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A Simulation-Driven Optimization Framework for Wind-Aware, Energy-Constrained Aerial Logistics Routing

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Abstract

Aerial logistics systems are increasingly being explored for time-critical operations such as emergency response, medical supply delivery, and rural connectivity. However, conventional routing approaches often assume static, symmetric travel costs that do not capture the environment-dependent nature of aerial transportation. In practice, wind speed and wind direction can directly affect energy consumption, route feasibility, and remaining battery reserve. This paper presents a simulation-driven routing framework for environment-aware aerial logistics in which directed edge costs are computed dynamically using a reduced-order energy model. The framework estimates edge energy from route distance, travel bearing, payload, vehicle characteristics, and wind alignment, allowing the routing cost matrix to change across environmental scenarios. A geospatially grounded rural logistics network with a central depot and multiple county-level service locations is used for evaluation. Controlled wind scenarios are simulated to isolate the impact of wind direction on routing decisions. Results show that wind produces asymmetric edge costs, triggers route-switching behavior, and creates measurable differences between distance-based and environment-aware routing solutions. Compared with distance-based routing, the proposed approach reduces energy consumption under several wind scenarios while preserving route-level battery feasibility. These findings demonstrate the importance of treating aerial logistics routing costs as dynamic outputs of system behavior rather than fixed network attributes.

Keywords

Vehicle Routing Optimization, Wind-Aware, Simulation-Based Optimization, Aerial Logistics Systems, Energy-Constrained Routing

Biographies

Dr. Kuldeep Rawat is currently the Thorpe endowed professor & dean of the School of Science, Aviation, Health, and Technology at Elizabeth City State University (ECSU). He earned an M.S. in Computer Science, an M.S. in Computer Engineering and a Ph.D. in Computer Engineering from the Center for Advanced Computer Studies (CACS) at the University of Louisiana-Lafayette. Dr. Rawat has served as Principal Investigator on numerous federally funded grants, including those from the US Department of Commerce, NASA, the Department of Energy, the National

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Dr. Chandra Asthana is an Associate Professor in the department of aviation and emergency management at Elizabeth City State University. He completed his undergraduate education in aeronautical engineering at the Indian Institute of Technology (Kharagpur), the postgraduate education in aeronautical engineering and Ph. D. in control systems design at the Indian Institute of Science. He has worked at Air India, Defense Research and Development in India, CAE Inc. in Montreal Canada, Lockheed Martin in Netherlands. He has taught at McGill and Concordia University in Canada. His research interests are in aviation, aerodynamics, control system design, modeling, simulation of aircraft and unmanned aerial vehicles, damper design with MR fluid, teaching and mentoring undergraduate and graduate students. Dr. Asthana may be reached at cbasthana@ecsu.edu.