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# Shelf space re-allocation for out of stock reduction

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A B S T R A C T

A planogram is a detailed visual map that establishes product positions over a shelf in a retail store. It is designed to support an innovative merchandising approach, to increase sales and profits, to supply the best location of a product for suppliers and to better manage the shelves. Product selection and the shelf space reserved to each product is a central activity for retailers and Shelf Out of Stock (SOOS) events are often strongly related to planogram design. In this paper we present a solution to optimally re-allocate shelf space to minimize Out of Stock (OOS) events. The approach uses SOOS data coming in real time from a sensor network technology, named Shelf Detector System, and an Integer Linear Programming model that integrates a space elastic demand function. Experimental results, based on a real scenario in the diaper category in Belgium, have proved that the system can efficiently calculate a proper solution able to re-allocate space and reduce OOS events.

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## 1. Introduction

Shelf space optimization is a main topic in retail industries. Product selection as well as Shelf Space Allocation (SSA) are central activities for the retailers. There is the need for a retailer to offer the best assortment of products for the customers to satisfy their needs and to maximize his/her profits. Indeed, in a free choice system for customers, the retailer aims to stimulate also the purchases of products even if they are not really in the customer's needs. Many products are positioned, according to strategic choices, to make them more attractive (e.g., strawberries and whipped cream are usually positioned side by side) and therefore to increase the sales (see Abbott & Palekar, 2008). The retailer's effort, however, is frustrated by out-of-stock (OOS) events, i.e., the absence of a product on the shelf where the customer usually looks for it. In such situations customers usually behave in four different ways:

- buy a substitute product (same or different brand),
- postpone the purchase,
- resign the purchase,
- buy the product in another store.

The first two customer reactions generally entail a negligible loss of profit for the retailer whereas in the third and fourth case there is a missed sell and, in the worst case, even the lost of the customer for future purchases. It is generally recognized that OOS events cause substantial loss of profits for the retail industry. Hausruckinger et al. (2003) quantified such loss in 4 billions of euros per year in the past decade and this strengthen the importance of facing the shelf space allocation problem.

A product can be OOS because of either (*i*) it is not present in the store warehouse or (*ii*) it is present in the store warehouse but the shelf is not been refilled yet. In the former case the shortage of the product for the replenishment is due to external logistic reasons (e.g., mistakes during the orders, delay of the suppliers, out-of-date of perishable goods, etc). In the latter case the OOS depends on internal logistic issues that involve employees, store manager and refill planning policy.

The external logistic decisions usually influence the store environment in the medium-term and they consider endogenous aspects (e.g., retail supply chain issues, customer behavior and supplier choice). The forecasting models used to support the managers' decisions usually use aggregate demand functions (which leads to a constant selling rate) and see the store as a black box. On the contrary, the sell out of the store is influenced by promotions and discount campaigns as well as seasonal needs and variety of the assortment. Main causes of OOS events, according to Aastrup and Kotzab (2010), are inadequate space allocation, inexperienced personnel and ordering routine. Aastrup and Kotzab (2009) computed the impact of these causes in 98% of the cases. So the forecasting models are strongly influenced by aleatory factors.

On the other hand, internal logistic issues mainly face short-term decisions as warehouse management, replenishment organizations and costs, and staff-related issues (availability, scheduling,

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...). Refilling costs depend largely from frequency and management of the shelf replenishment operations, store layout and personnel costs. The employees are usually a scarce resource and the refill task is not scheduled with high priority in the task list. Under these conditions the optimal store managing is a very dynamic context in which routing and scheduling aspects play an important role. These aspects need the support of an appropriate IT structure as well as an adequate know-how for the store managers.

Alternatively, refilling cost reduction (and consequently profit increasing) can be obtained by an effective and efficient reallocation of products to the shelf that takes into account data durations and occurrences related to OOS in the short term. This paper faces the SSA problem through product reallocation using statistical data about sell out and OOS events.

This work is part of a project going on from several years in agreement between the italian SME Grottini Advanced Retail World (Grottini, 2015) and the Department of Information Engineering at the Università Politecnica delle Marche. This cooperation allowed the design and testing of several tools, which are also part of this paper, for retail analytics. In particular, in Frontoni, Mancini, Zingaretti, and Placidi (2014), Frontoni, Mancini, and Zingaretti (2015), the authors presented a novel embedded sensor network for planogram maintenance and for OOS detection, while in Frontoni et al. (2013), Liciotti, Contigiani, et al. (2014) and Liciotti, Zingaretti, and Placidi (2014) details of an intelligent system for customer behavior analysis have been proposed. All data coming from this system are used by a Decision Support System (Mancini, Frontoni, Zingaretti, & Placidi, 2013) to improve store performances and store/product layout or to improve shopper knowledge (Sturari et al., 2016).

This paper introduces the first Operational Research approach exploiting these data. We present an integer linear programming model that optimally re-allocate the shelf space on the base of Shelf Out of Stock (SOOS) and sell-out data coming in real time from a sensor network technology, named *Shelf Detector System* (SDS).

The paper is organized as follows. Section 2 illustrates the SSA problem and the hypotheses underlying the approach presented in the paper. A brief literature review is presented in SubSection 2.1. Section 3 presents the data collected and the parameters computed. Details of the proposed mathematical model are presented in Section 4. Implementation details and test results for both real and random instances are presented in Section 5. Conclusions are drawn in Section 6.

## 2. The Shelf Space (re-)Allocation Problem

Shelf Out of Stock (SOOS) events are often strongly related to *planogram* design (a planogram is the way how the stock keeping units (SKUs) are organized among the shelves).

An SSA solution aims to a better organization of the planogram to reduce OOS events. During a store day-life the planogram changes its level of available products and data can be collected from the shelves to monitor which product suffers more OOS events. Fig. 1 shows an example of a diaper planogram. Planograms are usually described in a standard data format. An XML file is the typical format of several planogram description softwares available in the market. The most famous is Spacemen, distributed by Nielsen (2015).

Considering the logistic and commercial aspects of the problem, the design of a planogram is faced in literature mainly in two ways. The first way expresses the demand of a product according to the model formulated by Corstjens and Doyle (1981). In this article the demand of a product is expressed as the space allocated to it and to its competitors using a function that takes into account the space elasticity and the cross-space elasticity. These two parameters are computed through regression analysis of the cross sectional data. The main idea behind this model is that the demand of a product increases according to the space reserved to it.

The second way to approach the SSA problem is to use the substitution demand model (Lancaster, 1966). The idea behind this model is to forecast the behavior of the customer when he does not find his preferred product on the shelf or to guide his preference during the purchase in the shop.

The aim of both these approaches is to maximize profits trying to minimize OOS events and offering the best assortment of products, which is mainly defined according to revenue, substitution policy and external contracts. More details about these approaches are presented in SubSection 2.1.

The study in this paper leads to an operative approach starting from the planogram previously designed and using the planner's results. Exploiting the SDS we have access to sell out data of about a hundred stores in a period of almost two years. This processing produces an amount of available statistical data highlighting the strong and the weak points of the actual planograms. Since we are not interested in redefining the assortment, a variation of the actual planogram is the only possible solution.

An issue related to the SSA problem is the internal logistic management. As analized in Aastrup and Kotzab (2010) the staff-related issue is one of the causes related with on shelf availability of a product. Collecting information from the last 40 years of researches, the "shelf service level" decreases of about 5–6% in the store. In fact, the shop assistant has many tasks to accomplish, among which shelf replenishment operations. Replenishments can happen as ordinary or extraordinary operations. The former happen periodically based on a daily or weekly schedule independently by the shop status (open or closed). The latter happen during the opening hours of the shop and it has to be scheduled together with the other tasks of the job description, and it is not taken for granted that the personnel can accomplish it. This issue is related to staff training, human resources management and workforce. In this paper we will not investigate this issue supposing that the workforce is fully absorbed in the daily task, it cannot be strengthen and the refill of a product happens just during an ordinary refill operation.

The approach described in this paper finds the best variation of the facing assigned to a product to maximize potential sell out and logistic cost savings, according to sell out statistics retrieved during a time period previously defined. In fact, it is possible to compute the maintenance cost of the shelves by analyzing the data. The SDS can detect when a product is OOS and when it is refilled on the shelf giving the period in which the product is unavailable. For the retailer each refill operation is a cost that can be computed considering the time that the shop assistant needs to fulfill this task and the hourly cost for the staff. By counting the OOS events in the time frame considered, it is possible to compute the total refilling cost of the product. Even if each product has a different refilling time we will assume that it is the same for each product in the same category.

Since the shelf length is established, increasing the number of facings of a product leads to a reduction of the number of facings of another one. Increasing the facings for a SKU can lead to a cost reduction of this product, but it goes to the detriment of other items in the same shelf. Consequently, the reduction of SOOS for a product can lead to a worst solution where the total managing cost increases due to the SOOS of other products. A function (or parameter) that expresses the SOOS probability can be used to prevent this situation or the analysis of the data can be used to define appropriate parameters that lead the model to a better configuration of the shelves. This aspect of the problem is modeled using

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