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Invited Review

# A classification of the literature on the planning of substitutable products ☆

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ABSTRACT

A company's assortment of products and corresponding inventory levels are constrained by available resources, such as production capacity, storage space, and capital to acquire the inventory. Thus, customers may not always be able to find a most preferred product at the time of purchase; this unsatisfied demand is often substituted with an alternative. In the extant literature, there have been an increasing number of studies that consider product substitution when planning product assortment, inventory, and capacity, in conjunction with pricing. In this paper we classify the literature on the planning of substitutable products published in the major OM and marketing journals during the past thirty years (1974–2013) and present a comprehensive taxonomy of the literature. One criterion is adopted to discuss modeling objectives, and three major criteria are provided to define the nature of product substitution, including substitution mechanism, substitution decision maker, and direction of substitutability. We also identify research gaps to provide guidance for related research in the future.



## 1. Introduction

Product substitution in general refers to "the use of one product to satisfy demand for a different product" within a specific product category (Chopra & Meindl, 2010). Although the concept of a "category" of merchandise is not well defined (Van Ryzin & Mahajan, 1999), the term refers to a group of homogeneous or similar products composed of alternative attributes (such as color, size, and speed variations). The phenomenon of product substitution has recently gained considerable attention in the operations management (OM) literature because it affects the effectiveness of companies' decisions with material/product planning, pricing and control.

The primary objective of this paper is to delineate the studies on assortment, inventory, capacity, and pricing of substitutable products. Specifically, we break down the current literature by the four major criteria: modeling objective, substitution mechanism, direction of substitutability, and substitution decision maker. A comprehensive taxonomy is developed not only to enhance understanding of the common characteristics in product substitution models but also to help identify the dearth in the literature which necessitates future research.

The terms, *choice* and *substitution*, are often used interchangeably in the literature, creating ambiguity. It is necessary to understand the semantic variations of these terms. "Choice" frequently refers to choice within a product category (assortment), and the term is popular in the product assortment problems (Mahajan & van Ryzin, 1999). Likewise, "substitution" may refer to the act of switching from one product to another in the assortment, choosing an alternative voluntarily that may not be the first choice (Gaur & Honhon, 2006). For instance, customers may exhibit probabilistic preference of one alternative to another, and customers' probabilistic choice is associated with customers' unpredictable behavior to a certain degree. In this case, a voluntary substitution happens even if the first preference is in stock. This concept of *substitution* is technically identical to the meaning of *choice*. The other semantic usage of *substitution* is associated with choosing a substitute when the first choice is out of assortment or out of stock (Kök & Fisher, 2007; Yücel, Karaesmen, Salman, & Türkay, 2009). Since our objective is to provide a clear taxonomy of the literature, we try to adhere to stricter definitions of choice and substitution. The term *choice* in the present study refers to

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the initial choice or a preferred product in the given assortment at the time of purchase. *Substitution* refers to the act of selecting any other alternative (substitute) when the preferred choice is unavailable.

The rest of the paper is organized as follows. In Section 2, we explain the modeling objectives and the nature of problems in general – assortment planning (AP), inventory decision (ID), capacity planning (CP), and pricing decision (PD) – associated with product substitution. In Section 3, we explore a set of specific criteria to classify the relevant literature, and we provide a detailed survey of each class. In Section 4, we summarize technical details of the methodology, such as objective functions and constraints. Finally, we provide suggestions for future research in Section 5.

## 2. Product substitution modeling objective: the areas of decisions

In order to create a taxonomy of product substitution research, we begin our discussion with the following scenarios.

**Scenario 1.** A customer wanted to purchase a Brand-A pain reliever. While visiting a drug store, the customer realized that a new pain-reliever had been released. Rather than purchasing the Brand-A pain-reliever, the customer decided to try the new pain-reliever.

**Scenario 2.** The most popular 2 gigabyte flash drives are almost out of stock due to the recent fire at the supplier's factory. The management of a computer manufacturer decides to substitute 4 gigabyte flash drives for 2 gigabyte ones to continue production.

**Scenario 3.** A customer who plans to visit China recognizes that prices of economy class tickets have increased significantly, owing to a sharp increase in demand for the route. Although the customer's initial choice is a seat in the economy class, the customer reserves a business class seat.

The above scenarios describe various mechanisms for product substitution, *i.e.*, substitution mechanism. We use the term, *substitution mechanism*, to describe explicit stimuli that may incite to customers' or suppliers' product substitution behavior. In Scenario 1, the customer voluntarily chooses a substitute, triggered by the fact that the substitute is newly added in the assortment. This type of substitution mechanism can be best described as assortment-based substitution. Strictly speaking, the action of choosing an alternative out of the pull of substitutable products is customers' choice problem. Diverse patterns of consumers' choice lead to an assortment planning problem for the retailer who must decide upon the collection of products to maximize its revenue or profit.

If demand for a specific product could not be met, the demand remains unfulfilled or it may be fulfilled with a substitute as illustrated in Scenario 2. In other words, stockouts of a customer's first choice motivates the customer to defer the purchase or to choose available substitutes. This scenario is an example for inventory-based substitution mechanism. The company must make optimal quantity (or lot-sizing) decisions, considering substitution among the products, in order to minimize the total inventory costs which may include shortage cost. Scenario 3 is unique because the customer's substitution behavior is driven by a change in the relative price of substitutable product. This type of substitution mechanism is named price-based substitution. Since a particular product's price affects the demands for other substitutable products, the company must identify the optimal pricing policy to maximize its revenue or profit. The details of these substitution mechanisms will be described again in Section 3.

Using various substitution mechanisms described in the scenarios above, researchers have focused on the four areas of decisions: assortment planning (AP), capacity planning (CP), inventory decision (ID), and pricing decision (PD) as illustrated in Fig. 1 as well as the first column of Table 1. A number of studies deal with joint problems, combining two or more areas of decisions.

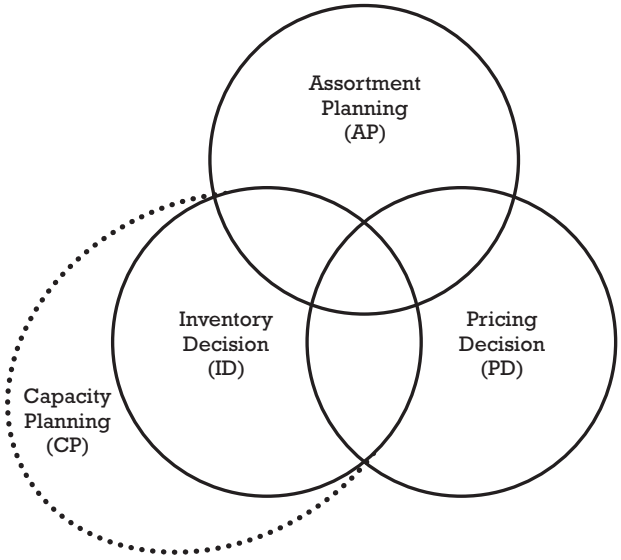


**Fig. 1.** Area of decision and modeling environment under product substitution.

### 2.1. Assortment planning (AP)

Assortment planning (for retailers in particular) is to define a set of substitutable products to carry in the assortment which usually represents a homogeneous product category. In the simplest form of assortment planning, prices of products are fixed constant, and the primary decisions are binary – whether to include a certain product into the assortment or not. Due to resource constraints such as budget and space, retailers are unable to offer a complete selection of products with unlimited inventory levels, a strategy that has many advantages from a marketing perspective (Quelch & Kenny, 1994). One of the benefits of adding variants to an assortment is to increase the likelihood that consumers will purchase something from the assortment (Van Ryzin & Mahajan, 1999). On the other hand, offering a full-range assortment is likely to entail substantial costs, including costs for inventory, shipping, and merchandise presentation (Smith & Agrawal, 2000). More alternatives reduce the volume of demand for each variant and increase the relative variability of demand for each variant (Van Ryzin & Mahajan, 1999). Substitution among products makes it possible for a retailer to maximize profit with an assortment that is smaller in range than the entire product population. Thus, it may not be beneficial for a rational profit maximizer to offer a full-range of assortment to capture all demand.

In the assortment planning problems, the demand function is known or deterministic, and product substitution is readily possible at a certain degree of substitution cost. It is also assumed that product variants carried are horizontally differentiated. Identical prices and costs are often incorporated for modeling convenience (Van Ryzin & Mahajan, 1999). However, several models relax these assumptions of identical prices and costs. For example, Li (2007) develops a generalized model with unequal cost parameters. Pentico (1974) considers probabilistic demand patterns with stockouts, substitutions, and holding costs, and Pentico (1976) extends the assortment problem by adopting a non-linear cost function. Pentico (1988) also explores a two-dimensional substitution problem; for example, both length and strength might be evaluated when choosing a steel beam.

In another stream of research, assortment planning is integrated into inventory decision problems (joint decisions of product assortment and inventory). The width of assortment and the depth of inventory tend to move in opposite directions under customers' substitution behavior. Indeed, an increasing number of studies have recently investigated the joint decisions of assortment and inventory. These