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Two-echelon drone–truck collaborative TSP-based routing for humanitarian logistics with time windows and stochastic demand

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A B S T R A C T

In humanitarian logistics emergency material transportation and distribution, trucks offer large load capacity and long driving range, whereas drone transportation is independent of ground road conditions but constrained by battery life and payload capacity. The coordination of the two can therefore provide complementary advantages. In this paper, the traveling salesman problem is formulated for a two-echelon emergency material distribution process, spanning transportation from the central warehouse to the distribution center and then to the demand points. In the first stage, transportation from the central warehouse to the distribution center is performed by trucks. In the second stage, trucks and drones collaboratively carry out material distribution from the distribution center to the demand points. Based on the above scenario, this paper aims to minimize the total cost of completing all distribution tasks. The model considers capacity constraints at distribution centers, time window constraints at demand points, and stochastic demand, and establishes a two-echelon traveling salesman problem for humanitarian logistics with truck–drone collaboration. Based on the particle swarm optimization (PSO) framework, a heuristic algorithm named PSO-VD is proposed, which transforms the discrete traveling salesman problem into a continuous encoding and integrates drone routes into truck routes using the 2-opt method. In small-scale instances, the solutions obtained by PSO-VD are compared with those of commercial solvers, demonstrating that the proposed algorithm achieves high accuracy with low computational time. For instances with up to 12 demand points, the algorithm obtains solutions within 150 seconds, with an accuracy deviation of less than 10 % compared to exact solution methods. The applicability of the algorithm proposed in this paper has been demonstrated through large-scale numerical examples. Sensitivity analyses are conducted on key parameters, including the time window penalty coefficient, drone speed, and drone battery capacity, yielding practical managerial insights.

A R T I C L E   I N F O

Keywords:
Humanitarian logistics;
Two-echelon routing;
Drone–vehicle collaboration;
Stochastic demand;
Time windows;
Capacity constraint;
Vehicle routing problem (VRP);
Travelling salesman problem (TSP);
Heuristic algorithm;
Particle Swarm Optimization (PSO)

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Izvirni znanstveni članek

Dvonivojsko usklajeno načrtovanje poti drona in tovornjaka na osnovi problema trgovskega potnika za humanitarno logistiko s časovnimi okni in stohastičnim povpraševanjem

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P O V Z E T E K

V humanitarni logistiki za nujni prevoz in razdeljevanje materiala tovornjaki zagotavljajo veliko nosilnost in dolg doseg, medtem ko je transport z droni neodvisen od cestne infrastrukture, vendar omejen z zmogljivostjo baterije in nosilnostjo. Usklajeno delovanje obeh načinov prevoza omogoča izkoriščanje njunih komplementarnih prednosti. V prispevku je problem trgovskega potnika formuliran za dvonivojski proces nujne distribucije materiala, ki zajema prevoz iz osrednjega skladišča do distribucijskega centra ter nadaljnjo distribucijo do točk povpraševanja. V prvi fazi se prevoz izvaja s tovornjaki, v drugi pa tovornjaki in droni usklajeno razdeljujejo material iz distribucijskega centra do točk povpraševanja. Cilj modela je minimizacija skupnih stroškov distribucije ob upoštevanju kapacitet distribucijskih centrov, časovnih oken na točkah povpraševanja in stohastičnega povpraševanja. Na tej osnovi je vzpostavljen dvonivojski problem trgovskega potnika za humanitarno logistiko z usklajenim delovanjem tovornjakov in dronov. Na osnovi optimizacije z rojem delcev (PSO) je predlagan hevristični algoritem PSO-VD, ki diskretni problem preslika v zvezno kodiranje ter z uporabo metode 2-opt integrira poti dronov v poti tovornjakov. Primerjave s komercialnimi optimizacijskimi orodji pri manjših primerih kažejo visoko natančnost ob nizkem računalniškem času. Pri primerih z do 12 točkami povpraševanja algoritem doseže rešitve v manj kot 150 sekundah, pri čemer odstopanje od točnih rezultatov ne presega 10 %. Uporabnost predlaganega pristopa je potrjena tudi z obsežnimi numeričnimi primeri ter analizami občutljivosti ključnih parametrov, vključno s kaznijo za časovna okna, hitrostjo dronov in kapaciteto baterij.

P O D A T K I   O   Č L A N K U

Ključne besede:
Humanitarna logistika;
Usmerjanje na dveh ravneh;
Usklajeno delovanje dronov in vozil;
Stohastično povpraševanje;
Časovna okna;
Omejitve kapacitet;
Problem usmerjanja vozil (VRP);
Problem trgovskega potnika (TSP);
Hevristični algoritem;
Optimizacija z rojem delcev (PSO)

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