Guest Editorial Diversification in Urban Transportation Systems and Beyond: Integrating People and Goods for the Future of Mobility

THE increasing growing need for optimization of transportation in a sustainable and green environment is fundamental for the future of mobility. Companies, governments, and non-governmental institutions are trying to find new ways to contribute to this challenge. In particular, the approach is to improve the efficiency and the quality of the movement of diversification of an integrated way of transportation of people and goods. Many people may need to be at some location at some point in time, or many goods may need to be transported to nearby destinations with the same packaging conditions. The main goal of this Special Issue was to integrate the most recent advances in transportation that connect the hybrid point of view. In particular, key contributions integrate several interesting topics related to earning algorithms for the integration of passengers and goods, gamification techniques, semantic data, blockchain, and edge computing. Other topics in urban mobility, railway, and highways were considered, and hot topics on shared autonomous vehicles (SAVs) brought huge value. Moreover, the Internet of Things (IoT) opens the doors for new development in Vehicle to Everything (V2X), which are crucial for the development of new services that generate business and social impact in the future of a diversified way of the integration of passengers and goods mobility.

I. INTRODUCTION

Modern cities are complex socio-technical entities that exist to provide services effectively to their residents and visitors. In the *transportation* context, **people** need to travel quickly and conveniently between locations at different scales, ranging from a trip of a few blocks to a journey across town or further. At the same time, **goods** need to be timely delivered considering the needs of both the users and the businesses.

The continuous growth of population and the expansion of urban centers bring us new mobility challenges for public and private stakeholders and people living in crowded cities, particularly considering the exponential increase of the amount of data to be extracted and exploited [1].

Examples of such technologies are the dynamic introduction of fares, and the application of artificial intelligence technologies based on big-data analytics and crowdsourcing [2], [3].

The provision of mobility services for people and goods effectively to residents and visitors is a **complex**

socio-technical system task to city public managers. Smart mobility systems aim to support the efficient exploitation of the city transport facilities as well as **sustainable mobility within the urban environment**. In the last few years, several cities indicated interest in using **Autonomous Vehicles** (**AV**) **for the "last-mile" mobility services**. With them, it seems to be easier to get people and goods around using fewer vehicles.

AVs are beginning to be thought of as a new mobility/delivery service in the city centers where narrow streets are not easily served by traditional buses, and new mobility strategies are required [4], [5]. They allow them to serve critical areas with minimal new infrastructure and reduce noise and pollution.

Connected and autonomous vehicle technology and services for the mobility of people and goods in mixed-mode environments can improve efficiency, safety, and cleanliness. From this point of view, autonomous vehicles must take into consideration people's acceptance [6] to get the market diffusion of new technology.

An example of technology is the use of **data platforms** for the customization of bus routes in city centers. This process is very useful for the creation of environmental friendliness and congestion alleviation in metropolitan areas. Furthermore, **gamification** techniques empower **citizen engagement** and traveler behavior toward green and sustainable actions.

Gamification techniques that empower autonomous driving based on game theory are key challenges to non-cooperative decision-making. Gamification is a key business opportunity for small-medium companies aiming at changing the parading in transportation with diversity strategies.

A key hot topic in the business environment is the **eco**platooning for cooperative automated vehicles (CAVs) under Mixed Traffic Flow is becoming very common. This phenomenon could be viewed as an issue for technology and policy development and a great business opportunity for the future of mobility services towards green transportation. It is crucial for energy-efficient and secure driving, being also a key research challenge in this sector [7], [8].

Leveraging on current research based on autonomous shutters for public transportation of people and goods, a new model [9] is capable of empowering companies to explore new business models with social impact, thus increasing the diversity capacity of transportation in smart cities.

The social aspects related to the improvement of the flow of mobility of people and goods in city centers are key

1558-0016 © 2021 IEEE. Personal use is permitted, but republication/redistribution requires IEEE permission. See https://www.ieee.org/publications/rights/index.html for more information.

Digital Object Identifier 10.1109/TITS.2021.3067410

factors towards the creation of a **better environment that enables new businesses in smart cities** [10]. In particular, the understanding of mobile data flow in smart cities for the **recommendation of better mobility habits** for people is a key business opportunity for public and private partnerships.

Another business opportunity is the concept of learning algorithms for transportation of people and goods, which is critical in the business of last-mile delivery due to a large amount of on-line sales, thought out large platforms of e-commerce. Furthermore, toward integrating people and goods in a new mobility framework, it is fundamental to the creation of software platforms capable of taking into consideration the needs of different actors [11].

II. SPECIAL ISSUE GOALS

For this Special Issue, our assumption is that radical changes will be introduced in the transport systems. These changes will transform the current transport modes, and a higher level of autonomy will be used compared to the present, e.g., with the adoption of connected autonomous vehicles and improved signaling. While attempting to reduce congestion, technologies have already shown their positive impact on making streets cleaner and safer. Nevertheless, living in a profit-driven society, these technologies will eventually attract private investment; however, what is the most adequate funding scheme for a technology-driven transport system? Who will cover the infrastructure installation and maintenance costs for electric vehicles and connected and autonomous cars? Furthermore, the future relies on digital data and digital connectivity, highlighting the need is to protect the privacy of the public.

In this Special Issue, we are interested in contributions discussing how we can safeguard society and ensure a high quality of life for all in a diverse and technology-dependent transport system. In particular, we are interested in the following **themes**:

- designing an inclusive transport system, e.g., engaging the public into the design of technological solutions;
- ensuring that sustainable technological solutions are integrated into future transport systems, e.g., modernizing regulatory frameworks, societal needs, and strategic transport planning (we can say smart cities but we need to define the term, as it varies across disciplines);
- the use of technologies for transport studies, environmental assessment, and resilience in artificial intelligence.

III. SPECIAL ISSUE SUMMARY

For mobility diversification to be effective, there needs to be a mix of commonality combined with elements that explore the boundaries of this conceptual space. We can explore this with the notion of betweenness centrality, which describes how nodes in networks influence other nodes to greater or lesser extents. This approach, made famous by Google's Page and Brin with their PageRank algorithm, uses a matrix representation of the links and weights between the nodes of a network to construct an Eigenvector that lists nodes from most to least influence [12]. While the Google approach uses inbound and outbound hyperlinks, words in documents can also be used [13]. Using this approach, we can look at which articles in this Special Issue are most central to the concepts described in these articles, and also which articles add the most diversity to this issue.

To explore these relationships, one of the editors (Dr. Feldman) developed an interactive tool (Figure 1) that shows the ordering of the documents in this issue and the word network that connects them. Once normalized by document length, the four articles that are at the top of the list, or most central are Distefano *et al.*'s "Trustworthiness for transportation ecosystems: The blockchain vehicle information system," Hu *et al.*'s "Eco-platooning for cooperative automated vehicles under mixed traffic flow," Manchella *et al.*'s "FlexPool: A distributed model-free deep reinforcement learning algorithm for joint passengers and goods transportation, and Lv *et al.*'s "Diversified technologies in Internet of Vehicles under intelligent edge computing."

This is reasonable, since these four papers focus on the role of the **vehicle as the central element of their approaches**, while also addressing broad themes in intelligent transportation research.

By this measure, the most central paper is Mazzara's, which presents "an all-encompassing scenario laying at the intersection of several domains, including manufacturing, logistics, traveling, insurance, maintenance, and trading." These transactions are guaranteed by blockchain. The sprawling nature of the problem ensures that many aspects of intelligent transportation are touched upon.

The following three articles all deal with aspects of **communicating between and the coordination of vehicles**. Hu describes research that creates string-stable groups of coordinating vehicles, or platoons, that can optimize their behavior with respect to energy footprint, even when sharing the road with less-predictable human drivers. Manchella approaches the optimal dispatching of vehicles to service the joint transportation of goods and services using a deep learning model that uses reinforcement learning to discover optimal strategies rather than depend on an explicit, pre-defined model. Finally, Lv's article focuses on moving these processes out to the vehicles themselves as an efficient internet of vehicles that not only include vehicles but also communicate with roads, infrastructure, and pedestrians.

After removing these papers from the list and recalculating for centrality, we find that urban transportation represents a cluster of research in this issue. Chen et al. discuss their work on customized bus scheduling, which optimizes bus stops stops, route design, and timetables using an objective function that minimizes passengers' inconvenience, the total number of stops among all routes, and costs. This model is validated using data from the Beijing transportation network. Autili et al. address coordinating urban cooperative transport systems using the CHOReVOLUTION IDRE, an EU-supported platform that uses the concept of *choreographies* as a framework for supporting reuse-based development of internet-connected services, in this case, transportation. Iovino *et al.*, on the other hand, look at the problem of bus transit from the perspective of the user who needs real-time information about bus fleets to create an optimal route at a given time. The authors can assemble a transit graph containing this information using a recurrent LSTM network. The effectiveness of the approach

Name:	Phil C:\Users\Phil\Google Driv			Standa Ne	Scho WVM si	7	▼ Ad	ditional Ter	S				Sea
Open file			e Driv	Quotes? vehicle service drive passenger network route control									CI
Open folder				Sorted term/document eigenvectors:									
Session Name:	Phil-centrality			Term					Document				
				Name	Weight	Count	Rank	Delta	Name	Weight	Count	Rank	Delta
elected: Open Delete		vehicle	1.00	531	1	0	mazzara-3054996.pdf	1.43	514		4		
514 tits-mazzara-3054996.pdf				service	1.00	258	3	1	chen-3056122.pdf	0.86	857	3	1
Weight:				drive	1.00	152	7	4	aggarwal-3048361.pdf	0.70	1046	2	-1
				passenger	1.00	206	2	-2	lv-3019756.pdf	0.86	848	4	0
Top 0 10			10	network	1.00	172	5	0	ma-3048520.pdf	0.68	1084	1	-4
Linked to Selected:				route	1.00	192	4	-2	lv-3036984.pdf	1.10	668	6	0
Nam	ne (Count	Percent	control	1.00	123	11	4	pompilio-3059394.pdf	1.24	590	7	0
vehicle	7	9	15.4 🏠	request	1.00	103	6	-2	kumar-3040557.pdf	0.94	783	8	0
service	3	2	6.2	decision	1.00	97	26	17	iovino-3053373.pdf	1.17	626	9	0
blockchain	3	0	5.8	computing	1.00	90	12	2	baburajan-3040904.pdf	1.10	666	11	1
(scheme	1.00	121	14	3	cao-3040909.pdf	1.98	371	13	2
Reset Weights Normalize Docs		value	1.00	107	10	-2	luo-3048362.pdf	0.81	903	10	-2		
Use Single Counts				choreography	1.00	63	60	47	marconi-3049792.pdf	0.94	778	12	-1
				collection	1.00	103	43	29	sobral-3056228.pdf	1.40	525	14	0
rank (0.213 seconds)			\$	energy	1.00	131	17	2 ~					

Fig. 1. Interactive Term/Document Centrality Tool.

was validated against ground-truth data from the local bus system of L'Aquila Italy.

The rest of the article in this issue explore the less-traveled areas of intelligent transportation systems: Li et al. explore ways of collecting data fairly using networks of UAVs that have limited speed and flight times. Lv et al. approach the particularly thorny problem of coordinating the behavior of autonomous vehicles and human drivers coordinating lanechanging using a model derived from a Stackelberg equilibrium from noncooperative game theory. Lou et al. perform detailed research into electric train power management and regenerative braking. Cao et al. provide an approach for developing transportation recommender systems that go beyond the basic "A to B" solutions to produce personalized options that range from the efficient to the frivolous. Kazhamiakin et al. approach personalization from a different angle, involving the use of gamification as a way of encouraging sustainable transportation choices. Finally, Sobral et al. dig into the semantics of the terms that represent origin-destination knowledge. They do this by creating and visualizing ontologies that represent this knowledge using the affordance of heat map matrices.

Finally, as someone who just used unstructured text analytics to frame this section, I cannot help but appreciate Baburajan *et al.* and their research into evaluating autonomous vehicle questionnaire response using topic modeling on openended responses and comparing those with closed-form answers. In everything from bus schedules to getting along on the roads to answering surveys, we must never forget that **transportation systems exist to support people**. Our systems always need to reflect this important fact.

IV. RESEARCH CHALLENGES FOR THE FUTURE OF MOBILITY

The future moves relentlessly to more sustainable, equitable, efficient, and convenient mobility. Achieving these goals,

if desirable to all, raises quite a few research challenges. This Special Issue shows that there co-exist different research streams concerned with diversity in transportation systems, and new ones will certainly appear in the next few years. The future of mobility will rely on strengthening the **collaboration between research and practice**, involving citizens, urban planners, and academia in pursuing the common goal of safer, sustainable, inclusive, and equitable mobility.

Mobility data curation is a fundamental and critical research challenge. First, it is easier to collect mobility data than to handle and transform it into insightful information and knowledge. Transport operators, agencies, or governments collect and store vast volumes of data daily, but seldom is this data used and analyzed. Second, most of the research challenges regarding the future of mobility rely on the availability and reliability of collected data over time [14]. It is not possible to assess the impact of a transport policy or the effect of a new mobility service or technology if data is not properly curated. Lastly, the protection of our personal digital identities as, for example, the establishment of rules that simultaneously allow the exploitation of data collected from Automatic Fare Collection (AFC) systems while guaranteeing the anonymity of the riders, are essential to creating a trustworthy environment.

Research on the **impact of autonomous vehicles on urban mobility** will continue to increase since they will definitely shape the future of the cities. Communications infrastructure, vehicle collaboration protocols, and data collection schemes are already active research areas. Challenges regarding **ethics**, **safety, and security of autonomous vehicles**, as well as their role in the optimal mix of ride-sharing services, will become more prominent once they become part of our daily lives [15]. Public transport planning and operations is a traditional line of research. Today, more than ever, network planning, timetabling, routing, and dispatching operations have become increasingly connected, integrated, and optimized across modes of transportation. The availability of real-time information and increasingly powerful computation tools make it possible to handle the whole transportation network, integrating different modes and operators. Then, it would be possible, for example, to develop integrated optimization tools aiming at the synchronization and robustness of timetables and schedules [16], handling disruptions [17], and automating parts of the planning process. Research on these topics will increase ridership, reduce waiting times, and, ultimately, increase the attractiveness of public transports.

Urban mobility is far more comprehensive than traditional public transportation. In recent years, we have witnessed the emergence of new concepts, new mobility services, with different business models. Traditional public transportation is becoming complemented with the demand for responsive transportation services, micro-mobility, or ride-sharing services. Through Mobility-as-a-Service apps, riders can plan, pay, and use any transport mode or service in an integrated and seamless way. It is increasingly important to research on the topic of decision support systems and frameworks that would help urban planners and transport operators in choosing the optimal mix of mobility services to offer, together with the definition of equitable and inclusive fare structures [18]. Behavioral, collaborative, simulation-based, or gamification models could play an important role in this area, allowing to simulate and evaluate scenarios that would improve the mobility experience while decreasing the costs involved.

In this complex and diverse ecosystem, there is still plenty of space left for the **active involvement of the citizens** in the definition and evaluation of a system that is meant to suit their needs. Independently of the data collected daily from intelligent transportation systems, which may provide individual mobility and activity profiles, or origin-destination matrices, it is of utmost importance to research on participative and collaborative methods that would promote the integration of a varied and inclusive sample of citizens in the urban mobility characterization process.

The Guest Editors would like to express their deep gratitude to all the authors who have submitted their valuable contributions and to the numerous and highly qualified anonymous reviewers. The selected contributions, which represent the current state-of-the-art in the field, will be of great interest to the community. They would like to thank the IEEE publication staff members for their continuous support and dedication. Additionally, they particularly appreciate the tireless support from Prof. Azim Eskandarian, the Editor-in-Chief of IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS.

> ANTONIO BUCCHIARONE, *Lead Guest Editor* Fondazione Bruno Kessler 38123 Trento, Italy e-mail: bucchiarone@fbk.eu

SANDRO BATTISTI, *Guest Editor* Fondazione Bruno Kessler 38123 Trento, Italy e-mail: s.battisti@fbk.eu TERESA GALVÃO DIAS, *Guest Editor* Faculty of Engineering University of Porto 4099-002 Porto, Portugal e-mail: tgalvao@fe.up.pt

PHILIP FELDMAN, *Guest Editor* ASRC Federal Beltsville, MD 20705 USA e-mail: philip.feldman@asrcfederal.com

REFERENCES

- M. Curado, L. Tortosa, J. F. Vicent, and G. Yeghikyan, "Understanding mobility in Rome by means of a multiplex network with data," *J. Comput. Sci.*, vol. 51, Apr. 2021, Art. no. 101305.
- [2] L. Zhu, F. R. Yu, Y. Wang, B. Ning, and T. Tang, "Big data analytics in intelligent transportation systems: A survey," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 1, pp. 383–398, Jan. 2019.
- [3] R. C. Shit, S. Sharma, K. Yelamarthi, and D. Puthal, "AI-enabled fingerprinting and crowdsource-based vehicle localization for resilient and safe transportation systems," *IEEE Trans. Intell. Transp. Syst.*, early access, Feb. 2, 2021, doi: 10.1109/TITS.2021.3053942.
- [4] G. Li et al., "Risk assessment based collision avoidance decision-making for autonomous vehicles in multi-scenarios," *Transp. Res. C, Emerg. Technol.*, vol. 122, Jan. 2021, Art. no. 102820. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0968090X20307257
- [5] P. Liu and W. D. Fan, "Exploring the impact of connected and autonomous vehicles on mobility and environment at signalized intersections through vehicle-to-infrastructure (V2I) and infrastructure-tovehicle (I2V) communications," *Transp. Planning Technol.*, vol. 44, no. 2, pp. 129–138, Feb. 2021.
- [6] S. Karnouskos, "Self-driving car acceptance and the role of ethics," *IEEE Trans. Eng. Manag.*, vol. 67, no. 2, pp. 252–265, May 2020.
- [7] D. Ngoduy, N. H. Hoang, H. L. Vu, and D. Watling, "Multiclass dynamic system optimum solution for mixed traffic of human-driven and automated vehicles considering physical queues," *Transp. Res. B, Methodol.*, vol. 145, pp. 56–79, Mar. 2021.
- [8] T. Pan, R. Guo, W. H. K. Lam, R. Zhong, W. Wang, and B. He, "Integrated optimal control strategies for freeway traffic mixed with connected automated vehicles: A model-based reinforcement learning approach," *Transp. Res. C, Emerg. Technol.*, vol. 123, Feb. 2021, Art. no. 102987.
- [9] A. Bucchiarone, S. Battisti, A. Marconi, R. Maldacea, and D. C. Ponce, "Autonomous shuttle-as-a-service (ASaaS): Challenges, opportunities, and social implications," *IEEE Trans. Intell. Transp. Syst.*, early access, Oct. 1, 2020, doi: 10.1109/TITS.2020.3025670.
- [10] S. Battisti, "Digital social entrepreneurs as bridges in public–private partnerships," J. Social Entrepreneurship, vol. 10, no. 2, pp. 135–158, 2019.
- [11] J. Winter, S. Battisti, T. Burström, and S. Luukkainen, "Exploring the success factors of mobile business ecosystems," *Int. J. Innov. Technol. Manage.*, vol. 15, no. 3, Jun. 2018, Art. no. 1850026.
- [12] L. Page, S. Brin, R. Motwani, and T. Winograd, "The pagerank citation ranking: Bringing order to the Web," Stanford InfoLab, Stanford, CA, USA, Tech. Rep., 1999.
- [13] A. Kritikopoulos, M. Sideri, and I. Varlamis, "Wordrank: A method for ranking Web pages based on content similarity," in *Proc. 24th Brit. Nat. Conf. Databases (BNCOD)*, 2007, pp. 92–100.
- [14] Z. Tu, F. Xu, Y. Li, P. Zhang, and D. Jin, "A new privacy breach: User trajectory recovery from aggregated mobility data," *IEEE/ACM Trans. Netw.*, vol. 26, no. 3, pp. 1446–1459, Jun. 2018.
- [15] Y. Zhao, X. Guo, and H. X. Liu, "The impact of autonomous vehicles on commute ridesharing with uncertain work end time," *Transp. Res. B, Methodol.*, vol. 143, pp. 221–248, Jan. 2021.
- [16] X. Guo, J. Wu, H. Sun, X. Yang, J. G. Jin, and D. Z. W. Wang, "Scheduling synchronization in urban rail transit networks: Trade-offs between transfer passenger and last train operation," *Transp. Res. A*, *Policy Pract.*, vol. 138, pp. 463–490, Aug. 2020.
- [17] K. Gkiotsalitis and O. Cats, "Timetable recovery after disturbances in metro operations: An exact and efficient solution," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 10, 2020, doi: 10.1109/TITS.2020.3041151.
- [18] G. Smith and D. A. Hensher, "Towards a framework for mobility-as-aservice policies," *Transp. Policy*, vol. 89, pp. 54–65, Apr. 2020.



Antonio Bucchiarone is currently a Senior Researcher in the Motivational Digital Systems (MoDiS) Unit, Fondazione Bruno Kessler (FBK), Trento, Italy. His main research interests include self-adaptive (collective) systems, domain-specific languages for socio-technical systems, smart mobility, and multi-agent-based modeling and simulation. He has been actively involved in various European research projects in the field of Self-Adaptive Systems, Smart Mobility, and Service-Oriented Computing. He was the General Chair of the 12th IEEE International Conference on Self-Adaptive and Self Organizing Systems (SASO 2018). He is an Associate Editor of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS (T-ITS), the IEEE SOFTWARE, and *IEEE Technology and Society Magazine*.



Sandro Battisti received the Ph.D. degree from Politecnico di Milano, Milan, Italy. He is currently responsible for the Mobility Program with Fondazione Bruno Kessler (FBK), Trento, Italy. He has more than 20 years of experience in the management of technology, innovation, and business development of ICT-based solutions in Brazil, Italy, Finland, the U.K., the USA, Germany, and France. He has proven track records in managing projects and programs in the domains of Smart Mobility, Connected Vehicles, Last Mile Logistics, and Smart Retail. He has considerable international experience in leading complex projects and programs and negotiating with multiple stakeholders. His research interests include technology, innovation, and entrepreneurship has been published in relevant international journals, such as IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS (T-ITS), *Journal of Social Entrepreneurship, International Journal of Services Technology and Management*, and *International Journal of Innovation and Technology Management*. He is an Associate Editor of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATIONS ON INTELLIGENT TRANSPORTATIONS ON INTELLIGENT TRANSPORTATIONS on INTELLIGENT TRANSPORTATION SYSTEMS (T-ITS), *Journal of Services Technology and Management*, and *International Journal of Innovation and Technology Management*. He is an Associate Editor of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATIONS ON INTELLIGENT TRA

TRANSPORTATION SYSTEMS (T-ITS).



Teresa Galvão Dias received the degree in mathematics from the University of Coimbra, and the master's degree in electrical and computers engineering, and the Ph.D. degree in sciences of engineering from the University of Porto, since 2005. She is currently an Assistant Professor with the Faculty of Engineering, University of Porto, and a Senior Researcher with INESC TEC, Porto. She has participated in several national and European Research and Development projects in areas related to transportation systems and mobility. She collaborates regularly with the largest public transport companies in Portugal as a Researcher and a Consultant and was responsible for the development and implementation of several innovative systems for the operational planning, mobile ticketing, and passenger information in several of those companies. The academic and professional background led her to have a broad and multidisciplinary perspective of the current transportation and mobility challenges. Her main research interests are operational research, data science, human–computer interaction, and transportation systems. She has more than 70 scientific publications and supervised nine Ph.D. students and more than 100 M.Sc. students.

She is the Co-Founder and the CEO of OPTOptimização e Planeamento de Transportes, SA, a company that develops innovative solutions for the optimization of public transport operation, the provision of passenger information, and mobility management.



Philip Feldman is currently ASRC Federal's AI/ML Futurist. His most recent work has been to develop reliable, resilient neural network architectures using evolutionary algorithms combined with model ensembles. His Ph.D. work at the University of Maryland explores how to detect user belief-based behavior patterns to determine trustworthiness of information in scale-free and domain independent ways. He has extensive experience with time series analysis, natural language processing, machine learning, control systems, high-performance graphics, and agent-based simulation. He has more than 35 years of professional experience in industry and government, including work for NASA, NOAA, NIST, and the Department of Defense. He has written or contributed to numerous papers and patents including publications in machine learning, agent-based simulation, medical simulation, computational sociology, and AI ethics. He has also worked in motion picture special effects including Predator and Star Trek IV.