

This is a repository copy of *Coverage based testing for V&V and Safety Assurance of Self-driving Autonomous Vehicle :A Systematic Literature Review*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/155680/>

Version: Other

---

### **Proceedings Paper:**

Tahir, Zaid and Alexander, Rob [orcid.org/0000-0003-3818-0310](https://orcid.org/0000-0003-3818-0310) (2020) Coverage based testing for V&V and Safety Assurance of Self-driving Autonomous Vehicle :A Systematic Literature Review. In: The Second IEEE International Conference On Artificial Intelligence Testing. The Second IEEE International Conference On Artificial Intelligence Testing, 13-16 Apr 2020, Keble College. , GBR

---

### **Reuse**

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

### **Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.

# References of papers included in SLR after coarse-grained inclusion exclusion step

- [1] Z. Micskei, Z. Szatmári, J. Oláh, and I. Majzik, "A Concept for Testing Robustness and Safety of the Context-Aware Behaviour of Autonomous Systems," in *Agent and Multi-Agent Systems. Technologies and Applications*, 2012, pp. 504–513.
- [2] M. P. Webster et al., "An Assurance-based Approach to Verification and Validation of Human-Robot Teams," *ArXiv*, vol. abs/1608.07403, 2016.
- [3] J. Morse, D. Araiza-Illan, K. Eder, J. Lawry, and A. Richards, "A fuzzy approach to qualification in design exploration for autonomous robots and systems," *IEEE Int. Conf. Fuzzy Syst.*, 2017.
- [4] A. Gambi et al., "A hybrid method of assurance and testing for improved confidence in autonomous space systems," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-March, no. 209989, pp. 1–12, 2018.
- [5] G. A. Martin and C. E. Hughes, "A scenario generation framework for automating instructional support in scenario-based training," *Spring Simul. Multiconference 2010, SpringSim'10*, no. 1998, pp. 1–6, 2010.
- [6] C. Rotondo, "A Survey for Testing Self-organizing, Adaptive Systems in Industry 4.0," no. March, 2019.
- [7] A. M. Nascimento et al., "A Systematic Literature Review about the impact of Artificial Intelligence on Autonomous Vehicle Safety," *arXiv Prepr. arXiv1904.02697*, 2019.
- [8] J. F. Leathrum, R. R. Mielke, Y. Shen, and H. Johnson, "Academic/Industry Educational Lab for Simulation-Based Test & Evaluation of Autonomous Vehicles," in *Proceedings of the 2018 Winter Simulation Conference*, 2018, pp. 4026–4037.
- [9] G. E. Mullins, A. G. Dress, P. G. Stankiewicz, J. D. Appler, and S. K. Gupta, "Accelerated Testing and Evaluation of Autonomous Vehicles via Imitation Learning," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 5636–5642, 2018.
- [10] I. R. Jenkins, L. O. Gee, A. Knauss, H. Yin, and J. Schroeder, "Accident Scenario Generation with Recurrent Neural Networks," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-Novem, pp. 3340–3345, 2018.
- [11] G. E. Mullins, P. G. Stankiewicz, R. C. Hawthorne, and S. K. Gupta, "Adaptive generation of challenging scenarios for testing and evaluation of autonomous vehicles," *J. Syst. Softw.*, vol. 137, pp. 197–215, 2018.
- [12] J. D'Ambrosio et al., "An MBSE Approach for Development of Resilient Automated Automotive Systems," *Systems*, vol. 7, no. 1, p. 1, 2019.
- [13] A. Kasoju, K. Petersen, and M. V. Mäntylä, "Analyzing an automotive testing process with evidence-based software engineering," *Inf. Softw. Technol.*, vol. 55, no. 7, pp. 1237–1259, 2013.
- [14] C. B. S. T. Molina, J. R. De Almeida, L. F. Vismari, R. I. R. Gonzalez, J. K. Naufal, and J. B. Camargo, "Assuring Fully Autonomous Vehicles Safety by Design: The Autonomous Vehicle Control (AVC) Module Strategy," *Proc. - 47th Annu. IEEE/IFIP Int. Conf. Dependable Syst. Networks Work. DSN-W 2017*, pp. 16–21, 2017.
- [15] I. Y. Noy, D. Shinar, and W. J. Horrey, "Automated driving: Safety blind spots," *Saf. Sci.*, vol. 102, no. March 2017, pp. 68–78, 2018.
- [16] G. E. Mullins, P. G. Stankiewicz, and S. K. Gupta, "Automated generation of diverse and challenging scenarios for test and evaluation of autonomous vehicles," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 1443–1450, 2017.
- [17] D. Loiacono, L. Cardamone, and P. L. Lanzi, "Automatic track generation for high-end racing games using evolutionary computation," *IEEE Trans. Comput. Intell. AI Games*, vol. 3, no. 3, pp. 245–259, 2011.
- [18] A. Gambi, M. Mueller, and G. Fraser, "Automatically testing self-driving cars with search-based procedural content generation," *Proc. 28th ACM SIGSOFT Int. Symp. Softw. Test. Anal. - ISSTA 2019*, pp. 318–328, 2019.
- [19] A. J. Alnaser, M. I. Akbas, A. Sargolzaei, and R. Razdan, "Autonomous Vehicles Scenario Testing Framework and Model of Computation." Dec-2019.
- [20] N. Rungta et al., "Aviation safety: Modeling and analyzing complex interactions between humans and automated systems," *ACM Int. Conf. Proceeding Ser.*, no. May, pp. 27–37, 2013.
- [21] D. O. T. Hs, "Basis of Design for Advanced Crash-Avoidance Technology Test Course," no. March, 2014.
- [22] J. B. Lyons, M. A. Clark, A. R. Wagner, and M. J. Schuelke, "Certifiable trust in autonomous systems: Making the intractable tangible," *AI Mag.*, vol. 38, no. 3, pp. 37–49, 2017.
- [23] F. Dinmohammadi et al., "Certification of Safe and Trusted Robotic Inspection of Assets," *Proc. - 2018 Progn. Syst. Heal. Manag. Conf. PHM-Chongqing 2018*, pp. 276–284, 2019.
- [24] C. Muhlbacher, G. Steinbauer, M. Reip, and S. Gspandl, "Constraint-based testing of an industrial multi-robot navigation system," *Proc. - 2019 IEEE Int. Conf. Artif. Intell. Testing, AITest 2019*, pp. 129–137, 2019.

- [25] C. S. Timperley, A. Afzal, D. S. Katz, J. M. Hernandez, and C. Le Goues, "Crashing Simulated Planes is Cheap: Can Simulation Detect Robotics Bugs Early?," *Proc. - 2018 IEEE 11th Int. Conf. Softw. Testing, Verif. Validation, ICST 2018*, pp. 331–342, 2018.
- [26] S. Noh, "Decision-Making Framework for Autonomous Driving at Road Intersections: Safeguarding Against Collision, Overly Conservative Behavior, and Violation Vehicles," *IEEE Trans. Ind. Electron.*, vol. 66, no. 4, pp. 3275–3286, 2019.
- [27] S. Ulbrich, T. Menzel, A. Reschka, F. Schuldt, and M. Maurer, "Defining and Substantiating the Terms Scene, Situation, and Scenario for Automated Driving," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2015-October, pp. 982–988, 2015.
- [28] W. G. Najm et al., "Description of Light-Vehicle Pre-Crash Scenarios for Safety Applications Based On Vehicle-to-Vehicle Communications," no. May, 2013.
- [29] J. M. James, D. W. Miller, and A. Saenz-Otero, "Development of a Verification and Validation Framework for Autonomous Soft-Docking of Spacecraft with Uncertain Dynamic Properties," 2016.
- [30] P. Junietz, W. Wachenfeld, K. Klonecki, and H. Winner, "Evaluation of Different Approaches to Address Safety Validation of Automated Driving," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-Novem, pp. 491–496, 2018.
- [31] C. D. Nguyen, A. Perini, P. Tonella, S. Miles, M. Harman, and M. Luck, "Evolutionary testing of autonomous software agents," *Proc. Int. Jt. Conf. Auton. Agents Multiagent Syst. AAMAS*, vol. 1, pp. 364–371, 2009.
- [32] C. D. Nguyen, A. Perini, and P. Tonella, "Experimental Evaluation of Ontology-Based Test Generation for Multi-Agent Systems," in *Agent-Oriented Software Engineering IX: 9th International Workshop, AOSE 2008 Estoril, Portugal, May 12-13, 2008 Revised Selected Papers*, Berlin, Heidelberg: Springer-Verlag, 2009, pp. 187–198.
- [33] G. J. Uriagereka, R. Lattarulo, J. P. Rastelli, E. A. Calonge, A. Ruiz Lopez, and H. Espinoza Ortiz, "Fault injection method for safety and controllability evaluation of automated driving," *IEEE Intell. Veh. Symp. Proc.*, no. Iv, pp. 1867–1872, 2017.
- [34] C. Torens and F.-M. Adolf, "Formal Requirements and Model-Checking for V&V Automation of a RPAS Mission Management System," 2015.
- [35] N. Li, D. W. Oyler, M. Zhang, Y. Yildiz, I. Kolmanovsky, and A. R. Girard, "Game theoretic modeling of driver and vehicle interactions for verification and validation of autonomous vehicle control systems," *IEEE Trans. Control Syst. Technol.*, vol. 26, no. 5, pp. 1782–1797, 2018.
- [36] S. Toma, E. Swanson, J. D. Smith, W. G. Najm, C. Volpe National Transportation Systems, and A. National Highway Traffic Safety, "Heavy Truck Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications," no. June, p. 86p, 2014.
- [37] G. Bagschik, A. Reschka, T. Stolte, and M. Maurer, "Identification of potential hazardous events for an Unmanned Protective Vehicle," *IEEE Intell. Veh. Symp. Proc.*, vol. 2016-Augus, no. Iv, pp. 691–697, 2016.
- [38] J. S. Brar and B. Caulfield, "Impact of autonomous vehicles on pedestrians' safety," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-March, pp. 714–719, 2018.
- [39] D. Araiza-Illan, A. G. Pipe, and K. Eder, "Intelligent agent-based stimulation for testing robotic software in human-robot interactions," *ACM Int. Conf. Proceeding Ser.*, pp. 9–16, 2016.
- [40] M. Wood et al., Safety First For Automated Driving (SaFD), "Safety first for automated driving," 2019.
- [41] J. Guo, U. Kurup, and M. Shah, "Is It Safe to Drive? An Overview of Factors, Metrics, and Datasets for Driveability Assessment in Autonomous Driving," *IEEE Trans. Intell. Transp. Syst.*, pp. 1–17, 2019.
- [42] Tolk, Andreas, "Merging Two Worlds: Agent-Based Simulation Methods for Autonomous Systems" (2015). Computational Modeling and Simulation Engineering Faculty Publications. 32. [https://digitalcommons.odu.edu/msve\\_fac\\_pubs/32](https://digitalcommons.odu.edu/msve_fac_pubs/32)
- [43] M. Lindvall, A. Porter, G. Magnusson, and C. Schulze, "Metamorphic Model-based Testing of Autonomous Systems," *Proc. - 2017 IEEE/ACM 2nd Int. Work. Metamorph. Testing, MET 2017*, pp. 35–41, 2017.
- [44] J. Bach, S. Otten, and E. Sax, "Model based scenario specification for development and test of automated driving functions," *IEEE Intell. Veh. Symp. Proc.*, vol. 2016-Augus, no. Iv, pp. 1149–1155, 2016.
- [45] D. Araiza-Illan, A. G. Pipe, and K. Eder, "Model-based Test Generation for Robotic Software: Automata versus Belief-Desire-Intention Agents," pp. 1–16, 2016.
- [46] A. L. Svenson, "NHTSA Update : Connected Vehicles V2V Communications for Safety V2V Overview," 2015.
- [47] A. Knauss, J. Schroder, C. Berger, and H. Eriksson, "Paving the roadway for safety of automated vehicles: An empirical study on testing challenges," *IEEE Intell. Veh. Symp. Proc.*, no. Iv, pp. 1873–1880, 2017.
- [48] P. Koopman, "Practical Experience Report: Automotive Safety Practices vs. Accepted Principles," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11093 LNCS, pp. 3–11, 2018.
- [49] E. Galin, A. Peytavie, N. Maréchal, and E. Guérin, "Procedural generation of roads," *Comput. Graph. Forum*, vol. 29, no. 2, pp. 429–438, 2010.
- [50] F. Taal, "Procedural Generation of Traffic Signs," pp. 1–7, 2016.

- [51] F. Taal, "Procedural Generation of Traffic Signs," (Masters' Thesis), Delft University of Technology, Netherlands, 2016.
- [52] A. Afzal, "Quality assurance automation in autonomous systems," ESEC/FSE 2018 - Proc. 2018 26th ACM Jt. Meet. Eur. Softw. Eng. Conf. Symp. Found. Softw. Eng., pp. 948–951, 2018.
- [53] D. Araiza-Illan and K. Eder, "Safe and Trustworthy Human Robot Interaction," *Humanoid Robot. A Ref.*, pp. 1–23, 2017.
- [54] T. Winkle, "Safety Benefits of Automated Vehicles: Extended Findings from Accident Research for Development, Validation and Testing," in *Autonomous Driving: Technical, Legal and Social Aspects*, M. Maurer, J. C. Gerdes, B. Lenz, and H. Winner, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2016, pp. 335–364.
- [55] T. Menzel, G. Bagschik, and A. M. Maurer, "Scenarios for Development, Test and Validation of Automated Vehicles," *IEEE Intell. Veh. Symp. Proc.*, vol. 2018-June, pp. 1821–1827, 2018.
- [56] R. Alexander, H. Hawkins, and D. Rae, "Situation coverage – a coverage criterion for testing autonomous robots," pp. 1–20, 2015.
- [57] A. Knauss, J. Schroder, C. Berger, and H. Eriksson, "Software-related challenges of testing automated vehicles," *Proc. - 2017 IEEE/ACM 39th Int. Conf. Softw. Eng. Companion, ICSE-C 2017*, pp. 328–330, 2017.
- [58] A. Pütz, A. Zlocki, J. Bock, and L. Eckstein, "System validation of highly automated vehicles with a database of relevant traffic scenarios," *12th ITS Eur. Congr.*, no. June, pp. 1–8, 2017.
- [59] D. Araiza-Illan, D. Western, A. G. Pipe, and K. Eder, "Systematic and Realistic Testing in Simulation of Control Code for Robots in Collaborative Human-Robot Interactions," in *Towards Autonomous Robotic Systems, 2016*, pp. 20–32.
- [60] A. C. Serban, E. Poll, and J. Visser, "Tactical safety reasoning. A case for autonomous vehicles," *IEEE Veh. Technol. Conf.*, vol. 2018-June, no. 1, pp. 1–5, 2018.
- [61] E. Rocklage, "Teaching self-driving cars to dream: A deeply integrated, innovative approach for solving the autonomous vehicle validation problem," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-March, pp. 1–7, 2018.
- [62] J. Shin and J. Woo, "Test and evaluation for the autonomous multi-zone navigation coverage test in IEC 62885-7," *Int. Conf. Control. Autom. Syst.*, vol. 2017-October, no. Iccas, pp. 1949–1951, 2017.
- [63] F. Wotawa, "Testing Autonomous and Highly Configurable Systems: Challenges and Feasible Solutions," in *Automated Driving: Safer and More Efficient Future Driving*, D. Watzenig and M. Horn, Eds. Cham: Springer International Publishing, 2017, pp. 519–532.
- [64] H. Altinger, F. Wotawa, and M. Schurius, "Testing Methods Used in the Automotive Industry: Results from a Survey," in *Proceedings of the 2014 Workshop on Joining AcadeMiA and Industry Contributions to Test Automation and Model-Based Testing, 2014*, pp. 1–6.
- [65] P. Helle, W. Schamai, and C. Strobel, "Testing of Autonomous Systems - Challenges and Current State-of-the-Art," *INCOSE Int. Symp.*, vol. 26, no. 1, pp. 571–584, 2016.
- [66] A. Gaujens, A. Benini, A. Mancini, and S. Longhi, "Testing of cooperative tasks for Unmanned Aerial and ground platforms," *MESA 2014 - 10th IEEE/ASME Int. Conf. Mechatron. Embed. Syst. Appl. Conf. Proc.*, no. Mcdc, pp. 1–6, 2014.
- [67] S. Feng, Y. Feng, C. Yu, Y. Zhang, and H. X. Liu, "Testing Scenario Library Generation for Connected and Automated Vehicles, Part I: Methodology," *ArXiv*, vol. abs/1905.03419, 2019.
- [68] S. Feng et al., "Testing Scenario Library Generation for Connected and Automated Vehicles, Part II: Case Studies," pp. 1–12, 2019.
- [69] R. D. Alexander, R. Ashmore, and A. Banks, "The State of Solutions for Autonomous Systems Safety," 2018.
- [70] G. Palmer, A. Selwyn, and D. Zwillinger, "The 'Trust V': Building and Measuring Trust in Autonomous Systems," in *Robust Intelligence and Trust in Autonomous Systems*, R. Mittu, D. Sofge, A. Wagner, and W. F. Lawless, Eds. Boston, MA: Springer US, 2016, pp. 55–77.
- [71] P. Nitsche, "Safety-critical scenarios and virtual testing procedures for automated cars at road intersections," 2018.
- [72] A. Lamm and A. Hahn, "Towards critical-scenario based testing with maritime observation data," *2018 Ocean. - MTS/IEEE Kobe Techno-Oceans, Ocean. - Kobe 2018*, 2018.
- [73] N. Baumgartner, W. Gottesheim, S. Mitsch, W. Retschitzegger, and W. Schwinger, "Towards duplicate detection for situation awareness based on spatio-temporal relations," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 6427 LNCS, no. PART 2, pp. 1097–1107, 2010.
- [74] A. Andrews, M. Abdelgawad, and A. Gario, "Towards world model-based test generation in autonomous systems," *Model. 2015 - 3rd Int. Conf. Model. Eng. Softw. Dev. Proc.*, pp. 165–176, 2015.
- [75] S. Ulbrich et al., "Towards a Functional System Architecture for Automated Vehicles," pp. 1–16, 2017.
- [76] L. Cardamone, P. L. Lanzi, and D. Loiacono, "TrackGen: An interactive track generator for TORCS and Speed-Dreams," *Appl. Soft Comput. J.*, vol. 28, pp. 550–558, 2015.
- [77] M. R. Zofka et al., "Traffic Participants in the Loop: A Mixed Reality-Based Interaction Testbed for the Verification and Validation of Autonomous Vehicles," *IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC*, vol. 2018-Novem, pp. 3583–3590, 2018.

- [78] D. Wilkie, J. Sewall, and M. C. Lin, "Transforming GIS data into functional road models for large-scale traffic simulation," *IEEE Trans. Vis. Comput. Graph.*, vol. 18, no. 6, pp. 890–901, 2012.
- [79] M. Fränzle, T. Gezgin, H. Hungar, S. Puch, and G. Sauter, "Using Guided Simulation to Assess Driver Assistance System," in *FORMS/FORMAT 2010, 2011*, pp. 195–205.
- [80] V. Agaram et al., "Validation and Verification of Automated Road Vehicles," in *Road Vehicle Automation 3*, G. Meyer and S. Beiker, Eds. Cham: Springer International Publishing, 2016, pp. 201–210.
- [81] M. Paulweber, "Validation of Highly Automated Safe and Secure Systems," in *Automated Driving: Safer and More Efficient Future Driving*, D. Watzenig and M. Horn, Eds. Cham: Springer International Publishing, 2017, pp. 437–450.
- [82] T. Tettamanti, M. Szalai, S. Vass, and V. Tihanyi, "Vehicle-In-the-Loop Test Environment for Autonomous Driving with Microscopic Traffic Simulation," *2018 IEEE Int. Conf. Veh. Electron. Safety, ICVES 2018*, 2018.
- [83] M. Fisher et al., "Verifiable Self-Certifying Autonomous Systems," *Proc. - 29th IEEE Int. Symp. Softw. Reliab. Eng. Work. ISSREW 2018*, pp. 341–348, 2018.
- [84] S. A. Redfield and M. L. Seto, "Verification Challenges for Autonomous Systems," in *Autonomy and Artificial Intelligence: A Threat or Savior?*, W. F. Lawless, R. Mittu, D. Sofge, and S. Russell, Eds. Cham: Springer International Publishing, 2017, pp. 103–127.
- [85] D. Meltz and H. Guterman, "Verification of safety for autonomous unmanned ground vehicles," *2014 IEEE 28th Conv. Electr. Electron. Eng. Isr. IEEEI 2014*, pp. 1–5, 2014.
- [86] C. Pek, P. Zahn, and M. Althoff, "Verifying the safety of lane change maneuvers of self-driving vehicles based on formalized traffic rules," *IEEE Intell. Veh. Symp. Proc.*, no. Iv, pp. 1477–1483, 2017.
- [87] T. Sotiropoulos, J. Guiochet, F. Ingrand, and H. Weaselynck, "Virtual Worlds for Testing Robot Navigation: A Study on the Difficulty Level," *Proc. - 2016 12th Eur. Dependable Comput. Conf. EDCC 2016*, pp. 153–160, 2016.
- [88] Waymo, "On the road to Fully Self-driving - Waymo Safety Report," *Waymo Saf. Rep.*, 2018.
- [89] A. Andrews, M. Abdelgawad, and A. Gario, "World Model for Testing Autonomous Systems Using Petri Nets," *Proc. IEEE Int. Symp. High Assur. Syst. Eng.*, vol. 2016-March, no. October, pp. 65–69, 2016.