A Quick Reaction Vehicle Routing Problem for Humanitarian Logistics

Oded Berman, Dmitry Krass, Alireza Rahimi-Vahed

A Quick Reaction Vehicle Routing Problem for Humanitarian Logistics

Oded Berman Dmitry Krass Alireza Rahimi-Vahed

Rotman School of Management

University of Toronto

Every year, more than 500 disasters are estimated to strike our planet, affecting millions of people, damaging infrastructure, and changing social and economic conditions. An efficient Humanitarian Logistics (HL) system is important to enhance the implementation of relief operations. While there are many facets to HL (see [1]), from pre-disaster resource and supply positioning to long-term post-disaster recovery planning, one important aspect is the most efficient use of the available resources to provide immediate relief following the occurrence of a disaster event.

The speed of the response is often of essence. While, in the aftermath of the disaster event, the location of the affected areas and the number of people residing in these areas is known, the actual state of affairs on the ground may not be known until the area is visited by the relief personnel. Moreover, the longer it takes to visit a particular location, the larger the potential cost, in terms of possible lives lost and/or property damage. This link between cost and time-to-response has been well documented in medical emergency literature (e.g., the "golden hour'' to treat trauma patients [2]). Not only is the condition of the affected people likely to worsen with the delay, the fear of the spread of disease and increasing property damage is present in events ranging from earthquakes to floods to large-scale power outages.

The need for quick response was well-illustrated in a Dec. 2013 "ice storm" in Ontario, Canada where a series of ice rain events led to large-scale collapse in the electrical system, leaving large areas of the city without power for long periods of time: about 300,000 people were affected at the height of the storm and it took more than 20 days to restore power to some areas [3]. This long-term outage had a number of consequences for the affected population, including loss of communications (as cell phones lost power), rapid loss of heat (due to rather extreme cold temperatures at the time), food spoilage, etc. People with limited mobility and the elderly were at particular risk. Moreover, the risk was clearly increasing with the length of time it took to restore power. Toronto Hydro (the local power company) deployed all available resource, supplemented with help from other jurisdictions, but the lack of coordination and communication breakdown plagues the recovery efforts [3]. One of the sources of uncertainty was the amount of time it would take to restore power to a certain neighborhood once the crews were dispatched there, as the damage and the required repairs could only be ascertained on-site.

Similar evidence can be found in the record of most other large-scale events: need to organize quick response with the available resources, rapidly growing costs (real or potential) as a result of response delays, and the need to visit affected sites before full determination of the amount of efforts required to provide relief could be made.

In this paper, we present a model aimed at delivering the needed resources to affected areas as quickly as possible; we call it the Quick Reaction Vehicle Routing Problem (QRVRP). The key features of QRVRP are as follows. We assume that a homogeneous fleet of finite-capacity vehicles stationed at a pre-determined depot (or a set of depots) is available. At time 0, we learn the locations of demand nodes and the number of customers (the demand) at each node. Each node is also characterized by a time-dependent failure probability function, representing the probability that a customer "dies" (or suffers serious damage) if the first response arrives at time t. The expected on-scene times for each node are also known. The objective is to develop a routing plan that maximizes the expected number of "saved" customers, under the constraints on the number and capacity of the available vehicles.

This problem differs in several key respects from the well-studied Vehicle Routing Problem (VRP), which is typically aimed at designing a routing plan for effective long-term operations. Thus, the typical objectives of VRPs are to minimize the total distance traveled by the vehicle fleet, or the total transportation costs and the number of vehicles required ([4]) – aspects that are not very relevant to post-disaster relief settings described earlier. We note that there is some literature on the pre-positioning and transportation of supplies for disaster relief (see e.g., [6]-[10]). Most of these focus on uncertainties related to pre-disaster decisions on supply and depot positioning and, with the exception of [10], ignore the vehicle routing aspects. None of these papers consider the time-varying failure probabilities.

The complexity of the QRVRP is strongly related to the behavior of failure probabilities over time. In this paper, we study two different failure patterns, "regular" and "fast". In the case of the regular pattern, we suppose that the probabilities increase (approximately) linearly over time, while in the fast pattern, they are assumed to grow exponentially. For each case, we explore the special structure of QRVRP to develop mathematical programming formulations, upper bounds and heuristic techniques. Table 1 summarizes the main characteristics of each pattern. In this table, the first two columns display the pattern name and probabilities' growing speed, respectively. Column 3 shows the mathematical programming model to which the QRVRP can be converted in each case. Finally, Column 4 presents the bounding techniques that we use, in each pattern, to generate tight upper bounds.

To analyze the efficiency of the proposed algorithms, various test problems are solved and the obtained results are compared and analyzed to the ones provided by CPLEX and the proposed upper bounds. Extensive computational experiments show that (a) ignoring the time-related failure pattern (e.g., by using standard VRP techniques) can result in large departures from optimality and (b) that the heuristics perform quite well, in terms of solution quality and computational time. We also discuss several extensions and important open problems.

Pattern	**Growing speed**	**Mathematical programming model**	**Bounding technique**
Smooth	Fast linear	*K*-Travelling Repairmen Problem (*K*-TRP)	Capacitated Minimum Spanning Tree (CMST)
	Slow linear	Multiple Knapsack Problem (MKP)	Surrogate and Lagrangian Relaxations
Fast	Exponential	Piecewise Linear Approximation (PLA)	Capacitated Minimum Spanning Tree (CMST)

References

[1] M. Çelik, O. Ergun, B. Johnson, P. Keskinocak, A. Lorca, P. Pekgun, J. Swann, Humanitarian Logistics, Tutorials in Operations Research (2012) 18-49.

[2] "Atls, Advanced Trauma Life Support Program for Doctors", American College of Surgeons (2008).

[3] "Catastrophic Ice Storm Blankets GTA", CP24, http://www.cp24.com/weather/catastrophic-ice-storm-blankets-gta-1.1604254.

[4] "Ice storm aftermath: Four ways Toronto is vulnerable when freak weather hits", Toronto Star (Jan 10, 2014).

[5] P. Toth, D. Vigo, The vehicle routing problem, 2002.
[6] G. Barbarosoglu, Y. Arda, A two-stage stochastic programming framework for transportation planning in disaster response, Journal of the Operational Research Society 55 (2004) 43-53.
[7] J. Zhu, K. Huang, D. Liu, J. Han, Resources Allocation Problem for Local Reserve Depots in Disaster Management Based on Scenario Analysis, in: The 7th International Symposium on Operations Research and its Application. Lijiang, China, 2008, pp. 395-407.
[8] H. O. Mete, Z. B. Zabinsky, Stochastic optimization of medical supply location and distribution in disaster management, International Journal of Production Economics 126 (2010) 76-84.
[9] J. Salmeron, A. Apte, Stochastic optimization for natural disaster asset prepositioning, Production and Operations Management 19 (2010) 561-574.
[10] Z. Shen, M. Dessouky, F. Ordóñez, A two-stage vehicle routing model for large-scale “bioterrorism ˝ emergencies, Networks 54 (2009) 255-269.