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A rough-cut approach for evaluating location-routing decisions via approximation algorithms

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ABSTRACT

The first step in most location-routing projects involves bringing the primary stakeholders on board and securing funding for implementation of the required changes. To this end, practitioners often need a good feasible solution together with a lower bound on the cost of any solution to the problem at hand, rather than exact solutions based on detailed and accurate parameter estimates. In this article, we present a simple methodology for assessing the quality of the current distribution network as well as for identifying opportunities for improvement. We incorporate the potential use of different transportation technologies at different layers of the network. We demonstrate the versatility of the proposed rough-cut approach by means of two real life implementations: (i) redesigning the supply network of the Casino Group, a supermarket chain in southeast France, and (ii) redesigning the household material recycling network of the city of Calgary, in Canada.

1. Introduction

In order to be able to provide timely service to their customers, many firms face the need to improve their responsiveness by introducing regional distribution centres (RDCs). These intermediate facilities are aimed at better linking the demand zones with the production facilities, warehouses or central distribution centres (CDCs). Among other benefits, the introduction of RDCs may play an important role in the reduction of the total distance travelled by the firm's distribution vehicles, mitigating transportation costs while improving customer service. The establishment of RDCs, however, requires the firm to make decisions pertaining to their location as well as the routes to be followed by the vehicles in serving the firms clients i.e. the location-routing problem.

The problem is complex, and implementing its solution, in many cases, requires significant investments in both monetary and human resource terms. Decisions need to be taken at different managerial levels, involving different functional areas in the company. The first phase of decisions are often made based on aggregate information about the costs and benefits of the alternative actions. Only if the potential benefits are significant, then the firm will be interested in engaging in a full-scale data collection/estimation process ultimately leading to network restructuring.

The firm faces the problem of simultaneously deciding the location of its RDCs and defining the routes that will be used by the trucks departing from each of the RDCs. The prevailing literature addressing the location-routing problem targets

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the identification of good quality solutions. However, rather than an implementable solution, in many cases what the firm needs is a solid understanding of the potential upside of engaging in a thorough restructuring of its distribution network. The aim of our work is to develop an easily implementable technique that will provide managerial insights –in the form of bounds– for companies dealing simultaneously with location and routing decisions. Notice that this is a *rough-cut* approach, since the decisions made during this first phase are not based on very detailed and precise information abut the costs and benefits of each alternative.

Although the Lagrangian Relaxation technique is a common approach for deriving “feasible solution-lower bound” pairs, its direct use in the location-routing problem is not a promising avenue, mostly because of the (very large) number and complexity of the constraints of the problem. As an alternative, in the spirit discussed by Silver (2004), in this article we develop a relatively easy-to-implement approximation algorithm that returns a feasible solution together with a lower bound on the distribution costs, that serves as a benchmark for both the status quo (i.e. the current network) and the provided feasible solution.

The proposed methodology is based on a pragmatic transformation of the distances between the candidate locations and the demand nodes. Such transformation allows us to incorporate the routing-related information into the location problem, reducing the location-routing problem to a (simpler) k-median problem. The locations resulting from the solution to the k-median problem (which constitute a lower bound for the location-routing problem) are then used as an input to a vehicle routing problem whose solution –for which an algorithmic procedure is provided– is a feasible solution to the original problem.

It is also important to highlight that the resulting benchmark can be used for understanding the impact of other factors such as truck-fleet capacity utilization; transportation technology alternatives (i.e. different types of trucks); overall distance traveled by the firm’s fleet (as a function of number of facilities); CO_2 emissions, among others.

The rest of the article is organized as follows: Section 2 provides an overview of the most relevant literature. In Section 3, we introduce the location-routing problem and provide the analytical framework for its analysis. The lower bounds and the feasible solution for the routing problem are also developed in this Section. The section concludes with the presentation of a hypothetical example that illustrates the working of the proposed procedure. In Section 4, we present an outline of our experience with two real life implementations: (i) the redesign of the supply network of Casino Group, a supermarket chain in southeast France; and (ii) the redesign of the domestic waste collection and recycling network of the city Calgary. Section 5 concludes the article with some remarks and directions for further research.

2. Literature overview

Location and routing problems have attracted the interest of researchers for a very long time. This interest has given rise to an important amount of literature that addresses each of these problems separately. Concerning facility location, the surveys by Daskin (1995); 2008); Eiselt and Marianov (2011); Farahani and Hekmatfar (2009); Snyder (2010) and Drezner (2014) provide an excellent account of the evolution of the discipline over the last 60 years. Meanwhile, Golden et al. (2008); Laporte (1992); Laporte et al. (2000); Toth and Vigo (2001) and Laporte (2009) provide a comprehensive account of the vehicle routing problem’s history and development.

Within location-routing contexts, there exists a volume of literature that either addresses location problems where transportation is considered as a fixed input to the problem (Álvarez-Miranda et al., 2015; Berman et al., 2007; 2009; Ceder et al., 2015; Yun et al., 2015); or routing problems with a pre-defined location set (Badeau et al., 1997; Huang et al., 2013; Liu et al., 2003).

Even though the intuition that the decision about the location of a number of facilities and the design of the routes that will serve them should be made simultaneously was already present in literature since about 50 years ago (Maranzana, 1964; Webb, 1968), the article by Perl and Daskin (1985) is one of the first attempts for incorporating routing into location analysis. Shortly after, Salhi and Rand (1989) established that taking the location and routing decisions independently may lead to suboptimal results. This is true even in those cases where the location decisions are made for the long term (Salhi and Nagy, 1999). The works by Laporte (1988); 1989), Min et al. (1998) and Nagy and Salhi (2007) provide excellent accounts of the early developments and the techniques used to address the location-routing problem. Other contributions consider location routing problems with distance constraints (Berger et al., 2007); within large scale network design contexts (Crainic et al., 2009; Javid and Nader, 2010; Javid and Seddighi, 2013; Melkote and Daskin, 2001; Ouyang, 2007; Silva et al., 2014); or propose multiperiod problems (Klibi et al., 2010). The surveys by Drexl and Schneider (2014); 2015) provide a extensive overview of the recent developments in the field.

Based on the observation that most of the available literature addressed the location-routing problem as a mixed-integer problem, Dasci and Verter (2001) developed an alternative approach based on the use of continuous functions for representing the spatial distribution of demand. Their formulation is capable of providing insight on the effect of variations in the model’s parameters on the final location decisions. One of the main assumptions of their work is that the demand density over the market region is almost constant. However, the work of Murat et al. (2010) suggests that the use of continuous functions is not always easy to apply, in particular when demand is sparse and concentrated. In fact, continuous modeling may require the use of complex algorithms when demand density shows considerable spatial variations. Other interesting references that work with continuous formulations are Schwardt and Dethloff (2005); Smilowitz and Daganzo (2007) and Salhi and Nagy (2009).