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A hierarchical clustering and routing procedure for large scale disaster relief logistics planning

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ABSTRACT

We describe a hierarchical cluster and route procedure (HOGCR) for coordinating vehicle routing in large-scale post-disaster distribution and evacuation activities. The HOGCR is a multi-level clustering algorithm that groups demand nodes into smaller clusters at each planning level, enabling the optimal solution of cluster routing problems. The routing problems are represented as capacitated network flow models that are solved optimally and independently by CPLEX on a parallel computing platform. The HOGCR preserves the consistency among parent and child cluster solutions obtained at consecutive levels. We assess the performance of the algorithm by using large scale scenarios and find satisfactory results.

1. Introduction

Disaster relief logistical planning is crucial for the effectiveness and speed of response in aid distribution programs, such as health, food, shelter, water and sanitation. In disaster response logistics, distribution of relief materials and evacuation of injured persons are two major activities. The evacuation of the injured takes place primarily during the initial response phase, whereas the distribution of relief materials tends to continue for a longer time.

Beamon and Balcik (2008) define the objective of the disaster relief supply chain as "to provide humanitarian assistance in the forms of food, water, medicine, shelter, and supplies to areas affected by large scale emergencies". Tomasini and Van Wassenhove (2009) point out the differences between commercial and humanitarian supply chains and state that the ultimate effective humanitarian supply chain management has to be able to respond to multiple interventions as quickly as possible and within a short time frame.

In this study, we focus on the last stage of the relief supply chain, in particular, "the last mile distribution problem" that arises in disaster response. Based on the logistics module of the UNDP's Disaster Management Training Programme, Balcik et al. (2008) define the last mile distribution problem as "the last stage of humanitarian operations that involves delivery from local distribution centers (tertiary hub) or from central warehouses (secondary hub) to a population in need (beneficiaries)".

Here, we extend the above definition to include both delivery and pickup functions, and call it "the last mile delivery and pickup problem", where the last mile delivery is concerned with materials transported from warehouses to affected locations and the last mile pickup is concerned with the evacuation of injured people from affected areas to hospitals.

In a post-disaster situation, the Disaster Coordination Center (DCC) conducts air surveys over affected areas and information starts to flow from districts using other channels as well. Hence, the DCC has very rough estimates of the quantities of

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aid materials to be delivered to survivors in various areas. Similar estimates are made for the rising number of urgent evacuations while access to the region is enabled. Here, it is assumed that the operational logistics plans are made based on such estimates. These plans are updated as more precise information reaches the DCC. It is also noted that during post-disaster relief activities, requests on transportation capacity often surpass the available capacity significantly and vehicles depart from and arrive to warehouses/hospitals with full load. Therefore, it is not quite possible to modify the courses of vehicles en route whenever new information arrives. Usually, new requests are assigned to vehicles that are about to complete their tours. The latter approach reduces the nervousness of the logistics plans that might be caused by the rough estimates of parameters that the DCC puts into the plans.

An efficient network flow model and a parallel hierarchical optimization guided "cluster and route" procedure (HOGCR) are proposed here for preparing the transportation plans of the last mile delivery and pickup problem described above. The goal of the model is to minimize total travel time of vehicles and to promote efficient resource utilization while respecting vehicle and supply availability restrictions.

The proposed HOGCR is able to deal with large scale relief networks (here scenarios of up to 1000 nodes are tested), achieving a good quality solution within a few minutes of CPU time. The HOGCR applies the "divide and conquer" approach, where the relief network is divided recursively into demand node clusters until the final cluster sizes enable the optimal solution of the cluster networks' routing problems. The procedure is hierarchical because each demand node cluster also includes the warehouse and hospital nodes with their allocated partial capacities. The latter allocation is optimized in an upper level aggregate problem. Hence, the consistency of the transportation capacity, hospital space and supply availability is preserved throughout the planning hierarchy. In the HOGCR, the routing problems of cluster networks are solved in parallel and independently, creating a computationally efficient environment.

The HOGCR is a novel approach in both the emergency and the commercial logistics-vehicle routing literature, where Genetic Algorithms, Tabu Search and Scatter Search are proposed (Archetti et al., 2006, 2008; Yi and Kumar, 2007; Campos et al., 2008; Berkoune et al., 2010; Lin Batta et al., 2011) as well as methods such as sequential MIP solution (Chen et al., 2007). These approaches can solve networks with up to 300 nodes and their solution quality has not been verified against optimal solutions.

In the subsequent sections of this paper, we describe the HOGCR and test the performance of the algorithm on a number of hypothetical disaster relief networks as well as on a large scale earthquake scenario for the city of Istanbul.

2. Survey of models proposed for disaster relief logistics

Commercial and humanitarian supply chains are very different in nature (Tomasini and Van Wassenhove, 2009). While commercial chains are concerned with profit maximization, humanitarian chains are involved with maximizing the beneficiaries' satisfaction (Beamon and Balcik, 2008). Yet, in the disaster relief literature, we observe different objective functions described in logistical models concerned with the last mile relief distribution (Balcik et al., 2008). Examples include maximizing unsatisfied demand, minimizing travel time and minimizing total delivery delay.

We now discuss the model structures previously proposed by researchers. There are three basic approaches used in modeling the last mile distribution and pickup problem in disaster relief. These approaches differentiate according to the manner in which they represent vehicle routes. In the first modeling approach (Barbarosoglu et al., 2002; DeAngelis et al., 2007) each vehicle route is represented by a binary variable of multiple indices that define the vehicle and route identification, and starting and ending nodes. When the number of routes and vehicles used in the operation is large, the number of binary variables increases significantly, leading to a model of restricted applicability. The second modeling approach (Mete and Zabinsky, 2010) is to enumerate all feasible routes between all pairs of supply and demand nodes. Then, the decision of assigning a route to each vehicle is represented as a binary variable in the model and a capacitated assignment problem is solved rather than a vehicle routing problem. This approach explodes the size of the problem when the relief network is large, because the number of routes grows exponentially. The third modeling approach (Haghani and Oh, 1996; Ozdamar et al., 2004; Yi and Ozdamar, 2007) is to construct a dynamic network flow model whose outputs are not vehicle routes. The outputs of this model consist of vehicle and material flows that have to be parsed in order to construct vehicle routes and loads. Yi and Ozdamar (2007) show that this approach is more efficient than the first modeling approach, because the model has integer variables of three indices that represent the starting and ending nodes and the travel starting time of the vehicle. The size of this model does not depend on the number of routes or vehicles used, rather, it depends only on the number of nodes in the network and the length of the planning horizon. Ozdamar and Yi (2008) try to solve this problem with a constructive algorithm that can solve test instances of limited size (up to 80 nodes) while Yi and Kumar (2007) use Ant Colony Optimization.

Though dynamic network models are more compact, their disadvantage lies in determining the length of the planning horizon, T, that has to be specified. If T is too short, then, some of the goods remain undelivered despite the availability of supplies. On the other hand, if T is too long, then the problem size becomes large and only small relief networks can be handled by the model. Obviously, the correct size of this parameter cannot be known a priori until the model is solved. A second disadvantage of the dynamic network models lies in representing travel times between pairs of nodes in terms of integral time periods. This is impractical, because each travel time has to be a multiple of the smallest travel time between all pairs of nodes in the network that in turn leads to a significant increase in problem size. Finally, in post-disaster situations, it might not be worth to spend resources and time to run dynamic models if the model cannot be solved fast enough, especially, where large scale relief operations are concerned. Since model inputs are at best roughly estimated, a static