s for the Roadside – What Affects the encroachment rate?”** 2013 Joint Meeting of the TRB AFB20 Committee and the AASHTO Technical Committee on Roadside Safety (TCRS), New Orleans, Louisiana, July 7-12, 2013.
33. **C.E. Carrigan, “Using the New and Improved Roadside Safety Analysis Program”** Workshop 163 of the 2012 Transportation Research Board Annual Meeting, 2012.

## SPONSORED RESEARCH PROJECTS

1. **“National In-Service Performance Evaluation Guidelines for Defining Acceptable Roadside Safety Hardware,”** National Cooperative Highway Research Program (NCHRP) Project 22-58, National Academy of Sciences, \$400,000.
2. **“Development of Methods to Evaluate Side Impacts for Next Edition MASH – Phase II,”** National Cooperative Highway Research Program (NCHRP) Project 22-32a, National Academy of Sciences, \$530,000.
3. **“Delivery of Multiple NHI Courses: Roadside Safety Design (380069), Combating Roadway Departures (380117), Road Safety Audits (380032A)”** Federal Highway Administration National Highway Institute TOPR HITNHI230299PR
4. **“In-Service Performance Evaluation (ISPE) of Roadway Safety Features”** Alabama Department of Transportation, Arizona Department of Transportation, Florida Department of Transportation, Illinois Department of Transportation, Iowa Department of Transportation, Massachusetts Department of Transportation, Tennessee Department of Transportation, and Texas Department of Transportation, \$239,642.
5. **“Crashworthiness of Roadside Hardware on Curbed Roadways,”** National Cooperative Highway Research Program (NCHRP) Project 22-50, National Academy of Sciences, \$400,000.
6. **“Data and Analysis Technical Assistance (DATA) Teams,”** Federal Highway Administration TOPR No. HSSP220027PR.
7. **“New Training Course Development: Roadside Safety Hardware MASH Evaluation Training,”** Federal Highway Administration - National Highway Institute FHWA Contract HTSNHI220116PR/Task Order 693JJ322F00124N.
8. **“A Safe System Approach Framework to Roadway Departure in the United States,”** Federal Highway Administration TOPR No. HSST220023PR
9. **“New Training Course Development: In-Service Performance Evaluation (ISPE) of Roadside Hardware,”** Federal Highway Administration - National Highway Institute, FHWA Contract DTFH6117D00027L/Task Order 693JJ321F000290.
10. **“In-Service Performance Evaluation of New England Transportation Consortium (NETC) Steel Bridge Railings,”** New England Transportation Consortium Project T202008004.

11. **“Texas In-Service Performance Evaluation (ISPE): Evaluation of Roadside Hardware Installation and Maintenance Cost Increases,”** Texas Department of Transportation TxDOT Contract No. 48-9IDP5009.
12. **“A Transportation Agency Data Collection Practice for Use with In-Service Performance Evaluations (ISPEs),”** National Cooperative Highway Research Program (NCHRP) Project 22-44, National Academy of Sciences, \$400,000.
13. **“Develop Guide for Bridge Curb/Railing and Approach Treatment for Extremely Low Volume Roads,”** Federal Highway Administration TOPR No. HRDS02200006PR.
14. **“Pilot FHWA In-Service Performance Evaluation of Guardrail End Terminals: Data Analysis,”** Project Summarization, and Report Development, Federal Highway Administration TOPR No. HDRS20190002PR.
15. **“Multi-State In-Service Performance Evaluations of Roadside Safety Hardware,”** National Cooperative Highway Research Program (NCHRP) Project 22-33, National Academy of Sciences, \$650,000, 2022.
16. **“Addressing Roadside Safety: A Systemic Approach to Hardware Replacement Analysis to Support MASH Implementation,”** National Cooperative Highway Research Program (NCHRP) Project 20-07(401), National Academy of Sciences, \$100,000, 2021
17. **“Development of Methods to Evaluate Side Impacts for Next Edition MASH,”** National Cooperative Highway Research Program (NCHRP) Project 22-32, National Academy of Sciences, \$500,000, 2020.
18. **“Development of Safety Performance Based Guidelines for the Roadside Design Guide,”** National Cooperative Highway Research Program (NCHRP) Project 15-65, National Academy of Sciences, \$300,000, 2022.
19. **“Recommended Guidelines for the Selection and Placement of Test Levels 2 through 5 Median Barriers,”** National Cooperative Highway Research Program (NCHRP) Project 22-31, National Academy of Sciences, \$577,000, 2022.
20. **“Guidelines for Shielding Bridge Piers,”** National Cooperative Highway Research Program (NCHRP) Project 12-90, National Academy of Sciences, \$450,000, 2018.
21. **“Consideration of Roadside Features in the Highway Safety Manual,”** National Cooperative Highway Research Program (NCHRP) Project 17-54, National Academy of Sciences, \$1,310,000, 2018.
22. **“Development of a Strategic Plan for the AASHTO SCOD Technical Committee on Roadside Safety,”** National Cooperative Highway Research

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

Program (NCHRP) Project 20-07(360), National Academy of Sciences, \$75,000, 2015.

23. **“Recommended Guidelines for the Selection of Test Level 2 through 5 Bridge Railings,”** National Cooperative Highway Research Program (NCHRP) Project 22-12(03), National Academy of Sciences, \$250,000, 2014.
24. **“Update of the Roadside Safety Analysis Program (RSAP),”** National Cooperative Highway Research Program (NCHRP) Project 22-27, National Academy of Sciences, \$600,000, 2012.
25. **“In-Service Evaluation of Flexible Pavement in Maine,”** Maine Department of Transportation, 2009.
26. **“Development of an On-Line Guide to Luminaire Supports,”** Wyoming Department of Transportation Pooled Fund Study, 2007.
27. **“Development of an On-Line Guide to Small Sign Support Hardware,”** National Cooperative Highway Research Program, Project 20-7(214), 2006.
28. **“Development of an On-Line Guide to Bridge Railing Hardware,”** National Cooperative Highway Research Program, Project 20-7(196), 2006.

## **HIGHWAY IMPROVEMENT PROJECTS**

1. Roadway safety assessment of multiple roads in Aurora, Illinois.
2. Design and construction inspection of improvements for Staples Hill Road in Canton, Maine.
3. Design of roadway improvements and coordination of signal timing for eleven signalized intersections along US Route 20 and US Route 202 in Westfield, Massachusetts.
4. Design of roadway and intersection improvements along Route 12 in Auburn, Massachusetts.
5. Conceptual planning of improvements to the interchange of Interstate 495 and Interstate 290 in Marlboro, Massachusetts.
6. Evaluation of alternatives for dividing the State Route 12 and US Route 20 overlap in Auburn, Massachusetts.
7. Construction inspection of the new Massachusetts Turnpike (Interstate 90) and State Route 146 interchange.

CV, Christine E. Carrigan, P.E., Ph.D.

Updated January 22, 2025

8. Development of construction bid documents for maintenance of pavement and concrete median barriers in Holden, West Boylston, Sterling, and Lancaster, Massachusetts along Interstate 190.

## **COURSE DEVELOPMENT AND TEACHING**

1. **Multi-State In-Service Performance Evaluations (ISPEs) of Roadside Safety Hardware:** This new course provides continuing education to engineers on the procedures developed under NCHRP Project 22-33 for conducting ISPEs. Teaching is based on a combination of lectures and case studies. This course was co-taught by Dr. Carrigan to NCHRP Project 22-33 Pilot States in 2020 and 2021.
2. **Using the New and Improved Roadside Safety Analysis Program version 3 (RSAPv3):** This new course provides continuing education to engineers on the use of the Roadside Safety Analysis Program (RSAPv3). Teaching was based on a combination of lectures and case studies. Dr. Carrigan has co-taught this course at various TRB sponsored meetings in 2012, 2013, and 2014. This course was converted to a TRB webinar and co-taught in 2013. This course was co-taught to:
  - Representatives of the Florida DOT in 2015.
  - Representatives of the Washington DOT and Washington consulting firms in 2018.
  - Representatives of the Maricopa County DOT in 2019.
  - Representatives of the Florida DOT and several Florida consulting firms in 2021.
3. **Software Applications in Civil Engineering:** This new course focused on integrating practice concepts, sharing of computer-generated models/designs, project communication, and introduction of three-dimensional software modeling applications. Teaching was based on a combination of lectures and labs which represent the progression of design and drafting exercises of an industrial subdivision. The modeling-centered course was developed for sophomores, as background for inclusion of modeling concepts in junior and senior level courses and for application in junior and senior design projects. Dr. Carrigan co-taught this course at WPI during the 2008 A term and 2009 B term.
4. **Computer Integrated Methodologies in Civil Engineering:** This course was redesigned to include site and transportation software applications employed for design and construction of roads and proposed sites. Teaching was based on a combination of literature review, lectures, and labs. Dr. Carrigan taught the site and transportation module at WPI during the Spring 2008 semester.
5. **Civil Engineering and Computer Fundamentals:** This course provided an introductory-level Civil and Environmental Engineering (CEE) course in which modules representative of the different civil engineering sub-disciplines are taught

to the students. A new transportation module, including the use of AutoCAD Civil 3D, was developed to introduce basic Transportation engineering concepts, including the process of highway design, and to introduce a modern design tool which produces a graphical representation of the highway design. Dr. Carrigan taught the new transportation module at WPI during the 2008 D term.

6. **Introduction to Transportation Engineering:** This course was revised to include AutoCAD Civil 3D highway design support software. Dr. Carrigan taught this course at WPI during the 2007 A term.