Expert Systems With Applications 57 (2016) 104–116

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

A decision support system for coordinated disaster relief distribution

Christian Fikar*, Manfred Gronalt, Patrick Hirsch

Vienna, Institute of Production and Logistics, University of Natural Resources and Life Sciences, Feistmantelstraße 4, 1180 Vienna, Austria

ARTICLE INFO

Article history:
Received 4 January 2016
Revised 21 March 2016
Accepted 22 March 2016
Available online 24 March 2016

Keywords:
Humanitarian logistic
Unmanned aerial vehicle
Last-mile distribution
Decision support system
Coordination
Simulation optimization

ABSTRACT

This paper presents a simulation and optimization based decision-support system (DSS) to facilitate disaster relief coordination between private and relief organizations. The DSS simulates disasters and plans shipments of relief goods via transfer points to demand points in the affected area. This enables decision-makers to analyze the last-mile distribution of goods by scheduling and routing trucks, off-road as well as unmanned aerial vehicles. Roads which are closed or opened during a disaster are considered allowing a dynamic adaptation to real world conditions and a comprehensive analysis over a rolling time-horizon. A mixed-integer problem formulation, an agent-based simulation, a heuristic-based scheduling and routing procedure as well as a Tabu Search metaheuristic are applied to analyze the given decision problem. Coordination between private and relief organization shows to be especially beneficial if time-losses resulting from closed roads are high and substantial unexpected demand occurs. Furthermore, results highlight the importance of selecting suitable transfer points and the potential of simulation and optimization based DSSs to improve disaster relief distribution.

1. Introduction

Disaster relief operations are substantially impacted by the availability of transportation infrastructure (Berariu, Fikar, Gronalt, & Hirsch, 2015). Furthermore, demand for products during disaster are highly irregular and may fluctuate drastically (Xu, Qi, & Hua, 2010), which additionally challenges operations. During the Tohoku disaster of 2011 in Japan, a sudden demand in food and water occurred, particularly in areas which were not highly damaged (Holguín-Veras et al., 2014). While average household spending on non-perishable food increased significantly, especially households with high opportunity costs of shopping were not able to stockpile food to their desired levels (Naohito, Moriguchi, & Noriko, 2014). Multiple businesses sensed this opportunity; however, faced obstacles due to power-outages, lack of experience and limited staff availability (Holguín-Veras et al., 2014). As a consequence, Holguín-Veras et al. (2014) conclude, among others, a need for supporting systems and closer cooperation between private and public organizations.

Private organizations play vital roles in disaster response. During Hurricane Katrina in 2005, Wal-Mart, e.g., supplied the affected area before the Federal Emergency Management Agency (FEMA) arrived, leading to wide-ranging praise from the public sector (Horwitz, 2009). While private organizations have substantial amount of data and the logistical know-how to deal with disruptions in supply and demand, relief organizations have the equipment and regulative decision-making power needed to ship goods efficiently through damaged areas. One potential enabler for cost-efficient coordination are unmanned aerial vehicles (UAVs), commonly called drones. For instance, one commercial release promises less than half of the costs of manned aerial cargo distribution by transporting up to 2,700 kg at approximately 150 km/h remotely (Sauvageau, 2011). While doubt exists about the widespread applicability in humanitarian logistics, mostly due to legal, ethical, safety and privacy issues, UAVs are already tested in various areas and show promising results, especially for the delivery of medical supplies (OCHA, 2014).

Fig. 1 defines coordination as studied in this paper. Goods are delivered to relief organizations at a selected receiving transfer point. After transshipment, the relief organization delivers the goods to a second transfer point, bridging the affected area either with off-road vehicles or UAVs. At this transfer point, goods are transshipped and delivered to their final location. Multiple decisions have to be taken, precisely if a coordination should be performed, where to transship as well as routing and scheduling decisions of shipments, UAVs and off-road vehicles.

Decision support systems (DSS) for humanitarian logistics used in practice mainly focus on information management and often lack optimization tools (Ortuño et al., 2013). To close this gap, vehicle routes, the selection of transfer points and scheduling of

* Corresponding Author. Tel.: +43 1 47654 4413.
E-mail addresses: christian.fikar@boku.ac.at (C. Fikar), manfred.gronalt@boku.ac.at (M. Gronalt), patrick.hirsch@boku.ac.at (P. Hirsch).

http://dx.doi.org/10.1016/j.eswa.2016.03.039

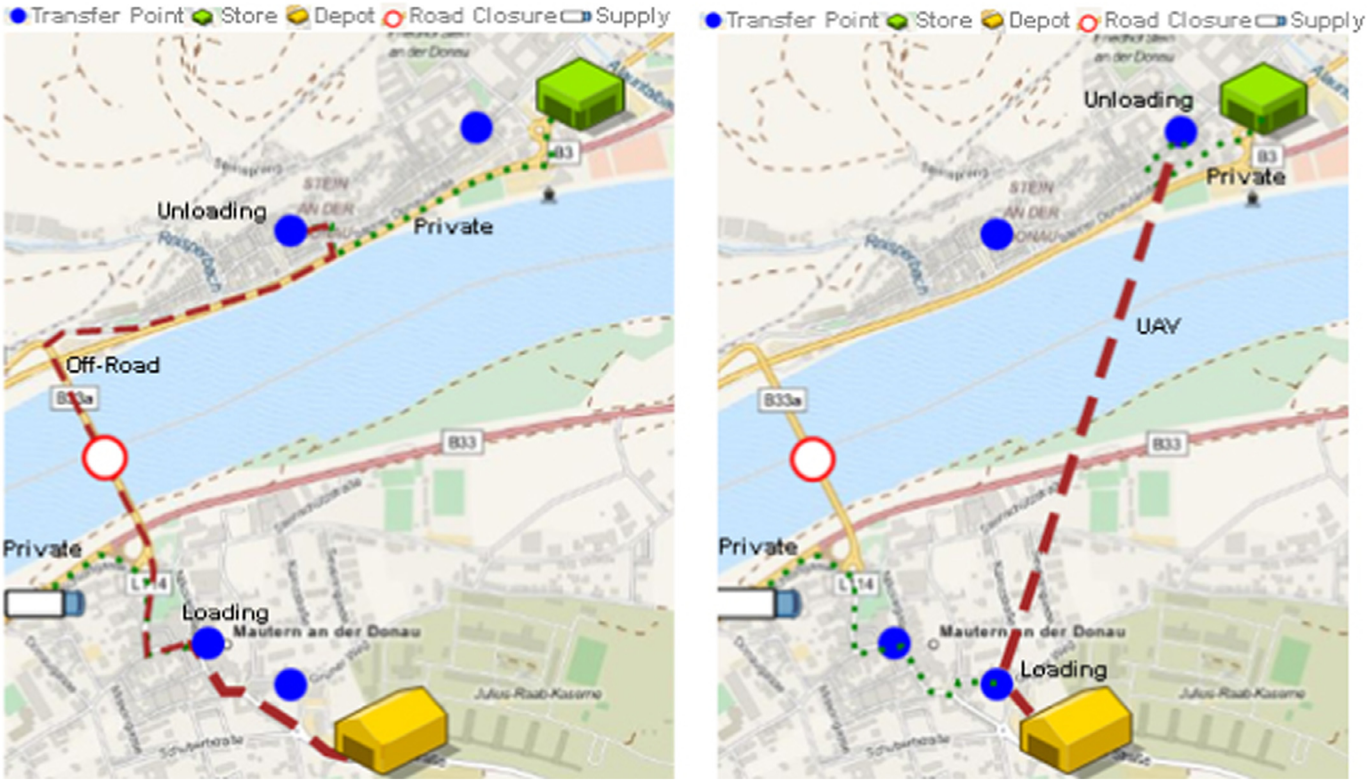

Fig. 1. Shipment coordination with off-road vehicles (left) and UAVs (right).

requests are optimized in our DSS. Therefore, the contribution of this paper is threefold: (i) it introduces a mixed-integer programming (MIP) model formulation to model coordinated disaster relief distribution, (ii) presents a simulation and optimization based DSS to solve and analyze the corresponding problem setting and (iii) discusses impact on disaster relief coordination. A preliminary description of the DSS and selected experiments were published in Fikar, Gronalt, Goellner, and Hirsch (2015).

The paper is structured as follows: Section 2 provides an overview of related work and Section 3 describes the problem and gives the corresponding mathematical formulation. The developed DSS is introduced in Section 4; computational experiments are presented and discussed in Section 5 and concluding remarks are made in Section 6.

2. Related work

DSSs are widely used in humanitarian logistics. For an overview on humanitarian logistics DSSs, refer to Ortuño et al. (2013). Van Hentenryck, Bent, and Coffrin (2010) study stochastic last-mile distribution during disasters by developing a three stage solution approach. Storage and customer allocation, repository routing as well as fleet routing are considered. Utilizing MIP, constraint programming and large neighborhood search techniques to analyze a set of different disaster scenarios, the authors report significant improvements on water allocation benchmarks. Emergency facility locations in Turkey under random network disruption are analyzed in Salman and Yücel (2015). A Tabu Search metaheuristic is proposed to place facilities in the pre-disaster stage. Whenever a direct route is damaged, i.e. a road, the cheapest alternative path is chosen. Network failures are further studied in Ahmadi, Seifi, and Tootooni (2015) by solving a two-stage stochastic program with multiple scenarios considering standard relief times. The authors report a significant reduction in costs and uncovered demand. Mitigation of network disruption is investigated by Snediker, Murray, and Matisziw (2008). A spatial DSS is introduced and results on a study of a telecommunications network are presented.

Özdamar and Ertem (2014) highlight two challenges of humanitarian logistics models; unacceptable computational time to solve large-scale problems and a lack of systems, which analyze disasters without being either too simple or too complex. To tackle these challenges, our paper implements an agent-based simulation and combines it with optimization procedures. Agent-based simulations are used for various stochastic problems. Within transport logistics, most of the related literature focuses on operational and single modal problems (Davidsson, Henesey, Ramstedt, Törnquist, & Wernstedt, 2005). In humanitarian logistics, agent-based simulations are, e.g., used to investigate evacuations (e.g. Wagner & Agrawal, 2014; Yin, Murray-Tuite, Ukkusuri, & Gladwin, 2014).

A wide range of work deals with the optimization of facility locations, which, from a given set of candidates, derives an optimal subset of facilities. For a survey on facility-location problems, refer to Verter (2011). To coordinate shipments in the problem studied in our paper, transfer points for coordination have to be selected, where, due to limited resources, only a subset can be in operation. In a survey on disaster relief routing, de la Torre, Dolinskaya, and Smilowitz (2012) note that few journal articles in this field exist, even though there is a high potential of optimization. Through interviews with representatives of relief organizations and the process of conducting an extensive literature review, the authors further conclude that the importance of multi-period stochastic models is that they enable practitioners to gain insights and to generate rules of thumb. The vehicle routing problem included in our DSS can be defined as an extension of the full truckload pickup and delivery problem. Gronalt, Hartl, and Reimann (2003) propose four savings based heuristics for the problem, which produce solutions of high quality within short computational times. In contrast to our optimization problem, no network disruption occurs and