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An integer programming model for hierarchical workforce scheduling problem

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Abstract

In this paper, an integer programming model for the hierarchical workforce problem under the compressed workweeks is developed. The model is based on the integer programming formulation developed by Billionnet [A. Billionnet, Integer programming to schedule a hierarchical workforce with variable demands, European Journal of Operational Research 114 (1999) 105–114] for the hierarchical workforce problem. In our model, workers can be assigned to alternative shifts in a day during the course of a week, whereas all workers are assigned to one shift type in Billionnet's model. The main idea of this paper is to use compressed workweeks in order to save worker costs. This case is also suitable for the practice. The proposed model is illustrated on the Billionnet's example problem and the obtained results are compared with the Billionnet's model results.

Keywords: Integer programming; Personnel; Scheduling; Hierarchical workforce; Compressed workweek

1. Introduction

Organizations can adopt a variety of scheduling flexibility policies to work hours in an operating day [1]. This idea supports that labours can be assigned to alternative shifts (i.e., 8 hours, 10 hours, 12 hours) in a day during the course of a week. The alternative shifts on each workday can be defined for a hierarchical workforce problem in which a higher qualified worker can substitute for a lower qualified one, but not vice versa.

A compressed workweek (alternative shifts) is a workweek arrangement which lets labour work fewer days a week, but usually a longer day to fully or partially compensate the hours lost due to the extra free days [2]. If the only one shift (i.e., 8 hours) is allowed for scheduling of labour, assuming that employees can only take 2 off-days, then they will be working 5-day. If alternative shift types like 8 hours, 10 hours and 12 hours are used simultaneously, it will be possible to reduce labour cost. Moreover, the alternative shifts provide flexibility to the scheduler in determining the schedule that gives minimal labour costs.

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In literature, there have been a few published studies on hierarchical workforce problem (see the papers of Billionnet [3], Hung and Emmons [4], Hung [5], Narasinhan [6,7], Emmons [8], Emmons and Burns [9]). In addition, the advantages of the compressed workweeks have been discussed in literature (see the paper of Hung [10]). Also, for the workforce scheduling literature, the paper of Ernst et al. can be seen [11]. Billionnet's [3] integer programming formulation is based on single-shift off-day scheduling of a hierarchical workforce with variable demands developed by Hung [5].

2. Billionnet's integer programming formulation

In this section, Billionnet's [3] mathematical model is given in detail for a better understanding of the proposed model. The objective of this model is to determine an optimal hierarchical workforce in which a higher qualified worker can substitute for a lower qualified one, but not vice versa. Daily labour requirements within a week may vary, but each worker must receive n off-days in the week. Billionnet's [3] mathematical model is given as follows:

$$\text{Minimize } Z = \sum_{k=1..m} c_k w_k$$

subject to

$$\sum_{l \geqslant k} x_{klj} + y_{kj} = w_k \quad (k = 1, \ldots, m;\ \ j = 1, \ldots, 7) \tag{1}$$

$$\sum_{j} y_{kj} \geqslant w_k n \quad (k = 1, \ldots, m) \tag{2}$$

$$\sum_{k \leqslant l} x_{klj} = d_{lj} \quad (l = 1, \ldots, m;\ \ j = 1, \ldots, 7) \tag{3}$$

$$x_{klj}, y_{kj}, w_k \text{ integer } (k = 1, \ldots, m;\ \ l = k, \ldots, m;\ \ j = 1, \ldots, 7). \tag{4}$$

The decision variables: w_k ($k = 1, \ldots, m$) is the number of workers of type k and x_{klj} is the number of workers of type k ($k = 1, \ldots, m$) assigned to a work of type l ($l \in \{1, \ldots, m\}$, $l \geqslant k$) on day j, $j = 1, \ldots, 7$. y_{kj} is the number of type k workers ($k = 1, \ldots, m$) who take day j off ($j = 1, \ldots, 7$). The model is specifically as follows:

(1) A facility is staffed 7 days a week, Monday through Sunday. The days are abbreviated to be 1, 2, 3, 4, 5, 6 and 7.
(2) All workers are full timers and they are classified into m types, with type 1 the most qualified, type 2 the next most qualified, and so on. The cost of a type k worker is c_k and $c_1 > c_2 > \cdots > c_m$. This cost takes into account the number of off-days received by the worker each week.
(3) For each day labour requirements are defined in terms of numbers of type l work to be executed, type 2 work to be executed,..., and type m work to be executed. Specifically, d_{lj} works type l must be executed on day j, $j = 1,\ldots,7$. Each of the work type requires one worker and type l work can be executed by type k worker provided $l \geqslant k$ (a higher qualified worker can substitute for a lower qualified worker, but not vice versa).
(4) Each worker must receive n-off-days each week, where $n = 2, 3, 4$ for 5-day, 4-day and 3-day workweeks, respectively.
(5) The objective is to find minimal labour cost and a corresponding schedule that satisfies the labour and off-days requirements.

3. The proposed integer programming formulation

The proposed model is based on Billionnet's integer programming formulation for hierarchical workforce problem with variable demands and tries to minimize the number of scheduled workers for a facility that operates less than 24 hours a day and 7 days a week. The proposed model can be given as follows: