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A MILP model and heuristic approach for facility location under multiple operational constraints

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ABSTRACT

In the present work, we study a multi-period facility location problem featuring many realistic constraints. In order to take into account vehicle routing from distribution centers to customers while maintaining a manageable size of the optimization problem, we develop a two-phase solution approach. In the first phase, the average distances and costs of transport from distribution centers to customers are evaluated using an exact clustering procedure based on a set-partitioning formulation. These costs serve as input to the facility location problem in the second phase, which is formulated as a mixed integer linear program and solved using a state-of-the art commercial solver. Many numerical experiments using real life data from the automotive industry are carried out in order to derive some insights related to multi-period modeling. We first show that in our case study, using static assignment decisions is better for the company as the corresponding operational benefit outweighs the additional cost to be incurred. We then compare the outputs of the multi-period model with those of its single-period counterpart. Finally, to cope with the computational difficulties encountered during the numerical experiments, we propose a linear relaxation based heuristic to solve larger instances of the problem. The heuristic method provides good quality solutions while significantly improving computation times.

1. Introduction

Major industrial companies put considerable efforts on optimizing the planning of their supply chains in order to reduce costs, decrease lead times and improve the service offered to customers. One key question at the strategic planning level is designing the supply chain network and deciding where to locate factories and distribution centers (DCs). This question leads to studying network design and facility location problems (FLP) which aim at selecting the best locations for new facilities and assigning customers to the opened sites while optimizing a given objective function (see e.g. the reviews proposed in Owen and Daskin (1998) and more recently in Melo, Nickel, & Saldanha da Gama, 2009a). Although these problems have been widely studied during the last decades, diverse challenges encountered by firms nowadays raise new questions on how to model and solve complex real-life situations. Several recent works have thus focused on improving the practical relevance of facility location models by incorporating different operational features and constraints. For example, maximum capacity and single sourcing constraints have been widely considered in the literature of facility location (Park, Lee, & Sung, 2010; Yu, Lin, Lee, & Ting, 2010). Imposing maximum capacities aims at modeling the limitation of space and resources in each location whereas requiring to manage all the deliveries of a given customer from a unique distribution center is a way to simplify day-to-day logistics operations. Another type of constraint that can be included in a facility location model is the limitation of the maximum distance between a customer and a distribution center serving him. This ensures a better proximity to customers and a higher service level (Moon & Chaudhry, 1984; Sáez-Aguado & Trandafir, 2012).

Given that the temporal aspects of real world problems can be better captured with dynamic formulations than with static models (Owen & Daskin, 1998), recent works in facility location have developed a considerable interest in optimizing dynamic systems (see Arabani and Zanjirani Farahani (2012) for a recent review on facility location dynamics). Dynamic systems are related to two main features: uncertainty (e.g. in the prediction of input parameters) and time-dependency. Time-dependent or multi-period models consider parameters that vary over time-periods, such as demand, prices and costs and introduce the possibility of adapting

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decisions to variations in these parameters. In the present work, we formulate a multi-period facility location model taking into account time-varying customer demand. The overall network structure consists of three levels: plants in the first level, distribution centers (DCs) in the second one and customers in the third one. We assume that the number and location of the plants as well as the number and location of the customers are fixed. Given the demand of customers in each time-period and a list of potential DCs, our main concern is to locate DCs and to assign customers to them in such a way as to minimize the total distribution costs.

The model studied in this paper integrates many realistic features that have not been simultaneously taken into account in the literature of multi-period FLP. Constraints of maximum covering distance, single sourcing, minimum volume on transport links as well as minimum volume and maximum capacity on distribution centers are combined in the model. The network modeled involves two types of transport: "primary" transport from plants to DCs and "secondary" transport from DCs to customers. The main difference between these two kinds of transport is that trucks used in primary transport follow direct routes from plants to DCs while those used in secondary transport have to visit more than one customer before returning back to the DC. Such grouping of several shipments into one truck is a common practice considered by companies in order to reduce transport costs through the use of full truckloads, while ensuring frequent shipments. This introduces however more complexity to the modeling and solving of the network design problem as a Vehicle Routing Problem (VRP) should be integrated with the main facility location problem, which results in a combined location-routing problem (LRP). Although several works in the literature addressed single-period location-routing problems (see e.g. Yu et al., 2010), only few models were studied in the field of multi-period location routing; works like Afshar and Haghani (2012), Albareda-Sambola, Fernandez, and Nickel (2012), Laporte and Dejax (1989), Prodhon (2011) and Yi and Ozdamar (2007) are worth mentioning in this context. However, in these papers, exact solutions could be found only for problems of small size. For instance, in Albareda-Sambola et al. (2012), the MILP solver terminated without even having found a feasible solution to eight of the ten instances considered (involving 10 facilities, 40 customers and 12 time-periods).

In the present work, we propose an original way to take into account vehicle routing in a FLP while keeping a manageable size for the optimization problem. Through a two-phase solution approach, we approximately solve a multi-period LRP for real-life industrial instances: the first phase uses an exact clustering method for secondary transport distance and cost identification whereas the second phase deals with a FLP that considers the results of the first phase as input parameters. In order to validate this approach, we present several numerical experiments using real-life data from the automotive industry. We first propose an exact solution to the FLP using a state-of-the-art MILP solver, which provides us with interesting insights related to multi-period modeling. We evaluate the difference between static and dynamic assignment decisions in terms of costs and network structure and compare the outputs of the multi-period model with those of its single-period counterpart. Finally, to cope with computational difficulties encountered during the numerical experiments, we investigate a linear relaxation based heuristic procedure to solve larger instances of the problem.

The remainder of this paper is organized as follows. In Section 2, we investigate the value of multi-period FLP and discuss some connections with the existing literature. In Section 3, we present the modeling choices considered in this paper, including problem costs and constraints as well as customer representation. In Section 4, the first phase of the 2-stage solution approach is explained and the clustering problem is formulated. The second phase of the solution approach is described in Section 5, involving the mathematical formulation of the facility location problem. Computational results and a qualitative analysis for a case study from the automotive industry are presented in Section 6. In Section 7, an efficient heuristic procedure and the related numerical results are investigated whereas conclusions and suggestions for further research are presented in the last section.

2. Literature on multi-period FLP: value and modeling considerations

In real-life problems, input parameters such as demand quantities, prices and costs are likely to vary from period to period over an extended time-horizon. Accordingly, dynamic, multi-period or time-dependent FLP, as opposed to single-period or static FLP should be considered, in this section, we do not aim at providing an exhaustive review on multi-period FLP and SCNDP. Our intent is rather to explain why multi-period models should be used and to propose a general overview of the main tactical/operational features and constraints considered in these models.

One may wonder why multi-period models should be considered for facility location if this kind of approach increases the complexity of the optimization problems. One of the reasons is that a single-period model does not consider the variation of the problem parameters from period to period and thus may lead to solutions which could be sub-optimal or even infeasible when exposed to demand or price fluctuations for example. The difference in the network structure and total cost should be evaluated by comparing the optimal solution of the dynamic problem with the optimal solution of its static counterpart (re-evaluated a posteriori using the right dynamic parameters). In their recent work Nickel and Saldanha da Gama (2015), Melo and Saldanha Da Gama referred to this as finding "the value of the multi-period solution". To the best of our knowledge this kind of numerical comparison was only addressed in Alumur, Nickel, Saldanha da Gama, and Verter (2012). The authors provided details on how to evaluate data variation from period to period using assumptions on volume increase and yearly inflation rates. They also explained the advantages of a dynamic model as compared to a static one based on a case study in the context of reverse logistics network design for washing machines and tumble dryers.

When the planning horizon is long (typically more than 2 years), customer demand is likely to vary along time because of the growth or decline of the company sales from year to year. When considering mid-term planning (typically one year as in the case study addressed in Section 6), changes in demand from period to period are mainly explained by seasonality. In this case, an optimal solution found using multi-period modeling is likely to significantly differ from an optimal solution found using single-period modeling for a same problem. Consider, for instance, the classical problem of capacitated FLP, in which seasonal customer demand is introduced. Assume that there are four seasons, two seasons with a very low demand and two seasons with a very high demand and that opened DCs must remain open during the whole planning horizon. In such a situation, the solution obtained with a multi-period model is likely to open more DCs than the solution obtained with a single-period model. The reason is mainly related to the constraints of maximum capacity on DCs. These constraints may be problematic during periods of peak demand that are captured in the multi-period model but not considered in the single-period model, which uses average demand values. The solution of the single-period model may even be infeasible if exposed to large fluctuations in demand. In the problem variant studied in this paper, such feasibility issues would be frequently encountered as minimum volume and maximum capacity constraints