SCHEDULING A HIERARCHICAL WORKFORCE WITH FLEXIBLE BREAK ASSIGNMENTS AND VARIABLE DEMANDS

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Abstract: In service organizations, customer demand varies over the course of an operating day and across the day off an operating week. While organizations assign employees to weekly tour schedules in an attempt to satisfy the fluctuating customer demand, they must arrange personnel shift and day off schedules and also their break times equally. We consider a hierarchical workforce in which a higher qualified worker can substitute for a lower qualified one, but not versa. The objective is to determine an optimal hierarchical workforce problem, which frequently gives least cost labor mix. Daily labor requirements within a week may vary, but each worker must receive n off-days and multiple flexible breaks in a week. In this paper, an integer-programming model is presented, which combines hierarchical workforce problem and schedules break periods for shifts within the specified break windows. The form of integer programming model is very efficient way for solving workforce-scheduling problems.

Keywords: *Hierarchical Workforce Scheduling, Integer Programming, Flexible Break*

1. Introduction

One of the crucial tasks encountered in a service system is the effective scheduling of manpower. Understaffing will lower the total labor cost while it will result in poor service quality, and overstaffing will improve the service quality while it will result in underutilization and excessive labor costs. In the personnel-scheduling problem, the key challenge is to match the size of the workforce to the varying demand pattern, while maintaining a reasonable balance between the labor cost and customer satisfaction (Topaloğlu and Özkarahan, 1997) . Moreover, generating high-quality schedules for workforce is a critical task. Because, results from ergonomics (BEST, Guidelines for shift workers, Bulletin of European Time, European for the Improvement of Living and Working Conditions) indicate that workforce schedules have a profound impact on the health and satisfaction of employees as well as on their performance at work (Aykin, 2000) . Dantzig (Billionnet, 1999) developed the first integer-programming model of the general manpower-scheduling problem and the other researchers have used his general model for their extensions. Glover and McMillan (Aykin, 1996) give a good survey of the common shift scheduling problems. In addition, there are several important researches about staff scheduling problem for service system in literature (Gaballa and Pearce, 1979, Musliu et al., 2002).

Integer programming is a classical tool in scheduling problems and can be applied practical operations research. The technique is well known and reliable but it must be handled carefully, since some integer programming formulations can require a large amount of computer time (Dantzig, 1954). We consider here the problem studied by Hung (Lau, 1996). In this study, we proposed new break constraints to his integer model. The objective is to determine an optimal hierarchical workforce in which a higher qualified worker can substitute for a lower qualified one, but not versa.

2. Flexible Break Assignment and Shift Start Times

The shift-scheduling problem involves determining the number of employees to be assigned to various shifts and the timing of their breaks within the limits allowed by legal, union, and company requirements. To improve manpower utilization and lower labor costs, flexibility in shift types, the start times, length, number and duration of breaks is provided. Flexibility in scheduling relief and lunch breaks for a given shift is provided with break windows specifying the time intervals within which employees assigned to that shift must start and complete their breaks (Bealieu et al., 2000).

Aykin (1996) proposed implicit formulation for the general shift-scheduling problem. Like Bechtold and Jacobs (1990), He modeled the break placements implicitly (Carter and Lapierre, 2001). The formulation given in Aykin (1996) defines separate break variables for each shift. This approach extends the implicit break representation idea introduced in Gaballa and Pearce (1979) (Hung, 1994). Aykin (2000) extended the model of Bectold and Jacobs (1990) and compared these two modeling approaches through solving (optimally) 220 problems involving as many as 32928 shift variations (Bealieu et al., 2000). Due to Aykin's model has flexible break constraints for each shift; we used his model constraint approach for our hierarchical workforce problem.

3. Scheduling Environment

1. A facility is staffed 7 days a week, Monday through Sunday, These can abbreviated to be 1,2,3,4,5,6 and 7. **2.** All workers full timers and they are classified into m-types, with type 1 the most qualified, type 2 next most qualified and so on. The cost of a type-k worker is c_k and $c_1>c_2>….>c_m$. This cost takes into account the number of off-days received by the worker each week. **3.** For each day labor requirements are defined in terms of numbers of type-1 works to be executed, type-2 works to be executed,…, and type-m works to be executed. Specifically, d_{ij} works of type i must be executed on day j, j=1,….7. Each of the work completely requires one worker and a type-i work can be executed by a type-k worker provided $i \geq k$ (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 system operates less than 24 hours daily. **6.** Planning periods are equal in length. **7.** Each shift is given two relief break and one lunch break. **8.** Breaks start and end during the shifts. **9.** No understaffing is allowed. **10.** The objective is to find the minimal labor cost and a corresponding schedule that satisfies the labor, off-days and break requirements.

3.1. Integer Programming Model

Define the decision variables. Let w_k (k=1,….m) be number of workers of type k and X_{kij} as the number of workers of type k (k=1,….m) assigned to a work of type i ($i\in\{1,….m\}$, $i\geq k$) on day j, j= 1,…..7. Let y_{kj} be the number of type-k workers (k=1,..,m) who take day j off (j=1,..,7). We define H as the set of all shifts including all feasible combinations of shift start times and lengths. Let U_{khjl}, R_{khjl} and V_{khjl} be the break variables representing the number of employees assigned to shift h and taking their first relief, lunch, and second relief breaks in planning period l, respectively. Let $B1_h$, BL_h and $B2_h$ be sets of planning periods forming the first relief, lunch, and second relief break windows of shift h, respectively. In this formulation, the first break variable U_{khjl} is defined only for $l\in B1_h$, lunch break variable R_{khjl} for $l\in BL_h$, and the second relief break variable V_{khjl}, for $l\in B2_h$, Further, define $T1_l$, TL_l, and $T2_l$ as the sets of shifts for which period l is a break start time wihin the break windows for first relief, lunch and second relief break, respectively. Also a_{hl} be one if period l is in the shift span (a work or a break period during the shift) of shift h and zero otherwise. The general hierarchical workforce problem can then be formulated as follows:

$$\text{Minimize} \sum_{k=1..m} c_k w_k \qquad \text{Subject to:}$$

$$\sum_{i\geq k} X_{kij} + y_{kj} = w_k \quad \text{(k=1....m; j=1.....7)} \quad \textbf{(1)}, \qquad \sum_j y_{kj} \geq w_k n \quad \text{(k=1....m)} \quad \textbf{(2)}, \qquad \sum_{k\leq i} X_{kij} = d_{ij} \quad \text{(i=1......m; j=1.....7)} \quad \textbf{(3)}$$

$$\sum_{h\in H} a_{hl} X_{kij} - \sum_{h\in T1_l} U_{khjl} - \sum_{h\in TL_l} R_{khjl} - \sum_{h\in T2_l} V_{khjl} - \sum_{h\in T1_{l-1}} R_{khjl-1} \geq 0 \quad \text{(k=1....m; j=1.....7 l=1….48)} \quad \textbf{(4)}$$

$$X_{kij} - \sum_{l\in B1_h} U_{khjl} = 0 \quad \text{for all } h\in H \text{ (k=1....m; j=1.....7 l=1….48)} \quad \textbf{(5)} \qquad X_{kij} - \sum_{l\in BL_h} R_{khjl} = 0 \quad \text{for all } h\in H \text{ (k=1...m; j=1..7 l=1..48)} \quad \textbf{(6)}$$

$$X_{kij} - \sum_{l\in B2_h} V_{khjl} = 0 \quad \text{for all } h\in H \text{ (k=1...m; j=1..7 l=1..48)} \quad \textbf{(7)} \qquad X_{kij}, y_{kj}, U_{khjl}, R_{khjl}, V_{khjl} \geq 0$$

and integer **(8)**

When an optimal solution of (HWIP1) has been determined it is easy to find a schedule. We know y_{kj} the number of type k workers (k=1,…m) who take day j off. We have just to schedule the off-days for each worker of each type. For a given type we first assign one off-day to each worker, then second off-day to each worker and so on. In this way, each type-k worker will receive at least n off-days. It will be always possible since the total number of off-days assigned to type k workers ($\sum_j y_{kj}$) is greater than or equal to the number of type k workers (w_k) multiplied by the number of off-days which must be received by every worker each week (n) because of the second set of constraints in (HWIP1). In the above formulation, break windows are specified by $B1_h$, BL_h and $B2_h$. Break windows determine the earliest and latest break start times and break placement requirements in the break constraints. Break constraints (6)-(8) associated with each shift in break constraints and demand constraints (5). The scheduling environment considered in the test problems along four dimensions related with break placement: relief and lunch break window sizes, shift start time pattern, cyclical-acyclical operations, and demand pattern. Employee demand is assumed to be determined for 48 quarter-hour (4×12 hours) planning periods, L={ 1,…..,48}. Concerning the shift start times, we considered; 9-hour shifts starting by 15 minute. Each employee is assumed to be given one 30- minute lunch break and two 15- minute relief breaks (one before and one after the lunch break). The break windows with reference to "ideal" break times as follows: the ideal first relief break time for a shift is specified as 2 hours after the start of the shift, the ideal lunch start time is 4 hours and 15 minutes (4 hours of work plus the first relief break) after the start of the shift, and the ideal second relief break time is 6 hours and 45 minutes (6 hours of work plus the first relief and lunch breaks) after the start of the shift (Bealieu et al., 2000) .

4. Computational Results and Conclusion

We describe our computational experiments about (HWIP1). We tested the model on a set of 24 randomly generated problems with a number of types ranging from 2 to 5 and with a number off-days ranging from 2 to 4. d_{ij} is randomly generated and uniformly distributed between 0-20 and the vector c is (12,8,6,5,2). For each value of the pair {number of types, number of off-days} we solved two problems. We used the IP solver GAMS. Table 1 gives the information about the mean value, for two problems, of computational time. In fact 24 IP problems were solved in less 1 min on Pentium III 450 computer. We see in Table 1 that the computation time increases with types of worker. The results did not changed for different off-days.

Table 1. Computation time in seconds required computing of (HWIP1) (mean value for two instances)

	2 off-days	**3 off-days**	**4 off-days**
2 types	9.97	9.50	9.30
3 types	15.16	14.60	14.80
4 types	23.53	21.19	21.58
5 types	28.12	28.28	27.63

To the best of our knowledge, this is the first application of such an approach to this type of problem. The aim of this study was to develop a methodology for tackling the discontinuous scheduling problem that encompasses break timing flexibility, shift-length flexibility and off-days length flexibility. It is assumed that the workday is less than 24 h, and that there is enough rest periods between the subsequent shift of an employee for maintaining his or her mental and physical health.

We have seen in this paper that integer programming was an efficient technique to solve a classical personnel-scheduling problem on a microcomputer. The solution is easy to obtain by using packet program (GAMS). Moreover the integer programming approach allows us to easily solve some interesting variants the initial problem.

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