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A multi-objective model for inventory and planned production reassignment to committed orders with homogeneity requirements

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ABSTRACT

Certain industries are characterized by obtaining non-homogeneous units of the same product. However, customers require homogeneity in some attributes between units of the same and different products requesting in their orders. To commit such orders, an estimation of the homogeneous product to be obtained can be used. Unfortunately, estimations of homogenous product quantities can differ considerably from real distributions. This fact could entail the impossibility of accomplishing the delivery of customer orders in the terms previously committed. To solve this, we propose a multi-objective mathematical programming model to reallocate already available homogeneous products in stock and planned production to committed orders. The main contributions of this model are the consideration of the homogeneity requirement between units of different lines of the same order, the allowance of partial deliveries of order lines, and the specification of some relevant attributes of products to accomplish with the customer homogeneity requirement. Different hypotheses are proved through experiments and statistical analyses applied to a ceramic tile company. The ε-constraint method is used to obtain an implementable solution for the company. The weighted sum method is used when proving other hypotheses that offer some managerial insights to companies.

1. Introduction

Customers usually express requirements in their orders in terms of quantity and delivery date. However, several situations emerge where customers require homogeneity among units of the same product or different products for certain attributes that are relevant for them. These attributes refer to functional or aesthetical reasons because units of the same or different products need to be assembled, packed or presented together. For instance, customer orders in the agricultural sector should be served with units of the same fruit belonging to the same quality, size and weight. This is also valid for the furniture sector, where colour uniformity among units of the same product (e.g. chairs) or among products (e.g. chairs and table) impacts the final value of the products perceived by customers. Thus, colour and grain sorting are necessary.

Another example is the ceramic sector, where the nature of the raw material (clay) and components (frits and enamels) employed during ceramic tile production, and the variability of the environmental conditions during this process, means obtaining units with different tone, gage and quality attributes from a unique production batch (Alemany, Alarcón, Ortiz, & Lario, 2008; Grillo, Alemany, & Ortiz, 2016). In this sector, customers require product homogeneity for quality, tone and gage for all the units that compose an order line. Customers also require gage homogeneity for units of different order lines that are to be jointly installed for functional and aesthetic reasons. To ensure serving customer orders with the required homogeneity, classification stages are included during production processes.

The causes that generate product heterogeneity are mainly uncontrollable because the non-homogeneity of the raw material and components usually coming from the nature or the productive process itself. The above aspects make the homogeneous quantities of each product in planned production batches to be uncertain. In such a way, that only the homogeneous quantities of stocked products are really known. However, the Order Promising Process (OPP) should decide based on both, the uncommitted availability of products in stock and in planned batches, which customer order proposals to be committed and an accurate due date for them (Kiralp & Venkatadri, 2010). For this reason, the distribution of production batches into homogeneous sub-lots should be estimated during the OPP. However, due to the inherent aforementioned uncertainty, discrepancies between the estimated homogeneous quantities in batches and real ones are quite likely to occur. This circumstance can lead to some orders committed during the

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OPP not being served as there is not enough quantity of homogeneous product, although enough total quantity exists. This shortage situation can occur even with high stock levels and causes a poor customer service level since it is caused by homogeneity requirements (HR). One solution would be to simply refuse any orders that cannot be served (Fung, Cheung, Lee, & Kwok, 2005). However, this decision could very negatively impact both the customer and the company, so better solutions for the shortage problem are necessary.

One solution for minimising this problem is Shortage Planning (SP), which refers to the activities to be performed if stock becomes unavailable (Framinan & Leisten, 2010). Some examples of SP activities are negotiation with customers (late supply, partial shipments, etc.) and decisions about supply alternatives (outsourcing, substitutive products, etc.). Another possible solution to this problem is reallocating inventories to previously committed orders to improve the customer service level and to increase profits (Alarcón, Alemany, Lario, & Oltra, 2011; Lee, Jung, Eum, Park, & Nam, 2006). Other strategies to improve customer satisfaction, such as postponement, are not possible in this case. The reason is that postponement attempts to delay product differentiation as much as possible until orders are received (Kisperska-Moron & Swierczek, 2011) in order to face uncertainty in customised orders. Delayed product differentiation has proven capable of reducing inventory requirements and ensuring high product availability at the same time (Lee, Billington, & Carter, 1993). However, in the problem under study, uncertainty is not on the customer orders' side because we deal with already committed orders and, therefore, known with certainty. On the contrary, uncertainty is on the supply side, because of the final availability of homogeneous quantities cannot be known until they have been produced and classified.

In this paper, a multi-objective mathematical programming (MOILP) model to reallocate available homogeneous stocked and planned quantities that are already committed orders in ceramic companies is proposed. Although some publications have addressed the SP problem in the ceramic sector (Alemany, Alarcón, Oltra, & Lario, 2013; Alemany, Grillo, Ortiz, & Fuertes-Miquel, 2015; Boza, Alemany, Alarcón, & Cuenca, 2014), none has considered HR among units that comprise different order lines, nor the allowance of partial deliveries of order lines, which are some of the novelties of this proposal. This requires not only the differentiation among the homogeneous sublots from the same batch (as previously done), but also the attributes specification for each sublot. This model pursues maximisation of profits and minimisation of order lines served with delays, plus minimisation of the partial deliveries of order lines. The consideration of the last two objectives, as well as the combination of all the objectives, is another contribution of this paper. Some hypotheses are proposed that provide some managerial insights. The model is executed for a different set of scenarios, whose results are statistically analysed to prove the proposed hypotheses.

The rest of the paper is structured as follows: Section 2 describes the problem under study, while Section 3 presents a literature review on the SP problem. Section 4 introduces the MOILP model, which is validated through an experimental design applied to a ceramic tile company in Section 5. Finally, Section 6 offers the main conclusions and the identified future research lines.

2. Problem description

The starting situation contemplates the existence of orders previously committed to customers by means of the OPP. In an ideal situation where the homogeneous planned and real quantities coincide, customer orders are delivered during execution activities as promised. However, discrepancies between the planned and real homogeneous quantities usually occur due to the uncertainty in the homogeneous quantities of the same product in planned production batches. When this happens, it is necessary to verify that the obtained homogeneous quantities are sufficient to serve already committed orders. If not, it will not be possible to serve all the committed orders as previously planned.

To solve this situation, the reallocation of updated available homogeneous quantities both in stock and planned to already committed orders is proposed to minimise the negative impact for both the company and the customer. This reallocation process should meet not only the committed quantity and due date as usual, but also the HR among the units that comprise an order line in all its attributes, and among the units of different order lines that belong to the same series in the gage attribute.

The characteristics of the company and products, customers, orders and delivery flexibility involved in the problem, as well as the reallocation objectives, are described below.

Company and product characteristics:

- The existence of a ceramic production plant composed of several parallel production lines that work according to a Make-To-Stock strategy is assumed.
- The products, once produced, are classified into homogeneous sublots based on their attributes: quality, tone, and gage.
- The products that can be assembled together belong to the same series (e.g. units of two ceramic tiles products which are combined to form a mosaic floor, or units of ceramic skirting boards and ceramic tiles for paving which are assembled together).

Availability of products:

- The existing stock and planned quantities to be produced in the Master Production Schedule (MPS) are used during the reallocation process, but only for first quality products.
- The stocked quantities at the beginning of the planning horizon are already classified into homogeneous sublots. So, their attributes (tone and gage) are known.
- The production batches defined in the MPS (planned batches) are divided into different homogeneous sublots by an estimated distribution. The sum of all homogeneous sublots of a batch must equal the batch size.

Customers:

- The orders previously committed during the OPP (firm orders) are considered for reallocation.
- Two types of customers are distinguished when reallocating available homogeneous quantities to already committed orders: priority and non-priority customer orders.
- An order can be composed of one order line or more. For each order line, the required product and the demanded quantity are detailed. The same finished product can be claimed in more than one order line (e.g. two lines of an order can demand the same product if these quantities are to be assembled separately), but only one product can be requested in each order line.
- The committed due date for each order is known and previously agreed on with customers through the OPP. It is the same for all their order lines.
- An order line must be reserved with a homogeneous product so that all units of the product must have the first quality, and the same tone, and gage, but customers do not specify the tone and gage requested in their orders.
- The order lines with the products that belong to the same series must be booked with the products that present the same gage.
- An order can be served only if all the lines that comprise it are served.

Flexibility in delivery:

- A maximum delivery delay is defined for each order. The real delivery date of an order after the reallocation process is comprised