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# Production planning and scheduling in the glass container industry: A VNS approach<sup>☆</sup>

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## ABSTRACT

Inspired by a case study, this paper reports a successful application of VNS to the production planning and scheduling problem that arises in the glass container industry. This is a multi-facility production system, where each facility has a set of furnaces where the glass paste is produced in order to meet the demand, being afterwards distributed to a set of parallel molding machines. Since the neighborhoods used are not nested, they are not ordered by increasing sizes, but by means of a new empirical measure to assess the distance between any two solutions. Neighborhood sizes decrease significantly throughout the search thus suggesting the use of a scheme in which efficiency is placed over effectiveness in a first step, and the opposite in a second step. We test this variant as well as other two with a real-world problem instance from our case study.

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## 1. Introduction

Inspired by a case study, a variant of the variable neighborhood search (VNS) is introduced to tackle the production planning (especially lotsizing) and scheduling problem (PPS) that arises at the long-term planning level of the glass container industry. A typical company has several plants equipped with furnaces. Each furnace distributes glass to a set of parallel molding machines. The production planning main constraint is the color of glass melted in the furnace. The goal is to define a 12 month rolling horizon plan that assigns colors to furnaces, schedules color campaigns within each furnace, and assigns products to machines monthly. Due to the very high sequence dependent setup times in color changeovers, color campaigns lotsizing and scheduling have to be done simultaneously. Furthermore, products cannot be

aggregated into families, thus increasing the complexity of the problem. Only major setups (multiple family joint setups) are considered, i.e., changeovers between two products sharing the same color are disregarded. The review (Karimi et al., 2003) pinpoints the scarce literature devoted to lotsizing and scheduling problems with family joint setups, regarded as an interesting research area to develop heuristics. (Schaller, 2007) considers the problem of scheduling on a single machine when family setup times exist, but the author does not deal with lotsizing.

Many real-world production planning problems are combinatory and multi-objective by nature. Modeling even simplified abstractions of those problems often leads to untractable NP-hard problems (see, for instance, (Bouchriha et al., 2007) for the capacitated lotsizing problem (CLSP) that appears on a paper machine). Consequently, several heuristic procedures have been proposed over the years to solve large scale instances. Local search (or neighborhood search) heuristics are improvement algorithms that start with an initial solution and try to find iteratively better solutions in the neighborhood of the incumbent solution. Naturally, both their effectiveness and efficiency are closely related to the

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neighborhood structures used. Several frameworks have been developed to improve the performance of local search heuristics, avoiding the entrapment in local optima through different search schemes that cross barriers in the solution space typology. VNS is a recent local search based approach that makes use of systematic changes of the neighborhood structure during the search (Hansen and Mladenovic, 2001).

Throughout the search, neighborhood sizes decrease significantly, thus suggesting the use of a scheme in which efficiency is placed over effectiveness in a first step, and the opposite in a second step. We make use of a new empirical measure to assess the distance between two solutions that allows us to order different neighborhoods. This new VNS scheme combines features of other two, to obtain a compromise between efficiency and effectiveness.

In Section 2 we first present the glass container production system and the production planning and scheduling problem that arises at a tactical level. We then propose an exact formulation of this problem. In Section 3 we explain the solution approach to tackle this problem. Numerical experiments are given in Section 4. The paper ends with a short summary and outlook.

## 2. Production planning and scheduling problem

In this section we present the production planning and scheduling problem that arises at a tactical level in the glass container industry and describe a suitable model to formulate it.

### 2.1. Production system

We are dealing with a multi-facility production system, where each facility (plant) has a set of furnaces where the glass paste is produced in order to meet the demand. The glass paste is continuously distributed to a set of parallel molding machines that shape the finished product (see Fig. 1).

Each molding machine has several characteristics that restrict the set of products which can be allocated on it. Moreover, both the number and the type of mold equipments may also limit the number of machines on which a product can be allocated at the same time. Only one color of glass can be produced at any time in each furnace. Machines served by the same furnace produce only one color of glass containers at a time. Additionally, there are high sequence dependent setup times involved in color changeovers (e.g., the color changeover from cobalt blue to emerald green takes 120 h), clearly inducing color long runs and, therefore, furnace color's specialization. There is little freedom for varying output to match fluctuations in demand since furnaces and machine lines operate on a 24h, seven days a week basis. Due to economies of scale in natural gas consumption and structural constraints, machine idleness is not allowed and, consequently, machines fed by the same furnace must process during the same amount of time. Each machine can only run one product at a time.

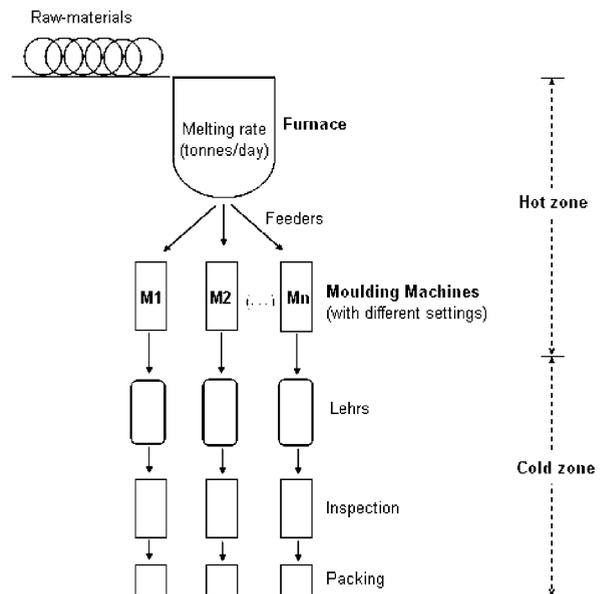


Fig. 1. Glass container production process layout.

The formed containers are then passed through a reheating kiln (“lehr”), a strict automatic inspection and a palletizing operation. A thorough description of the glass container manufacturing process and its constraints is held in Almada-Lobo et al. (2006).

We note that the production planning is only constrained by the hot area (see Fig. 1) of this semi-continuous manufacturing process.

Following the hierarchy proposed in Almada-Lobo et al. (2006), the production planning process is decomposed in two broad levels: long-term planning, with a tactical nature, and a more operational short-term planning. Richard and Proust (2000) focus on the short-term planning. This paper deals with the upper level, whose general management objectives are to maximize met demand and facilities' throughput, and to minimize inventory levels. We will tackle this multi-objective optimization problem by combining various objectives into a single-one, by means of a weighting function a priori defined by the decision maker.

This level's output is a 12 month rolling horizon plan that assigns colors to furnaces, schedules color campaigns within each furnace, and assigns the products to machines monthly (at this level, monthly product demand forecasts are provided). Fig. 2 illustrates a partial plan for the first month of two furnaces: A and B with three and five machines, respectively. For instance, the product with reference O104 will be produced on machine A1 for three days within the first color campaign of the first period.

As discussed in Almada-Lobo et al. (2006), the machine balancing constraints and the technology differences between machines (even those of the same furnace) do not allow us to aggregate machines into furnaces. Moreover, we do not aggregate common technology and color products into families, apart from other reasons, to avoid

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