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Keywords

manpower planning, scheduling, relief breaks

Disciplines

Hospitality Administration and Management | Management Information Systems

Comments

SCHEDULING WORKFORCE RELIEF BREAKS IN ADVANCE VERSUS IN REAL-TIME

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Abstract

This paper focuses upon employee rest breaks, or reliefs, in workforce scheduling. Historically, the workforce scheduling literature has largely ignored reliefs, as less than 18% of the 64 papers we surveyed scheduled reliefs. The argument has been that one need not schedule reliefs in advance, since they can easily be scheduled in real-time. We find this argument to be flawed. We show that failing to schedule reliefs in advance will have one of two undesirable outcomes. First, there will be a less profitable deployment of labor should all reliefs actually be taken in real-time. Second, if some reliefs are never assigned or if relief-timing restrictions are relaxed so that more reliefs may be assigned in real-time, there will be a disgruntled and less productive workforce and perhaps violations of contractual obligations. Our findings are supported by anecdotal evidence drawn from commercial labor scheduling software.

Keywords

Manpower planning; Scheduling; Relief breaks

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1. Introduction

Managers of services such as customer contact (call-in) centers, grocery stores, emergency rooms, and restaurants typically have faced uncertain levels of customer demand during various times of the day. Today, even businesses such as airports with largely reservation-based demand face unpredictability in customer demand at their various services. For example, lines at the ticket counter and the subsequent lines for security screening depend on when and how many passengers initially opt to check their baggage. To improve the customer service levels while minimizing labor, managers like the option of adjusting staffing in real-time. Typical strategies are allowing surplus workers take their break or go home early if demand is lower than expected or keeping workers longer or postponing breaks if demand is higher than expected (Thompson, 1999b). In order to gain this flexibility, managers commonly schedule coffee breaks or reliefs (short breaks) in advance and then make adjustments during the work day. As these reliefs and other breaks are typically required in most labor contracts, it is important to look at how well these strategies work in achieving the objectives of meeting customer demand while minimizing labor costs and providing for the required breaks. Towards this goal, this paper compares two methods of relief scheduling, in-advance and real-time, on the relevant measures of cost and percentage of assigned breaks.

Workforce scheduling is comprised of four distinct tasks (Thompson, 1993). Task one (FORECAST) forecasts customer demand for the service (Thompson, 1998a). Task two (TRANSLATE) translates the forecasts of customer demand into employee requirements, using, as one input, the value that customers place on good, quick service (Thompson, 1998b). Task three (SCHEDULE) develops a workforce schedule that, ideally, only has employees working when they are necessary to deliver the service (Thompson, 1999a). Task four (CONTROL) controls the delivery of the schedule in real-time (Thompson, 1999b). CONTROL is necessary since actual customer demand rarely equals that forecast, and because the employees may fail to perform as scheduled. For example, employees may be sick or late, or they may have to stay home to care for a sick child. FORECAST, TRANSLATE and SCHEDULE are planning activities, while CONTROL is a control activity.

There is an extensive literature on workforce scheduling. The primary reasons for this interest are that workforce scheduling is a difficult problem facing managers of service delivery systems and the fact that labor is often the greatest expense under managerial control. The majority of the literature has focused on SCHEDULE (Beaumont, 1997; Bechtold et al., 1991; Bechtold and Jacobs, 1990; Brusco and Jacobs, 1993, 1998; Easton and Rossin, 1991; Li et al., 1991; Loucks and Jacobs, 1991; Mabert and Showalter, 1990; Thompson, 1990, 1992). Several papers have addressed TRANSLATE or the linkage between TRANSLATE and SCHEDULE (Goodale and Tunc, 1998; Goodale et al., 2003a, b; Thompson, 1993, 1995b, 2004). However, the literature on CONTROL is scant (the exceptions being Hur et al., 2004; Thompson, 1999b). This is despite the fact that CONTROL is crucial to efficient delivery of the service. A service system whose manager performs FORECAST, TRANSLATE, and SCHEDULE very well, but CONTROL poorly, will likely have a lower level of service at a higher cost than a system who has a manager that is particularly adept at CONTROL.

In this paper, we examine the scheduling of reliefs—breaks of 15 minutes or less (typically the ‘‘coffee break’’). As shown in Table 1, reliefs have largely been ignored in the workforce scheduling literature, with under 15% of the 75 papers we surveyed incorporating reliefs. The offered rationale is that they can be taken in real-time; that is, dealt with during the work day. Undoubtedly, leaving the scheduling of reliefs solely to real-time increases the difficulty of performing CONTROL well. Also, we believe that deferring the scheduling of reliefs to CONTROL offers a convenient means of avoiding the increase in problem complexity that reliefs pose. For example, the problem environment we describe in Section 3 contains 89,651 unique shifts when reliefs are considered, but only 3566 unique shifts when reliefs are ignored. Consider the effect of this difference on problem complexity for a work schedule containing 50 shifts. Assume, for the sake of illustration, that 0.01% of the possible combinations of 50 shifts without reliefs are feasible schedules, but that only 0.000000000001% of the possible combinations of 50 shifts with reliefs are feasible schedules. There are then 0.0001 * (3566)50 = 4.065E+173 feasible solutions when reliefs are not scheduled, while there are 0.00000000000001 * (89,651)50 = 4.244E+233 feasible solutions when reliefs are scheduled, or 1.044E + 60 times as many solutions. Clearly, reliefs greatly increase problem complexity.

A key assumption in the paper is that management desires that employees receive reliefs. There are two drivers for this assumption. First, contractual obligations often require that employees be given reliefs. Second, there is a body of literature showing the benefit of reliefs on productivity (for example, Janaro and Bechtold, 1985; Morgan and Pitts, 1985). Given our assumption, if reliefs are not scheduled in advance, they must be taken in real-time.

The objective of this paper is to conclusively determine whether reliefs should be scheduled in advance, or scheduled in real-time.[1] That is, we wish to determine whether or not researchers will have to confront the growth in problem complexity that reliefs pose, or if they may, in good conscience, continue to avoid scheduling reliefs. The paper thus offers one of the first investigations into a CONTROL-related workforce scheduling issue in an environment with overlapping shifts (shifts that can start at any time of the day rather than predefined day, swing, and graveyard shifts). The criterion used in the investigation is schedule cost, i.e., cost required to schedule employees to meet a specified service criterion.

[1] A related issue is whether reliefs should be scheduled in advance, but rescheduled in real-time. This investigation is beyond the scope of the current paper.

The structure of the paper is as follows. Section 2 presents the formulation of the workforce scheduling problem that we employ. Section 3 describes a set of test problems we developed and the approaches we used to evaluate the outcomes of scheduling and failing to schedule reliefs in advance. Section 4 presents and discusses the results of the investigation. Finally, Section 5 presents our conclusions, including suggestions for additional research.

2. The workforce scheduling problem

Throughout the investigation, we use the representation of the workforce scheduling problem presented by Dantzig (1954). His representation, which we call WSP, is

$$\text{Min } Z = \sum_{t \in T} c_t x_t \tag{1}$$

$$\text{subject to } \sum_{t \in T} a_{tp} x_t \geq r_p \text{ for } p \in P \tag{2}$$

$$x_1 \geq 0 \text{ and integer for } t \in T, \tag{3}$$

where

$P =$ set of planning intervals in the daily operating horizon;

$T =$ set of unique shifts that can be scheduled

$x_i =$ number of employees working shift t

$$a_{tp} = \begin{cases} 1 \text{ if period } p \text{ is a working period of shift } t \\ \quad\quad\quad\quad \text{otherwise} \end{cases}$$

$r_p =$ number of employees needed in period p to deliver the specified level of service.

WSP's objective (1) measures the total cost associated with the schedule. Constraint set (2) ensures that sufficient staff are present in each planning period to deliver the specified level of customer service. Constraint set (3) imposes the integer nature of the variables.

Breaks are incorporated into this model ((1)–(3)) via the a_{tp} coefficients, where a_{tp} takes a value of one in a working period of a shift and a value of zero otherwise. For example, consider the case of a daily planning horizon of sixty four 15-minute planning intervals and a 6-hour shift that starts in period one and that has single-period reliefs in its 5th and 18th periods and a four-period meal break beginning in its 10th period. The a_{tp} coefficients for this shift would be four consecutive ones (for the first work stretch), a zero (for the first relief), four consecutive ones (for the second work stretch), four consecutive zeros (for the meal break), four consecutive ones (for the third work stretch), a zero (for the second relief), six consecutive ones (for the fourth and final work stretch), and, finally, 40 consecutive zeros (for the non-work periods from the end of the shift to the end of the planning horizon).[2]

With WSP, r_p is the ideal staff size for period p. A perfectly-matched schedule will exactly match capacity to demand by providing the ideal number of staff in each period. All perfectly-matched schedules are not necessarily optimal, however. For example, since we assume that reliefs are paid, a perfectly-matched schedule with 20 shifts (with two reliefs per shift) would typically be less costly than a perfectly-matched schedule with 21 shifts (with two reliefs per shift), since the latter includes 42 periods of paid, but unproductive relief time while the former included only 40 such periods. Further, an optimal schedule is not necessarily perfectly-matched, since limited flexibility, by precluding satisfying the ideal staffing levels in all periods, can lead to over scheduling of labor.

3. An experiment in relief scheduling

In this section we describe the set of problems we developed to investigate relief scheduling, and the four approaches to relief scheduling that we evaluated.

3.1. Test environment

This subsection describes a set of 100 test problems we developed to determine whether reliefs should be scheduled in advance or deferred to real-time. In developing the test problems we strove to create problems representative of those occurring in a diverse range of service environments. Each problem has a 16-hour operating day broken into 64 15-minute intervals.
The problems varied on three dimensions: the ‘‘shape’’ of the ideal staffing levels (four factor levels); the mean ideal staffing levels (five levels); and the variation in the ideal staffing levels across periods (five levels). The four ‘‘shapes’’ had one, two, three, and numerous daily peaks in the ideal staffing levels. One daily peak in demand often occurs in retail facilities on weekends. Two daily peaks are often observed in service environments where demand is related to commuters; for example, drop-off and pick-up demand at dry cleaners. Three daily demand peaks commonly occur in restaurants. Numerous daily peaks are observed in service environments where there are multiple components of customer demand, for example, counter staffing requirements in airport terminals.

The five levels of mean ideal staffing levels were 5, 10, 20, 40, and 80 employees. The lower staffing levels can be seen in small grocery stores, while the higher levels can be observed in modestly sized telemarketing operations. The five levels of variation in ideal staffing levels had amplitudes of ±20%, 40%, 60%, 80%, and 100% of the mean ideal levels. The rationale for including a range of variability is that higher variability makes it harder to provide the ideal number of staff in every period. As such, high variability in the ideal staffing levels should offer greater opportunities for the real-time slotting of reliefs into periods of surplus staffing. Fig. 1 illustrates the employee

[2] This example is taken from the first shift shown in Table 3.

requirements in the eight problems with a mean requirement of 20 employees and lowest and highest variability in the ideal staffing levels. The staffing patterns we considered are consistent with those from a number of earlier studies (see, for example, Thompson, 1996b, 1997).

For each of the 100 problems, the operative restrictions on allowable shifts were as follows: shifts are between 6 and 9 hours in length, including an hour-long, unpaid meal break. The meal break is preceded and followed by at least 2.25 and no more than 5 hours of paid time. During each pre- and post-meal break work-stretch, a paid, 15-minute relief is required. Regardless of whether the reliefs are scheduled in advance or real-time, each relief must be preceded and followed by at least 1 hour and no more than 3.75 hours of work.

These shift-defining restrictions, coupled with the 64-planning period operating day, resulted in a total of 89,651 unique shifts when reliefs are considered, and a total of 3566 unique shifts when reliefs are ignored. The number of possible workforce schedules is appreciably larger than these numbers, however, as discussed in the introduction, and so the reliefs greatly increase problem complexity.

3.2. Relief scheduling approaches

To investigate the issue of whether reliefs should be scheduled in advance or in real-time, we used three approaches to relief scheduling. The first, Relief Scheduling Approach One, or RSA1, is the only approach that schedules reliefs in advance (i.e., simultaneously with shifts). That is, since RSA1 includes reliefs when solving WSP, the workforce schedule is developed while explicitly considering the need for reliefs. For each problem, RSA1 provides the basic schedule against which the other schedules are compared.

The second approach, RSA2, does not schedule reliefs either in advance or in real-time. That is, RSA2 solves WSP ignoring reliefs. RSA2's solutions are thus equivalent to initial workforce schedules found in environments where relief scheduling occurs solely in real-time. By comparing RSA2's schedules to those of RSA1, we can determine if there are fundamental differences between schedules developed considering the need for reliefs and those developed without consideration of reliefs.

We developed the third approach to further investigate the effect of failing to schedule reliefs in advance. This approach attempts to assign reliefs to previously developed schedules that disregard reliefs. That is, approach three (RSA3) attempts to insert reliefs into the schedule found using RSA2. RSA3 maximizes the number of reliefs that can be assigned to RSA2's schedule, without scheduling fewer than the ideal number of staff required in any period. Since RSA3 only allows the relief timing to vary, it has the effect of slotting breaks into periods of surplus staffing—those periods with more than the ideal number of staff. By examining the number of reliefs that can be assigned into periods of surplus staffing, we can determine the validity of an argument like ‘‘one need not schedule reliefs in advance, since reliefs can always be taken in periods of surplus staffing.’’ As we shall see, the ability to slot reliefs into periods of surplus staffing is curtailed by the timing and amount of surplus staffing. To match relief to shifts in RSA3, we used the following Relief Assignment Model, or RAM:

$$\text{Max} \qquad Z = \sum_{j \in S} \left(\sum_{b \in B_j^1} y_{jb}^1 + \sum_{\{b \in B_j^2} y_{jb}^2 \right) \tag{4}$$

subject to

$$\sum_{j \in S} \left(\sum_{\{b | b \in B_j^1, b = p\}} y_{jb}^1 + \sum_{\{b | b \in B_j^2, b = p,\}} y_{jb}^2 \right) \leq v_p \text{ for } p \in P, \tag{5}$$

$$\sum_{b \in B_j^1} y_{jb}^1 \leq 1 \text{ for } j \in S, \tag{6}$$

$$\sum_{b \in B_j^2} y_{jb}^2 \leq 1 \text{ for } j \in S, \tag{7}$$

$$y_{jb}^1 = \{0,1\} \quad for\ j \in S, b \in B_j^1, \tag{8}$$

$$y_{jb}^2 = \{0,1\} \quad for\ j \in S, b \in B_j^2, \tag{9}$$

where

S = set of shifts scheduled in the solution to RSA2;

B_j^1 = set of valid periods for the first relief of scheduled shift j;

B_j^2 = set of valid periods for the second relief of scheduled shift j;

$y_{jb}^1 = \begin{cases} 1 \text{ if relief 1 of scheduled shift } j \text{ is assigned to period } b; \\ 0 \text{ otherwise} \end{cases}$

v_p = surplus of staffing in period p from the solution to RSA1.

RAM’s objective (4) is to maximize the number of reliefs assigned. Constraint set 5 ensures that reliefs can only be scheduled into periods of surplus staffing from the solution of RSA2. Constraint sets (6) and (7) ensure that no more than one instance of the first and second reliefs are assigned for each scheduled shift. Finally, constraint sets (8) and (9) impose the binary nature of the relief assignment variables.

We used the commercial software combination of GAMS (Brooke et al., 1992) and OSL (IBM Corporation, 1991), respectively to generate and solve RAM and the variants of WSP required by RSA1 through RSA3. We limited the solution times to 3 minutes on the equivalent of a Pentium IV-2.0 GHz based personal computer, and used the best integer solution obtained in that interval if the best solution was not verified as being optimal.

4. Results and discussion

We begin the presentation of results by showing and discussing the outcomes for the first problem, and then move to a summary of the outcomes for all 100 problems.

4.1. Problem one

Table 2 presents the ideal staffing levels for problem one. As we noted earlier, the ideal staff size is the minimum number of employees that delivers the specified service level. Tables 3–5 present the solutions to RSA1 through RSA3. Table 3 shows that RSA1's optimal schedule contained 14 shifts and 9 employee-periods of surplus staffing. Table 4 shows the optimal solution for RSA2. This schedule contains 14 shifts and 27 periods of surplus staffing. One might at first think that 27 of the 28 necessary reliefs (=14 shifts times 2 reliefs per shift) for RSA2's schedule could be assigned to the periods with surplus staffing. The optimal solution for RSA3, presented in Table 5, shows that this is not possible. RSA3's solution shows that only 18 of the 28 necessary reliefs can be assigned to periods of surplus staffing (due to relief assignment rule constraints), leaving surplus staffing of 9 (=27–19) employee-periods and 10 unassigned breaks.

Taken as a whole, the schedules illustrated in Tables 3–5 show that there are two noticeable differences between an optimal schedule developed considering reliefs (RSA1's schedule in Table 3) and a schedule developed for the same problem but in ignorance of reliefs (RSA2's schedule in Table 4). First, since it fails to recognize the lost productive time, the latter approach schedules insufficient work time to cover all the necessary breaks. Second, the times at which the surplus work was scheduled does not match very well with the times that breaks must be taken. Indeed, there was one shift (shift 8 in Table 5) that actually would not have received ANY breaks when breaks were not scheduled in advance. The combination of these shortcomings means that if one MUST give breaks, they WILL result in reduced levels of customer service, since many of the breaks will have to be scheduled at times when surpluses do not occur. Moreover, since too little productive time is scheduled, the employees would never really be able to compensate for the periods with reduced service levels. As we shall see in the next subsection, the results on problem one are very representative of the results across all 100 problems.

4.2. All problems

Table 6 summarizes the results of the complete investigation. For each model, it reports the mean schedule cost, MSC; the percentage of reliefs that are assigned, PRA; and the average number of shifts in the schedule, ANS. Table 6 categorizes the results based on the number of daily peaks in the ideal staffing levels.

The complete results in Table 6 show distinct similarities to the results on problem one. Clearly, there are substantial differences in schedules developed with regard to reliefs (using RSA1) and those that are developed without regard to reliefs (using RSA2). First, RSA2 tends to schedule more shifts than RSA1. This result is not surprising, in that RSA2 ignores the fixed charge of paid, but unproductive relief time.[3] However, the increased number of shifts increases the difficulty of real-time relief scheduling due to the increased number of required reliefs. One avenue we did not investigate is whether this increase in the number of scheduled shifts may be mitigated by exploiting the multiple optimal schedules that often exist in workforce schedules. Second, RSA2 fails to schedule enough labor to allow reliefs to be inserted entirely in periods of surplus staffing. Overall, only about 40% of the necessary reliefs can be inserted into periods of surplus staffing (see the results for RSA3). The problems vary greatly in the percentage of reliefs that can be assigned in periods of surplus staffing—averaging between 12% and 78% of reliefs assigned across the problem categories. Third, RSA2 frequently fails to schedule enough labor to allow all necessary reliefs to be inserted without having fewer than the minimum acceptable staff size in some period.

Recall that a period’s ideal staffing level is the smallest number of staff that will deliver the ideal level of customer service. Having fewer than the ideal number of staff means that the staff will not be able to keep pace with customers arrivals, leading to long lines, long delays for service, and very unprofitable operations. Clearly, then, it is problematic to assign reliefs to schedules developed without regard to them.

Relaxing the relief timing restrictions is one way of increasing the number of reliefs RSA3 can assign in real-time. Consider one scenario where the original relief timing restrictions are valid (based on contractual obligations, management and employee desires, and productivity considerations) and a second scenario where the original relief timing restrictions are overly tight (i.e., invalid). In the former scenario, relaxing the restrictions risks a less productive and disgruntled workforce and, perhaps, contract violations. In the latter scenario, it is still unlikely that RSA3 will be able to assign the necessary 150% more reliefs than it previously assigned.[4] If the relaxed relief timing restrictions are indeed valid, then it seems sensible to use these correct restrictions when developing a schedule that includes reliefs (RSA1).

Finally, we have heard the argument that scheduling reliefs is unimportant since demand in real-time will never be what is forecast. This logic has a major flaw. As the results with RSA3 show,

[3] Schedules developed without regard to reliefs will be problematic even if reliefs are unpaid. This is because there is insufficient surplus staffing, at the right times, in which to slot the reliefs.

[4] Since RSA2 only assigned 40% of the necessary reliefs, on average, 60% of the reliefs were unassigned. Thus 150% more reliefs must be assigned.

insufficient labor is generally scheduled when reliefs are ignored. For reliefs to be given in real-time, without having fewer than the ideal staff size in any period, implies that demand forecasts generally exceed actual demand (i.e., there is a particular type of forecast bias). Trying to correctly over-specify demand forecasts so that sufficient but not excess labor is available in real-time to schedule reliefs seems a very indirect and ineffective way of dealing with reliefs compared to scheduling them in advance (and, if desired, rescheduling them in real-time).

5. Conclusions

Historically, the high level of flexibility inherent in work schedules with reliefs hindered the search for optimal solutions to scheduling models. Development in the 1990s of implicit representations of workforce scheduling problems (Bechtold and Jacobs, 1990; Thompson, 1995a) has lessened this barrier. Indeed, optimal solutions to integer programming models that would require over 89,000 variables in an explicit formulation often can be found in a few minutes on a PC using an implicit model. With an implicit model we were able to evaluate alternative approaches to the relief scheduling problem.

Commercial labor scheduling systems offer anecdotal evidence of the value in scheduling breaks. Table 7 lists three vendors of commercial labor scheduling systems. To find the commercial vendors, we went to the Yahoo URL listing labor management tools.[5] From a list of approximately 20 companies, we examined their on-line documentation, looking for vendors offering tools with some automated scheduling component (rather than simply an aid to manual scheduling). For such venders, we also attempted to determine whether their software had the capability to schedule breaks. In fact, the three vendors listed in Table 7 not only were the only ones offering automated scheduling tools, but their systems all scheduled breaks.

To summarize, it initially appears that it is better to ignore reliefs (i.e., because RSA2's schedules are less costly than those of RSA1). However, the results show that failing to schedule reliefs in advance will have one of the following undesirable outcomes. First, there will be a less profitable deployment of labor, due to poor service, should all reliefs be assigned in real-time within the established relief-timing restrictions (as shown by the results that RSA3 can schedule only 43% of the necessary reliefs). Specifically, there will be too many shifts and insufficient total labor scheduled when reliefs are ignored. With too many shifts scheduled, too many paid, non-work reliefs must be scheduled, thus increasing costs. With insufficient labor scheduled, the reliefs cannot all be assigned only in periods of surplus staffing, resulting in costly occurrences of short staffing. Second, if some reliefs are not given, there will be a disgruntled and less productive workforce (as shown by the results of RSA3, only about 40% of the required reliefs can be slotted into periods of surplus staffing).

[5]http://dir.yahoo.com/Business_and_Economy/Business_to_Business/Computers/Software/Business_Applications/Scheduling_and_Task_Management/Employee_Scheduling/

Third, more reliefs may be assigned in real-time if the relief timing restrictions are relaxed. However, if the original restrictions are valid (based on contractual obligations, management and employee desires, and productivity considerations), this also risks disgruntled and less productive employees and possibly contractual obligations; while if the relaxed restrictions really are valid, then it makes sense to use them when developing the schedule with reliefs. Only by scheduling reliefs in advance, then, can the problems posed by real-time relief scheduling be avoided.

Our results illustrate the fallacy of the commonly held assumption that managers can schedule reliefs in real-time with negligible impact on schedule profitability. This finding is consistent with a recent study by Hur et al. (2004), who found that, in a fast service environment, real-time schedule adjustments made by computer-based heuristics were more profitable than adjustments made by experienced managers. Our finding has an exceedingly important implication for research on workforce scheduling. To increase the realism of their work, researchers should incorporate relief scheduling into the procedures they develop. Again, because reliefs were considered in less than 18% of our sample of 64 published studies, the field has significant work to do moving forward to ensure its relevance to practicing managers.

Future research also should evaluate strategies that managers use for real-time rescheduling of reliefs. For example, in some industries, we have observed that managers schedule breaks in advance but modify the timing of these breaks based on actual customer demand. Conceivably, managers can further improve profitability by effective relief rescheduling in real-time.[6]

[6] We wish to acknowledge the feedback provided by Michael Brusco on an earlier version of this paper.

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Table 1. Literature summary of reliefs (rest breaks) and meal breaks

Reference	No. breaks scheduled	Meal breaks scheduled	Reliefs (rest breaks) scheduled
Alfaresm (2000)	X		
Alvarez-Valdes et al. (1999)	X		
Aykin (2000)	X		
Bailey (1985)	X		
Bailey and Field (1985)		X	
Baker et al. (1972)	X		
Bard (2004)		X	
Bartholdi et al. (1981)		X	X
Beaumont (1997)		X	
Bechtold and Brusco (1995)	X		
Bechtold et al. (1991)		X	
Bechtold and Jacobs (1990)		X	
Bechtold et al. (1984)		X	X
Bechtold and Showalter (1985)		X	
Bechtold and Showalter (1987)		X	
Brusco and Jacobs (1993)		X	
Brusco and Jacobs (1998)	X		
Brusco and Jacobs (2000)		X	
Brusco and Jacobs (2001)		X	
Brusco and Johns (1995)		X	
Buffa et al. (1976)		X	X
Dantzig (1954)		X	
Easton and Rossin (1991)		X	
Easton and Mansour (1999)		X	
Goodale and Thompson (2004)		X	
Henderson and Berry (1976)		X	X
Henderson and Berry (1977)		X	X
Holloran and Byrn (1986)		X	X
Hur et al. (2004)		X	
Gaballa and Pierce (1979)		X	
Glover et al. (1984)		X	X
Goodale and Tunc (1998)	X		
Goodale et al. (2003a,b)	X		
Jacobs and Bechtold (1993)		X	
Janaro and Bechtold (1985)		X	X
Jaumard et al. (1998)	X		
Keith (1979)		X	X
Kolesar et al. (1975)		X	
Krajewski et al. (1980)		X	
Li et al. (1991)	X		
Loucks and Jacobs (1991)		X	

Reference	No. breaks scheduled	Meal breaks scheduled	Reliefs (rest breaks) scheduled
Mabert and Showalter (1990)		X	
Mabert and Watts (1982)	X		
McGinnis et al. (1978)	X		
Melachrinoudis and Olafsson (1995)	X		
Moondra (1976)		X	
Morris and Showalter (1983)		X	
Parker and Larsen (2003)	X		
Segal (1974)		X	X
Showalter et al. (1977)		X	
Showalter and Mabert (1989)		X	
Thompson (1990)		X	
Thompson (1992)		X	
Thompson (1993a)		X	
Thompson (1993b)		X	
Thompson (1995a)		X	
Thompson (1995b)		X	
Thompson (1996a)		X	
Thompson (1996b)		X	
Thompson (1996c)		X	
Thompson (1997)		X	
Vakharia et al. (1992)	X		
Vohra (1988)		X	
Wilson and Willis (1983)		X	X
Number of references (% of total)	16 (25.0)	48 (75.0)	11 (17.2)

Table 2. Ideal staff sizes by period for problem one

Period	ISL	Period	ISL	Period	ISL	Period	ISL
1	5	17	5	33	6	49	6
2	5	18	5	34	5	50	6
3	4	19	6	35	5	51	4
4	5	20	6	36	5/6	52	4
5	3	21	4	37	6	53	6
6	3	22	5	38	7	54	3
7	4	23	5	39	6	55	4/5
8	5	24	7	40	6	56	4
9	3	25	6	41	7	57	4
10	4	26	7	42	5	58	3
11	5	27	7	43	7	59	5
12	5	28	5	44	6	60	4
13	4	29	7	45	5	61	4
14	6	30	5	46	4	62	5
15	5	31	7	47	4	63	3
16	6	32	6	48	4	64	3

ISL = ideal staffing level.

Table 3. Optimal RSA1 solution to problem one

Per	Shift														ISS	ASS	NSS
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
1	w	w	w	w	w										5	5	0
2	w	w	w	w	w										5	5	0
3	w	w	w	w	w										4	5	*1*
4	w	w	w	w	w										5	5	0
5	r	w	w	w	w										3	4	*1*
6	w	r	r	w	w										3	3	0
7	w	w	w	w	w										4	5	*1*
8	w	w	w	w	w										5	5	0
9	w	w	w	r	w										3	4	*1*
10	m	w	w	w	w										4	4	0
11	m	w	w	w	w	w									5	5	0
12	m	w	w	w	w	w									5	5	0
13	m	w	w	w	r	w									4	4	0
14	w	w	w	w	w	w									6	6	0
15	w	m	w	w	w	w									5	5	0
16	w	m	w	w	w	w	w								6	6	0
17	w	m	w	w	w	r	w								5	5	0
18	r	m	w	w	w	w	w								5	5	0
19	w	w	m	w	w	w	w								6	6	0
20	w	w	m	m	w	w	w	w							6	6	0
21	w	w	m	m	m	w	r	w							4	4	0
22	w	w	m	m	m	w	w	w							5	5	0
23	w	r	w	m	m	w	w	w							5	5	0
24	w	w	w	w	m	w	w	w							7	7	0
25		w	w	w	w	w	w	r							6	6	0
26		w	w	w	w	w	w	w							7	7	0
27		w	w	w	w	w	w	w							7	7	0
28			r	w	w	w	w	w							5	5	0
29			w	w	w	m	w	w	w	w					7	7	0
30			w	r	r	m	w	w	w	w					5	5	0
31			w	w	w	m	w	w	w	w					7	7	0
32			w	w	w	m	m	w	w	w					6	6	0
33				w	w	w	m	w	w	w					6	6	0
34				w	w	w	m	m	r	r	w	w			5	5	0
35						w	m	m	w	w	w	w			5	5	0
36						w	w	m	w	w	w	w			5/6	6	0
37						w	w	m	w	w	w	w			6	6	0
38						w	w	w	w	w	w	w			7	7	0
39						w	w	w	w	w	r	w			6	6	0
40						r	w	w	w	w	w	r	w		6	6	0

Per	Shift														ISS	ASS	NSS
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
41						w	w	w	m	w	w	w	w		7	7	0
42						w	r	r	m	w	w	w	w		5	5	0
43						w	w	w	m	w	w	w	w		7	7	0
44						w	w	w	m	w	w	w	r		6	6	0
45						w	w	w	w	m	m	m	w		5	5	0
46							w	w	w	m	m	m	w		4	4	0
47							w	w	w	m	m	m	w		4	4	0
48							w	w	w	m	m	m	w		4	4	0
49							w	w	w	w	w	w	m		6	6	0
50							w	w	w	w	w	w	m		6	6	0
51								w	w	w	w	w	m		4	5	*1*
52								w	w	w	w	w	m		4	5	*1*
53								w	w	w	w	w	w		6	6	0
54									r	r	w	w	w		3	3	0
55									w	w	w	w	w		4/5	5	0
56									w	w	r	w	w		4	4	0
57									w	w	w	r	w		4	4	0
58									w	w	w	w	r		3	4	*1*
59									w	w	w	w	w		5	5	0
60									w	w	w	w	w		4	5	*1*
61									w	w	w	w	w		4	5	*1*
62									w	w	w	w	w		5	5	0
63											w	w	w		3	3	0
64											w	w	w		3	3	0

RSA1 develops a workforce schedule that includes reliefs. Per = planning period; w = work period; m = meal period; r = relief; ISS = ideal staff size; ASS = actual staff size; NSS = net staff size (=ASS − ISS).

Table 4. Optimal RSA2 solution to problem one

Per	**Shift**														**ISS**	**ASS**	**NSS**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
1	w	w	w	w	w										5	5	0
2	w	w	w	w	w										5	5	0
3	w	w	w	w	w										4	5	*1*
4	w	w	w	w	w										5	5	0
5	w	w	w	w	w										3	5	*2*
6	w	w	w	w	w										3	5	*2*
7	w	w	w	w	w										4	5	*1*
8	w	w	w	w	w										5	5	0
9	w	w	w	w	w										3	5	*2*
10	m	w	w	w	w										4	4	0
11	m	w	w	w	w	w									5	5	0
12	m	m	w	w	w	w	w								5	5	0
13	m	m	w	w	w	w	w								4	5	*1*
14	w	m	w	w	w	w	w								6	6	0
15	w	m	m	w	w	w	w								5	5	0
16	w	w	m	w	w	w	w								6	6	0
17	w	w	m	w	w	w	w								5	6	*1*
18	w	w	m	m	w	w	w								5	5	0
19	w	w	w	m	w	w	w								6	6	0
20	w	w	w	m	w	w	w								6	6	0
21	w	w	w	m	m	w	w								4	5	*1*
22	w	w	w	w	m	m	w								5	5	0
23	w	w	w	w	m	m	w								5	5	0
24	w	w	w	w	m	m	w	w	w						7	7	0
25		w	w	w	w	m	m	w	w						6	6	0
26		w	w	w	w	w	m	w	w						7	7	0
27		w	w	w	w	w	m	w	w						7	7	0
28			w	w	w	w	m	w	w						5	6	*1*
29			w	w	w	w	w	w	w						7	7	0
30				w	w	w	w	w	w						5	6	*1*
31				w	w	w	w	w	w	w					7	7	0
32					w	w	w	w	w	w					6	6	0
33					w	w	w	m	w	w	w				6	6	0
34						w	w	m	w	w	w				5	5	0
35							w	m	w	w	w	w			5	5	0
36							w	m	w	w	w	w			5/6	5	0
37							w	w	w	w	w	w			6	6	0
38							w	w	w	w	w	w	w		7	7	0
39							w	w	m	w	w	w	w		6	6	0
40							w	w	m	w	w	w	w		6	6	0

Per	**Shift**														**ISS**	**ASS**	**NSS**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
41							w	w	m	w	w	w	w	w	7	7	0
42							w	w	m	m	w	w	w	w	5	6	*1*
43							w	w	w	m	w	w	w	w	7	7	0
44							w	w	w	m	w	w	w	w	6	7	*1*
45							w	w	w	m	m	m	w	w	5	5	0
46								w	w	w	m	m	w	w	4	5	*1*
47								w	w	w	m	m	w	w	4	5	*1*
48								w	w	w	m	m	w	w	4	5	*1*
49								w	w	w	w	w	m	w	6	6	0
50								w	w	w	w	w	m	w	6	6	0
51								w	w	w	w	w	m	m	4	5	*1*
52								w	w	w	w	w	m	m	4	5	*1*
53								w	w	w	w	w	w	m	6	6	0
54										w	w	w	w	m	3	4	*1*
55										w	w	w	w	w	4/5	5	0
56										w	w	w	w	w	4	5	*1*
57										w	w	w	w	w	4	5	*1*
58										w	w	w	w	w	3	5	*2*
59										w	w	w	w	w	5	5	0
60										w	w	w	w	w	4	5	*1*
61										w	w	w	w	w	4	5	*1*
62										w	w	w	w	w	5	5	0
63												w	w	w	3	3	0
64												w	w	w	3	3	0
UnS	R2		R2	R2	R2		R1, R2		R1	R1	R1	R1					

RSA2 develops a workforce schedule that ignores reliefs. Per = planning period; w = work period; m = meal period; r = relief; ISS = ideal staff size; ASS = actual staff size; NSS = net staff size (=ASS − ISS); UnS = unscheduled reliefs.

Table 5. Optimal RSA3 solution to problem one

Per	Shift														ISS	ASS	NSS
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
1	w	w	w	w	w										5	5	0
2	w	w	w	w	w										5	5	0
3	w	w	w	w	w										4	5	*1*
4	w	w	w	w	w										5	5	0
5	r	r	w	w	w										3	3	0
6	w	w	r	r	w										3	3	0
7	w	w	w	w	r										4	4	0
8	w	w	w	w	w										5	5	0
9	w	w	w	w	w										3	5	*2*
10	m	w	w	w	w										4	4	0
11	m	w	w	w	w	w									5	5	0
12	m	m	w	w	w	w	w								5	5	0
13	m	m	w	w	w	w	w								4	5	*1*
14	w	m	w	w	w	w	w								6	6	0
15	w	m	m	w	w	w	w								5	5	0
16	w	w	m	w	w	w	w								6	6	0
17	w	w	m	w	w	r	w								5	5	0
18	w	w	m	m	w	w	w								5	5	0
19	w	w	w	m	w	w	w								6	6	0
20	w	w	w	m	w	w	w								6	6	0
21	w	r	w	m	m	w	w								4	4	0
22	w	w	w	w	m	m	w								5	5	0
23	w	w	w	w	m	m	w								5	5	0
24	w	w	w	w	m	m	w	w	w						7	7	0
25		w	w	w	w	m	m	w	w						6	6	0
26		w	w	w	w	w	m	w	w						7	7	0
27		w	w	w	w	w	m	w	w						7	7	0
28			w	w	w	w	m	r	w						5	5	0
29			w	w	w	w	w	w	w						7	7	0
30				w	w	r	w	w	w						5	5	0
31				w	w	w	w	w	w	w					7	7	0
32					w	w	w	w	w	w					6	6	0
33					w	w	w	m	w	w	w				6	6	0
34						w	w	m	w	w	w				5	5	0
35							w	m	w	w	w	w			5	5	0
36							w	m	w	w	w	w			5/6	5	0
37							w	w	w	w	w	w			6	6	0
38							w	w	w	w	w	w	w		7	7	0
39							w	w	m	w	w	w	w		6	6	0
40							w	w	m	w	w	w	w		6	6	0

Per	**Shift**														**ISS**	**ASS**	**NSS**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
41							w	w	m	w	w	w	w	w	7	7	0
42							w	r	m	m	w	w	w	w	5	5	0
43							w	w	w	m	w	w	w	w	7	7	0
44							w	w	w	m	w	w	r	w	6	6	0
45							w	w	w	m	m	m	w	w	5	5	0
46								w	w	w	m	m	w	r	4	4	0
47								w	r	w	m	m	w	w	4	4	0
48								w	w	w	m	m	w	w	4	5	*1*
49								w	w	w	w	w	m	w	6	6	0
50								w	w	w	w	w	m	w	6	6	0
51								w	w	r	w	w	m	m	4	4	0
52								w	w	w	w	w	m	m	4	5	*1*
53								w	w	w	w	w	w	m	6	6	0
54										w	r	w	w	m	3	3	0
55										w	w	w	w	w	4/5	5	0
56										w	w	r	w	W	4	4	0
57										w	w	w	r	W	4	4	0
58										w	w	w	w	W	3	5	*2*
59										w	w	w	w	W	5	5	0
60										w	w	w	w	R	4	4	0
61										w	w	w	w	W	4	5	*1*
62										w	w	w	w	W	5	5	0
63												w	w	W	3	3	0
64												w	w	W	3	3	0

RSA3 takes the workforce schedule developed ignoring reliefs (i.e., RSA2's schedule), and attempts to assign as many reliefs as possible to periods with surplus staffing. Per = planning period; w = work period; m = meal period; r = relief; ISS = ideal staff size; ASS = actual staff size; NSS = net staff size (=ASS − ISS).

Table 6. Summary of results for the three approaches on the 100 problems

Demand peaks		**1**	**2**	**3**	**Numerous**	**Overall**
# Prob		**25**	**25**	**25**	**25**	**100**
	MSC	1923.92	2485.40	2460.88	2526.36	2349.14
RSA 1	PRA	100.00	100.00	100.00	100.00	100.00
	ANS	62.76	107.88	100.68	105.40	94.18
	MSC	1803.44	2305.80	2340.00	2481.68	2232.73
RSA 2	PRA	0.00	0.00	0.00	0.00	0.00
	ANS	81.20	108.88	101.40	105.92	99.35
	MSC	1803.44	2305.80	2340.00	2481.68	2232.73
RSA 3	PRA	12.16	40.27	42.62	78.10	43.29
	ANS	81.20	108.88	101.40	105.92	99.35

RSA1 develops a workforce schedule that includes reliefs. RSA2 develops a workforce schedule that ignores reliefs. RSA3 takes the workforce schedule developed ignoring reliefs, and attempts to assign as many reliefs as possible to periods with surplus staffing. Demand peaks = number of peaks in the ideal staffing pattern. MSC = mean schedule cost, in labor-period-equivalents. PRA = percentage of reliefs assigned. ANS = average number of shifts in the schedule.

Table 7. Summary of three commercial labor scheduling systems found at the Yahoo site[a]

Company name	**URL**	**Product name**	**Breaks scheduled**
Atlas Business Solutions, Inc.	http://www.abs-usa.com	Visual Staff Scheduler® PRO 5.0	Yes
Global Management Technologies	http://www.gmtcorp.com	GMT Planet	Yes
Schedule Source	http://www.schedulesource.com	eSchedule 4.1	Yes

[a]http://dir.yahoo.com/Business_and_Economy/Business_to_Business/Computers/Software/Business_Applications/Scheduling_and_Task_Management/Employee_Scheduling/

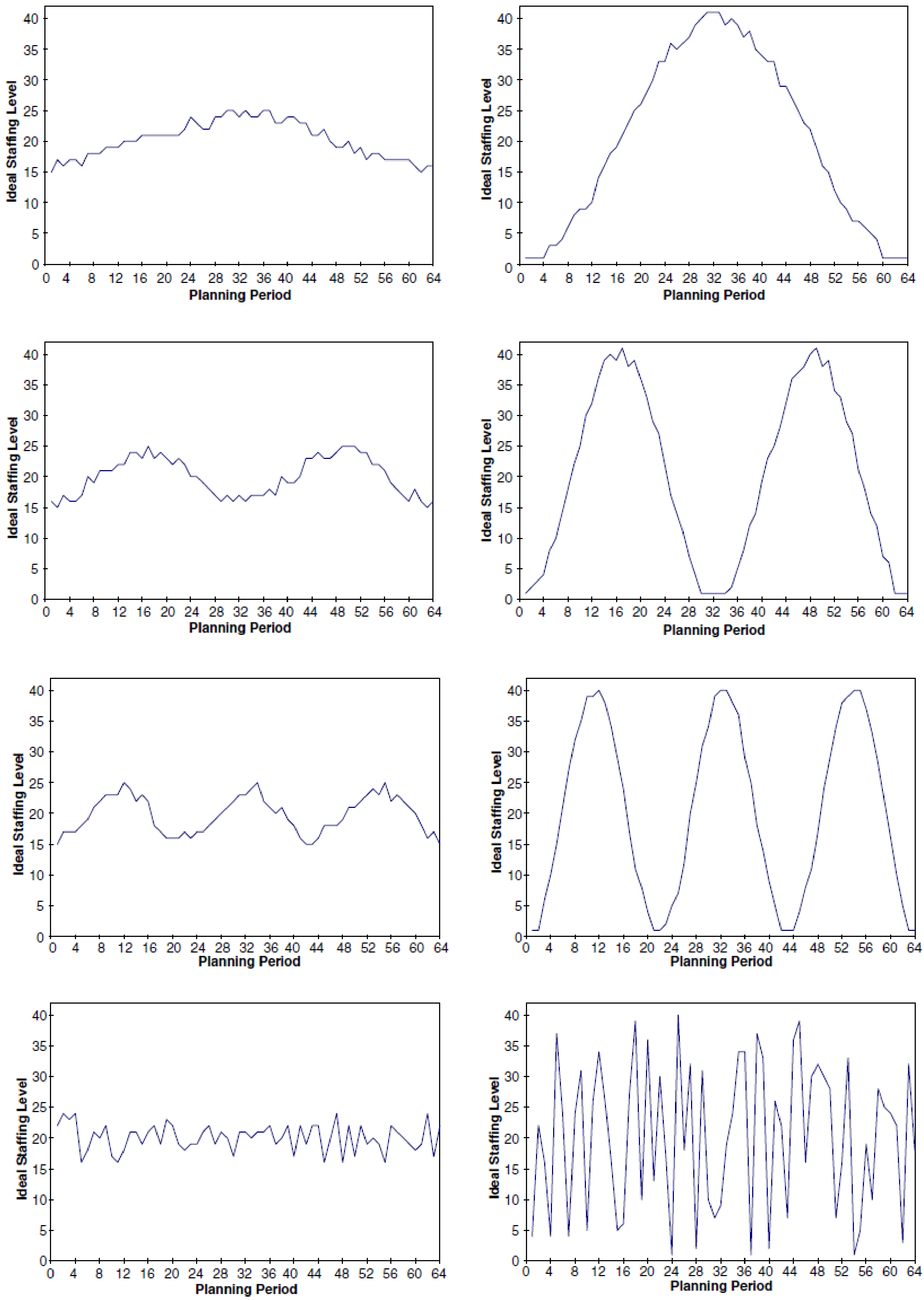

Figure 1. Eight examples of the ideal staffing level patterns.