The Journey from Powertrain Control to Emerging Mobility Systems

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My research interests span several fields, including analysis, optimization, and control of cyber-physical (CPS) systems; decentralized stochastic systems, stochastic scheduling, and resource allocation. The overarching goal of my research is to establish a rigorous theoretical framework aimed at enhancing our understanding of the behavior of large scale, complex CPS systems and develop decentralized control algorithms for making such systems able to learn to improve their performance over time while interacting with their environment. As we move to increasingly complex cyber-physical systems with an expanded feature space, fundamentally new approaches are needed to understand the impact on system behavior of the interplay between subsystems of different physical processes, at different scales, or between decision points in an engineered system. The emphasis is on applications related to connected and automated vehicles (CAVs), smart cities, and sociotechnical systems. My interest in developing control algorithms that could make systems able to learn their optimal operation started early on, while I was still at graduate school, when I read an article about the discrepancy between true fuel economy of a vehicle and the one posted on the window sticker. The article was discussing the implications of the driver's driving style on engine operation, and stated that the state-of-the-art control methods, by that time, consist of static controllers which cannot optimize engine operation for different driving styles but only for predetermined ones. This article provided inspiration that eventually led to forming the topic of my dissertation. In my dissertation [1], I developed the theoretical framework [2–5] and control algorithms [6–8] that can turn the engine of a vehicle into an autonomous intelligent system capable of learning its optimal operation in real time while the driver is driving the vehicle. I modeled the evolution of the state of the engine as a control Markov chain [9] and proved [10] that it eventually converges to a stationary probability distribution deemed characteristic of the driver's driving style. Through this approach, the engine progressively perceives the driver's driving style [11] and eventually learns to operate in a manner that optimizes specified performance criteria, e.g., fuel economy, emissions with respect to the driver's driving style. The framework also allows the engine to identify the driver, and thus it can adjust its operation to be optimal for any driver based on what it has learned in the past regarding her/his driving style. The outcome of my dissertation research eventually led to a US patent [12].

Moving to General Motors Research & Development as a Senior Researcher, I had the chance to continue working on self-learning control for advanced powertrain systems. I led several projects on autonomous intelligent propulsion systems and developed computational mathematical models and control algorithms towards making highly energy-efficient and eco-friendly vehicles. I was a member of the team that demonstrated successfully the implementation of self-learning control algorithms [13] in two demo vehicles, Saturn Aura and Opel Vectra.

When I joined Oak Ridge National Laboratory (ORNL) as an Alvin M. Weinberg Fellow, although the focus of my fundamental research interests remained the same, the emphasis of the applications shifted from powertrain systems to vehicles, and then to CAVs. At ORNL, I had the chance to work across different technical areas including stochastic optimal control [14–16], optimal design and power management control and routing of hybrid electric vehicles (HEVs) and plug-in HEVs (PHEVs) [17–27], and driver's feedback systems [28–30]. The latter eventually led to a technology [31] that was licensed in SanTed Project Management LLC. I also contributed to the solution of problems that included smart buildings aimed at optimizing energy system parameters to (1) improve sustainability, (2) facilitate cost-effective energy generation, and (3) allocate demand optimally to different energy sources, e.g., solar, renewable, etc [32–34]. On the fundamental research front, I established the theoretical framework for the analysis and stochastic control of complex systems consisting of interactive subsystems [35]. In particular, I developed a duality framework and showed that the Pareto control policy minimizes the long-run expected average cost criterion of the system while also presented a geometric interpretation of the solution and conditions for its existence. I provided theoretical results showing that the Pareto control policy provides an equilibrium operating point among the subsystems, and if the system operates at this equilibrium, then the long-run expected average cost per unit time is minimized. This result implies that the Pareto control policy can be of value when we seek to derive the optimal control policy for complex systems online. Later on, and in my role as the Deputy Director of the Urban Dynamics Institute at ORNL, I developed several initiatives with the goal to investigate how we can use scalable data and informatics to enhance understanding of the environmental implications of CAVs and improve transportation sustainability and accessibility. I contributed towards the development of a decentralized optimal control framework whose closed-form solution exists under certain conditions, and which, based on Hamiltonian analysis, yields for each vehicle the optimal acceleration/deceleration, in terms of fuel consumption. The solution allows the vehicles to cross merging roadways without creating congestion, and under the hard safety constraint of collision avoidance [36–40].

When I joined the University of Delaware, I established the Information and Decision Science (IDS) Laboratory with the vision to advance the state of the art in the analysis, optimization, and control of cyber-physical (CPS) networks. The overarching goal of the IDS Lab is to enhance our understanding of the behavior of large scale, complex CPS networks consisting of multiple entities (or agents). The emphasis is on applications related to emerging mobility systems and sociotechnical systems. Emerging mobility systems are typical CPS networks where the cyber component (e.g., data and shared information through vehicle-to-vehicle and vehicle-to-infrastructure communication) can aim at optimally controlling the physical entities (e.g., CAVs, non-CAVs). A mobility system encompasses the interactions of three heterogeneous dimensions: (1) transportation systems and modes, e.g., CAVs, shared mobility, and public transit integrated with advanced control algorithms, (2) social behavior of drivers, operators (for autonomous vehicles), and travelers (or pedestrians) interacting with these systems, and (3) information management of data available and shared information. The constellation of these three dimensions constitutes a sociotechnical system that should be analyzed holistically. The CPS nature of emerging mobility systems is associated not only with technological and information management dimensions but also with human adoption (social dimension). My students and I, in conjunction with my collaborators, have made contributions on the technological dimension of mobility systems by developing control algorithms for optimal coordination of CAVs [41–72] and identifying potential research paths with connected autonomous systems [73]. However, I came to realize that current methods analyze, design, and optimize a mobility system without considering the social dimension resulting in systems that might not be acceptable by the drivers, travelers, and the public. In particular, one key research question that still remains unanswered is "how can we develop an energy-efficient mobility system that can be widely acceptable by drivers, travelers, and the public?" To address this question, my students and I are taking the following research steps that combine the three aforementioned dimensions [74–76]: (1) explore how advanced control technologies in conjunction with Big Data from vehicles and infrastructure can improve the efficiency of transportation systems and modes, e.g., eliminate stop-and-go driving, reduce congestion; (2) investigate public attitudes toward emerging transportation systems and identify the human behavioral and emotional responses to systems such as CAVs and shared mobility, and (3) address the negative rebound effects of improving the efficiency of transportation systems by exploring whether household activities and travel demand might increase if the efficiency of the transportation systems improves. Step 1 will identify the new congestion patterns of optimized transportation systems and modes. Step 2 will examine public reaction, adoption, and use of a potential energy-efficient mobility system, which will determine the urban planning, public policy, and governance frameworks to enable the system-wide optimal outcomes. Step 3 will determine the new levels of travel demand and, eventually, the impact on vehicle miles traveled. The expected outcome of my group's research in this area will aim at identifying a mobility system which is not only energy efficient but also acceptable by the drivers, travelers, and the public.

Another research direction that my students and I are currently working is towards establishing a theoretical framework and control algorithms to enhance our understanding of flocking [77–82] and the behavior of large scale, decentralized CPS networks [83–86]. One common characteristic in CPS networks is that the models used cannot predict their behavior. In particular, one research question that still remains unanswered is "how can we establish a framework aimed at both predicting and affecting the behavior of a CPS network?" To address this question, my students and I are taking the following research steps: (1) explore the communication structure of CPS networks; (2) investigate how data in a CPS network that is increasing with time can be "compressed" to a sufficient statistic taking values in a time-invariant space (structural results); (3) implement a desired emerging behavior in a class of CPS networks involving multiple self-interested agents, each with private information and preferences. Step 1 will provide the modeling framework of the information structure of CPS networks which is necessary to understand how information is propagated within different classes of CPS networks. Step 2 will provide the structural results required for implementing a decentralized control framework to control CPS networks. Step 3 will aim at imposing the conditions among the agents under which a CPS network will exhibit the desired behavior. The expected outcome and foundation of my group's research in this area will aim at enhancing our understanding of the behavior of large scale, complex CPS networks and develop, networking capabilities to analyze, model, simulate, and predict complex phenomena.

References

[1] A. A. Malikopoulos, *Real-Time, Self-Learning Identification and Stochastic Optimal Control of Advanced Powertrain Systems.* ProQuest, 2011.

[2] A. A. Malikopoulos, P. Y. Papalambros, and D. N. Assanis, "A State-Space Representation Model and Learning Algorithm for Real-Time Decision-Making Under Uncertainty," in *ASME 2007 International Mechanical Engineering Congress and Exposition*, 2007, pp. 575–584.

[3] A. Malikopoulos, "A rollout control algorithm for discrete-time stochastic systems," in *ASME 2010 Dynamic Systems and Control Conference, DSCC2010*, vol. 2, 2010.

[4] A. A. Malikopoulos, "Convergence properties of a computational learning model for unknown markov chains," in *2008 Proceedings of the ASME Dynamic Systems and Control Conference*, 2008, pp. 73–80.

[5] A. Malikopoulos, P. Papalambros, and D. Assanis, "A real-time computational learning model for sequential decision-making problems under uncertainty," *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, vol. 131, no. 4, 2009.

[6] A. A. Malikopoulos, P. Y. Papalambros, and D. N. Assanis, "A learning algorithm for optimal internal combustion engine calibration in real time," in *ASME 2007 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, 2007, pp. 91–100.

[7] A. Malikopoulos, D. Assanis, and P. Papalambros, "Real-time self-learning optimization of diesel engine calibration," *Journal of Engineering for Gas Turbines and Power*, vol. 131, no. 2, 2009.

[8] A. Malikopoulos, Z. Filipi, and D. Assanis, "Simulation of an Integrated Starter Alternator (ISA) system for the HMMWV," *SAE Technical Papers*, 2006.

[9] A. Malikopoulos, P. Papalambros, and D. Assanis, "Online identification and stochastic control for autonomous internal combustion engines," *Journal of Dynamic Systems, Measurement and Control, Transactions of the ASME*, vol. 132, no. 2, pp. 1–6, 2010.

[10] A. A. Malikopoulos, "Convergence properties of a computational learning model for unknown Markov chains," *J. Dyn. Sys., Meas., Control*, vol. 131, no. 4, pp. 041 011–7, 2009.

[11] A. Malikopoulos, D. Assanis, and P. Papalambros, "Optimal engine calibration for individual driving styles," *SAE Technical Papers*, 2008.

[12] A. A. Malikopoulos, "Method, control apparatus and powertrain system controller for real-time, self-learning control based on individual operating style," *US Patent 8,612,107*, Dec 2013.

[13] A. Malikopoulos, "Method for real-time, self-learning identification of fuel injectors during engine operation," *US Patent 8,676,476*, mar 2014.

[14] ——, "Equilibrium control policies for Markov chains," in *Proceedings of the 50th IEEE Conference on Decision and Control*, 2011, pp. 7093–7098.

[15] A. Malikopoulos, V. Maroulas, and J. Xiong, "A multiobjective optimization framework for stochastic control of complex systems," in *Proceedings of the American Control Conference*, 2015, pp. 4263–4268.

[16] A. Malikopoulos, "Centralized stochastic optimal control of complex systems," in *2015 European Control Conference*, pp. 721–726.

[17] S. Park, A. Malikopoulos, M. Kokkolaras, and D. Jung, "Thermal management system modelling and component sizing for heavy duty series hybrid electric vehicles," *International Journal of Heavy Vehicle Systems*, vol. 18, no. 3, pp. 272–287, 2011.

[18] A. Malikopoulos and D. Smith, "An optimization model for plug-in hybrid electric vehicles," in *Proceedings of the 2011 Technical Conference of the ASME Internal Combustion Engine Division*, 2011.

[19] A. Malikopoulos, "Impact of component sizing in plug-in hybrid electric vehicles for energy resource and greenhouse emissions reduction," *Journal of Energy Resources Technology, Transactions of the ASME*, vol. 135, no. 4, p. 041201, 2013.

[20] ——, "Stochastic optimal control for series hybrid electric vehicles," in *Proceedings of the American Control Conference*, 2013, pp. 1191–1196.

[21] ——, "Online identification of power required for self-sustainability of the battery in hybrid electric vehicles," in *ASME 2014 Internal Combustion Engine Division Fall Technical Conference, ICEF 2014*, vol. 2, 2014.

[22] ——, "Supervisory power management control algorithms for hybrid electric vehicles: A survey," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 5, pp. 1869–1885, 2014.

[23] M. Shaltout, A. Malikopoulos, S. Pannala, and D. Chen, "Multi-disciplinary decision making and optimization for hybrid electric propulsion systems," in *2014 IEEE International Electric Vehicle Conference, IEVC 2014*, 2014.

[24] S. Pourazarm, C. G. Cassandras, and A. Malikopoulos, "Optimal routing of electric vehicles in networks with charging nodes: A dynamic programming approach," in *2014 IEEE International Electric Vehicle Conference (IEVC)*. IEEE, 2014, pp. 1–7.

[25] M. Shaltout, A. Malikopoulos, S. Pannala, and D. Chen, "A Consumer-Oriented Control Framework for Performance Analysis in Hybrid Electric Vehicles," *IEEE Transactions on Control Systems Technology*, vol. 23, no. 4, pp. 1451–1464, 2015.

[26] A. A. Malikopoulos, "Pareto Efficient Policy for Supervisory Power Management Control," in *Proceedings of the 2015 IEEE 18th International Conference on Intelligent Transportation Systems*, 2015, pp. 2443–2448.

[27] ——, "A Multiobjective Optimization Framework for Online Stochastic Optimal Control in Hybrid Electric Vehicles," *IEEE Transactions on Control Systems Technology*, vol. 24, no. 2, pp. 440–450, 2016.

[28] J. Rios-Torres and A. Malikopoulos, "An overview of driver feedback systems for efficiency and safety," in *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, 2016, pp. 667–674.

[29] A. Malikopoulos and J. Aguilar, "Optimization of driving styles for fuel economy improvement," in *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, 2012, pp. 194–199.

[30] A. A. Malikopoulos and J. P. Aguilar, "An Optimization Framework for Driver Feedback Systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14, no. 2, pp. 955–964, 2013.

[31] A. Malikopoulos, "Driver feedback for fuel efficiency," *US Patent App. 14/323,875*, mar 2015.

[32] I. Sharma, J. Dong, A. Malikopoulos, M. Street, J. Ostrowski, T. Kuruganti, and R. Jackson, "A modeling framework for optimal energy management of a residential building," *Energy and Buildings*, vol. 130, pp. 55–63, 2016.

[33] J. Dong, T. Kuruganti, A. Malikopoulos, S. Djouadi, and L. Wang, "Home energy management based on optimal production control scheduling with unknown regime switching," in *Proceedings of the American Control Conference*, 2017, pp. 2054–2059.

[34] J. Dong, A. Malikopoulos, S. Djouadi, and T. Kuruganti, "Application of optimal production control theory for home energy management in a micro grid," in *Proceedings of the American Control Conference*, vol. 2016-July, 2016, pp. 5014–5019.

[35] A. Malikopoulos, "A duality framework for stochastic optimal control of complex systems," *IEEE Transactions on Automatic Control*, vol. 61, no. 10, pp. 2756–2765, 2016.

[36] J. Rios-Torres, A. Malikopoulos, and P. Pisu, "Online Optimal Control of Connected Vehicles for Efficient Traffic Flow at Merging Roads," in *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, 2015, pp. 2432–2437.

[37] J. Rios-Torres and A. A. Malikopoulos, "Automated and Cooperative Vehicle Merging at Highway On-Ramps," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 4, pp. 780–789, 2017.

[38] ——, "Impact of connected and automated vehicles on traffic flow," in *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*, 2017, pp. 1–6.

[39] J. Rios-Torres and A. Malikopoulos, "A Survey on the Coordination of Connected and Automated Vehicles at Intersections and Merging at Highway On-Ramps," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 5, pp. 1066–1077, 2017.

[40] ——, "Energy impact of different penetrations of connected and automated vehicles: A preliminary assessment," in *Proceedings of the 9th ACM SIGSPATIAL International Workshop on Computational Transportation Science, IWCTS 2016*, 2016.

[41] A. A. Malikopoulos, C. G. Cassandras, and Y. J. Zhang, "A decentralized energy-optimal control framework for connected automated vehicles at signal-free intersections," *Automatica*, vol. 93, pp. 244–256, 2018.

[42] A. A. Malikopoulos, S. Hong, B. B. Park, J. Lee, and S. Ryu, "Optimal control for speed harmonization of automated vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 7, pp. 2405–2417, 2019.

[43] J. Rios-Torres and A. A. Malikopoulos, "Impact of partial penetrations of connected and automated vehicles on fuel consumption and traffic flow," *IEEE Transactions on Intelligent Vehicles*, vol. 3, no. 4, pp. 453–462, 2018.

[44] A. Stager, L. Bhan, A. Malikopoulos, and L. Zhao, "A Scaled Smart City for Experimental Validation of Connected and Automated Vehicles," in *15th IFAC Symposium on Control in Transportation Systems: CTS 2018*, pp. 130–135.

[45] L. Zhao, A. Malikopoulos, and J. Rios-Torres, "Optimal control of connected and automated vehicles at roundabouts: An investigation in a mixed-traffic environment," *IFAC-PapersOnLine*, vol. 51, no. 9, pp. 73–78, 2018.

[46] Y. Zhang, C. Cassandras, and A. Malikopoulos, "Optimal control of Connected Automated Vehicles at urban traffic intersections: A feasibility enforcement analysis," in *Proceedings of the American Control Conference*, 2017, pp. 3548–3553.

[47] Y. Zhang, A. Malikopoulos, and C. G. Cassandras, "Decentralized Optimal Control for Connected and Automated Vehicles at Intersections Including Left and Right Turns," in *56th IEEE Conference on Decision and Control*, 2017, pp. 4428–4433.

[48] L. Zhao and A. A. Malikopoulos, "Decentralized optimal control of connected and automated vehicles in a corridor," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 2018, pp. 1252–1257.

[49] D. Assanis, L. Zhao, and A. A. Malikopoulos, "Characterization of the new class of driving cycles for connected and automated vehicles," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2018, pp. 3668–3673.

[50] L. E. Beaver, B. Chalaki, A. M. Mahbub, L. Zhao, R. Zayas, and A. A. Malikopoulos, "Demonstration of a Time-Efficient Mobility System Using a Scaled Smart City," *Vehicle System Dynamics*, vol. 58, no. 5, pp. 787–804, 2020.

[51] B. Chalaki and A. A. Malikopoulos, "An optimal coordination framework for connected and automated vehicles in two interconnected intersections," in *2019 IEEE Conference on Control Technology and Applications (CCTA)*. IEEE, 2019, pp. 888–893.

[52] B. Chalaki, L. E. Beaver, and A. A. Malikopoulos, "Experimental validation of a real-time optimal controller for coordination of cavs in a multi-lane roundabout," in *31st IEEE Intelligent Vehicles Symposium (IV)*, 2020, pp. 504–509.

[53] B. Chalaki and A. A. Malikopoulos, "A hysteretic q-learning coordination framework for emerging mobility systems in smart cities," in *2021 European Control Conferences(to appear)*, 2021.

[54] B. Chalaki, L. E. Beaver, B. Remer, K. Jang, E. Vinitsky, A. Bayen, and A. A. Malikopoulos, "Zero-shot autonomous vehicle policy transfer: From simulation to real-world via adversarial learning," in *IEEE 16th International Conference on Control & Automation (ICCA)*, 2020, pp. 35–40.

[55] B. Chalaki and A. A. Malikopoulos, "Optimal control of connected and automated vehicles at multiple adjacent intersections," *arXiv preprint arXiv:2008.02379*, 2020.

[56] ——, "Time-optimal coordination for connected and automated vehicles at adjacent intersections," *arXiv preprint arXiv:1911.04082*, 2020.

[57] W. D. Connor, Y. Wang, A. Malikopoulos, S. G. Advani, and A. K. Prasad, "Impact of connectivity on energy consumption and battery life for electric vehicles," *IEEE Transactions on Intelligent Vehicles*, vol. 6, no. 1, pp. 14–23, 2020.

[58] K. Jang, E. Vinitsky, B. Chalaki, B. Remer, L. Beaver, A. A. Malikopoulos, and A. Bayen, "Simulation to scaled city: zero-shot policy transfer for traffic control via autonomous vehicles," in *Proceedings of the 10th ACM/IEEE International Conference on Cyber-Physical Systems*, 2019, pp. 291–300.

[59] A. M. I. Mahbub, L. Zhao, D. Assanis, and A. A. Malikopoulos, "Energy-Optimal Coordination of Connected and Automated Vehicles at Multiple Intersections," in *Proceedings of 2019 American Control Conference*, 2019, pp. 2664–2669.

[60] A. M. I. Mahbub and A. A. Malikopoulos, "Conditions for state and control constraint activation in coordination of connected and automated vehicles," *Proceedings of 2020 American Control Conference*, pp. 436–441, 2020.

[61] A. M. I. Mahbub, A. Malikopoulos, and L. Zhao, "Impact of connected and automated vehicles in a corridor," in *Proceedings of 2020 American Control Conference, 2020*. IEEE, 2020, pp. 1185–1190.

[62] A. M. I. Mahbub and A. A. Malikopoulos, "Conditions to Provable System-Wide Optimal Coordination of Connected and Automated Vehicles," *Automatica (in review)*, 2020.

[63] A. I. Mahbub, A. A. Malikopoulos, and L. Zhao, "Decentralized optimal coordination of connected and automated vehicles for multiple traffic scenarios," *Automatica*, vol. 117, p. 108958, 2020.

[64] A. M. I. Mahbub, V. Karri, D. Parikh, S. Jade, and A. Malikopoulos, "A decentralized time- and energy-optimal control framework for connected automated vehicles: From simulation to field test," in *SAE Technical Paper 2020-01-0579*. SAE International, 2020.

[65] A. M. I. Mahbub and A. Malikopoulos, "Concurrent optimization of vehicle dynamics and powertrain operation using connectivity and automation," in *SAE Technical Paper 2020-01-0580*. SAE International, 2020).

[66] A. A. Malikopoulos and L. Zhao, "A closed-form analytical solution for optimal coordination of connected and automated vehicles," in *2019 American Control Conference (ACC)*. IEEE, 2019, pp. 3599–3604.

[67] ——, "Optimal path planning for connected and automated vehicles at urban intersections," in *Proceedings of the 58th IEEE Conference on Decision and Control, 2019*. IEEE, 2019, pp. 1261–1266.

[68] A. A. Malikopoulos, L. E. Beaver, and I. V. Chremos, "Optimal time trajectory and coordination for connected and automated vehicles," *Automatica*, vol. 125, p. 109469, 2021.

[69] L. Zhao, A. A. Malikopoulos, and J. Rios-Torres, "Optimal control of connected and automated vehicles at roundabouts: An investigation in a mixed-traffic environment," in *15th IFAC Symposium on Control in Transportation Systems*, 2018, pp. 73–78.

[70] L. Zhao and A. A. Malikopoulos, "Decentralized optimal control of connected and automated vehicles in a corridor," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, Nov 2018, pp. 1252–1257.

[71] L. Zhao, A. M. I. Mahbub, and A. A. Malikopoulos, "Optimal vehicle dynamics and powertrain control for connected and automated vehicles," *Proceedings of 2019 IEEE Conference on Control Technology and Applications (CCTA)*, pp. 33–38, 2019.

[72] L. Zhao, A. A. Malikopoulos, and J. Rios-Torres, "On the traffic impacts of optimally controlled connected and automated vehicles," in *Proceedings of 2019 IEEE Conference on Control Technology and Applications (CCTA)*. IEEE, 2019, pp. 882–887.

[73] L. Zhao and A. A. Malikopoulos, "Enhanced mobility with connectivity and automation: A review of shared autonomous vehicle systems," *IEEE Intelligent Transportation Systems Magazine*, 2019.

[74] I. V. Chremos and A. A. Malikopoulos, "Social Resource Allocation in a Mobility System with Connected and Automated Vehicles: A Mechanism Design Problem," in *Proceedings of the 59th IEEE Conference on Decision and Control, 2020*. IEEE, 2020, pp. 2642–2647.

[75] ——, "A Socially-Efficient Emerging Mobility Market," *arXiv preprint arXiv:2011.14399*, 2020.

[76] ——, "Design and stability analysis of a shared mobility market," in *2021 European Control Conference*, 2021 (to appear).

[77] L. E. Beaver and A. A. Malikopoulos, "A Decentralized Control Framework for Energy-Optimal Goal Assignment and Trajectory Generation," in *IEEE 58th Conference on Decision and Control*, 2019, pp. 879–884.

[78] ——, "An Energy-Optimal Framework for Assignment and Trajectory Generation in Teams of Autonomous Agents," *Systems & Control Letters*, vol. 138, April 2020.

[79] L. E. Beaver, C. Kroninger, and A. A. Malikopoulos, "An Optimal Control Approach to Flocking," in *2020 American Control Conference*, 2020, pp. 683–688.

[80] L. E. Beaver and A. A. Malikopoulos, "An Overview on Optimal Flocking," *arxiv:2009.14279*, 2020.

[81] ——, "Beyond Reynolds: A Constraint-Driven Approach to Cluster Flocking," in *IEEE 59th Conference on Decision and Control*, 2020, pp. 208–213.

[82] L. E. Beaver, M. Dorothy, C. Kroninger, and A. A. Malikopoulos, "Energy-Optimal Motion Planning for Agents: Barycentric Motion and Collision Avoidance Constraints," in *2021 American Control Conference (to appear)*, 2021.

[83] A. Dave and A. A. Malikopoulos, "Decentralized Stochastic Control in Partially Nested Information Structures," in *IFAC-PapersOnLine*, vol. 52, no. 20, Chicago, IL, USA, 2019, pp. 97–102.

[84] ——, "The Prescription Approach to Decentralized Stochastic Control with Word-of-Mouth Communication," *IEEE Transactions on Automatic Control (in review, arXiv:1907.12125)*, 2020.

[85] ——, "Structural results for decentralized stochastic control with a word-of-mouth communication," in *2020 American Control Conference (ACC)*. IEEE, 2020, pp. 2796–2801.

[86] A. Malikopoulos, "On team decision problems with nonclassical information structures," in *arXiv:2101.10992*, 2021.