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A DSS for production planning focused on customer service and technological aspects

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ABSTRACT

Production planning and control in manufacturing systems cover several aspects, at different hierarchical levels, including decisions on production and inventory quantities, resource acquisition, production allocation and sequencing. We consider a problem that is typical of companies that manufacture products in production plants placed in different production areas worldwide. A solution framework for the production allocation and balancing problems based on mathematical programming is proposed. Its computational efficiency is improved using techniques from constraint programming, in order to make it possible to solve real world instances of the problems. An industrial test case is used as a benchmark to prove the effectiveness of the proposed approach.

1. Introduction

Production planning and control in manufacturing systems cover several aspects, at different hierarchical levels, including decisions on production and inventory quantities, resource acquisition, production allocation and sequencing. Consequently, different and often contrasting objectives can be pursued; as well as several constraints may need to be considered. In this paper, we address the case of a manufacturing company with production sites spread on a global scale: once a set of orders is given, each characterized by a certain due date, they must be allocated to the production sites and scheduled over time in order to fulfill both customer satisfaction and technological requirements. We present a decision support system (DSS) being developed to provide production managers with an effective tool for this task. The DSS is a software package based on mathematical programming models defined and solved within a user customizable decision framework. Customer satisfaction aspects include two main issues: respect of the agreed due dates and quality level requirements. The decision system considers the former as a strict constraint, while the latter translates into a set of production sites approved by each customer. Hence, not all production orders can be manufactured in any site. Furthermore, there might be a preference level among the sites allowed for a given order. On the other hand, technological requirements are related to production and logistics-related issues, such as the opportunity to group similar products in a same production site as well as optimize the usage of resources and materials available at each site.

Decision support methods have been developed in the literature over the last years to address the ever-growing need for enterprises to manage worldwide spread activities. Supply chain planning involves several aspects at different hierarchical levels; they have been classified, among the others, in [1] as: strategy, major resources capacity planning, tactical production planning, scheduling, execution and feedback. This work addresses tactical production planning and scheduling issues. Trial-and-error approaches are often adopted in this area, as described in detail in [2]. Mathematical programming techniques in general and linear programming in particular have been widely used for production planning issues since the 1960s, see [3] for instance. Since from those early years, however, it appeared clear how managing the whole production as a single, monolithic problem was not an efficient solution to realize effective decision support systems. In [4], for instance, the problem was already divided into three different levels: strategic planning, management control and operations control. Linear programming-based production planning tools typically operate at a higher, aggregate production level. In order to address production planning problems at a deeper detail, integer and, often, binary variables need to be introduced into the mathematical model. This leads to more complex models such as the ones described in [5]. A thorough analysis of planning and scheduling applications as applied in both manufacturing and services industries can be found in [6].

Several approaches exist to decision-making and DSSs can be adapted to various domains. Hence, a DSS can be defined and developed following different approaches. According to [7], a DSS

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is simply *a computer-based system that aids the process of decision making*; in more precise terms, [8] defines a DSS as *an interactive, flexible and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface and allows for the decision maker's own insights*. We designed a DSS that is intended to help the decision maker take his decisions using results coming from data analysis and mathematical programming-based optimization procedures. The DSS is being tested on actual case studies and promising results are presented in the paper, along with hints for future improvements and investigations.

The paper is organized as follows. Section 2 synthetically describes the addressed problem, along with possible scenarios where such a problem might be encountered. The problem is then decomposed and the proposed approach for the two subproblems is analyzed in Sections 2.1 and 3.4. The developed decision support system and its application to a test case coming from the furniture manufacturing sector are described in Sections 4 and 5, also providing computational results. Final remarks and possible future developments are shown in Section 6.

2. The problem

The production planning problems found in any large manufacturing company typically encompass aspects that can be addressed at several levels and using different approaches and techniques. Let us consider a firm that has its headquarters in Europe, for instance, and several manufacturing plants both in Europe and in more cost-effective countries such as China, Brazil, Vietnam, India, etc. Such a company will surely have to coordinate both material and information flows among its facilities. Several commercial solutions exist that address such problems using a general purpose approach, using best practices for instance. We rather focus on production specific aspects that are often ignored or roughly treated by such tools.

Production plants spread over a world wide scale are often effectively grouped into production areas in order to optimize logistics and supply chain related issues, such as raw materials provisioning. We hence define a production area as a set of plants located within a relatively small geographical region, such as South Europe, East Europe, China, South America, etc.

We consider two succeeding problems: (1) given a set of orders to be manufactured within a mid-term time horizon (such as a week), each order already assigned to a given production area, a specific production plant has to be determined in order to optimize both technological and quality requirements; (2) manufacturing activities within each plant have to be balanced throughout smaller time units (such as days in the considered example).

2.1. Production allocation

Orders can be typically assigned to a production area by a standard, commercial MRP software, where maximum emphasis is placed on material flows and supply chain coordination, optimizing the availability of materials when and where needed. What we propose is an extremely configurable production allocation tool, that helps the user decide where to manufacture each production order within a certain area and in a given time horizon, after the orders selection for the area/time interval has already been done by a standard MRP.

Many aspects need to be considered when addressing such a problem, including very business-specific details such as technological constraints, quality requirements, plant-related skills, etc. We propose a decision support system based on mathematical programming and constraint programming that allows the user to specify, with an arbitrarily deep detail level, all the aspects to be included in the allocation procedure.

3. The proposed approach

The basic allocation unit from a user perspective is a production order, hence an item to be manufactured in the production area within the given production time interval. Actually, each production order can usually be decomposed into the production phases that can be individually assigned to different departments inside the same plant or even among different plants. Hence, the very basic allocation unit for the allocation problem is a *task*, i.e. a production phase of an order that can be considered as inseparable for the sake of the allocation problem.

The allocation problem is solved using a two steps approach: in the former, constraint programming techniques are used to check for unfeasibilities and to determine a subset of the initial solution space, in the latter, such smaller space is used in order to formulate and solve a reduced mathematical model.

The balancing problem is solved using a pure mathematical programming approach. Hence, a mathematical model is developed and its solution is demanded to a commercial solver.

3.1. Allocation: constraint programming phase

Without considering any other aspect, each task could be virtually assigned to any production plant in the selected area. Let us denote with i a production order, with j a production plant and with k a production phase. The generic binary decision variable x_{ijk} for the allocation problem can then be introduced. Being N the number of orders to be assigned, M the number of available plants and P the number of production phases, the initial solution space, the pool of all possibly selectable (i,j,k) triplets, before considering any other constraint, has the cardinality of $N \times M \times P$. In typical production systems N can range from hundreds to tens of thousands, while both M and P can range up to some tens. A purely mathematical programming approach can easily lead to large, practically intractable problems.

We propose a hybrid framework that uses techniques widely used in constraint programming approaches with mathematical programming: such method leads to a substantial reduction of the space of all solutions to be considered. Such reduced solution space is then used to formulate a smaller integer linear programming (ILP) model, that can be solved to optimality through standard branch and bound solver engines. Constraint propagation is used throughout this phase in order to eliminate those (i,j,k) triplets that are not feasible.

Furthermore, constraint propagation is used to check for unfeasibilities before the definition of the mathematical model. This approach allows the proposed tool to alert the user with unfeasibility issues at an earlier time, much before than it would be possible formulating the problem as a unique, whole mathematical model. An exemplification of the proposed approach is shown in Fig. 1. In the picture, the grayed part of the triplets set after the constraint propagation block represents the triplets that have been marked as not valid by the propagation.

3.2. Rules

In the addressed production allocation problem, it is important to provide the user with the ability to define and consider several