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A hierarchical approach to solve a production planning and scheduling problem in bulk cargo terminal

Gustavo Campos Menezes [a,b,*], Geraldo Robson Mateus [a], Martín Gómez Ravetti [c]

[a] Departamento de Ciência da Computação, Universidade Federal de Minas Gerais, Av. Antônio Carlos 6627, CEP 31270-010, Belo Horizonte, MG, Brazil
[b] Departamento de Eletroeletrônica e Computação, Centro Federal de Educação Tecnológica de Minas Gerais, Avenida Doutor Antônio Chagas Diniz 655, CEP 32210-160, Cidade Industrial, Contagem, MG, Brazil
[c] Departamento de Engenharia de Produção, Universidade Federal de Minas Gerais, Av. Antônio Carlos, 6627, CEP 31270-901, Belo Horizonte, MG, Brazil

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ABSTRACT

The integration of planning and scheduling decisions is key to obtain an efficient and reliable production operation in a modern manufacturing and service company. In this work we propose a mathematical model for this integration, the model is defined considering logistic operations at bulk port, however is generic enough to be adapted to several situations. The integration takes place in a hierarchical scheme where the problems exchange data and they are solved through a commercial solver and heuristics. When scheduling is not feasible, capacity information is forwarded to production planning to adjust or indicate the use of new tasks. The model and algorithms are validated considering data from a real case. Computational results show the efficiency of the approach, producing strong bounds for large instances.

1. Introduction

In production systems, production planning and scheduling problems are critical for profitability of companies, correct use of resources and to meet deadlines. These problems are applicable in a broad range of sectors, such as the casting industry (Camargo, Mattiolli, & Toledo, 2012; de Souza, Jr, Bretas, & Ravetti, 2015), the food industry (Rocco & Morabito, 2014), and cargo transportation in port terminals (Robenek, Umang, & Bierlaire, 2014). Even though planning and scheduling belong to two different decision levels (from strategic to operational), there is a strong relation between them and there is extensive literature on solution models and strategies (Drexl & Kimms, 1997; Meyr & Mann, 2013; Phanden, Jain, & Verma, 2013; Ramezanian, Saidi-Mehrabad, & Teimoury, 2013). Published strategies can be divided into hierarchical and integrated approaches.

In a broad sense the production planning decides when and how many products must be produced, and the decisions are usually associated to cost trade-offs. Instead, scheduling problems take into account shop-floor settings and determine how the production must be executed. Their objectives are usually time-related. The independent optimization of these problems can clearly lead to non-optimal solutions, thus the need to combine the decisions levels. Integrated methods consider both problems simultaneously; that brings better solutions in exchange of a greater computational complexity. Another approach is a heuristic procedure, where in a hierarchical fashion the production planning and scheduling problems and solutions exchange data.

The problem motivating this research can be defined as follows: lets consider a variety of products arriving at a logistics terminal (supply), they need to be transferred to meet the demand or to a local storage area. To make this transfer, products need a feasible route of equipment. On the one hand, the planning problem must take decisions regarding when to move the material and where to move it. On the other hand, the scheduling problem deals with making the planning feasible, that is, determining a route of equipment to be use at each time period. Different routes have different capacities. They may share equipment creating conflicts when used during the same time period.

The focus of our work and the main contributions of this article are related to the integrated solution methodology to deal with a complex problem with real size instances. In this manuscript, we propose the use of a hierarchical framework to solve a production planning and scheduling problem for the delivery of products. The methodology uses a combination of heuristics and mathematical formulations; the novelty of the method is on the combination of this algorithms to deal with the trade-off between medium and short term decisions. Moreover, based on the scheduling solution

* Corresponding author at: Departamento de Ciência da Computação, Universidade Federal de Minas Gerais, Av. Antônio Carlos 6627, CEP 31270-010, Belo Horizonte, MG, Brazil. Tel.: +55 31 3409 5860; fax: +55 31 3409 5858.

E-mail addresses: gcm@dcc.ufmg.br (G.C. Menezes), mateus@dcc.ufmg.br (G.R. Mateus), martin.ravetti@dep.ufmg.br (M.G. Ravetti).

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additional constraints are generated to strengthen the production planning. To link this problem with two levels of information we use the capacity of the routes.

In addition, to this contribution, the hierarchical framework, and a mathematical model are built to address a real storage and transportation problem, that occurs in a Brazilian bulk terminal. This problem is also common in iron ore port terminals and has not been fully investigated in the literature. The experiments are validated considering data from a real case and the computational results show the effectiveness of algorithms and model.

The remainder of this article is structured as follows: Section 2 presents the literature review. Section 3 defines the problem on which a mathematical programming model is based. Section 4 presents some sets and variables used in the mathematical formulation (the complete model is available in the appendix). Section 5 discusses the solution strategy applied and the main algorithms developed. Section 6 is dedicated to computational results and the manuscript ends with conclusions and future research directions.

2. Literature review

The interaction (integrated or hierarchical form) between Planning and Scheduling is not a new concept, and various efforts have been made toward this goal, such as in Ozdamar and Yazgac (1999), Meyr (2000), Wu and Ierapetritou (2007), Gaglioppa, Miller, and Benjaafar (2008), Mateus, Ravetti, Souza, and Valeriano (2010), Kis and Kovcs (2012), and, more recently, Meyr and Mann (2013) and Wolosewicz, Dauzre-Prs, and Aggoune (2015). You, Grossmann, and Wassick (2011) and Calfa, Agarwal, Grossmann, and Wassick (2013) also address integrated problems. In You et al. (2011), it is investigated an integrated production problem, whose goal is to determine at each period which products to manufacture, as well as to establish an optimal capacity modification plan, such that future demand is satisfied. Calfa et al. (2013) investigate the integration of Planning and Scheduling of a Network of Batch Plants. The problem is to define the amount of products to be produced in each time period, the allocation of products to batch units and the detailed timing of operations and sequencing of products.

The solution strategies adopted by the works were: Bilevel Decomposition and Lagrangean Decomposition in You et al. (2011), and Bilevel and Temporal Lagrangean (Calfa et al., 2013). These approaches have succeeded in solving large-scale industrial problems. Although the problems considered in those two works are different from the one analyzed in this article, the solution approach is similar. They deal with real and complex industrial problems and explore decomposition and communication mechanisms between the subproblems. The strategies proposed (Bilevel and Lagrangian) can also be seen as hierarchical, since the problems are decomposed and solved separately.

As previously discussed, the central problem study in this article involves the flow of products between supply nodes, storage areas and demand nodes. In this sense, the primary contributions from the literature are related to the product flow in bulk cargo terminals (iron ore, coal, grains). The references highlighted below are related to mathematical models and exact and heuristic algorithms for problems in this sector.

Bilgen and Ozkarahan (2007), study the problem of blending and allocating ships for grain transportation. The authors develop a mixed-integer linear programming model with constraints involving blending, loading, transportation, and storage of products. Conradie, Morison, and Joubert (2008) address the optimization of the flow of products (in this case coal) between mines and factory. Kim, Koo, and Park (2009) study the allocation of products in the stockyard. This problem is solved using a mixed-integer programming model. Barros, Costa, Oliveira, and Lorena (2011) develop an integer linear programming model for the problem of allocating berths in conjunction with the storage conditions of the stockyard. Solutions are obtained using optimization packages and Simulated Annealing. Boland, Gulezynski, and Savelsbergh (2012) address the problem of managing coal stockpiles in Australia. In the study, it is necessary to choose which equipment will be used for transporting goods to be piled in the stockyard (preferably near the berth where the ship will be loaded), and how to synchronize the whole process. Singh et al. (2012) present a mixed-integer programming model for the problem of planning the capacity expansion of the coal production chain in Australia. The model seeks alternatives to expand capacity to fulfill the demand while minimizing infrastructure costs and demurrage. Finally, Robenek et al. (2014) proposes an integrated model for the integrated berth allocation and yard assignment problem in bulk ports, with solutions obtained by a branch and price algorithm.

Although these research works address various important aspects of the challenges found in bulk cargo terminals, we did not find articles investigating the integration of product flow and scheduling routes. Such problematic is very usual and must be solved in several bulk terminals.

3. Problem description

The port terminal under study possesses several types of equipment for loading iron ore onto ships: car dumpers, conveyor belts, ore stackers, reclaimers and ship loaders. Iron ore is the main commercialized product, and it is the only product considered in this work. There are primarily three types of iron ore being handled: lump, sinter and pellet. Several other products can be derived from these raw materials and differ in their chemical and physical characteristics.

To better understand the planning and scheduling problem consider the following scenario. There is a set of supply nodes or reception subsystem, where products are available for transportation, storage nodes or stockyards and demand nodes or delivery subsystem (points of shipping products). Specialized equipment with predefined capacities is used to transport the products within the network. An equipment route between nodes has a given capacity and handle one product at a time. Fig. 1 provides a schematic representation of the problem.

The number of routes is limited and they may share equipment. Thus, if two different products are assigned to routes sharing equipment, these routes must be active at non-overlapping intervals. Fig. 2 shows a case where two routes (routes 1 and 2) share the same equipment.

The stockyard subsystem consists of large areas for storage. Each storage area is further subdivided into smaller subareas called storage blocks. The dimensions of each storage block can vary and

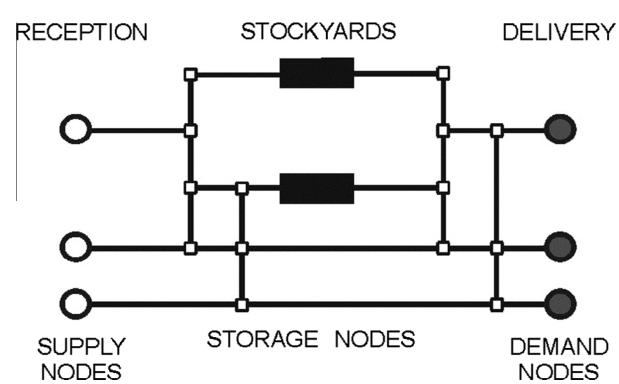

Fig. 1. Reception, stockyards and delivery systems.