

Digital Twin for Emergency Evacuations from Toxic Gas Incidents caused by Electric Vehicle Fires

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Abstract

We present a practical digital-twin simulation for mass evacuation when an electric bus ignites at a fixed site (charging station or bus depot), releasing toxic gases in dense urban space. The system helps planners anticipate time-evolving conditions and choose faster, safer actions. The architecture comprises four parts. (1) A gas dispersion model that uses Aerial Location of Hazardous Atmosphere (ALOHA) software to generate hazard-segmented threat zones (e.g., PAC levels), projecting these zones onto the facility and nearby road network as dynamic high-risk and medium-risk areas. (2) A site-space evacuation system that models movement within the facility (e.g., charging station/bus terminal/vehicle interiors) with rules and potential-field which considered local layout, obstacles, and crowding. (3) A roadway evacuation system for evacuees and vehicles on surrounding roads, with behaviors distinct from the site layer (e.g., transition rules dependent on distance and density, density-dependent speeds, rerouting around toxic masks) and guidance toward assembly points. (4) A strategy system presently scoped to two levers: allocating priority of usable links proximate to the fire for fire engines and ambulances, and selection of perimeter assembly points. The system is being instantiated for Kaohsiung, Taiwan, using open road-network and pedestrian-flow data with scenarios over incident time/location, wind, and gas release magnitude. Key performance indicators are total evacuation time and total toxic-exposure time. We employ a heuristic algorithm to select assembly points and assign usable links priority, reducing both metrics. By linking site-level and road-level evacuation, the model better matches real operations and gives clearer guidance on where to block roads, route people, and speed emergency response.

Keywords

OR in disaster relief, Evacuation, Digital twin, Agent-based simulation, Toxic gas incident

Biographies

Shin-Tang Fan is a graduate student in the Department of Industrial Engineering and Engineering Management at National Tsing Hua University (NTHU), Taiwan, where he is pursuing an M.S. degree after earning his B.S. from the same department. His academic interests center on operations research, systems simulation, and simulation optimization, with a focus on developing analytical and computational methods to support complex decision-making.

Kuo-Hao Chang is a Professor of Industrial Engineering and Engineering of National Tsing Hua University. He received his PhD in Industrial Engineering from Purdue University in 2008. Professor Chang's research interests include data analytics, applied probability and statistics, and simulation optimization. He was the winner of the 2012 Bonder Scholar Research Award from INFORMS, 2015 IIE Transactions Best Application Paper Award, 2015 K.D. Tocher Medal from The OR Society, 2015 Ta-You Wu Memorial Award from the Ministry of Science and Technology and 2016 Junior Investigators Research Award from the Academia Sinica and 2017 IEEE Transactions on Semiconductor Manufacturing Best Paper Award. He is currently the Associate Editor of several prestigious international journals, including the IEEE Transactions on Automation Science and Engineering, the Asia-Pacific Journal of Operational Research, and the International Journal of Simulation and Process Modeling. Professor Chang and his team has successfully carried out many projects in collaboration with companies, including TSMC, LiteOn, UMC, VisEra, YOMURA, ITRI, III etc. Professor Chang is an active member of INFORMS, IIE and a senior member of IEEE.