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The multi-depot split-delivery vehicle routing problem: Model and solution algorithm

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ABSTRACT

Logistics and supply-chain management may generate notable operational cost savings with increased reliance on shared serving of customer demands by multiple agents. However, traditional logistics planning exhibits an intrinsic limitation in modeling and implementing shared commodity delivery from multiple depots using multiple agents. In this paper, we investigate a centralized model and a heuristic algorithm for solving the multi-depot logistics delivery problem including depot selection and shared commodity delivery. The contribution of the paper is threefold. First, we elaborate a new integer linear programming (ILP) model, namely: Multi-Depot Split-Delivery Vehicle Routing Problem (MDSDVRP) which allows establishing depot locations and routes for serving customer demands within the same objective function. Second, we illustrate a fast heuristic algorithm leveraging knowledge gathering in order to find near-optimal solutions. Finally, we provide performance results of the proposed approach by analyzing known problem instances from different VRP problem classes. The experimental results show that the proposed algorithm exhibits very good performance when solving small and medium size problem instances and reasonable performance for larger instances.

1. Introduction

The technological transformations that are taking place over the last few decades have brought about new challenges to the conventional supply chain operations in organizations ranging from private enterprises to governmental institutions. The changing global economy and agile infrastructure have placed high demand for systematic and automated planning of large-scale commodity delivery operations. In this respect, academic and industrial research and development efforts are being pursued for logistics operational plan generation. In this article, we intend to explore a subset of such large-scale planning requirements and analyze how multiple distribution centers (depots) and vehicle routing paths can be derived together, if possible, in a centralized planning environment to deliver commodities within predefined constraints and limited vehicle capacity. The specific focus of this study is the multi-depot split-delivery and location routing problem. The proposed technique can efficiently compute near-optimal solutions for problem instances where the combined cost (distribution center establishment and vehicle routing) needs to be minimized.

1.1. Motivation and background

Business organizations address their logistics pursuits at three different levels. These levels are often referred as: Strategic, Operational and Tactical [1]. Strategically, decision makers locate depots for serving the customers. Various network partitioning and resource allocation algorithms are applied on external inputs to choose depot locations in the vicinity of the customers. Once the depots are chosen, operational decision makers solve the underlying routing problem as per the requirements. The problem types at this level are often characterized as: traveling salesman problem (TSP), vehicle routing problem (VRP), traveling repairman problem (TRP), etc. Analytical, heuristic and meta-heuristic algorithms are used to solve the routing problems where the typical objective is to minimize routing cost. The results of these planning processes are a set of vehicle routes. Finally, the tactical officers proceed to execute the routing tasks in compliance with previously taken decisions. The need for large-scale quick logistic delivery planning is vital for situations like humanitarian aid distribution, disaster relief, rescue operations and national crises. However, such a multi-level decision making exhibits notable gaps to find optimal partitioning and routing in the transportation network for commodity delivery [2]. Furthermore, traditional logistics planning

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and its subsequent execution phase(s) heavily depend on human expertise in decision making that exhibit intrinsic limitations in handling large and complex operations. In this respect, an efficient and sufficiently automated mechanism for sharing responsibilities in commodity delivery may offer better situational response.

A relevant situation can be mentioned from the experience of the well-known Haiti disaster in the aftermath of the January 2010 earthquake [3]. In this crisis situation, the response operations started the delivery of essential commodities to more than 300,000 injured and 1.5 million homeless people [3]. Several organizations, such as: International Rescue Committee (IRC), Management Sciences for Health (MSH), and International Federation of Red Cross (IFRC), teamed up to deliver drugs and supplies to out-of-stock clinics and health facilities from multiple operational Emergency Response Units.[1] It was well documented that the overwhelming emergency requirements caused delay in shelter preparation [3]. Renowned news channels also reported on the mismanagement in cooperation for shared delivery arrangement among participating organizations.[2] The logistics delivery planning is also an important research problem for the supply chain management. In the commercial sectors, trade related surface transportation has been constantly increasing in North America. Between 2009 and 2010, the total value-added of the Transportation and Warehousing sector has been growing approximately by 4.3% [4]. In Canada, the Gross Domestic Product (GDP) in the Transportation and Warehousing sector has increased from \$50.2 billion in 2001 to \$58.4 billion in 2010 [4]. The United States Department of Transportation has issued a notable report stating that the surface transportation trade between North American Free Trade Agreement (NAFTA) partners has been increased by 11.5% in January 2012 compared to January 2011 at \$75.5 billion [5]. Alongside, a Gartner report reveals that the market for intelligent transportation planning software holds the key to the success of the multi-organizational response. The report also indicates a 20.6% increase of worldwide Transport Management System software revenue from 2007 (\$538 million) to 2008 (\$648 million) and a growth in the field through 2012 (up to \$963 million) [6].

1.2. Problem elaboration

Multi-Depot Split-Delivery Vehicle Routing Problem (MDSDVRP) handles commodity delivery to customers (demand points) that are represented as nodes in a complete graph named as transport network. Given a set of nodes (V) and a set of edges (E), where E is a relation in ($V \times V$), a transport network is a complete graph $G = (V, E)$. Each edge of the graph provides the traversal cost (c_{ij}) between the corresponding two nodes i and j. Usually, a transport network is composed of different node types: Customers (N) and Depots (D). While customer nodes are characterized with deterministic demand (integer) for commodity (δ_i), depot nodes (having no demand) alternatively host vehicles ($k = 1, 2, \ldots K$) to supply customers. In case of predefined depots and customers, a solution for an MDSDVRP instance gives the routes for each vehicle that minimizes the overall routing cost to serve all customer demands. In our proposed formulation, we further consider that if the depots are not predefined, the solution to MDSDVRP will determine the optimal location(s) of the depot(s) within the set of customer nodes. In this case, assuming that the newly found depot(s) will serve their own need(s), the goal of problem is then to minimize the combined depot establishment and routing cost.

In actuality, vehicle routing can be seen as a core problem in supply chain/logistics planning, with conceptual, empirical and behavioral aspects. A holistic view of the supply chain process offers an overarching perspective spanning over various facets such as facility location, vehicle routing and environmental impact. In this respect, focusing on a single aspect, for example minimizing the routing cost without considering facility locations may result in higher warehousing cost and larger externalities such as: pollution, and congestion. In the usual setup, the problem of multi-depot split delivery vehicle routing is considered with the common assumptions of Split-Delivery VRP (SDVRP) and Multi-Depot VRP (MDVRP) under which we essentially consider a vehicle routing problem involving commodity delivery as an abstract conceptual optimization problem [7] with few empirical details. The participating entities are depots (as starting/ending points for vehicles), customers (with deterministic demand) and vehicles (with predefined and available capacity). Typical abstractions are observed in terms of unlimited route length (not considering required stop-overs for rest, etc.) as well as deterministic infrastructure analysis (fixed traversal cost across transport network nodes, etc.). Another prevalent abstraction is to consider the problem of facility location separate as specifically employed by cluster first-route second approaches [2]. However, in this work, we emphasize the importance of considering together the problems of location allocation and vehicle routing.

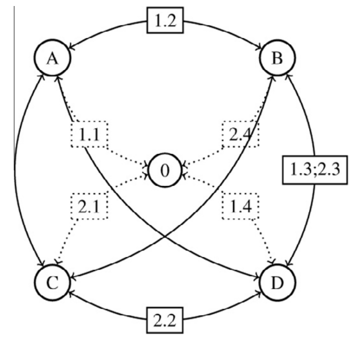

Fig. 1. An example transport network of customers and depots.

The optimization goal of VRP is the overall cost minimization based on the cost assigned on each edge of the transportation network. In the literature the deterministic capacitated-VRP (CVRP) is a well-studied NP-hard combinatorial optimization problem having several variants and extensions [8]. In fact, the CVRP is composed of two problems: Bin-Packing and Routing. The Bin Packing Problem (BPP) addresses an optimal allocation of commodity to vehicles having deterministic capacity. The routing problem deals with the most efficient routing possible using the loaded vehicles. We may note that in shared commodity delivery settings (which represent practical aspects at the requirements level), it is possible to determine the feasibility of a problem instance by requiring the total vehicle capacity to be greater or equal to the total demand. In other words, MDSDVRP will always yield a solution if the total available capacity is equal or more than the total demand. In this respect, MDSDVRP is less restrictive than some of the other VRP variants for which there may be no feasible solution (e.g. some customers having demands larger than the capacity of a single vehicle). However, MDSDVRP still belongs to the NP-hard class of problems [9,10] and is therefore intractable when approached with an exact algorithm. It is worthy to mention that it has a notable larger solution space since splitting the delivery among different vehicles is subject to combinatorial explosion. Consequently, we detail an effective heuristic technique that yields good near-optimal solutions.

1.3. Objectives

In the scope of this article, we aim at investigating an advanced decision support platform to address a combined problem of depot

[1] MSH and IRC to Partner in Haiti; link: http://www.msh.org/news-bureau/msh-and-irc-to-partner-in-haiti.cfm.

[2] BBC, What is delaying Haiti's aid?; link: http://news.bbc.co.uk/2/hi/americas/8472670.stm.