57º SBPO
SIMPÓSIO BRASILEIRO DE PESQUISA OPERACIONAL
Gramado • RS
DE 5 A 9 DE OUTUBRO DE 2025

Algorithms for solving routing problems with drones: a systematic literature review

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ABSTRACT

The development of drones in routing solutions is increasing its appearance in the literature. More problem variants and the addition of drones to classical routing problems are being modeled. The high increase of papers in just a few years makes it difficult to track the advances in literature. This paper aims to present a systematic literature review, presenting a compact view of a wide range of years (from 2000 to March of 2025) and answer relevant questions about the state-of-the-art such as the most recurrent studied variants, most used methods to solve the problem, and other questions. The complete systematic protocol is presented. The literature revision is highly important in guiding promising and new leads and also prevents the proposal from being what was already proposed.

KEYWORDS. Routing problem with drone. Systematic Literature Review. Combinatorial Optimization.

Logistics and Transport, Metaheuristics, and Discrete Optimization.

DOI: 10.59254/sbpo-2025-212493
https://proceedings.science/p/212493?lang=pt-br

1. Introduction

Drones have the potential to boost the industry, improving the logistic processes by delivering goods faster when combining drones and trucks, and making deliveries with lower logistics costs. Moreover, drones can also access areas that trucks cannot reach or have difficulty accessing.

In 2013, Amazon CEO Jeff Bezos announced that the company was developing the idea of using drones for the delivery of small packages. DHL then initiated a similar project to deliver medical supplies and other urgent packages on a small island in northern Germany. Google X conducted a similar project using the drone "Project Wing" with properties similar to those of a plane [Sacramento et al., 2019]. A growing interest has emerged in the use of drones for solving routing problems and achieving improved solutions, by reducing the total cost of the logistic processes or the total amount of time required for deliveries.

The literature presents an increasing number of papers involving algorithms to solve routing problems with drones in recent years. Several problem variants, benchmarks, and solution methods are being proposed in a few years, difficulting to track the literature advances. This paper presents a systematic literature review covering a long period (from 2000 to March 2025), using three highly relevant search engines. The study addresses four research questions related to state-of-the-art algorithms to solve routing problems involving at least one drone.

The remainder of this paper is organized as follows. The steps of the systematic literature review are outlined in the next sections, starting with the definition of the protocol (Section 2) and then its application to the selected search sources (Section 3). Then, in Section 4, the answers to the research questions are presented, based on the articles chosen during the process, and finally, the conclusions are discussed in Section 5.

2. Protocol

A systematic review is a research method that employs explicit and structured procedures to identify, gather, and synthesise evidence from studies addressing well-defined questions [Page et al., 2022]. It constitutes a secondary study that analyses and summarises primary studies related to a specific research question [Kitchenham et al., 2007]. In this work, the following research questions were defined: (RQ1): When and where the papers are being submitted?; (RQ2): What are the most commonly studied variants of routing problems involving drones?; (RQ3): What are the most used benchmarks? and (RQ4): Which solution methods are the most commonly used? The data collection was conducted on three search engines, Scopus, IEEE Xplore, and ACM Digital Library, in the period of 2000 to March 2025 and the process was performed manually using the search string:

```
(algorithm OR heuristic OR metaheuristic OR matheuristic OR solver ) AND (
 "vehicle routing problem with drones" OR vrpd OR "traveling salesman problem
with drone" OR tspd OR fstsp OR "flying sidekick traveling salesman problem" OR
 "drone routing problem" ) AND ( benchmark OR comparison OR "state-of-the-art")
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Any paper written in English or Portuguese, retrieved using the chosen search string, and addressing an optimization method to solve a routing problem involving at least one drone was included in the list of resulting articles. To filter articles obtained during the data collection process, inclusion and exclusion criteria were established as detailed in Table 1.

The process was conducted in two phases. In the first phase, the selection of articles was based on paper title and abstract, and in the second phase, the full article was considered. The selected full papers were retrieved from the CAPES database, as well as from other sources such as ResearchGate and the authors' personal websites.

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Inclusion criteria	The research presents an algorithm to optimize or solve a routing problem or variant that also includes at least one drone.
Exclusion criteria	**Reason1:** the research is not written in English or Portuguese.
	Reason2: the research is only an abstract, a conference annals or is not a primary study (surveys, systematic mapping...)
	Reason3: The research does not fulfill the inclusion criteria.

Table 1: Inclusion and exclusion criteria.

3. Conducting the review

The results obtained after conducting the review process based on the protocol presented in Section 2, are summarized in the diagram presented in Figure 1, generated following the PRISMA[1] [Page et al., 2022].

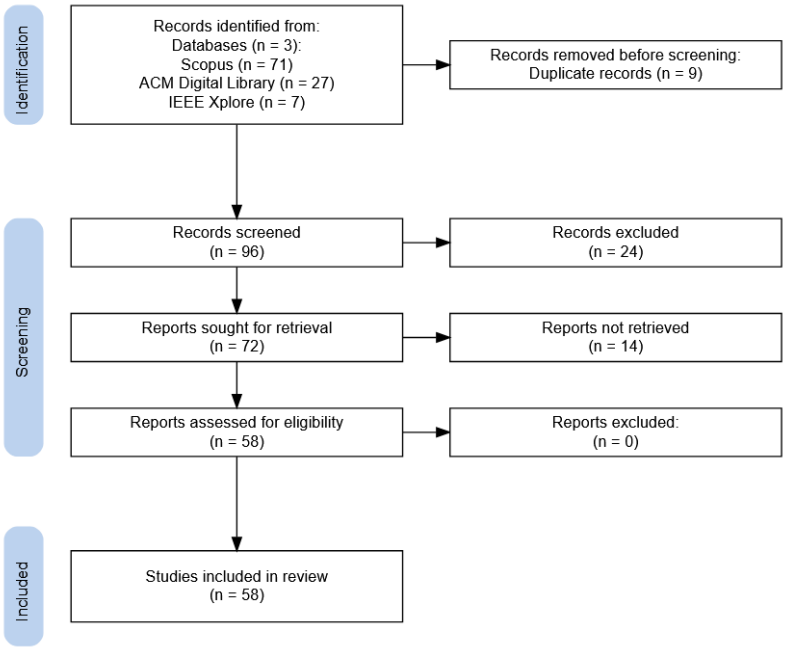


Figure 1: The PRISMA diagram of the Systematic Literature Review Process.

The initial list of articles generated from the search string applied to the three selected search engines resulted in a total of 105 records, including 9 duplicates. The first phase of the review (analyzing the articles based on their title and abstract) was carried out on 96 articles. This step led to the elimination of 24 additional articles though the exclusion criteria. The second phase (reading the full text of the articles) was conducted on 72 articles, 14 of which were eliminated based on the exclusion criteria, leaving 58 articles to be analyzed in order to address the research questions.The final collection of analyzed articles is shown in Table 2.

4. Answering the research questions

4.1. RQ1: When and where the papers are being submitted?

To answer this question, the histogram presented in Figure 2 shows the number of articles published per year from 2000 to March of 2025 on the topic, according to the conducted literature review.

[1] *Preferred Reporting Items for Systematic reviews and Meta-Analyses*

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Citation	Paper title
[Zhao et al., 2025]	A matheuristic solution for efficient scheduling in dynamic truck–drone collaboration
[Peng et al., 2025]	Transportation and carbon emissions costs minimization for time-dependent vehicle routing problem with drones
[Lichau et al., 2025]	A branch-cut-and-price approach for the two-echelon vehicle routing problem with drones
[Bogyrbayeva et al., 2025]	Reinforcement Learning for Efficient Drone-Assisted Vehicle Routing
[Ramadhan et al., 2025]	The truck traveling salesman problem with drone and boat for humanitarian relief distribution in flood disaster: Mathematical model and solution methods
[Wang et al., 2025]	Truck–drone routing problem with stochastic demand
[Imran and Won, 2024]	SmartPathfinder: Pushing the Limits of Heuristic Solutions for Vehicle Routing Problem with Drones Using Reinforcement Learning
[Mahmoudinazlou and Kwon, 2024]	A hybrid genetic algorithm with type-aware chromosomes for Traveling Salesman Problems with Drone
[Stodola and Kutěj, 2024]	Multi-Depot Vehicle Routing Problem with Drones: Mathematical formulation, solution algorithm and experiments
[Hue et al., 2024]	The Vehicle Routing Problem with Drones and Flexibility Demands
[Ren et al., 2024a]	Time-dependent hydrogen fuel cell vehicle routing problem with drones and variable drone speeds
[Ren et al., 2024b]	A competitive heuristic algorithm for vehicle routing problems with drones
[Shi et al., 2024]	Optimal decision-making of post-disaster emergency material scheduling based on helicopter–truck–drone collaboration
[Zhu et al., 2024]	Plug-In Hybrid Electric Vehicle Traveling-Salesman Problem with Drone
[Yılmaz et al., 2024]	A new evolutionary optimization algorithm with hybrid guidance mechanism for truck-multi drone delivery system
[Zhai et al., 2024]	A Collaborative Drone-Truck Delivery System With Memetic Computing Optimization
[Boccia et al., 2024a]	New features for customer classification in the flying sidekick traveling salesman problem
[Hokama et al., 2024]	A faster heuristic for the traveling salesman problem with drone
[Blufstein et al., 2024]	Decremental State-Space Relaxations for the Basic Traveling Salesman Problem with a Drone
[Boccia et al., 2024b]	Exact and heuristic approaches for the Truck–Drone Team Logistics Problem
[Cui et al., 2024]	Dynamic collaborative truck-drone delivery with en-route synchronization and random requests
[Meng et al., 2024]	The multi-visit drone-assisted pickup and delivery problem with time windows
[Wang et al., 2023]	A Two-Stage Stochastic Model for Drone Delivery System with Uncertainty in Customer Demands
[Das et al., 2024]	Parcel Delivery Using Drones in the Presence of Obstacles
[Ren et al., 2023]	The time-dependent electric vehicle routing problem with drone and synchronized mobile battery swapping
[Moeini et al., 2023]	A Bi-objective Routing Problem with Trucks and Drones: Minimizing Mission Time and Energy Consumption
[Imran et al., 2023]	A-VRPD: Automating Drone-Based Last-Mile Delivery Using Self-Driving Cars
[Kloster et al., 2023]	The multiple traveling salesman problem in presence of drone- and robot-supported packet stations
[Yu et al., 2023]	Solving the Flying Sidekick Traveling Salesman Problem by a Simulated Annealing Heuristic
[Gunay-Sezer et al., 2023]	A Hybrid Metaheuristic Solution Method to Traveling Salesman Problem with Drone
[Nishira et al., 2023]	An Integer Programming Based Approach to Delivery Drone Routing under Load-Dependent Flight Speed
[El-Adle et al., 2023]	A variable neighborhood search for parcel delivery by vehicle with drone cycles
[Yanpirat et al., 2023]	Sustainable last mile parcel delivery and return service using drones
[Mara et al., 2023]	Electric Vehicle-Drone Routing Problem with Optional Drone Availability
[Qu et al., 2023]	A hybrid algorithm for drone routing problem with time windows
[Meng et al., 2023]	The multi-visit drone routing problem for pickup and delivery services
[Kyriakakis et al., 2023]	A GRASP/VND algorithm for the energy minimizing drone routing problem with pickups and deliveries
[Tao et al., 2022]	An Adaptive Large Neighborhood Search Algorithm for Wind Farm Inspection Using a Truck with a Drone
[Masmoudi et al., 2022]	Vehicle routing problems with drones equipped with multi-package payload compartments
[Gu et al., 2022]	A hierarchical solution evaluation method and a hybrid algorithm for the vehicle routing problem with drones and multiple visits
[Mara et al., 2022]	An adaptive large neighborhood search heuristic for the flying sidekick traveling salesman problem with multiple drops
[Liu et al., 2022]	The flying sidekick traveling salesman problem with stochastic travel time: A reinforcement learning approach
[Sundar et al., 2022]	A branch-and-price algorithm for a team orienteering problem with fixed-wing drones
[Luo et al., 2021]	Hybrid multi-objective optimization approach with Pareto local search for collaborative truck-drone routing problems considering flexible time windows
[Wen and Wu, 2022]	Heterogeneous multi-drone routing problem for parcel delivery
[Betti Sorbelli et al., 2022]	Greedy algorithms for scheduling package delivery with multiple drones
[Dell'Amico et al., 2021]	Algorithms based on branch and bound for the flying sidekick traveling salesman problem
[Boccia et al., 2021]	A column-and-row generation approach for the flying sidekick travelling salesman problem
[Chen and Lei, 2021]	A hybrid immune algorithm for the min-cost flying sidekick traveling salesman problem
[Dinh et al., 2021]	Ants can solve the parallel drone scheduling traveling salesman problem
[Nguyen et al., 2020]	A Monte Carlo tree search for traveling salesman problem with drone
[Schermer et al., 2020]	A branch-and-cut approach and alternative formulations for the traveling salesman problem with drone
[Cheng et al., 2020]	Drone routing with energy function: Formulation and exact algorithm
[Schermer et al., 2019]	A matheuristic for the vehicle routing problem with drones and its variants
[De Freitas and Penna, 2018]	A Randomized Variable Neighborhood Descent Heuristic to Solve the Flying Sidekick Traveling Salesman Problem
[Suteris et al., 2018]	Route schedule optimization method of unmanned aerial vehicle implementation for maritime surveillance in monitoring trawler activities in Kuala Kedah, Malaysia
[Yurek and Ozmutlu, 2018]	A decomposition-based iterative optimization algorithm for traveling salesman problem with drone
[Marinelli et al., 2018]	En route truck-drone parcel delivery for optimal vehicle routing strategies

Table 2: The final list of articles obtained from the systematic literature review conducted.

The histogram indicates that algorithms for solving routing problems with drones represent an emerging field of study, with a consistent increase of the number of publications from 2019 to 2024. No papers in this topic were identified before 2018, highlighting the relatively recent and growing interest in the literature. Moreover, decreases in the number of publications are observed from 2018 to 2019 and from 2024 to 2025. However, in the latter, only the first third of 2025 has elapsed.

Table 3 shows the frequency distribution (in percentage) of articles listed in Table 2, categorized by publication source (conference or scientific journal). The highest percentage of publications belongs to *Transportation Research Part C: Emerging Technologies* with 12.07% of the publications. The second most recurrent source identified is *European Journal of Operational Re-*

DOI: 10.59254/sbpo-2025-212493
https://proceedings.science/p/212493?lang=pt-br

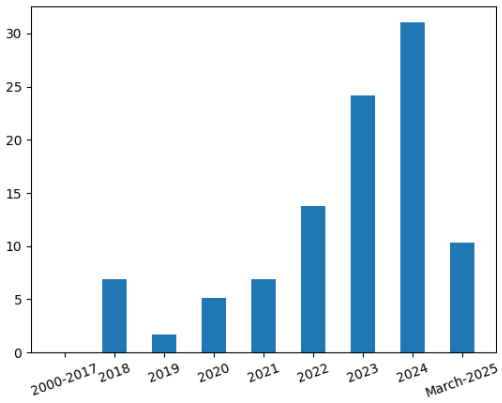


Figure 2: Frequency of papers publications in time.

search with 10.34%, followed by *Expert Systems with Applications*, with 8.62% and the others, with the distribution as presented in Table 3. The *Winter Simulation Conference* is the scientific event most frequent chosen as a publication vehicle, accounting for 3.45% of the papers.

JOURNAL	**Freq. (%)**	**JOURNAL**	**Freq. (%)**
Transportation Research Part C: Emerging Technologies	12.07	International Journal of Supply Chain Management	1.72
European Journal of Operational Research	10.34	Optimization Letters	1.72
Expert Systems with Applications	8.62	Networks	1.72
Transportation Research Part E: Logistics and Transportation Review	6.90	Engineering Applications of Artificial Intelligence	1.72
Computers and Operations Research	5.17	Drones	1.72
IEEE Transactions on Intelligent Transportation Systems	3.45	IEEE Transactions on Systems, Man, and Cybernetics: Systems	1.72
Computers Industrial Engineering	3.45	IET Intelligent Transport Systems	1.72
Omega	3.45	Systems	1.72
EURO Journal on Transportation and Logistics	1.72	Transportation Research Record	1.72
Advanced Engineering Informatics	1.72	Electronic Notes in Discrete Mathematics	1.72
Applied Sciences	1.72	Mathematics	1.72
Asian Transport Studies	1.72	INFORMS Journal on Computing	1.72
CONFERENCE	**Freq. (%)**	**CONFERENCE**	**Freq. (%)**
Winter Simulation Conference	3.45	Genetic and Evolutionary Computation Conference	1.72
International International Conference on Contemporary Computing	1.72	International Conference on Computational Science and Its Applications	1.72
IEEE International Conference on Intelligent Transportation Systems	1.72	IEEE International Conference on Networking, Sensing and Control	1.72
China Automation Congress	1.72	Congress on Evolutionary Computation	1.72
International Conference on Distributed Computing and Networking	1.72	IEEE International Conference on Intelligent Robots and Systems	1.72

Table 3: Publication sources of the papers.

4.2. RQ2: What are the most commonly studied variants of routing problems involving drones?

To address this question, we adopted a strategy of analyzing the underlying problem involving the drone, as indicated by its name. For instance, in the case of Drone Routing Problem with Time Windows (DRPTW), we focused on the most comprehensive problem, namely the Drone Routing Problem. Similarly, in Vehicle Routing Problem with Drone and Multiple Visits (VRPD-MV), we considered the Vehicle Routing Problem with Drone as the main problem.

Figure 3 presents a pie chart illustrating the most recurrent core routing problems involving drones. The Vehicle Routing Problem with Drone (VRPD) and Traveling Salesman Problem with Drone (TSP-D) emerged as the most prevalent, each accounting for 26.23% of the occurrences reported in the literature. The third most recurrent core problem is the Flying Sidekick Traveling Salesman Problem (FSTSP) adressed in 19.67% of the papers, followed by Drone Routing Problem

DOI: 10.59254/sbpo-2025-212493
https://proceedings.science/p/212493?lang=pt-br

(DRP), with 6.56% and Truck-Drone Team Logistics (TDTL) and Drone Delivery Problem (DDP), both with 3.28%. The remaining 14.75% of the articles were classified under the "others" category, which includes publication venues with only one occurrence in the list of articles.

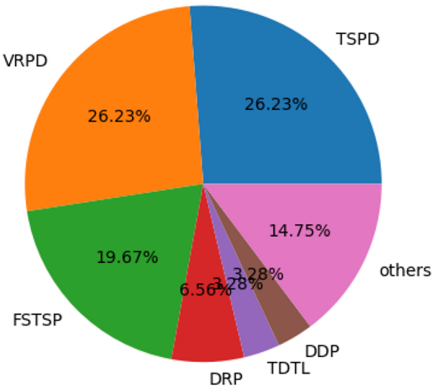


Figure 3: Frequency of the core routing problems with drones in literature.

For the second analysis, the complete variant was considered. For instance, the complete variant *Vehicle Routing Problem with Drone and Multiple Visits* would be accounted. However, for several papers, the major problems described before were also their complete problem of research. TSP-D, now, was the most studied variant, being the topic of 19.67% of the papers. The second variant was the FSTSP, present in 14.75% of the papers, and the third the VRPD, present in 9.84% of the papers. Specific and incremental variants were not common between different papers and many papers were proposing new variants. The three most adressed problems in the articles are briefly described in subsequent topics.

4.2.1. Traveling Salesman Problem with Drone (TSP-D)

A variant called Traveling Salesman Problem with Drone was proposed in 2016 and published in 2018 [Agatz et al., 2018]. In brief, this problem seeks to serve a set of clients using either a truck or a drone while minimizing the total tour length.

[Agatz et al., 2018] establishes four assumptions for the TSP-D: (a) the drone has a unit capacity and has to return to the truck after each delivery; (b) The pickup of orders from the truck can only occurs at customer locations, that is, the drone can only land on and depart from the truck when it is parked at a customer location or the depot; (c) The pickup and delivery of orders by both vehicles can be neglected; and (d) The recharging time of the drone can be neglected, e.g. by swapping batteries.

4.2.2. Flying sidekick Traveling Salesman Problem (FSTSP)

The Flying Sidekick Traveling Salesman Problem (FSTSP) was published in 2015 [Murray and Chu, 2015]. In brief, the problem involves a set of clients that must be served by both a truck and a drone, with the objective of minimizing the latest time at which either the truck or the drone (UAV) returns to the depot. Additional variables are considered, such as launch and recovery time, which are not accounted for in the TSP-D. In contrast to the TSP-D, where launching and returning to the same location is allowed, this is prohibited in the FSTSP. A complete proposal model can be found in [Murray and Chu, 2015].

4.2.3. Vehicle Routing Problem with Drones (VRPD)

The Vehicle Routing Problem with Drones variant was published in 2019 [Wang and Sheu, 2019]. Briefly, the VRPD is an extension of the Capacitated Vehicle Routing Problem (CVRP), that

DOI: 10.59254/sbpo-2025-212493
https://proceedings.science/p/212493?lang=pt-br

considers the addition of drones. In this variant, the drone can travel with a truck, take off to serve the customer, land at a service hub, and travel with another truck as long as the flying range and loading capacity limitations are satisfied. Initially, a set of trucks and a set of drones are located at the depot and docking hub nodes, ready to serve customers. The problem seeks to minimize the logistics cost of the fixed cost of employing trucks and the transportation costs of trucks and drones. The model's complete definition can be found in the proposal paper [Wang and Sheu, 2019].

4.3. RQ3: What are the most used benchmarks?

Table 4 depicts the benchmarks mentioned in at least three different papers of the review list, ordered from most to least used. The table columns present the adressed problem variant, the title and citation of the paper that proposes and/or utilizes the instances set and the link to access then, if available in the time of access. A TSP-D variant called min-cost TSP-D, which is an extension of the FSTSP described at [Ha et al., 2018], is included in the table.

Variant	Publishing paper	Disponible at
TSP-D	Optimization approaches for the traveling salesman problem with drone [Agatz et al., 2018]	*https://doi.org/10.5281/zenodo.1204676*
FSTSP	The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery [Murray and Chu, 2015]	*www.or.unimore.it/site/home/online-resources/exact-models-for-the-fstsp/documento1090067462.html*
min-cost TSP-D	On the min-cost traveling salesman problem with drone [Ha et al., 2018]	*link not avaiable anymore*
VRPD	An adaptive large neighborhood search metaheuristic for the vehicle routing problem with drones [Sacramento et al., 2019]	*https://doi.org/10.5281/zenodo.2572764*

Table 4: Four most used benchmarks for routing problems with drones.

4.4. RQ4: Which solution methods are the most commonly used?

Figure 4 presents a pie chart showing the distribution of solution methods for the problems identified in the list of reviewed papers, categorized into exact methods, metaheuristics, and other solution approaches. A paper may present multiple solution methods, and each of these was counted accordingly. Metaheuristics is the prevailing class of solution methods identified in the analyzed papers. Among them, the Genetic Algorithm was the most commonly used, appearing in 9.09% of the papers, followed by Simulated Annealing (7,58%), VNS (7.58%), ALNS (6.06%), and VND (6.06%), among others with fewer ocorrences. For exact methods, branch-and-cut was the most frequent employed (6.06%). Considering other solution methods, greedy heuristics were the most frequent employed (10.61%) followed by reinforcement learning, mentioned in 6.06% of the papers, Monte Carlo Tree Search (1.52%) and other less frequently used methods.

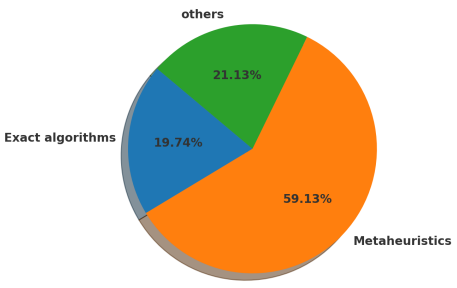


Figure 4: Classification of the solution methods in the literature.

DOI: 10.59254/sbpo-2025-212493
https://proceedings.science/p/212493?lang=pt-br

5. Conclusions

This paper presented the results obtained from a systematic literature review to analyze the state-of-art for routing problems with drones. Algorithms to solve this type of optimization problem have seen significant growth in recent years. Big tech companies, such as Amazon, Google, and DHL are increasingly investing in drone technology for deliveries, further driving the advancement in this field of study. The diversity of solutions proposed for the problem variants demonstrate improvements in delivery processes by incorporating drones into traditional operations, as seen in the TSP-D, which reduces total delivery times, and in the VRPD, which lowers logistics costs by utilizing fewer trucks. Future research could explore advancements in drone applications for routing problems, which are actively studied in the literature (see Table 2). While algorithmic improvements for existing routing problems formulations are under investigation, new problem variants are also emerging, offering new opportunities to integrate drones into routing solutions. The industry's growing interest in drone-assisted delivery systems, presents a promising direction for further researches.

Agradecimentos: O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior –Brasil (CAPES) – Código de Financiamento 001, do Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) processo (PQ 2021 315059/2021-4) e da Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) processo (JCNE 2021 E-26/201.451/2022).

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