A Heterogeneous Drone Model with Recharge and Drop-off Stations for Emergency Humanitarian Operations

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Abstract

In this paper, we formulate a drone routing optimization model for the delivery of multiple packages of light-weight relief items (e.g. vaccine, RTUF packages, etc.) to a certain number of remote locations within a disaster prone area. The proposed drone model focuses on the implementation of realistic features related to disaster situations and drone technology limitations. In particular, extra recharge and drop-off stations are implemented to extend the operating distance of the drone and reduce the distribution cost. Time windows and priorities rules are considered to account for the urgency of the situation in each demand location.

Keywords: Drone routing, Last-mile distribution, Humanitarian operations, Priority rules

1 Introduction

A rising number of natural and man-made disasters have hit several regions all over the world recently, causing thousands of victims [1]. Sudden and slow onset disasters of recent years indicate that mostly developing countries are vulnerable to natural catastrophes [2]. Urbanization, global population growth and land-shortage in developing countries increase the amount of people living in disaster-prone areas leading to even higher numbers of victims when disasters strike [3].

Humanitarian logistics in developing countries is characterized by insufficient information flow and a lack of investments in technology and communication. A massive lack of efficient coordination and collaboration between humanitarian stakeholders in various aid activities. Those impediments are intensified by the collapse of health facilities, the disruption of health systems and the breakdown of already on-going treatments in case of emergency. Contaminated water and poor sanitation conditions combined with low vaccination coverage often leads to water-, air- and vector borne diseases, e.g. cholera, dysentery, leptospirosis, hepatitis or malaria, as it was observed in the cholera epidemic in Mozambique in 2009 [4]. In addition to these conditions, aid agencies are often confronted with poor or inexistent infrastructure that is further disrupted in case of disasters, i.e. destroyed and blocked roads, collapsed bridges and debris-covered areas which hinder medical teams in reaching remote areas.

Consequently, last-mile distribution of relief items, e.g. ready-to-use therapeutic food (RTUF) - packages, purification tablets, vaccine, etc. into these regions, proves to be extremely difficult by means of traditional transport (off-road vehicles, trucks, etc.). Air cargo via helicopters is often also not applicable due to a lack of pilots as well as helicopters and land-based personnel in developing countries. Bringing such experts from outside to disaster locations is costly and often takes too long when time pressure to provide aid is extremely high. Consequently, practitioners on the ground are seeking for alternative means of transport that offer performance improvement in last-mile distribution [5].

Unmanned aerial vehicles (UAVs), or drones, are receiving increased attention from humanitarian organizations as they can support emergency operations along the entire disaster management cycle [6]. They can be autonomous or remotely operated. Drones are primarily used for emergency response mapping, cargo delivery and search and rescue missions during the preparedness and immediate response phases. In the context of last-mile distribution, they offer great potentials to overcome the problem of inaccessibility of remote locations for providing basic emergency items to beneficiaries.

The potentials and advantages of drone use in last mile distribution has recently turn into the focus of scientific attention, as models for optimal drone routing in mapping and cargo delivery have already been developed [7, 8]. Scott and Scott [9] review the current status of innovative drone delivery with a particular emphasis on healthcare. Dorling et al. [10] present two vehicle routing problems for drone delivery, taking into consideration the energy consumption by a multirotor helicopter in hover as a function of its battery weight and payload. The objective of the first optimization model is to minimize costs subject to a delivery time window and for the second it is to minimize the overall delivery time subject to a budget constraint.

In this paper, we formulate a drone routing optimization model for the delivery of multiple packages of light-weight relief items (e.g. vaccine, RTUF packages, etc.) to a certain number of remote locations within a disaster prone area. The proposed drone model focuses on the implementation of realistic features related to disaster situations and drone technology limitations and extends the discussion and the capabilities of the model in [5].

1.1 Model's assumpmtions

1.1.1 Heterogeneous fleet

In case of a disaster, NGOs try to intervene as quickly as possible using all available resources. We consider in our model the possibility to use various types of drones having different technological specifications and capabilities (payload, energy requirements, operating cost. . .) at the same time. The combination of drones with land based transport systems (possibly, with limited access to the disaster locations) is discussed.

1.1.2 Recharge stations

One of the major problems of the current drone technology is the limitation of the battery capacity which in turns limits the operating range of the drone. The maximum distance traveled by the drone is also function of its payload and flight conditions (weather, temperature,..). A fully loaded drone may not be able to reach remote locations. Therefore, intermediate recharge locations allow to extend the drone capabilities in terms of distance and to use its full capacity in terms of payload since returning to the base station for recharging will not be required. Such recharge locations can be installed in the preparedness phase within public infrastructure, e.g. schools, health centers, etc. and can be temporarily provided by NGOs via solar energy in case of total infrastructural breakdown. A discussion on how those recharge sites are implemented in practice is included. In particular, we discuss the implementation of fixed recharge stations, the use of mobile stations using SUVs and the choice of their positioning among candidate locations.

1.1.3 Drop-off locations

In the same context, the drone may be able to leave a part of its load in specific locations for energy saving purposes. The drone returns to the drop-off location to pick up those items and continue the distribution.

1.1.4 Time windows

Time is an important factor in disaster relief operations. Quick and targeted interventions may save lives. In case of epidemics, this may also help to stop or slow the spread of the disease. Hence, the model considers time windows in combination with the previously mentioned priority rules to fulfill the mission.

1.1.5 Priority rules

In a disaster situation, some locations must be treated with higher priority than others. An example of this situation is when a water-borne epidemics (say, cholera) follows the disaster. The outbreak locations must be supplied quickly with medicines, vaccines and water purification tablets while other locations connected to the affected area (e.g. downstream of watercourses) also require special attention. The remaining locations are served with lower priority.

Additionally to the main features discussed above, a discussion on partial recharge, partial delivery and asymmetric costs considering real life conditions is provided.

1.2 Results

The model is formulated as a mixed integer linear program (MILP) and solved using a commercial solver. Deriving from the criticality of fast emergency supply to remote locations, we set the objective of the model to minimize the total delivery time of relief items subject to service level. We conduct experiments using small and medium size examples to show how the specific features included in the model influence the optimal solution and the value of the objective function at optimality. In particular, it is shown how recharge and drop-off stations can extend the operating distance of the drone.

2 Conclusion

There is an increasing attention to the use of Unmanned Areal Vehicles in last-mile distribution in commercial as well as humanitarian settings. There are however numerous features that are specifically related to humanitarian operations in the response phase. In the event of a disaster, the existing infrastructure is disrupted and the use of terrestrial means of transport might not be possible. Additionally, there is a need for quick (time pressure) and targeted (priorities) intervention to save lives and limit the impact of the disaster.

By taking into consideration the particularities of humanitarian operations as well as the limitations of the current drone technology (battery capacity, payload limitation), we can develop realistic models and derive implementable solutions.

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