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Formulation of customers' shopping path in shelf space planning: A simulation-optimization approach

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ABSTRACT

Numerous studies confirm that customers' shopping behavior can highly be managed by many in-store factors such that retail managers try to systematically consider them in order to achieve a well-established solution for shelf-space allocation problem (SSAP). To assist them, we develop an approach based on two artificial intelligence techniques to facilitate well-designed shelf space management. We propose an iterative simulation-optimization approach that integrates customers' shopping path in the potential demand and introduces it by simulation in the optimization. A profit-based integer programming is also presented that the related computer program, being able to solve small-sized instances, applies important factors including shelf level utility, attraction of store' zones, allocated shelf space, number of product facings, and demand substitution effects. The problem is inherently a complex and large-sized problem; therefore, we develop two algorithms: GA and hybrid GA with imperialist competitive algorithm. The experimental results prove good performance of hybrid algorithm in terms of both the solution quality and computation time. By embedding this flexible and powerful framework in an expert tool, retail managers are capable of making effective decisions.

1. Introduction and literature review

Retail management is to develop a product mix to satisfy customers' demands and to affect customers' shopping decisions (Chen & Lin, 2007). The success of a retailer depends mainly upon the ability to match the changing environment by continually deciding on how much of which products to shelve, where and when (Castelli & Vanneschi, 2014). However, decision making in retail space management is a bit complex since various dynamic factors as well as prevailing constraints have to be considered simultaneously. So, the most important concern in this context is the development of a computer-based decision support tool according to the above-mentioned factors and constraints by which retail managers can effectively decides on the replenishment, displaying, and inventory control policies.

As Reyes and Frazier (2007) stated, most shopping decisions occur in the store and only 1/3 of shopping decisions is planned beforehand; various factors like shelf location, shopping path, shelf space and levels to which the items are located can excite the customers to purchase more and consequently change their demands. Larson and DeMarais (1990), Dreze, Hoch, and Purk (1994), and Larson, Bradlow, and Fader (2007) investigated those factors and stated that showroom inventory has a mental impression on the customers; location of items on the shelves influences the customers' shopping behavior; and the amount of traffic that various zones in a store receive is not the same and the shelf location has certain effects on the items' demands.

Underhill (1999) showed that the shelf levels between eye and knee level have a positive effect on the sales. Also, since the whole aisle does not usually be visited; thus, sales at the end of aisles are increased. Larson et al. (2007) focused on the customers' shopping path and travel patterns at the store. Hui, Bradlow, and Fader (2008) surveyed the relation between shoppers' path and their behaviors in terms of the visited zones, elapsed time in each zone and purchased items. Eisend (2014) presented a meta-analysis of 1268 estimates of shelf space elasticities and emphasized the application of shelf space variation as a useful marketing tool. In the following, we investigate studies in the literature in terms of demand function components and problem solving approaches.

Hansen and Heinsbroek (1979) developed a model assuming that the only factor affects the demands is allocated shelf space and proposed a heuristic algorithm based on generalized Lagrange multipliers technique. Corstjens and Doyle (1981) first incorporated both the space elasticity and cross space elasticity in their proposed model and solved it by a geometrical programming framework. Borin, Farris, and Freeland (1994) categorized the demands

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into four key concepts and formulated the effects of marketing variables in a model. They proposed a simulated annealing to solve the model. Irion, Al-Khayyal, and Lu (2004) developed a model considering interest rates, purchasing and listing costs and solved it using LINDO software. Murray, Talukdar, and Gosavi (2010) formulated the demands using the facing areas instead of the number of facings and solved the problem with a branch-and-bound based mixed-integer nonlinear programming algorithm.

Urban (1998) was the first author that integrated the shelf space problems with inventory control decisions. By the time, all the models assumed that the shelves are kept full but his demand rate was a constant function of the displayed inventory. He developed a generalized reduced gradient and GA to solve the model. Hwang, Choi, and Lee (2005) introduced a location multiplier in the demand function and assigned a weight to each shelf level. As the solution method, they suggested a gradient search heuristic and a GA. Demand in Hariga, Al-Ahmari, and Mohamed (2007) was denoted as a function of displayed inventory involving the space and cross space elasticity and location effects; however, they allowed the showroom inventory reaches zero. The mixed integer non-linear model was solved via LINGO software.

Lotfi, Rabbani, and Ghaderi (2011) considered budget, shelf space, holding times of perishable items, and number of replenishments in a bi-objective model. They proposed a minimum-maximum approach to introduce the demands. In a comprehensive model, Lotfi and Torabi (2011) investigated critical aspects such as inventory decisions, brand variety, different size of items, and budget of the item category. They assumed the loyal demands as a minimum and constant parameter; then calculated the maximum demands as a decision variable. A heuristic method based on the problem-specific rules was applied to solve the fuzzy mixed integer non-linear goal programming model. Castelli and Vanneschi (2014) considering the number of facing proposed a hybrid algorithm to address the shop shelf allocation problem that combined GA with a variable neighborhood search.

Chen, A-L. and Chang (2005) used data mining to identify customers' behavior. By comparing two sets of association rules, the changes in customers' behavior were identified. Chen and Lin (2007) applied association rule mining, instead of space elasticity to solve the SSAP. Tsao et al. (2014) took into account space-, cross-, and promotion-elastic demand. Moreover, they modeled interactions between the retailer and the manufacturers denoted as retailer-Stackelberg game. Tsai and Huang (2015) employed radio frequency identification systems to capture customers' moving behavior. Afterward, they proposed a three-stage data mining method and solved SSAP via the well-known Hungarian method. Hübner, Kuhn, and Kühn (2016) considered a newsvendor-based decision model with demand substitution effects and showed it has an important impact on the total profit. A heuristic procedure was proposed to solve it.

Accordingly, at first, the effect of customers' movement path on the shopping behavior as a critical factor has not been considered into the formulations. In fact, the utility of store' zones for attracting the customers and encouraging them to visiting and shopping has not yet been integrated to the SSAP optimization approaches since now while it seems to have a great effect on the customers' demands. Secondly, the in-store transfer cost from warehouse to the display shelves has not been taken into account in the past works. Meanwhile, it may be an unavoidable cost since it is strongly related to the SSAP decisions. Thirdly, retailers need computer-based expert tools by which they rapidly and effectively are able to handle the best SSAP decisions regarding the dynamic market environments. Notably, this expert tool should certainly be supported by a comprehensive simulation-optimization framework as well as an efficient solution algorithm. These issues are our motivations for conducting this study.

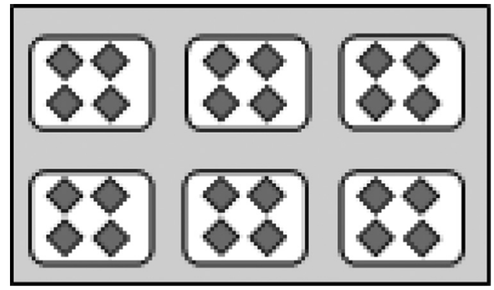

Fig. 1. A batch including 6 packages with 4 items.

This paper, for the first time, presents a new integrated demand function that simulates shopping paths to predict customers' movements in the store while simultaneously shelf level, shelf space, and substantial-and-random utilities of stores' zones are also considered. Then, a profit-based integer programming model is proposed which needs the demand variable. But, the proposed integrated demand as a complex function may not analytically be determined; so, it is calculated via simulation which evaluates the customers' movements on shopping path. Our model is inherently a SSAP considering the following aspects: (1) base and variable demands, (2) fixed and random utilities of zones, (3) in-store transfer, and (4) possibility of changing items' arrangement in shelves. After linearization, the proposed model is solved exactly by GAMS; however, no efficient exact algorithm exists to find the optimal solutions, even for the medium-sized instances. Hence, at first, we try to solve medium- and large-sized instances by GA as the most popular meta-heuristic algorithm. Then, we improve the GA performance to solve SSAP through hybridizing with Imperialist competitive algorithm (ICA). The GA power in achieving near-optimal solutions and the high speed of ICA toward convergence help that computation time is significantly decreased. Performance of the proposed solutions is compared in terms of solution quality and computation time using several numerical examples of different sizes. The results confirm that the achieved optimality is acceptable compared to the exact algorithm and better than GA. We believe that the proposed approach as an expert tool helps retail manager to have effective responses.

The rest of the paper is organized as follows. In Section 2, the mathematical model and linearization are described. Then, the simulation method for the potential customers' demands is developed in Section 3. In Sections 4 and 5, the solution methods are presented and analytical results and managerial insights are reported. We close with a conclusion and suggestions for future research.

2. Mathematical model

In this section, we develop a model to allocate various brands of items in different categories to multi-level shelves of limited spaces. In the profit objective function, transfer cost from the store's warehouse to display shelves is also involved. Generally, items in the store are organized in the form of some batches containing some packages with fixed size (see Fig. 1) and transferred gradually from warehouse into the shelves. As usual, after selling a batch of each item, another batch is replaced unless no stock is in warehouse. The store is divided into several zones whose attractions are considered to be different. The customers' demand may be divided into: (i) fixed pre-estimated loyal customers' demand and (ii) variable demand due to the potential customers and substitution. The demand of potential customers depends mainly upon the store conditions such as the zone in which the shelf located and the shelf space and levels to which the items are allocated.