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Innovative Applications of O.R.

Joint employee weekly timetabling and daily rostering: A decision-support tool for a logistics platform ☆

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ABSTRACT

To deal with their highly variable workload, logistics companies make their task force flexible using multi-skilled employees, flexible working hours or short-term contracts. Together with the legal constraints and the handling equipments' capacities, these possibilities make personnel scheduling a complex task. This paper describes a model to support their chain of decisions from the weekly timetabling to the daily rostering (detailed task allocation).

We divide the problem into three sub-problems depending on the type of decision to be made: (1) workforce dimensioning, (2) task allocation for a week, and (3) detailed rostering for a day. The three decisions are made sequentially, the output of a step being the input of the next one. Each step is modeled as a mixed integer linear program which is described and commented.

The proposed models are tested with industrial data as well as generated instances. From the observations made in an industrial context, we show that our model is an actual management tool supporting the managers in their operational decisions. This tool is currently used by the company which provided us with the industrial data. Based on the results with the generated instances, we present the conditions under which the models can be solved within a reasonable amount of time, and we assess the robustness of the daily rostering when the input data changes.

1. Introduction

Warehouses operate in a very competitive market, where purchasers keep pushing to knock the prices down (Klaus, 2011; Rebitzer, 2007). The logistics providers therefore have to show a high flexibility to be able to attract customers. Even if some operations can be automated, buying machines and adapting them to the customer's need is barely cost-effective (Naish & Baker, 2004). Therefore, most of the operations taking place in logistics platforms are done by human beings, which makes manpower the first cost center. It is thus crucial to stick to the activity volume when dimensioning the task force.

A difficulty is that the workload is variable: the number of arriving trucks and the number of orders to be prepared change every day. To be able to react accordingly, the workforce needs to be flexible: the number of working hours for a given employee may differ from one week to another. Short-term contracts can also be used to ensure more flexibility. All these parameters, together with other constraints such as the employees' qualifications, vacations, and the handling equipment availability, make *weekly timetabling* and *daily rostering* a complex process.

Wren (1996) defines *rostering* as "the placing, subject to constraints, of resources into slots in a pattern. One may seek to minimize some objective, or simply to obtain a feasible allocation. Often the resources will rotate through a roster". Following Ernst, Jiang, Krishnamoorthy, and Sier (2004), we use the words *personnel scheduling* to describe the whole process of constructing work timetables for an organization's staff, in order to satisfy the demand for its goods or services. As mentioned by Musliu, Gärtner, and Slany (2002), personnel scheduling algorithms consist of different stages related to each other, that can be solved simultaneously or in sequence, depending on the context. In this paper, we call *weekly timetabling* the part of the process which consists of determining the number of employees needed and allocating these employees to shifts (sets of consecutive time periods within a day) to meet the demand. The expression *daily rostering* refers to the assignment of tasks to employees on a daily level.

The problem presented in this article falls in the category of "multi-day personnel scheduling problems" defined by Brucker, Qu, and Burke (2011) in their general model for personnel scheduling. The authors underline that the "multi-day personnel scheduling problems" can be decomposed into two levels: in the first stage, the working days are assigned to the employees (i.e. weekly timetabling), whereas the second stage assigns a shift for each employee working on a given day, and a task for which the employee is qualified on each working period (i.e. daily rostering). Although

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weekly timetabling and daily rostering are intertwined, they are often treated separately in the literature; in this paper, we propose to deal with the two of them together through sequential solving. We also notice from the literature that the logistics field is not a common application area for personnel scheduling problems, and the few existing papers use heuristic methods to solve the problem. The model proposed in this paper meets the specific requirements of a logistics platform to support the personnel scheduling process for warehousing operations, and its solution is based on optimal methods (mixed integer linear programming).

Our purpose is to determine the working hours of all employees for one week, as well as their exact task allocation every day. All legal and job-related constraints must be included. We divide the problem into three steps, each representing a decision to be made. Each step is modeled by a mixed integer linear program.

The model has been tested in a logistics company, whose name is not cited for confidentiality reasons. A decision-support tool, based on the models described in the present article, is now used on a weekly/daily basis to support the managers' decisions.

The rest of the article is organized as follows. After a literature review (Section 2), we give in Section 3 an overview of the problem, the decision-making process, and the general notations. Section 4 details the first part of the model, namely the weekly timetabling (*steps 1* and *2*). Section 5 deals with the detailed daily rostering (*step 3*). Section 6 presents the numerical results, and concluding remarks are given in Section 7.

2. Literature review

Our review will focus on two aspects: firstly, Section 2.1 focuses on the application areas of personal scheduling problems, to see how the logistics field relates with the fields covered by current research. Secondly, in Section 2.2 we have a closer look at the working methods used in the literature to solve weekly timetabling and daily rostering problems.

2.1. Personnel scheduling in logistics

In logistics and especially for logistics providers, the main production resource is the human resource (Graham, 2003). Therefore, production planning consists mainly of workforce scheduling, which thus becomes a crucial point for the operations efficiency. The logistics industry faces several challenges which are specific to this field:

- The highly variable demand makes the workload very different from one day to another, which means that regular patterns cannot be used to create the workers' timetables;
- The qualifications are very specific to a person: two employees are very likely to have different skills and different licenses to drive the handling equipment. Therefore, the set of tasks mastered by a given employee will be different from the set of tasks mastered by any of his colleagues, and clustering the employees according to their skills does not simplify the problem;
- The unequal distribution of busy periods over a day does not fit a standard 8-hour shift: supervisors must therefore assign shorter or longer shifts, force some employees to take a day off, or hire temporary workers.

Personnel scheduling questions have been broadly studied for transportation systems (including airlines, railways and buses): the constraints tackled by the so-called *crew scheduling* problems are very specific, since the location of the crews is also a variable. The interested reader can refer to Castillo-Salazar et al. (2012) for a survey on workforce scheduling and routing. *Nurse scheduling* and, more generally, health care systems scheduling is also a major application area (see the survey by Burke, De Causmaecker, Vanden Berghe, & Van Landeghem (2004)), in which the problems are highly constrained because hospitals work around the clock. The main differences between the health care field and logistics are:

- The relative simplicity of the qualifications profiles used. As mentioned earlier, a logistics employee has qualifications that allow him to work only on specific tasks, while a nurse has one qualification which allows her to do all the tasks. Therefore, the daily rostering is not needed for nurses, since they know precisely what they are supposed to do when assigned to a given shift. The problem can be solved on a shift level.
- The shape of the coverage function (number of employees required each hour). As highlighted by De Causmaecker, Demeester, Vanden Berghe, and Verbeke (2004), hospital personnel scheduling problems are *permanence centered*, while warehouse personnel planning are based on *fluctuating demand*.

Overall, the granularity of the nurse timetabling problems is lower than staff timetabling for logistics and, more generally, for the service industry.

The service industries whose characteristics and requirements are the closest to the logistics area are retailing, call centers and postal service; for instance, the model proposed by Bard, Binici, and de Silva (2003) to schedule the United States Postal Service staff meets most of the constraints encountered in logistics operations. However, they focus on the long-range planning problem rather than the weekly scheduling problem. The weekly personnel scheduling problems raised in the US Postal Service mail processing are addressed by Wan (2005), who also deals with the US Postal service distribution centers, whose activities are typical logistics operations. But like Bard et al. (2003), he considers a homogeneous workforce, without distinctions in skills and qualifications.

The literature studying warehouse personnel scheduling as such is still very limited: no paper appears in the comprehensive review made by Ernst, Jiang, Krishnamoorthy, Owens, and Sier (2004), covering the literature until 2004 of more than 700 analyzed sources dealing with personnel scheduling problems. Only De Causmaecker et al. (2004) mention this field as an application area, since a small warehouse (20 employees) was included in the sample of Belgian companies they investigated to classify the scheduling problems. A recent state-of-the-art by Van den Bergh, Beliën, De Bruecker, Demeulemeester, and De Boeck (2013) reviews 291 articles from 2004 to 2012, in which Günther and Nissen (2010a, 2010b) are the only ones dealing with a real-world scheduling problem in logistics, comparing three heuristics and an evolutionary method to solve a daily rostering problem for a German logistics service provider with 65 employees. The model proposed by these authors is a multi-objective model. They seek to minimize the over and under-staffing, the extra hours worked every week, and the cases where the working days are too short, too long, or split up during a working day. The industrial data used is in open access. We will come back to these data at the numerical experiments section of our article (Section 6.2).

2.2. Sequential approach for joint weekly timetabling and daily rostering

The current paper proposes to solve in sequence a weekly timetabling and a daily rostering problem. We see from the articles gathered by Ernst et al. (2004) that these concepts (named a bit differently in the review, since the authors use the words "workforce planning", "shift scheduling" and "task assignment") are never studied at the same time: amongst the articles reviewed, 163 deal