Design of Distribution Systems in Grocery Retailing

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Abstract We examine a retail distribution network design problem that considers the strategic decision of determining the number of distribution centers (DC) as well as their type (i.e., central, regional, local), and anticipates the tactical decision of allocating products to different types of DC. The resulting distribution structure is typical for grocery retailers that choose to operate several types of DC storing a distinct set of products each. We propose a novel model considering the decision-relevant costs along the retail supply chain and present a case study of a major European retailer.

Keywords Location · Mixed-integer programming · Strategic planning

1 Introduction

Retailers planning to expand their business to a new geographical area are faced with the question of how to enhance or restructure their current logistics network. A similar problem applies for retailers whose distribution systems have evolved over time and are subject to potential restructuring, for example, because the network is not reasonably aligned with the current supplier/product portfolio anymore, or because the introduction of new technologies necessitates capacity adaptations.

From a strategic network design perspective, retailers have to decide, among many diverse issues, how many warehouses to use, where to locate them, and which functions they will take on [1]. Furthermore, the network structure that is established by these long-term decisions inherently frames the subsequent tactical planning

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problems. For instance, the possible distribution paths and storage locations for individual products obviously depend on the predefined network [2]. It is therefore necessary to anticipate the consequences for mid-term planning when designing the retail network structure.

We examine a scenario where a retailer chooses to operate a set of distinct distribution center (DC) types that directly serve a specific set of demand centers, i.e., a set of stores within a specific delivery area. The distribution path (including storage locations) of a certain product is determined accordingly by a product-to-DC type assignment. Each type of DC is primarily specified by the number of parallel warehouses and thus the extent of delivery area that each warehouse covers. A three-type network (central, regional and local DCs), for example, could feature one central warehouse, two regional warehouses, and several local warehouses, while the DCs of a certain type are usually similar in size and equipment. Figure 1 depicts an example of such a distribution system. This concept is a common variant in retail practice and is usually applied to place the various products at an appropriate location that minimizes inventory holding and transportation costs, while reducing operational complexity [2].

Retail-specific network design problems have been examined in multiple contributions. These studies often deal with exact solution approaches applied to simplified models (e.g., disregarding inventory holding and instore operations), with a focus on product flows (e.g., [3, 4]). Other studies focus on specific criteria, such as the selection of plants/suppliers [5], resilient network design [6], or network design with transportation discounts [7]. The novelty of our approach is the detailed design of the distribution network (considering the number of warehouses and their function), taking into account consequences for the subsequent product allocation to different types of DC. Our approach follows a holistic supply chain perspective that considers inbound transportation from suppliers to the warehouses, warehouse operations, inventory holding, outbound transportation from the warehouses to demand centers, and instore operations.

The remainder is organized as follows: In Sect. 2 we present a mathematical formulation and an approach for solving the planning problem described. Section 3 then presents the results when applying the approach suggested to the real-life case of a major European retailer. Section 4 summarizes our contribution.

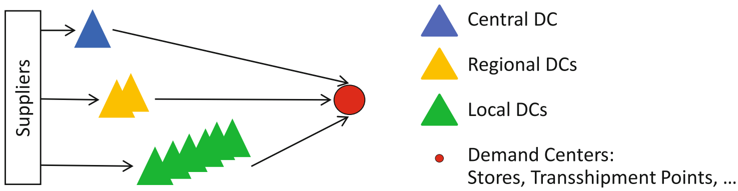

Fig. 1 Example of a three-type distribution system

2 Modeling Approach

We introduce a binary program for the network design problem that we denote as Network Design with Product Allocation (NDPA) model. Building on a predefined set of possible warehouse locations, the NDPA model determines the selection of specific DC types while minimizing total supply chain costs, anticipating the tactical product allocation decision. The locations of possible warehouses per DC type are a relevant input as they impact transportation costs in the distribution network to be designed. If the locations are not predetermined by existing structures or given preferences of the retailer, we suggest using a p-median approach in a preprocessing step to determine the warehouse locations, minimizing the sum of inbound and outbound transportation costs for each DC type considered. The p-median model is NP-hard, but, efficient algorithms exist that can solve instances of real dimensions in reasonable times [8]. The resulting warehouse locations are then used to specify the inbound and outbound distances in the NDPA model, for which we propose the following mathematical formulation:

$$\begin{aligned} \text{Minimize } \ Z = & \sum_{d \in D} c_d^{\text{DCfix}} \cdot z_d + \sum_{p \in P} \sum_{d \in D} c_d^{\text{DCvar}} \cdot x_{p,d} \\ & + \sum_{p \in P} \sum_{d \in D} c_{p,d}^{\text{InOutInv}} \cdot x_{p,d} \\ & + \sum_{d \in D} \sum_{l \in L} c^{\text{Instore}} \cdot y_{d,l}^{\text{Instore}} \end{aligned} \tag{1}$$

s.t.

$$\sum_{d \in D} x_{p,d} = 1 \qquad \forall p \in P \tag{2}$$

$$\sum_{p \in P} x_{p,d} - z_d \cdot M_1 \leq 0 \qquad \forall d \in D \tag{3}$$

$$\sum_{p \in P_l} x_{p,d} - y_{d,l}^{\text{Instore}} \cdot M_2 \leq 0 \qquad \forall d \in D, l \in L \tag{4}$$

$$x_{p,d} \in \{0, 1\} \qquad \forall p \in P, d \in D \tag{5}$$

$$y_{d,l}^{\text{Instore}} \in \{0, 1\} \qquad \forall d \in D, l \in L \tag{6}$$

$$z_d \in \{0, 1\} \qquad \forall d \in D \tag{7}$$

The objective function (1) minimizes the total supply chain costs considering warehouse (setup and operating), inbound transportation, inventory holding, outbound transportation and instore operations costs.

We split warehouse-related costs into a fixed block for every DC type d to be established (decision variable z_d, which indicates if a DC type d is used or not, and cost factor c_d^{DCfix}), and a size-dependent component (cost factor c_d^{DCvar} and decision variable $x_{p,d}$, which defines if a product p is assigned to type d). Investment costs are thus assumed to be dependent on the number of different SKUs, i.e., picking locations, assigned to a DC.

Inbound and outbound transportation as well as inventory holding costs are summarized in cost factor $c_{p,d}^{\text{InOutInv}}$. They are assumed to be product- and DC-type-specific and therefore also dependent on the assignment of products to a specific DC type (decision variable $x_{p,d}$). The transportation cost components reflect the distances and volumes from the DC locations to the suppliers and demand centers. Inventory holding costs especially account for the different degrees of demand pooling options that come along with the specific number of parallel warehouses that are established using a certain type of DC. One possibility for quantifying the inventory pooling effect is the so-called square root law [9, 10].

Costs arising from instore operations are considered by setting a penalty c^{Instore} for each additional DC type d to which products from a certain store layout category l are allocated (decision variable $y_{d,l}^{\text{Instore}}$). For details on the product allocation decision and the costs considered, we refer to [2].

The model is complemented by several restrictions. Constraint (2) ensures that each product is allocated to exactly one type of DC. Constraint (3) activates DC type d if any product p is allocated to this specific type. In Constraint (4), variable $y_{d,l}^{\text{Instore}}$ is set to 1 if at least one product of a certain store layout segment l is allocated to DC type d. The binary decision variables are defined in Constraints (5), (6) and (7).

The NDPA model is implemented in IBM ILOG Studio and solved using CPLEX v12.5. An optional post-processing stage reruns the p-median model using the solution of the DC-type selection and product allocation decision to improve the warehouse locations of the DC types selected.

3 Illustration

We implement the modeling approach with data from a major European retail chain located in Germany. The company's main assortment consists of approximately 9000 products that are sourced from about 300 suppliers. There are 36 transshipment points, which serve as local hubs for distinct subsets of stores. The transshipment points represent the demand centers in this case. Currently the company uses a three-type network design with one central warehouse, two parallel regional warehouses and six parallel local warehouses. Since the company is growing steadily, the question arises as to whether the current network still reflects the optimal configuration.

In order to evaluate the cost savings potential we investigate whether the current warehouse locations can be restructured such that total supply chain costs are minimized. For this brownfield approach new warehouse sites are disregarded. Since

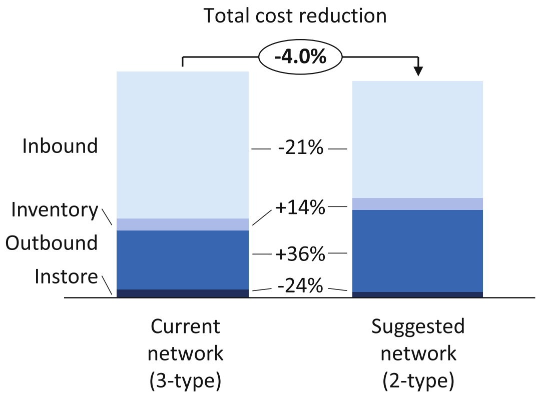

Fig. 2 Cost structure and potential savings in the case study applying NDPA

there are nine warehouse sites currently being used, the possible DC types to be chosen range from one central warehouse up to nine parallel (local) warehouses.

Our results show that 4% of total supply chain costs can be reduced if a two-type network is used instead of the current three-type network. More precisely, the configuration suggested comprises one central warehouse and five parallel regional warehouses. Figure 2 shows the cost components and the savings potential.

Besides the cost reductions that are achieved by limiting the number of DCs in use, major cost reductions can be achieved in inbound transportation by increased bundling potential if DC types are reduced. A positive effect can also be generated for instore logistics, while the more central structure means additional outbound transportation costs. Inventory costs play a minor role and increase slightly as the product allocation that is induced by the new network structure is more focused on transportation and bundling issues than on inventory pooling.

4 Summary and Outlook

In this paper we present a modeling approach for the retail network design problem with consideration of product allocations to different types of DC. We include costs arising from operating warehouses, inbound transportation, inventory holding, outbound transportation and instore operations.

The results from a case study indicate that considerable cost savings are possible when restructuring existing retail networks according to the modeling approach proposed. Additionally, the approach can be used when companies set up a distribution network in countries in which they already have a store network but no DCs.

Future research possibilities include the development of a heuristic that directly solves the integrated problem of network design and product allocation, taking into account the potential warehouse location decisions. The latter are assumed to be pre-defined in the model proposed. Other assumptions can be refined, such as including delivery frequencies based on truck loads instead of linearized transportation costs. The distinction of DC types can also be extended by including more criteria, e.g., the degree of warehouse automation and the respective costs.

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