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A distribution network design problem in the automotive industry: MIP formulation and heuristics

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ABSTRACT

We consider a multi-product distribution network design problem arising from a case-study in the automotive industry. Based on the realistic assumptions, we introduce minimum volume, maximum covering distance and single sourcing constraints, making the problem difficult to solve for large-size instances. We thus develop several heuristic procedures using various relaxations of the original MIP formulation of the problem. In our numerical experiments, we analyze the structure of the obtained network as well as the impact of varying the problem parameters on computation times. We also show that the implemented heuristic methods provide good quality solutions within short computation times on instances for which a state-of-the-art MIP solver does not produce any feasible solution.

1. Introduction

A considerable part of a company costs is devoted to the supply chain management, in particular logistics operations such as transport and storage. For instance, according to the CSCMP (Council Of Supply Chain Management Professionals) annual reports [9], the logistics costs as a percentage of the GDP in the USA varied between 7.9% and 9.9% in the last decade. This is why more attention and consideration has to be given to optimizing the supply chain planning. One key question at the strategic planning level is designing the supply chain network and more precisely locating the major facilities of the company, namely plants and distribution centres. In the present work, we deal with a multi-product distribution network design problem arising from a case-study in the automotive industry. The planning horizon that we consider is not very long (one year in our case-study). The overall network structure consists of three levels: assembly plants in the first level, distribution centres (DCs) in the second one and customers (car dealers) in the third one. We assume that the number and the location of the plants as well as the number and the location of the customers are fixed. Given a deterministic demand of customers for each product 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. In order to evaluate transport routes from DCs to customers, we construct groups of customers (clusters) using a clustering-based location-routing approach which allows dealing with large-size real-life instances. Moreover, we consider realistic hypotheses that have not been simultaneously taken into account in the literature. Namely, we introduce single sourcing restrictions and minimum volume constraints for both transport flows and facility throughputs. We also use maximum covering distance constraints, i.e. the length of the route between a DC and any cluster that it serves (computed as the length of the shortest route starting from the DC, visiting all the customers of the cluster then coming back to the DC) must not exceed a given distance. The combination of these operational features involves seeking a trade-off between conflicting objectives, thus the problem becomes difficult to solve for large-size instances (for some instances it is even difficult to find feasible solutions). This is why we develop efficient heuristic methods based on various relaxations of the original mixed integer programming (MIP) formulation of the problem. To the best of our knowledge, it is the first time that this kind of approach is applied to determine both location and assignment variables in a supply chain network design problem subject to minimum volume and distance constraints.

The paper is organized as follows. In the next section, we propose an overview of the related literature. Section 3 is devoted to the explanation of the modelling considerations and to the description of the mathematical formulation of the problem. Then, efficient heuristic procedures are investigated in Section 4 and

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computational results concerning our case-study are presented in section 5. Finally, some conclusions are provided in Section 6.

2. Position in the literature

Our research is related to two main literature streams, the first one being *facility location* and the second one *supply chain network design*. This is why we first propose an overview on these expanding fields. We then discuss the integration of minimum volume and distance constraints in supply chain network design problems.

2.1. Facility location and supply chain network design

In a classical facility location problem, the objective is to locate new facilities and to determine the related product flows on a given network, where the locations of demand points are known. In the present work, we focus on a discrete location problem, i.e. facility locations have to be chosen among a list of eligible sites. A survey on discrete location science can be found, among other, in [25].

A typical approach in supply chain network design problems is the use of integrated models, i.e. simultaneously modelling and solving the strategic location problem and other operational issues. This body of works includes production–distribution problems [32], location-inventory problems [3] and location-routing ones (LRP) [24]. In the context of our study, we were particularly interested in the latter problem; see e.g. [22] for an overview on the classification of LRP. From the related literature, we can mainly identify three different approaches when dealing with vehicle routing within supply chain network design problems. The first one can be called the explicit method as routes are explicitly modelled as decisions in the optimization problem (see e.g. [33]) but this may result in the formulation of large-size MIP, most of which are hard to solve. The second method consists in using the continuous approximation, i.e. expressing continuous functions to characterize the customer demand distribution and their locations (for instance in [29] continuous approximation is used to approximate the optimal routing costs). The major disadvantage in this case is the need to resort to strong assumptions such as a uniform demand distribution or a uniform customer density. Finally, it is also possible to use a sequential clustering-based method, as proposed by Barreto et al. in [5]. We chose to apply this method in order to have a good approximation of the routing costs while keeping a manageable size for the optimization problem. This allows dealing with real-life instances involving many customers.

2.2. Integration of minimum volume constraints and maximum distance constraints

One of the constraints involved in our model is the maximum covering distance constraint. A customer is said “covered” if there exists an opened facility situated within a pre-specified distance of it. In order to formulate this kind of distance constraints, we can either use covering objectives (mainly when locating public sites such as schools, police stations, hospitals, and parks) or impose covering distance constraints with any type of objective, usually cost or distance minimization. The literature dealing with covering objectives is abundant (see [10] for a recent literature review) whereas only a few papers, among which are [20,27,1,21], consider covering distance constraints.

In our network design model, a major feature is imposing a minimum volume on each transport link and on each opened DC. This is an approach used in facility location and supply chain network design to introduce flow consolidation. The literature devoted to this stream appears to be relatively scarce. Table 1

Table 1
Literature review on facility location and network problems featuring minimum volume constraints (NM = Not Mentioned).

Paper	Facility location decisions	Min volume constraints		Complicating features		Solution procedure and numerical results					
		Throughput of facilities	Transport quantity	Multi-product	Single sourcing	Number of integer variables in the largest instances considered	Number of continuous variables in the largest instances considered	State-of-the-art MIP solver	Linear relaxation based heuristic	Other heuristic	Specialized exact method
Krumke and Thielen [15]			X			NM	NM			X	X
Lim et al. [16]			X			10 890	0		X	X	X
Seedig [28]			X			50	50				X
Zhu et al. [34]			X			119 643	119 643	X			
Alumur et al. [2]	X	X		X		1200	58 000	X			
Barros et al. [6]	X	X		X		NM	NM		X		
Correia et al. [8]	X	X		X		1728	83 705	X			X
Geoffrion and Graves [11]	X	X		X	X	727	23 513				X
Guha et al. [12]	X	X			X	NM	NM			X	
Karger and Minkoff [13]	X	X			X	NM	NM			X	
Melo et al. [17]	X	X		X		270	732 810	X			
Melo et al. [18]	X	X		X		560	107 057	X	X		
Meyerson [19]	X	X			X	NM	NM			X	
Ndiaye and Alfares [23]	X	X			X	370	1810	X			
Sabri and Beamon [26]	X	X		X	X	27	214	X			
Svitkina [30]	X	X			X	NM	NM			X	
Thanh et al. [31]	X	X		X		2185	30 870	X	X		
Present work	**X**	**X**	**X**	**X**	**X**	**62 832**	**1632**	**X**	**X**		