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Mathematical models and solution approach for cross-training staff scheduling at call centers

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ABSTRACT

Call centers face demand variations over time across multiple service categories and typically employ a cross-trained workforce with flexible schedules to hedge against these fluctuations. In practice, it is often impossible to cross-train agents in each category, thus partial and limited cross-training are the norm. This adds another layer of complexity to determine the optimal mix of cross-trained workforce (on top of the shift and tour schedules) and has created a challenging problem in the optimization of staff schedules.

To solve this problem to its fullest extent, an integer program that addresses cross-training, shift schedule, days off and break assignments across multiple service categories is proposed. The model is hard to solve and a two-phase sequential approach is developed. The first phase is to find the optimal mix of the workforce, i.e., the categories to be cross-trained and the time periods in which they are to be deployed; the second phase is a smaller staff scheduling model to find the composition of the workforce and to construct their weekly tours. For all the test cases, which are of practical sizes, the two-phase sequential approach provided better solutions than the solution of the original model with a state-of-the-art commercial solver subject to imposed time limits.

Experimental results with data from a call center with nine categories clearly demonstrate the significance of cross-training. In fact, partial limited cross-training, where 30% of staff is cross-trained with two skills or 10% of staff is cross-trained with three skills, could result in considerable cost savings; however, these savings could diminish quickly with the increase of efficiency loss in secondary skills. Experiments also suggest that cross-training could be a more effective approach than part-time shifts to hedge against fluctuations across service categories.

1. Introduction

Call centers face demand variations throughout the day and the days of the week across multiple service categories. Call centers typically employ a flexible workforce of various shifts to cope with time varying demands and cross-train the workforce to balance workload across service categories. Because staffing could consist of as much as 60% to 70% of the total call center cost, effective solution of the staff scheduling problem is critical to these service centers – poor staff schedules can either lead to over-staffing, which incurs a high cost, or to under-staffing, which undermines service quality and causes loss of business [16].

The staff scheduling problem is typically solved in a hierarchical framework in several steps: a) determining the number of staff required to meet the service demand through a simulation or queuing study, b) determining strategically the size and composition of the workforce and constructing shifts and weekly tours, and c) assigning individual employees to shifts and weekly tours while taking into consideration absenteeism and variation in demand while maximizing employee preferences [20]. Because full cross-training, where agents are trained to perform all categories, is impossible, partial and limited cross-training have become the norm in practice. Here, partial cross-training is defined as a subset of the workforce being cross-trained [10] and limited cross-training is defined as agents being cross-trained with a subset of skills in appropriate combinations [29]. As such, besides shift assignment and tour construction, cross-training adds another layer of complexity to determine the optimal mix of cross-trained workforce, and has created a challenging problem to the optimization of staff schedules at call centers.

This paper focuses on the strategic analysis of the cross-training staff scheduling models (CTSSM). To solve the problem to its

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fullest extent, a large-scale mixed integer program is proposed that addresses cross-training decisions, shift schedules, days off and break assignments. The problem, however, is hard to solve, and a two-phase sequential approach (TPSA) is proposed to increase computational tractability. The first phase is to decide what subset of skills should be cross-trained and when cross-trained agents should be deployed; the second phase is to find the size of the workforce and to construct shifts and weekly tours based on cross-training and time interval combinations from the first phase. For all the test cases based on data from a retail support center, the approach provided better solutions much faster than the solution of the original model with a state-of-the-art commercial solver. Our computational experiments demonstrate that the optimal allocation of partial and limited cross-training could offer dramatic cost savings, and could be more effective to hedge against demand fluctuations across service categories than other options such as part-time shifts.

The remainder of the paper is organized as follows. Section 2 presents a review of the literature. Section 3 presents the detailed mathematical model for the cross-training staff scheduling problem. Sections 4 and 5 present the two-phase sequential approach and computational results. Section 6 presents the managerial insights for cross-training decision and finally conclusions are drawn in Section 7.

2. Literature review

The staff scheduling problem is a classical optimization problem and has seen various applications in call centers [9], airport stations [11], and postal facilities [24,6]. For a recent review, please see VandenBergh et al. [28].

The staff scheduling problem at call center is composed of shift scheduling, break assignment, days off scheduling, and cross-training assignment. Cross-training has only recently attracted much attention in the optimization of staff schedules; in view of this, the literature review is divided into two subsections: single-skill staff scheduling and multi-skill staff scheduling with cross-training.

2.1. Single-skill staff scheduling

2.1.1. Shift scheduling

The earlier work on shift scheduling goes back to Dantzig [17] where a set covering formulation was proposed. Segal [25] addressed a shift scheduling problem for telephone operators who were required to be given a lunch break and two relief breaks during their shifts. Bechtold and Jacobs [8] introduced the implicit modeling of breaks and derived three constraints that collectively ensured the feasibility of the break assignments.

2.1.2. Days off scheduling

Burns and Carter [12] provided a comprehensive solution to the days off assignment problem. They derived a set of lower bounds on the workforce size that took into account days off requirements and specific requirement for weekends off. Alfares [2] proposed an efficient algorithm for the tour scheduling problem that assigns two consecutive days off to employees.

2.1.3. Tour scheduling

Jarrah et al. [24] and Bard et al. [6] presented a full-scale model of the tour scheduling problem that includes shift scheduling, break assignment, and days off assignment in postal facilities. Bard [5] studied a hierarchical workforce scheduling with downgrading where a person in a higher skill category can be assigned to a job in a lower skill category. Bard et al. [7] addressed a two-stage stochastic staff scheduling model. In the first stage, before the demand is known, the number of employees is determined for the permanent workforce. In the second stage, the demand is revealed and workers are assigned to shifts during the week.

2.2. Multi-skill staff scheduling with cross-training

In production and service systems where workloads are imbalanced between operations, cross-training often arises as it enables workers to shift between operations and improves productivity. For cross-training studies in production systems please see Hopp et al. [22], in health care systems please see Wright and Mahar [30] and Gnanlet and Gilland [21].

The studies of call center cross-training can be classified into two categories: single-period cross-training pooling policy and multi-period cross-training assignment. The former assumes constant arrival rate and studies the decision on which groups should be pooled (cross-trained), the latter assumes varying arrival rate and aims to assign a cross-trained workforce to groups over the planning horizon.

2.2.1. Single-period cross-training pooling policy

Wallace and Whitt [29] studied call center routing and staffing problems by exploiting limited cross-training, and developed an algorithm to minimize the total staff subject to per-class performance constraints. Simulation experiments demonstrate that when each agent has only two skills in appropriate combinations, the performance is almost as good as when each agent has all skills.

Ahghari and Balcioglu [1] studied customer contact centers that provide different types of services to customers to assess the performance improvement via cross-training the agents. Their numerical studies indicated that limited cross-training with two skills per agent resulted in considerable performance improvements. However, unbalanced cases where each class of customers had the same arrival rate but different mean service times necessitated more cross-training at three skills per agent to have considerable improvement.

Tekin et al. [27] examined pooling strategies for call centers and the solution of two fundamental issues: how many departments to pool, and which departments to pool. The authors investigated the impact of different parameters, including mean service times, service time variability, and department size in deciding which departments to pool. The results showed that if the mean service times of the departments to be pooled were similar, pooling departments with the highest service time coefficient of variation reduced the expected delay the most.

Iravani et al. [23] modeled inbound call centers as parallel queuing systems with flexible servers. The authors proposed a work sharing network model and used its average shortest path length metric to predict the effectiveness of two alternative cross-training structures in terms of customer waiting times. The results show that the average shortest path length metric of the small world network theory is a simple deterministic solution approach to the complex stochastic problem of designing effective workforce cross-training structures in call centers.

2.2.2. Multi-period cross-training assignment

Campbell [13], and Campbell and Diaby [15] developed first a nonlinear generalized assignment model and then effective heuristics for allocating cross-trained workers in a multi-department service environment. Results show that a small degree of cross-training can capture most of the benefits – beyond a certain amount, additional cross-training adds little additional value, and the preferred amount (degree of cross-training) depends heavily on the level of demand variability. Brusco [10] extended Campbell's [13] model to include several nonlinear assignment objectives and

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