Socio-Economic Planning Sciences 45 (2011) 132–145

Contents lists available at ScienceDirect

Socio-Economic Planning Sciences

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

Invited Paper

# A logistics model for emergency supply of critical items in the aftermath of a disaster☆

Yen-Hung Lin [a], Rajan Batta [b,c,*], Peter A. Rogerson [b,d], Alan Blatt [b], Marie Flanigan [b]

[a] Department of Industrial Engineering, University of Arkansas, Fayetteville, AR 72701, United States
[b] Center for Transportation Injury Research, CUBRC, Buffalo, NY 14225, United States
[c] Department of Industrial and Systems Engineering, University at Buffalo (SUNY), Buffalo, NY 14260, United States
[d] Department of Geography, University at Buffalo (SUNY), Buffalo, NY 14260, United States

ARTICLE INFO

*Article history:*
Available online 12 May 2011

*Keywords:*
Vehicle routing problem
Humanitarian logistics
Prioritizing delivery
Disaster relief

ABSTRACT

This paper proposes a logistics model for delivery of prioritized items in disaster relief operations. It considers multi-items, multi-vehicles, multi-periods, soft time windows, and a split delivery strategy scenario, and is formulated as a multi-objective integer programming model. To effectively solve this model we limit the number of available tours. Two heuristic approaches are introduced for this purpose. The first approach is based on a genetic algorithm, while the second approach is developed by decomposing the original problem. We compare these two approaches via a computational study. The multi-objective problem is converted to a single-objective problem by the weighted sum method. A case study is presented to illustrate the potential applicability of our model. Also, presented is a comparison of our model with that proposed in a recent paper by Balcik et al. [6]. The results show that our proposed model outperforms theirs in terms of delivering prioritized items over several time periods.


## 1. Introduction

In recent years, much human life has been lost due to natural disasters. For example, at least 1836 people lost their lives in Hurricane Katrina in 2005, and 86,000 died in the Kashmir Earthquake in Pakistan in 2005 [31,32]. To mitigate damage and loss in disasters, studies in pre-disaster, during disaster, and post-disaster issues have been widely conducted in the past few years. A critical challenge is to transport sufficient essential supplies to affected areas in order to support basic living needs for those trapped in disaster-affected areas. Supplies that are essential for human survival include water, food (e.g., ready-to-eat meals), and prescription medications. In general, prescription medication (e.g., diabetic supplies) are needed most urgently, followed by water and food, respectively. The requirement for delivering essential supplies that have different priorities to a disaster-affected area provides the motivation for this work.

Logistics problems are often modeled as variants of the vehicle routing problem (VRP). The most recent comprehensive review of the VRP was provided by Ref. [23]. We now summarize some related literature that contains similar characteristics as ours. Three particular characteristics, appearing in the vehicle routing problem literature that are related to in our new logistics model are: soft time windows, multi-period routing, and split delivery strategy. It is noted that we use "depots" as distribution centers or warehouses and "nodes" as demand points throughout this paper.

A vehicle routing problem with soft time windows (VRPSTW) is a special case of the vehicle routing problem with time windows (VRPTW) and has been discussed in the literature, though not often. Contrary to the general time windows constraints, usually indicating the earliest and latest allowable service time of a node, the soft time windows denote that the both upper and lower bound of the time window can be violated with a suitable penalty. Taillard et al. [29] proposed a tabu search heuristic for VRPSTW. They employed a penalty cost that was added to the objective value when lateness at node locations occurred. Ioannou et al. [19] considered the VRPSTW for fleet planning to determine minimal fleet sizes and they proposed a nearest-neighbor method to solve the problem. Furthermore, Haghani and Jung [15] presented the

☆ This material is based upon work supported by the Federal Highway Administration under Cooperative Agreement No. DTFH61-07-H-00023, awarded to the Center for Transportation Injury Research, CUBRC, Inc., Buffalo, NY. Any opinions, findings, and conclusions are those of the Author(s) and do not necessarily reflect the view of the Federal Highway Administration.

* Corresponding author. Department of Industrial and Systems Engineering, University at Buffalo (SUNY), Buffalo, NY 14260, United States. Tel.: +1 716 6450972; fax: +1 716 6453302.
*E-mail address:* batta@eng.buffalo.edu (R. Batta).

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doi:10.1016/j.seps.2011.04.003

formulation for the dynamic vehicle routing problem with time-dependent travel times, soft time windows, multiple vehicles with different capacities, and real-time service requests.

Multi-period vehicle routing problems are not common in the literature due to their difficulties. In 2002, Angelelli and Speranza [1] proposed a tabu search algorithm for the periodic vehicle routing problem with intermediate facilities, where vehicles can renew their capacity. The same problem was investigated by Morugaya and Vanderbeck [25], who considered the tactical planning model to scheduling visits to clients and assigning them to vehicles over a given time horizon to satisfy service level, while optimizing routes in each time period. Ozdamar et al. [26] proposed a planning model integrated into a natural disaster logistics decision support system and they required that the time-dependent transportation problem be solved repetitively in given prolonged time periods.

A split delivery vehicle routing problem (SDVRP) is defined as follows: the demand of a node can be satisfied by more than one-time delivery instead of only one-time delivery allowed in the general VRPs. Dror and Trudeau [11] first showed that benefits could be expected through split deliveries both on total travel distance and the number of vehicles required. Belenguer et al. [7] proposed a lower bound for the SDVRP according to a polyhedral study of the problem. They used a cutting-plane algorithm for small size instances. Bompadre et al. [8] presented the lower bound for the VRP with and without split deliveries. Based on the lower bound they presented, they developed the quadratic iterated tour partitioning and the quadratic unequal iterated tour partitioning heuristics for the SDVRP. Archetti et al. [2] performed a worst-case performance analysis of the SDVRP. They concluded that the maximum cost savings that can be realized is at most 50%. Recently, Archetti et al. [4] used an empirical study and again showed that the largest benefits are obtained when average node demand is just over 50% of the vehicle capacity and when the variance of node demand is relatively small. In addition, algorithms developed for SDVRP can be found in [3,16,20,21].

The purpose of this work is to propose an efficient logistics planning strategy for disaster relief operations. Our proposed method should be able to fulfill the requirements of many disaster relief operations, such as quick response time, accurate deliveries of most needed items, on time deliveries, and fair service among several demand request points. The main contributions of this paper are follows:

- A new logistics model fulfilling the requirement of a quick responses and prioritizing deliveries for disaster relief is developed.
- Soft time windows, multi-period routing, and split delivery strategy are considered simultaneously in the new model.
- Two approaches of tour determination for the model are introduced and a performance analysis for both approaches is provided.
- The consequences of not prioritizing delivery are highlighted with the help of a disaster relief logistics case study.

The rest of this paper is organized as follows. Section 2 presents a tour-based mathematical formulation for the prioritized items delivery problem. The overall solution strategy is discussed in Section 3. Two heuristic approaches are introduced in Section 4 to determine a desirable set of tours. Some computational examples are provided in Section 5 to demonstrate the performance of the proposed approach. In Section 6, a case study of a disaster relief logistics effort is conducted to show the benefit of our new logistics model. Finally, Section 7 contains conclusions and suggestions for future work.

## 2. Tour-based formulation

### 2.1. Description and assumption

One of challenges to efficiently execute disaster relief operations is to obtain sufficient and accurate information from the disaster-affected area. Common sources to obtain raw data in disaster-affected areas include police officers, news media, phone calls, sensors and traffic cameras. Due to the chaotic situation, information received by Emergency Management Centers may be incomplete, duplicate, or inaccurate. Therefore, it becomes extreme difficult to correctly estimate useful information to facilitate disaster response. Jotshi et al. [22] introduced the use of a technology called data fusion that potentially can be implemented in a disaster scenario. Data fusion can be used to efficiently organize and interpret massive amounts of data flowing from the disaster-affected area to Emergency Response Centers when data is varied and alignment is required. Common data may appear in a disaster including reports of casualties, structural damage, road conditions and traffic flow.

In this paper, we assume that there are multiple nodes geographically dispersed and they are be served by a single depot to deliver goods. It is assumed that the supplies are unlimited in the depot and that the demand from various nodes over a planning horizon is known before the beginning of the planning. For modeling simplicity, demand is assumed unchanged during all planning time periods. Different prioritized items are required to be delivered to nodes via the transportation network. Urgency levels of items are differentiated based on their importance. For each type of item, the allowable delivered time periods are predefined to specify the nodes' expected waiting time to receive an item. If an item cannot be delivered within the allowable time periods, a penalty cost is incurred, although the item still can be delivered later. The longer the delay in delivering an item, the more severe the penalty cost.

Characteristics of the transportation mode and the delivery methods are considered. Multiple but limited numbers of identical vehicles are used to transport prioritized items. Vehicles are assumed to have limited weight and volume capacities. For each vehicle, tours are assigned in each period to deliver items to one or more nodes. Tours begin at the depot, continue to one or multiple nodes, and then return to the depot. The total working hours in a single time period for the operation are limited. Therefore, the total travel time of tours assigned to a single vehicle in a single time period cannot exceed the constrained working hours. We do not consider the time to load and unload items on or off the vehicle. Furthermore, any node can be served multiple times by a single vehicle or multiple vehicles to meet its demand, and the demand can also be satisfied fully or partially in a single delivery.

We would like to clarify two variables in the model before its formal introduction. The satisfaction rate at a node indicates the measure of how its demands of various items have been fulfilled during the relief operation period. It can be regarded as the node's service level. Therefore, the maximum difference of satisfaction rates between two nodes is a measure of equity of service levels between nodes.

### 2.2. Multi-objective logistics model

Based on the above assumptions and general description of the scenario, the new model considers a multi-item, multi-vehicle, multi-period, soft time windows, and split delivery strategy prioritized delivery problem and is constructed by a multi-objective tour-based integer programming formulation. In this section, we first summarize notation, parameters and decision variables, followed by a presentation of a mathematical formulation for the model.