The probabilistic drone routing problem applied to large-scale disasters

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In the last years, several major industrial disasters happened around the world. One example is the collapse of a mining dam near Brumadinho in 2019, Brazil, where a tide of mud containing water and toxic mining residues rushed down 80 kilometers of valley and killed about 270 people. Several shortcomings were noted during the rescue operations. One of the most notable was the complexity to search for survivors and victims, as the accident prevented access by land vehicles to the affected area. This situation can also appear in industrial technological disasters in urban areas.

This study focuses on the use of drones to identify survivors and victims in an area impacted by a major industrial disaster. The idea is therefore to use a fleet of drones equipped with thermal and optical sensors to cover a large area as quickly as possible, with priority regions. We are considering flying drones since they are able to move faster, they do not depend on ground conditions, and they are able to scan larger ares at once.

Several works proposed path planning and drone routing problems for post-disaster management. The authors in [1] investigated an application of the drone path planning in disaster relief and solved it with a partially observable Markov decision process, where past information are used to define the next step. Only one individual drone was used, and drones' autonomy was not considered. The work [2] addressed a drone route problem that assessed the damage caused by an earthquake, and tested a Simulated Annealing over a case study in Sicily, Italy. The authors in [3] developed a mathematical formulation and two metaheuristics for a drone routing problem, which aims at monitoring a disaster-affected region. The study [4] used drones to check the state of route networks, where stochastic damage levels were considered. Works [5, 7] survey several problems associated with the operational planning of drones that were solved through optimization approaches.

The new scientific issues focused here lie on (i) the use of a drone fleet (instead of a single one) with collision avoidance for the identification of survivors, (ii) the autonomy management, (iii) the targets' prioritization and identification. We define and solve the Probabilistic Drone Routing Problem (PDRP), which aims at scanning an area after a major industrial disaster, searching for survivors, victims, animals, etc. The area is transformed into a grid where each cell is a node. In such a way, a connected simple grid graph $G = (N, E)$ is obtained, where the node-set N and the edge-set E represent respectively each map cell and the shortest-path connection between two cells in terms of time, assuming a constant speed. For each node $i \in N$, p_i and q_i^t denote, respectively, the probability of an individual identification in i and the total number of persons yet unidentified before a visit t. The value of q_i^t is estimated using a probabilistic function. Due to its autonomy, each drone has to return to its base to recharge its battery. Given a homogeneous fleet of drones, an autonomy rate, a set of recharging areas, a heatmap, and a probability distribution to identify targets, the PDRP consists in defining a multitrip for each drone, *i.e.* a sequence of routes starting and ending at its base. A node can be scanned several times according to the nodes' interest and area priority. The objective is to maximize the target identification.

Several constructive greedy heuristics using one of the following criteria are used to generate initial feasible solutions : (a) the largest expected number of targets, (b) the nearest neighbor, and (c) a ratio of both. Then, these solutions are improved by an Adaptive Large Neighborhood Search (ALNS) [6]. The local search in ALNS uses six removal and five insertion operators, respectively. For the former, four operators remove some nodes from routes, while the other two remove some scans from nodes. For the latter, three operators insert new nodes into a route and the other two add scans to some nodes belonging to a route. In addition, two shaking procedures are defined for ALNS. The first one randomly removes some trips and adds new ones. The second one rebuilds a route such that all scans at a node i are done sequentially, *i.e.* a drone never returns to i after leaving it. Only feasible solutions are considered in the ALNS, in terms of autonomy, collision and assignment to a base.

The preliminary computational experiments are done on an Intel Core i7-1165G7 with 2.80 GHz clock and 32 GB of RAM, running Ubuntu Linux 20.04 LTS. The constructive heuristics and ALNS are implemented in C++ and compiled with GNU g++ 9.3.0. The instance set contains 11 theoretical grid graphs with up to 100 nodes. Time horizons of 2h and 4h are considered. The instances contain up to 4 drone bases, located at the corner of the grid. The results show that the solutions returned by the best constructive greedy heuristic (CGH) and by the ALNS identify, on average, 83.60% and 86.90% of the targets, respectively, in the 4h time horizon. Furthermore, the average running times for CGH and ALNS are respectively 0.10 s and 65.61 s. We are now considering a realistic instance from the explosion in the port of Beirut, Lebanon, 2020.

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