A CONCEPTUAL MODEL TO THE USE OF INTELLIGENT COOPERATIVE TRUCK AND DRONE LOGISTIC OPERATION

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ABSTRACT

Drones, also known as Unmanned Aerial Vehicle (UAV), has been considered the future of air transport for applications in the context of logistic operations. They can be used with trucks in an operation that leverage the advantages and disadvantages of each other, a problem known as Routing Problem with Drones (RP-D) in an operational research perspective. Recently, solution methods have been proposed to RP-D, but there is a valuable opportunity to develop a structured methodology in this field. This paper proposes a conceptual model from an analytical comparison of state-of-art metaheuristics, according to a sweep literature review. This conceptual model proposed consider the exact solution in small instances because can guarantee optimal solution and metaheuristic approach in not small instances, because can bring good solution in a reasonable time. This methodology is not meant to be complete but can be used to decide the best approach according to the size of the instance and can be enhanced by other recent methods as hybridization and artificial intelligence approaches.

Keywords: routing, drones, vehicle, methodology, metaheuristic.

1. INTRODUCTION

The term 'drones', a pilotless aircraft will be adopted to this study because many authors studied use this term but can be referred as Unmanned Aircraft Vehicle (UAV), unmanned aircraft system (UAS), remotely pilot vehicle (RPV), remoted pilot aircraft (RPA), and many others. It can be considered the future of air transportation for several applications in logistic industry and is predicted the potential market value for drone technology business service to reach several billions of dollars. Its advantages from a traditional vehicle can be described as the constant and high travelling speed, no need for physical road infrastructure, no exposure to traffic and congestion, and the directness of travel (Otto et al., 2018; Rojas Viloria et al., 2020; Moshref-Javadi et al., 2021). In this sense, Chung, Sah and Lee (2020) describe the complementary of truck and drone in speed, weight, capacity, range, and energy consumption in Figure 1.

Mode	Speed	Weight	Capacity	Range	Energy Consumption
Drone	High	Light	One	Short	Low
Truck	Low	Heavy	Many	Long	High

Figure 1 - Truck and Drone Complementary. Source: Chung, Sah and Lee (2020)

In the context of ongoing urbanization, rapid growth in direct e-commerce delivery, increasing and congestion level, these UAV-based benefits are mainly pronounced in urban areas, reducing delivery time, and increasing the responsiveness of logistics system. Many prominent industry players already noticed these benefits, as an example, Amazon, Google Wing, United Parcel Service (UPS), and Rakuten, which have been developing and testing drone delivery models, and recently started regular commercial drone deliveries, case of UPS (Moshref-Javadi et al., 2021).

This innovative solution in logistics impacts economic and environmental aspects and have gain interest among customers and logistic operators of truck-based drone delivery system. As such, the existent technology can be combined with new ones leading to new possible incremental innovation in delivery system, among which truck-drone delivery is promising (Baldisseri et al., 2022).

This hybrid truck-drone delivery system has applications in several vital applications such as: natural disaster with transportation network, to collect crucial information in emergency mission situation; emergency aid, facilitating, making quick and flexible while reducing the worker exposure to danger; first healthcare aid; intelligence, surveillance and reconnaissance (ISR) to visit a set of location; vaccines, water purification tablet and medicines transportation; delivery with the drones resupplying (Gonzalez-R et al., 2020).

So, this study aims to study recent articles that develop effective and efficient delivery application algorithms, as Elshaer and Awad (2020) pointed out metaheuristic methodology is widely recognized as efficient approach for many hard optimization problems, including VRP. In the way of improving modeling techniques and solutions, the interest is to analyze articles that use recent modeling techniques and propose a conceptual model that generalize this modeling techniques. For researchers, it will be giving an entry point into the topic, direction for future research and further reading. For practitioners, a guidance on some state-of-the-art literature and a conceptual model that can be used in truck and drone delivery intelligent system. Then, the main contribution can be summarized as follows:

- Review state-of-the-art article related to VRPD to address main steps in problem solving.
- Propose a conceptual model to implement solution of VRPD.

Even though, complex drone operation usually involves several tasks and has many barriers to be addressed that is out of scope of this article, such as:

- Military and Security Applications, because there is no sharp between military and civil applications and methods can be usually used in both contexts.
- Obstacle-avoiding path planning.
- Criteria to select the most suitable characteristic of drones.
- Cargo type and weight selection.
- Regulatory, environmental, economic influence.

The remainder of this paper is organized as follows: section 2 presents the theorical basis; section 3 defines the methodology used to address the problem; section 4 shows the results analysis; section 5 concludes with some directions for future research.

2. THEORETICAL BASIS

Drones and trucks have advantages and disadvantages, such as the truck restriction to the road network that can result is dispatching delay, while the drone limited weight, package, flight, and battery capacity. So, the effectiveness and efficiency of Drone Operation (DO) is better when drones are combined with trucks in a drone and truck combined operation (DTCO), because it can reduce the need of truck driver, can leverage the advantages and disadvantages of each other's, allow for the parallelization of different delivery operations, can reduce the total time required to serve all customers (Chung, Sah and Lee, 2020; Agatz, Bouman and Schmidt, 2018). In the Figure , there is an example of five customer locations to be served from the depot in which two parallelized drones are doing truck job by serving two customer locations, reducing the distance travelled by the truck and the total time required to serve all customers.

As can be seen in Figure , two customers are served by drones performing a dashed arrow (fly arc – a pair of ordered vertices performed by a drone flight) instead of truck (drive arc), leaving the truck to serve the other customers. This parallelization of different delivery tasks can reduce the total time to delivery logistics, but this phenomenon needs new models and innovative algorithms to exploit the best potential benefits from this innovative technology (Agatz, Bouman and Schmidt, 2018).

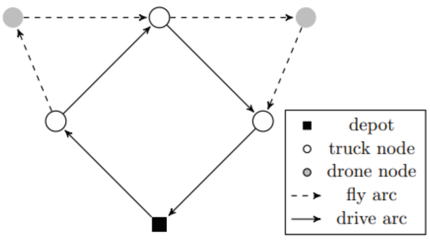

Figure 2 - Truck and Drone Routing Problem Example. Source: Agatz, Bouman and Schmidt (2018)

Although there are many advantages of using drones in cooperation with trucks, there is lots of challenges to DTCO, one of this is the NP-hard nature (class of algorithms in which where is no known polynomial-time algorithm to the problem) of Vehicle Routing Problem (VRP), according to, a class of routing problem whose objective is to determine a set of optimal routes performed by vehicles with limited capacity to serve a given set of customers (Wang and Sheu, 2019).

It is important to identify the variants of VRP, which Macrina et al. (2020) classify into classes target of Routing Problem with Drones (RP-D): 1. TSP-D (travelling salesman problem with drones), when just one truck and one or more drones perform the delivery; 1.1. Flying Sidekick Travelling Salesman Problem (FSTSP) when there is synchronization between truck and drone; 1.2. Parallel Drone Scheduling Travelling Salesman Problem (PDSTSP), when there is not synchronization between truck and drone; 2. VRPD (Vehicle Routing Problem with Drones), when many trucks and many drones perform the delivery, as can be seen in the Figure .

In addition to identify the problem, there is also a necessity of improving modeling techniques and solutions methodologies as addressed by Chung, Sah and Lee (2020), in which the small DTCO problems (up to 10 customers) may be solved by exact algorithm within a reasonable time, but for relatively larger problems exact algorithms may not work and can experience a curse of dimensionality.

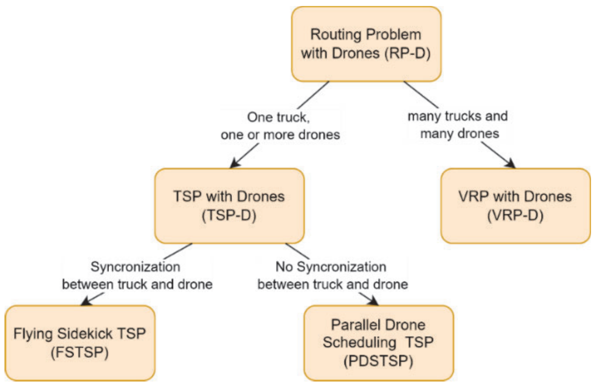

Figure 3 - Routing Problem with Drones. Source: Macrina et al. (2020).

Table 1 - Metaheuristic Techniques in Routing Problem. Source: Research Data.

Author	*Category*	*Approach*	*Topic*
Sacramento, Pisinger and Ropke (2019)	Single-Solution Based	ALNS – variant of LNS	An ALNS metaheuristic to to solve FSTSP, a variation of TSP-D
Huang et al. (2022)	Population-based	ACO	An ACO metaheuristic to VRP-D
Euchi and Sadok (2021)		GA	A GA metaheuristic to VRP-D

So as to define the main solution existents in the literature, Elshaer and Awad (2020), metaheuristic method to solve Vehicle Routing Problem into two categories: single-solution based, in which a single candidate is used to improve the solution and population-based, in which multiple candidates is used to improve the solution.

Then, it was selected to review in the next chapter one single-solution metaheuristic with high frequency of use in the literature and two population-based metaheuristics, because according to Elshaer and Awad (2020) they are one of the most frequently used in routing problems.

Adaptive Large Neighborhood Search (ALNS), the third most frequently used single-solution metaheuristics, have been studied by Sacramento, Pisinger and Ropke (2019) in a context of a variation of RP-D, which there is synchronization between one truck and drones, also known as Flying Sidekick Traveling Salesman Problem (FSTSP). In addition, observed that when the number of customers increases, it is difficult to exact methods used by CPLEX to solve in a reasonable time, as CPLEX spends 17h to solve 12.05.1 instance, while ALNS solved in a couple of seconds.

On the contrary, the study of Euchi and Sadok (2021) proposed the most frequently used population-based metaheuristic according to Elshaer and Awad (2020), the Genetic Algorithm (GA) have chosen an initial population and have varied this population conforming to a variation of sweep local search heuristic, also known as hybrid GAxSweepLS algorithm in a context of VRPD, reaching efficient solution quality and execution time compared to the methods proposed in the literature of up to 84% in some cases.

Other most frequently used population-based metaheuristic based on Elshaer and Awad (2020) is Ant Colony Algorithm (ACO), in which Huang et al. (2022) have applied the in the context of VRP-D, obtaining a cost-saving of over 30% for large instances of VRP and solutions 1% optimal for small instances. Then, the main studies discussed in result chapter can be summarized in Table 1.

In brief, there is several ways to do logistic operation with truck and drone, as there are many variants of Routing Problem with Drones. Each variant has their context in which the most appropriate solution method depends on the solution-time and solution-quality, as an example exact technique and metaheuristic technique. To address some state-of-the art solutions to identify a pattern to construct a conceptual model, a sweep literature review was made as can be seen in Table 1.

3. METHODS

There are four categories of solution methodologies, according to Chung, Sah and Lee (2020), the exact method, heuristics, continuous approximation, and metaheuristics. The first one is the classical and well implemented in commercial solvers as CPLEX and GUROBI, but not efficient method to solve large instances, because the VRP and TSP based problem are known to belong to NP-hard algorithm class, as an example of the solution time of CPLEX and GUROBI solver for 10 customers DTCO problem spending several hours to be solved.

Table 2 - Analytical Comparison

Author	Solution Technique	Context	Benchmarking Instances	Algorithm Parameter
Sacramento, Pisinger and Ropke (2019)	ALNS	VRPD	Benchmark 1	PT
Euchi and Sadok (2021)	GA	VRPD	Benchmark 2	PD
Huang et al. (2022)	ACO	VRPD	Benchmark 3	PD

ALNS: Adaptive Large Neighborhood Search

GA: Genetic Algorithm

ACO: Ant Colony Optimization

Benchmark 1: Random benchmark generated by the paper

Benchmark 2: Two groups of benchmarks: the first set correspond to instances of Benchmark 1 and the second set correspond to different scenarios of VRPD simulated by the paper

Benchmark 3: three sets of Feeder VRP (FVRP) with 50,100 and 200 customers, created by (Huang et al., 2022b)

VRP: Vehicle Routing Problem

VRPD: Vehicle Routing Problem with Drones

PT – parameter tuning experiment, documented in (Sacramento, 2017) and in (Ropke & Pisinger, 2006)

PD – The author declares the Parameter Setting of the algorithm but didn't declare if it was optimized by some tool.

The heuristic method can help to solve bigger instance but can be limited because needs to do assumptions, as can be showed in Murray and Chu (2015), which assumes drone-eligible customer nodes selected and removed from the truck route. The other method is continuous approximation, that replace the numerical method to analytical technique, show the data by a concise summary (Chung, Sah and Lee, 2020).

On the other hand, the present study focuses on metaheuristics, a high-level methodology to find a good solution that is proved to be effective for several DTCO problems with few or no assumptions. So, aims to study recent articles with high frequency of use metaheuristic methodologies, according to Elshaer and Awad (2020).

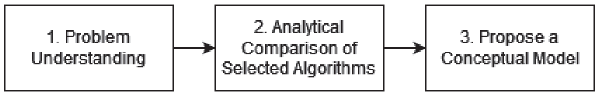

Figure 2 - Methodology used, adapted from Talbi (2009)

The analyze of implementations, algorithms parameter, pattern of solving VRP have been used to propose a conceptual model that has the purpose of generalize the methodologies studied. The methodology used is adapted from Talbi (2009), consisting in understand the problem, analyze the algorithms, and propose a conceptual model, as described in Figure 2.

4. RESULTS ANALYSIS

This section presents the conceptual model of state-of-the-art articles related to VRPD in a fluxogram with steps based on the these articles.

VRPD is a routing problem with a fleet of vehicles carries drones that leave for delivery and can be picked up by the those at the depot or one of the customer's locations objecting minimize the time required to serve all customers (Sacramento, Pisinger and Ropke, 2019). The techniques of problem-solving vary according to different strategies of exploration and exploitation. The ALNS is a single-based metaheuristic extension of the LNS algorithm that use the repair and destroy method with a weight adjusted dynamically during the search of solution. It was read other papers with different solution techniques to solve VRP problems, but they were discarded because weren't related of the VRPD problem of this study, as example the hybrid metaheuristic Tabu Search-Variable Neighborhood Descendent (Kyriakakis et al., 2022) and Greedy Random Adaptive Search Procedure (Bruglieri et al., 2022).

The Genetic Algorithm is a population-based metaheuristic with an initial set of solution (population) and, from the crossover, mutation, and selection operators, improve the solution until the defined number of interactions is reached. The Ant Colony Algorithm is also a population-based metaheuristic to solve hard combinatorial optimization problem, inspired by the foraging behavior of real ants, using a variable called pheromone and a function of updating pheromone as algorithm strategy to exploration and exploitation (Sacramento, Pisinger and Ropke, 2019; Euchi and Sadok, 2021; Huang et al., 2022)

To measure the metaheuristics, the benchmark used was based in datasets identified in the literature (Euchi and Sadok, 2021; Huang et al., 2022), and generated by the author (Sacramento, Pisinger and Ropke, 2019; Euchi and Sadok, 2021). Another step to analyze the performance is the parameter tuning, in which some studies just declared the value used in the algorithm (Euchi and Sadok, 2021; Huang et al., 2022), others declared there was a parameter tuning experiment (Sacramento, Pisinger and Ropke , 2019) that, in spite of not mentioned, this parameters can be tuned by tools as iRace (López-Ibáñez et al., 2016) and BNT (Chaves and Lorena, 2021).

From the analytical comparison in Table 2 and the theorical basis, it can be proposed a conceptual model of solution techniques. problems, defining the problem, selecting the instances, choosing the solution technique to solve the problem, parameter optimization to reaching good results, as in Figure 3.

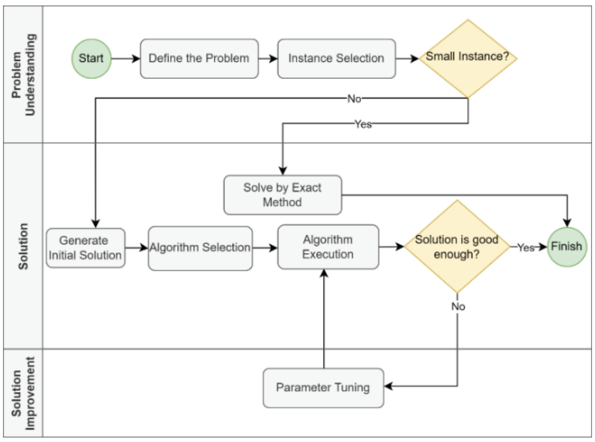

Figure 3 - Conceptual Model.
Source: Research data.

According to the Figure 3, the first phase is the problem understanding, defining the problem, choosing the instance according to the defined problem. The second phase is to select the more appropriate technique, if the instance is small, choose the exact method because there is not much computational effort. On contrary, the approximate method appropriate to find good solution is the metaheuristic, consisting in generate initial solution, select the better algorithm according to the problem defined. In the final phase, the solution can be improved by parameter tuning tool, to get better solutions.

To sum up, high-quality Vehicle Routing Problem with Drones was identified in the literature to construct the conceptual model of the Figure 3 following three phases: problem Understanding, defining the problem and selecting the instances; solution, selecting, executing the algorithm based on the problem understanding; solution Improvement, improving the solution using parameter tunning.

The study of (Talbi, 2009) was used as reference of some steps in the conceptual model to get a methodology and represent as the diagram in Figure 3. Other more recent study of (Osaba et al., 2021) propose a methodology to real world optimization problem giving recommendations and bad practices observed in the literature. Considering the theorical gap of improving modeling techniques and solution methodologies presented in the study of Chung, Sah and Lee (2020), this present paper can contribute to future research, which the conceptual model represented as a flow diagram presented in the Figure 3 can be extended with real world perceptions and others techniques as the combinations of hybrid metaheuristics, artificial intelligent techniques and others, giving a more generical methodology.

Restoring the drone issue of being used in a logistic context of delivery problem combined with ground vehicles, this structured methodology certainly will be helpful to be used in the future of logistic and air transport operation.

5. CONCLUSIONS

Therefore, drones have an innovative potential to be the future of air transportation complementing the capabilities of the already existing ground vehicle with drone main capabilities such as speed, no need to be in traffic congestion, low energy consumption.

This logistic operation is a research field with several applications, among which truck-drone delivery is an innovative promise technology that is expected to reach billions of dollars in the next years.

Some articles more recent and with the state-of-the art result was analyzed and identified key steps to construct a conceptual model that aims to generalize metaheuristic implementation of VRPD. In addition to the literature perspective, the practice perspective is to guide future researchers to a methodology of implementation of VRPD, not encountered in the literature.

In the future studies, the conceptual model can be enhanced by other steps, variables, and methods, such as artificial intelligence, simulation, hybrid metaheuristic towards a more general and complete conceptual model.

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