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Optimised buffer allocation to construct stable personnel shift rosters☆

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ABSTRACT

Organisations need to construct stable baseline personnel shift rosters based on forecasts about the future personnel demand and employee availability. However, variability arises in the short-term, which renders these forecasts incorrect and affects the quality of the personnel roster. In this paper, we study how to anticipate this variability by introducing capacity buffers in the personnel shift roster. We propose a new approach by solving an equivalent deterministic formulation of a stochastic personnel shift scheduling problem. In contrast to traditional approaches, the size and position of capacity buffers are not defined in advance but are adequately determined as an endogenous variable by the proposed optimisation model to align the available personnel capacity to the stochastic demand. We propose different strategies to define the anticipated uncertainty and to allocate capacity buffers accordingly. We validate the performance of these strategies through a comparison with a deterministic minimum cost strategy and a more traditional resource buffer strategy based on a three-step methodology. This methodology makes use of simulation and optimisation to mimic the hierarchical personnel planning process.

1. Introduction

According to Van den Bergh et al. [45], the incorporation of uncertainty is lacking in personnel scheduling models in the literature. This negatively impacts the quality and practical relevance of the proposed deterministic mathematical models and solution methodologies. The incorporation of uncertainty is complicated given the hierarchical nature of the personnel planning process, which consists of the strategic staffing phase, the tactical scheduling phase and the operational allocation phase [3,9]. The strategic staffing phase considers long-term decisions such as the personnel mix and budget required to meet the service demand. In the tactical scheduling phase, the objective is to obtain a high-quality baseline personnel roster that enables the organisation to offer a desired service level at a minimal personnel cost and maximal personnel satisfaction. This baseline roster is constructed for a medium-term period given a number of assumptions and predictions about the service demand and personnel capacity, i.e. the employee availability. However, variability arises in the short-term operational allocation phase. Due to this operational variability, the medium-term assumptions and predictions may not correctly represent the actual service demand and employee availability. Van den Bergh et al. [45] distinguish uncertainty of demand, uncertainty of arrival and uncertainty of capacity as three sources of variability in personnel scheduling. These sources may cause unexpected divergences between the service demand and employee availability, which results in employee shortages and overstaffing. These disruptions reduce the quality of the baseline personnel roster but can be (partially) recovered by adjusting the personnel roster via recourse, i.e. the reassignment of employees to recover shortages and the cancellation of scheduled working assignments to recover overstaffing. As such, these reassignments and cancellations help to ensure the desired service level but simultaneously have a negative impact on the personnel costs and satisfaction as schedule changes impact the personal lives of workers [6,31,34]. Moreover, the hierarchical nature of the personnel planning process establishes a dependency between the decision freedom in the lower-level phases and the decisions taken in the higher-level phases. This means that the tactical baseline personnel roster determines the available adjustment possibilities in the operational allocation phase. Given the importance of personnel costs as a part of the operating costs [23,45] and the importance of personnel satisfaction [6,34,44], it is therefore important to anticipate the operational variability in the tactical scheduling phase and build in a certain stability (or absorption capability) and/or flexibility (or adjustment capability) in the personnel roster [19,30].

A common approach to improve the stability, which reduces the number of required changes, is the proactive inclusion of capacity buffers. Previous research [10,27,32,35,41] has indicated that sufficiently large capacity buffers improve the stability of a personnel roster but that it is very difficult to position the capacity buffers

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in an intelligent way. The higher the resource buffer proactively included, the lower the number of personnel shortages but the higher the wage costs and the cost for cancelling redundant personnel. Based on this trade-off, the size and the positioning of the capacity buffers over the planning horizon should be carefully determined.

In this paper, we propose an optimisation model to adequately allocate capacity buffers in order to improve the stability of a personnel shift roster. In contrast to more traditional approaches, the size and position of the capacity buffers is not defined in advance. The proposed methodology determines the size and position of the capacity buffers internally to better align the available personnel capacity with the stochastic personnel demand and personnel availability. For the problem under study, we formulate an equivalent deterministic model of a stochastic personnel shift scheduling problem and introduce a buffer allocation mechanism. In doing so, we redefine the staffing requirements and introduce an artificial objective to allocate buffers over the planning horizon adequately. The newly defined staffing requirements characterise the anticipated uncertainty in order to establish an appropriate trade-off between the level of stability and the additional personnel cost. We propose different scaling strategies using *deviation measures* and an *uncertainty budget* to define the maximum allowable deviation from the expected staffing requirements. Since smaller-than-expected staffing requirements result in overstaffing and larger-than-expected staffing requirements in shortages, we investigate the ability of these strategies to define the staffing requirements in the tactical scheduling phase as a good representation of the uncertain service demand and employee availability in the operational allocation phase. Furthermore, a buffer allocation mechanism is included for which we visit different *uncertainty budget allocation strategies* to guide the personnel capacity and establish a buffer on the most appropriate shifts and days.

The applied methodology to increase the stability of a roster via the introduction of capacity buffers is conform to the concept of light robustness introduced by Fischetti and Monaci [25].

We utilise a problem-specific three-step methodology, which mimics the hierarchical personnel planning process, to validate the *expected* outcome based on an artificially generated dataset, which is set up according to a full factorial design, and a dataset containing real-life instances. In the first step, we utilise column generation to construct a baseline personnel shift roster for a medium-term period. During the roster construction in the tactical scheduling phase, we consider several strategies to characterise the anticipated uncertainty in the staffing requirements and the objective function in order to allocate adequate capacity buffers over the planning horizon. In the second step, we imitate the operational allocation phase and test the stability of the baseline personnel shift roster. Each day, we simulate the uncertainty of demand and capacity, and adjust the baseline personnel shift roster to restore its feasibility and/or workability. In the third step, the stability of the generated rosters is evaluated by comparing the planned and actual performance. Moreover, we compare our approach with more traditional approaches to include capacity buffers and the minimum cost baseline personnel shift roster, which is constructed based on the assumption of a deterministic operating environment. This comparison enables us to provide *managerial guidelines* to apply the knowledge captured by the proposed model in a practically relevant context.

The remainder of this paper is organised as follows. In Section 2, we provide a literature overview of strategies that can be applied to improve the stability in a scheduling context. In Section 3, we formulate an equivalent deterministic model of a general stochastic personnel shift scheduling problem with uncertain service demands and employee availabilities. We elaborate on the three-step methodology in Section 4. The test design and computational experiments are discussed in Section 5. In this section, we evaluate the formulated strategies and test their effectivity to improve the quality and stability of a personnel shift roster. Conclusions are drawn in Section 6.

2. Literature review

The deterministic personnel planning process has been extensively studied in the academic literature [9,22,23,45]. However, stochasticity and the construction of robust personnel rosters has only received limited attention in personnel scheduling [45]. A robust personnel roster is characterised by both stability and flexibility when disruptions occur [30]. A roster with these characteristics has the ability to restrict the number of changes that are required to react to disruptions. Hence, this roster primarily absorbs disruptions and requires limited adjustments in response to those disruptions that cannot be absorbed. In order to obtain such a roster, the personnel planner needs to adopt proactive strategies in the strategic staffing and tactical scheduling phases. These strategies build in a degree of robustness in the baseline personnel rosters, which increases the absorption and adjustment capability in the operational allocation phase. In order to efficiently and effectively react to disruptions in the operational allocation phase, the personnel planner should also apply reactive strategies that exploit the proactively built-in stability and flexibility.

The definition of resource buffers, i.e. time or capacity buffers, has been a common strategy to improve the roster *stability*. Time buffers aim to increase the duration between two consecutive duties [42]. As such, time buffers are especially applied in project management [26], personnel task scheduling problems [19,21,42] and job shop scheduling [13]. Cacchiani et al. [10] make use of a Langrangian heuristic to include an artificial objective that maximises the buffer times between trips for a train timetabling problem. Capacity buffers enlarge the personnel presence during specific time periods to anticipate a larger-than-expected demand and avoid shortages. This extra personnel can be obtained by formulating preferred staffing requirements in advance on top of the minimal staffing requirements [14,18,44]. Several authors [16,19,32,36,41,42] studied the inclusion of capacity buffers in the airline industry via the planning of reserve duties. They find that a sufficient number of reserve duties should be installed to prevent disruptions but this number should not be too high in order to ensure the availability of crew for other duties. The height of the capacity buffer is typically determined in a deterministic way in advance. Ingels and Maenhout [27] for example define capacity buffers via a fixed percentage on top of the expected staffing requirements and the inclusion of specific time-related constraints. Generally, it is recognised that the position of these duties (in time and space) has a major impact [27,32,35]. Another type of buffer is overtime, which increases the capacity during specific time periods while the total working time of employees augments [29].

Ionescu and Kliewer [30] and Shebalov and Klabjan [40] focus on roster *flexibility* by maximising the number of resource substitution possibilities for crew and aircraft scheduling [19]. Ingels and Maenhout [28] consider a general multi-skilled personnel shift scheduling problem. They define three types of employee substitution possibilities and devise different strategies to improve the roster flexibility. In the same context, Olivella and Nembhard [33] determine the optimal level of cross-training in teams.

Reactive strategies enable the recovery after the occurrence of a disruption in the operational allocation phase. Ideally, these strategies are applied in correspondence with proactive strategies. Reactive strategies certainly provide the opportunity to properly utilise the proactively built-in robustness in response to operational variability. The conversion of a reserve duty into a working duty is a general recovery action in the airline industry [1,2,43] and has