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Relay-Hub Network Design for Consolidation Planning Under Demand Variability

We study the design of large-scale relay logistics hub networks that are resilient to demand variability. We formulate a two-stage stochastic optimization model that integrates first-stage strategic decisions on hub location and capacity with second-stage tactical decisions on consolidation-based routing. To solve this problem exactly, we develop a three-stage branch-and-cut algorithm with nested integer L-shaped cuts and Benders decomposition. Our approach decomposes the problem twice: across stochastic demand scenarios and, within each scenario, across origin-destination pairs—yielding tractable network flow and shortest path subproblems. We validate our methodology by designing relay networks for finished vehicle deliveries in collaboration with a U.S.-based car manufacturer. Computational experiments show that our method efficiently generates near-optimal solutions for large-scale instances using sample average approximation. The resulting networks reduce average delivery costs by 11.9% compared to those based on deterministic demand and outperform designs that continuously approximate routing operations, especially under low and medium demand realizations. These results underscore the importance of incorporating consolidation-based routing at the design stage and offer actionable insights for logistics decision-makers seeking to enhance network flexibility under uncertainty.

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