Drone-Based Medical Supply Chain Optimization: Integrated Forward-Reverse Last-Mile Logistics with Financial Viability Analysis

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Abstract

The fast development of unmanned aerial vehicle (UAV) technology offers game-changing possibilities to healthcare logistics, especially last-mile delivery and reverse logistics. This paper formulates an overall mixed-integer non-linear programming (MINLP) model to optimize forward and reverse supply chain operations of medical technologies using drone technology. The main aims are to optimize the return on investment (ROI), reduce operational expenses, and the quality of the services according to the regulations. The model takes into consideration the critical operational aspects such as the cost of acquiring drones, the cost of charging and maintaining batteries, insurance cover, the need to comply with regulations, the infrastructure needs, the handling of products at controlled temperatures, time-constrained delivery, and medical waste and expired drugs reverse logistics. Strict comparison with traditional ground transportation is made on the basis of cost, delivery speed, carbon emission, reliability, and scalability aspects. Computational tests with real-world examples of healthcare networks also prove that drone-based systems can cut delivery bills by 35-45 percent in a 50 km service area, cut down emergency delivery of supplies by 60-70 percent, and cut carbon emissions by 55-65 percent compared to vehicles. A sensitivity analysis done in detail will ensure the soundness of the model to different demand patterns, regulatory requirements, and operating conditions. To support the idea of statistical reliability, Monte Carlo simulation of 10,000 iterations provides 95% confidence intervals. Strong predictive accuracy is validated by cross-validation of 50 real-world test cases with R 2 = 0.9847, RMSE = 186.45 and MAE = 142.33.

Keywords

Unmanned Aerial Vehicles, Medical Supply Chain, Last-Mile Delivery, Reverse Logistics, MINLP Optimization, Return on Investment, Supply Chain Management.