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# A drone fleet model for last-mile distribution in disaster relief operations

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ABSTRACT

Humanitarian assistance operates under conditions characterized by the collapse of health facilities, the disruption of health systems and the breakdown of already on-going treatments in case of emergency. In addition to these circumstances, aid agencies in developing countries are often confronted with poor or non-existent infrastructure that is further disrupted in case of disasters, i.e., destroyed roads and debris-covered areas which hinder medical teams in reaching remote locations. As the supply via trucks and helicopters is not applicable in this situation, alternative means of transport have to be considered. Unmanned aerial vehicles (UAVs) are receiving increased attention by humanitarian organizations as they can help overcoming last-mile distribution problems, i.e., inaccessibility to cut-off regions. This paper considers drone applications in last-mile distribution in humanitarian logistics and presents an optimization model for the delivery of multiple packages of light-weight relief items (e.g. vaccine, water purification tablets, etc.) via drones to a certain number of remote locations within a disaster prone area. The objective of the model is to minimize the total travelling distance (or time/cost) of the drone under payload and energy constraints while recharging stations are installed to allow the extension of the operating distance of the drone. The implementation of different priority policies is discussed. The model is solved as a mixed integer linear program and illustrated numerically with different scenarios.

## 1. Introduction

In recent years a rising number of natural and man-made disasters have hit several regions all over the world, causing thousands of victims and long-term damage to disaster-prone locations [5]. In order to maintain live-saving operations and to cover basic needs of the suffering population it is essential to plan, implement and control an efficient flow of relief goods and information into the affected areas [20]. Humanitarian logistics, as the technical term for this process, includes the procurement, transport and warehousing of relief goods from the point of origin to the beneficiaries' location.

A number of observed disasters in recent years such as the Haitian earthquake 2011, the tsunami in the Indian Ocean 2004, flooding in India in 2013 or the Horn of Africa crisis 2011, indicate that mostly developing countries are vulnerable to natural disasters [7]. There are hundreds of more crisis that do not attract as much attention but have equally devastating impact. 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 [9].

The impediments of humanitarian assistance in developing countries 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, such as diarrheal diseases, acute respiratory infections, malaria, leptospirosis, measles, dengue fever, viral hepatitis, typhoid fever, meningitis, as well as tetanus and cutaneous mucormycosis [22]. In such situations, quick response and rapid distribution of vital relief items, such as ready-to-use therapeutic food (RTUF) packages, water purification tablets, medical kits and vaccine into the affected regions could save lives and prevent or slow the spread of epidemics.

Massive problems and challenges of relief items distribution in developing countries are also associated to means of transport and transportation infrastructure. NGOs' vehicle resources in developing countries are quite limited and costly due to rising fuel consumption, maintenance and insurance. Development and emergency missions are generally conducted by aged truck fleets because of delayed vehicle replacement beyond the recommended time frame. An obsolete and poor conditioned vehicle fleet restricts loading capacities, thus leading to transport of light-weight items only. Land based motorized transport by humanitarian organizations is often limited to Sport utility vehicles (SUVs) and small trucks, because larger means of transport are not applicable under such conditions [1]. The major problem resulting from poor means of transport is the insufficient supply to rural areas because

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mid- and long distances cannot be overcome and product markets are not reachable for humanitarian organizations [18]. In addition to these conditions, aid agencies are often confronted with poor or inexistant infrastructure. Road surface quality in developing countries is further characterized by low percentages of paved roads and narrow road widths. Geographical characteristics, e.g. geographically dispersed islands or adverse terrain, represent additional impediments to the already challenging situation [17]. In the event of a disaster, the already poor conditions are further disrupted, as roads are flooded or blocked, small bridges are collapsed and land sections are covered with debris [15]. Under these conditions roads are impassable and many locations are completely unreachable by land based transportation means. Subsequently, last-mile distribution of relief items proves to be extremely difficult by means of traditional transport systems. Air cargo via helicopters is often also not applicable due to the lack of trained pilots as well as helicopters and land-based personnel in the disaster region. Bringing such human and material resources from outside to disaster locations is costly and often takes too much time when time pressure to provide aid is extremely high. Consequently, the call for developing alternative means of transport and the integration of innovative technologies in last-mile distribution is given. Practitioners as well as scientific communities state that there has to be more governmental support to design, develop and analyze methods, systems and innovations for potential applications in disaster response. Advanced technologies that are already in use within the commercial context have to be tested for their applicability in humanitarian logistics [26]. In this regard, unmanned aerial vehicles (UAVs), commonly referred to as drones, can provide solutions to the problems associated to current last-mile ground transportation. They seem to offer the potentials to save time and costs compared to traditional means of transport and make relief items supply to cut-off regions possible in the first place [31].

Drones are autonomous or teleoperated flying machines that do not require constant user control [12]. Drone applications have mainly been considered in the commercial supply chain context, focusing on the applications in cargo delivery, mapping, target covering and surveillance (see,e.g. [11,8,28,30,25]). In this respect, optimization models consider drones in combination with other means of transport. Numerous large companies, such as Amazon, DHL or Google [11,25] already show interest in drone applications for parcel delivery in urban areas.

Currently available cargo drones include fixed-wing, rotor and hybrid models, each of them with different specifications, capacities and drop-off systems. State of the art drones can deliver products with a maximum payload between 0.5 kg and 2.5 kg [14]. Conventional drones use batteries to operate their engines and need to be recharged after they run out of power. Recharging stations can be installed within existing infrastructure in advance to a disaster or can immediately be deployed in the response phase using mobile base stations, e.g. trucks or SUVs. This strategy has been tested by the Austrian Red Cross in cooperation with Land Rover in a project called “Hero”. Here, a Land Rover Discovery is used as a commando vehicle for drones, where take-off, landing and recharging during an ongoing operation is possible. Energy–aware drone routing problems are considered in [8,11,28] where the energy consumption of the drone is assumed to depend on one or more of the flight related parameters; payload, speed, distance and altitude. A drone routing model that integrates recharge stations in the context of surveillance is presented in [30].

Recently, the humanitarian community also became aware of the benefits of drone usage, as they can support emergency operations along the entire disaster management cycle, i.e. mitigation, preparedness, response and recovery stages [21]. Drones in humanitarian logistics can assist in emergency response mapping, damage assessment, cargo delivery and search and rescue (SAR) missions during the preparedness and immediate response phases [6]. Fire detection, imagery collection, monitoring and path planning also are among the most common drone applications to date (see, e.g. [16,23,10,3,8]). In the context of last-mile distribution, they offer great potentials to overcome the problem of inaccessibility to remote locations for providing basic emergency items to beneficiaries. In these situations drones offer the advantages to traverse heavy terrain, blocked streets, destroyed bridges

**Table 1**
Overview about scenario settings.

| Scenario | *M* (in packages) | *E* (in kJ) |
|---|---|---|
| 1 | 8 | 200 |
| 2 | 4 | 200 |
| 3 | 8 | 100 |
| 4 | 8 | 60 |

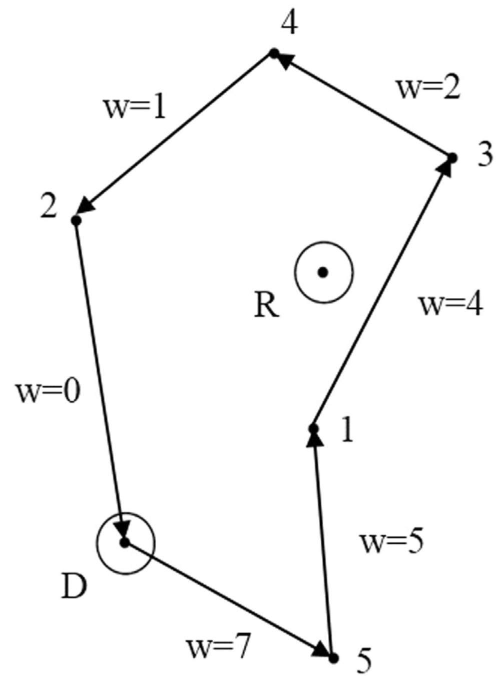


**Fig. 1.** Scenario 1.

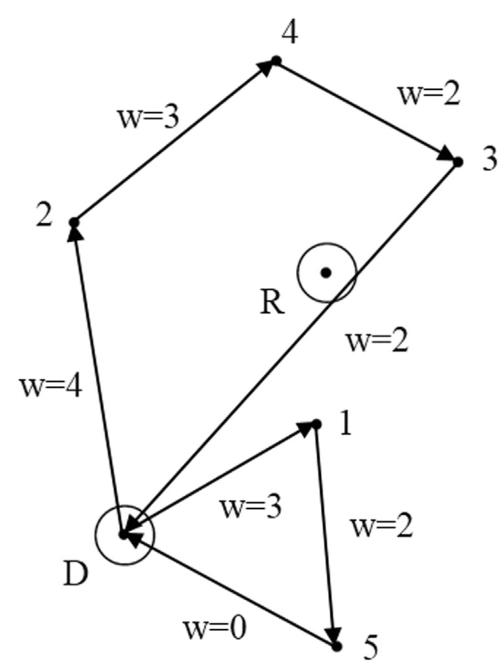


**Fig. 2.** Scenario 2.