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Selecting the appropriate input data set when configuring a permanent workforce

Jonathan F. Bard*

Graduate Program in Operations Research and Industrial Engineering, Department of Mechanical Engineering, University of Texas, 1 University Station C2200, Austin, TX 78712, USA

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Abstract

This paper explores the issue of choosing the best data to use when running a scheduling model to select a permanent workforce for a service facility. Because demand is assumed to vary over the day and throughout the week, the choice of the input data is crucial. If a week of low volume is selected, the solution might call for an insufficient number of workers; if a week of high volume is chosen, excessive idle time might be the result. Staff scheduling at mail processing and distribution centers (P&DCs) in the United States provides the backdrop. In operating these facilities, a critical objective is to manage overtime, part-time workers, and temporaries so that when volumes are high, additional costs are kept to a minimum, and when volumes are low the permanent workforce is almost never idle. In quantitative terms, this means selecting the size and composition of the workforce so that over the year, no more than a total number of overtime hours, part-time hours and temporary worker hours are used when demand exceeds some baseline and absenteeism is taken into account. To solve the problem, an engineering approach is proposed in which estimates of productivity are made based on a single run of the optimization model and the final data set is chosen to satisfy a small error tolerance. The full methodology is illustrated with data provided by the Dallas P&DC.

Keywords: Staff scheduling; Service industry; Data analysis; Integer programming; Workforce selection; Postal service

* Tel.: +1 512 471 3076; fax: +1 512 232 1489.
E-mail address: jbard@mail.utexas.edu.

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1. Introduction

The steady growth of the service industry and the increasing cost of labor have created a variety of new personnel planning and scheduling problems for management. With over 70% of the global workforce in non-manufacturing jobs and many workers paid by the hour, the opportunity for cost-saving is enormous. Somewhat surprisingly, the majority of service providers, such as the airlines, hospitals and support hotlines, are at the forefront in the use of technology in their business practices but still rely on manual methods and rules of thumb for managing the workforce. This is especially true when it comes to disruption management and real-time control.

Service organizations typically face demand that varies sharply throughout the day and over the week. Regardless of the environment, management's principal goal is to find the best mix of hourly employees so that demand is satisfied at minimum cost. At their disposal are options that include the use of full-time workers, part-time workers and overtime. The problem is complicated by labor laws, union contracts, absenteeism, and random fluctuations in demand.

The primary purpose of this paper is to present an integrated approach to determining the size and composition of a permanent workforce for organizations that operate under these conditions. In the most general sense, the problem can be viewed temporally and decomposed along the time axis. In the long run, the goal is to minimize personnel costs while meeting all service standards and contractual obligations. The first step is to find weekly schedules or tours for each employee in a given skill category. This means specifying the work days, their length, the daily start time, and the lunch break. Our focus is on tour scheduling at United State Postal Service (USPS) mail processing and distribution centers where these specifications constitute a 'bid job' (Bailey, 1985; Berman & Larson, 1993; Brusco, 1998; Jarrah, Bard, & deSilva, 1994; Malhotra & Ritzman, 1994). The results will be applicable, however, to a large portion of the service industry (e.g. see Dawid, Konig, & Strauss, 2001; Lin, Lai, & Hung, 2000). Others, including Gans and Zhou (2002) and Pinker and Larson (2003), have addressed a similar problem but with the emphasis on demand uncertainty, learning and turnover. Our major concern is data selection.

Once the regular workforce is determined, adjustments must be made on a weekly basis to account for planned leave and expected departures from assumed demand. To accomplish this, critical resources must be tracked and evaluated. The goal is to provide weekly schedules that balance overtime with the use of part-time and temporary labor so that all requirements are met at minimum cost and at minimum deviation from the baseline schedule. This can be thought of as a replanning problem.

Finally, at the day-to-day level, supervisors must deal with unplanned absenteeism, machine breakdowns, and unexpected spikes in demand; i.e. uncertainty. This is a real-time scheduling problem that falls under the heading of *control*. In the airline industry where bad weather, for example, can occasion flight delays and cancellations (Clausen, Hansen, Larsen, & Larsen, 2001; Thengvall, Bard, & Yu, 2000), the goal is to get back on track as soon as possible at minimum cost and with minimum deviation from the original schedule.

All three problems are interrelated but are solved for different planning horizons starting with the selection of the permanent workforce. In Section 2, we describe a USPS mail processing and distribution center (P&DC) and define the issues associated with the construction of bid jobs. This is followed in Section 3 with the presentation of a baseline model that can be used for this purpose. The model takes the form of a large-scale integer linear program that has been extensively refined over the last 10 years to meet a wide range of scheduling scenarios (Bard, Binici, & deSilva, 2003). The difficulty in using it effectively, though, relates to the selection of the 'proper' input data and the specification of a series of parameter values associated with leave, overtime, the use of temporary workers, and an extension of part-time worker hours. These are the central issue addressed in the paper, and are discussed in Sections 4 and 5. In Section 6, we present an algorithm for calibrating and running the model. A detailed example using data from the Dallas P&DC is examined in Section 7.

2. Description of mail processing facilities and the permanent workforce

The postal system comprises an interconnected web of components each competing for resources, and requiring detailed analysis and planning to assure a continuing degree of fiscal self-sufficiency. Headquarters provides a corporate infrastructure of services such as information and human resources management, and sets national policy regarding the use of technology and the acquisition of equipment. Field management is organized into 10 areas and 85 divisions. The system contains approximately 275 processing and distribution centers and more than 25 000 delivery units where carriers prepare their mail prior to delivery.

Postal operations have always been labor intensive. In 2000, 82% of the $68.9 billion budget was workforce related, largely for the 820 000 career employees. It has long been recognized that the only way to stem the rising labor costs is through the use of technology. The first efforts involved the introduction of mechanized equipment in the early 1960s to help sort the mail at the P&DCs. Subsequent activities have been aimed principally at finding ways to automate the myriad sorting and material handling functions performed by the distribution clerks and letter carriers in their respective offices. Today about 98% of all letter mail is sequenced automatically in the order that it is to be delivered by the carrier. This is done with the help of facer-cancellers, optical character readers, bar-code sorters, video coding systems, and flat sorting machines.

2.1. Worker categories

Although the word ‘automation’ is used to describe this equipment, clerks are still needed to operate and maintain each unit throughout the day. A P&DC has four types of workers: full-time regulars (FTRs), part-time regulars (PTRs), part-time flexibles (PTFs), and casuals. The first three are career employees which means that they have job security and benefits. Only a regular employee, though, is given a 5-day a week schedule, often with a constant start time. A flexible employee is generally assigned work one week at a time. He or she can have different start times and shift lengths each day assigned. Employees and managers generally prefer a constant start time for the entire week because of the consistency it offers. A *casual* is a temporary worker who is called in as needed, usually a day at a time, and receives no benefits (Malhotra, Ritzman, Benton, & Leong, 1992).

Full-timers work $8\frac{1}{2}$ consecutive hours each day, which includes a $\frac{1}{2}$ h lunch break (in reality, they are off the clock for the $\frac{1}{2}$-h lunch). Part-timers, on the other hand, may be assigned one of a variety of possible shift lengths ranging from 4 to $8\frac{1}{2}$ h (including the lunch break where applicable). All employees working $6\frac{1}{2}$ or more hours per day must be given a $\frac{1}{2}$ h lunch break.

P&DCs operate continually and are driven by service standards for completing the mail within a fixed time of its arrival. The schedules for regular workers are determined through a bidding system but the schedule for the part-timer flexibles can be changed at will. In cases where the entire workforce is not sufficient to meet demand, casuals or overtime is used. We examine these two options in detail in Section 5.

2.2. Bid jobs

The first component of tour construction involves shift scheduling to satisfy some percentage of the average daily demand (the primary purpose of this paper is to determine how the daily demand should be chosen). The corresponding objective is to find the optimal crew size and daily work assignment for each member of the crew, each day of the week (Aykin, 1996).

The second part of a bid job requires the specification of the days off (Burns & Carter, 1985; Emmons, 1985). The number and characteristics of those days (weekend days, weekdays or combinations thereof) vary according to the organization and the type of industry in which it operates. A general consideration is that sufficient slack must be provided throughout the week so that the days-off requirement is satisfied for every worker. The shift scheduling problem has to take this requirement into account when determining the optimal workforce size.

The third component of a bid job is the lunch break (Bechtold & Jacobs, 1990; Brusco & Jacobs, 2000). All shifts, except for those that are shorter than a specific number of periods, require a fixed length break. Depending on the nature of the work being performed, breaks might be staggered or coincident.

3. Outline of long-term planning model

In the baseline model, the workday is divided into 48 periods, each 30 min long. For accounting purposes the first period starts at 7:00 a.m. The USPS uses three intervals in a day for managerial purposes. A regular employee starts during one of these three intervals and works a shift of a predefined length. This gives rise to 48 different shifts, each 17 periods ($8\frac{1}{2}$ h) long for full-timers, including the lunch break. For part-timers, there are 24 different start times and five different shift lengths, making 120 different part-time shift types in all. Allowable shift lengths are 8, 10, 13, 15 and 17 periods, including the breaks where applicable.

Given these parameters, there are at least two different mathematical formulations of the tour scheduling problem. The traditional approach is based on a set-covering type model in which the columns represent weekly tours and the right-hand side constants represent demand. For the P&DC application, such a model would contain over 1 billion variables and hence be unsolvable with current technology. Alternatively, Bard et al. (2003) pursued a constraint-based approach that first solves a shift-scheduling problem for the week and post-processes the results to obtain tours. Their model is the one adopted here. To keep the presentation simple, PTFs, breaks, and the constraints needed to ensure two consecutive days off in a row (see Alfares, 1997) are omitted. Note that casuals are never considered explicitly in long-term planning.

The following notation is used in the development of the staff scheduling model.

Indices

d days of the week; $d=1,\ldots,7$
t time periods during a day; $t=1,\ldots,48$
f full-time shift types; $f=1,\ldots,n^F$
p part-time shift types; $p=1,\ldots,n^P$

Parameters

c_f prorated weekly cost of full-time shift f
c_p prorated weekly cost of part-time shift p
G_{ft} 1 if full-time shift type f covers period t; 0 otherwise
P_{pt} 1 if part-time shift type p covers period t; 0 otherwise
D_{dt} demand for period t on day d
n^F number of full-time shifts
n^P number of part-time shifts
ρ full-time to part-time labor ratio

Decision variables

x_{fd} number of employees assigned to full-time shift type f on day d
y_{pd} number of employees assigned to part-time shift type p on day d
w_f total number of full-time regular employees needed for shift type f
v_p total number of part-time regular employees needed for shift type p

$$\text{Minimize } z = \sum_{f=1}^{n^F} c_f w_f + \sum_{p=1}^{n^P} c_p v_p \tag{1a}$$

subject to

$$\sum_{f=1}^{n^F} G_{ft} x_{fd} + \sum_{p=1}^{n^P} P_{pt} y_{pd} \geq D_{dt}, \quad d = 1, \ldots, 7; \quad t = 1, \ldots, 48 \tag{1b}$$

$$\sum_{f=1}^{n^F} w_f \geq \rho \sum_{p=1}^{n^P} v_p \tag{1c}$$

$$w_f \geq \frac{1}{5} \sum_{d=1}^{7} x_{fd}, \quad f = 1, \ldots, n^F \tag{1d}$$

$$w_f \geq x_{fd}, \quad f = 1, \ldots, n^F; \quad d = 1, \ldots, 7 \tag{1e}$$

$$v_p \geq \frac{1}{5} \sum_{d=1}^{7} y_{pd}, \quad p = 1, \ldots, n^P \tag{1f}$$

$$v_p \geq y_{pd}, \quad p = 1, \ldots, n^P; \quad d = 1, \ldots, 7 \tag{1g}$$

$$w_f \geq 0, \quad v_p \geq 0, \quad x_{fd} \geq 0, \quad y_{pd} \geq 0 \quad \text{and integer} \quad \forall f, t, p, d \tag{1h}$$

The objective function (1a) minimizes the total weekly cost of the workforce. Constraint (1b) accounts for the demand requirements while (1c) ensures that the minimum ratio ρ of full-time to part-time employees is met. The remaining constraints (1d)–(1g) guarantee that each regular employee can be given two days off a week.

4. Calibrating the model

The long-term planning model has been successfully implemented in a decision support system called SOS (scheduling optimization system). Fig. 1 depicts its various components. Once the integer linear program (1d)–(1h) is solved with CPLEX, several post-processors are called to find 5-day a week schedules for the regular employees, daily assignments for the flexible employees, lunch breaks for each shift 7 h or longer, and daily workstation assignments for all employees. The coding has been done in Java to enable web access.

4.1. Input data and parameters

The main menu items for SOS are shown in Fig. 2. The user first selects or defines the shift types that the facility wants to consider. Next, the workstations must be specified in terms of machine types, number of workers required per machine, and the daily schedule for each workstation. These schedules constitute the primary input data for the problem and can be visualized as a set of 48×7 matrices, one for each machine or workstation. A ±1 entry in a matrix indicates whether or not the machine or workstation is active during the corresponding $\frac{1}{2}$ h period. After these data are entered, the wage set must be specified and parameters fixed in the template. Options include a guarantee of two consecutive days off, minimum percent of full-timers to part-timers, a window for day-to-day shift start times, minimum number of workers per shift, and several variations.

4.2. Parameter settings and data issues

Given a weekly equipment schedule for a processing and distribution center, SOS determines the optimal complement of full-time regulars, part-time regulars and part-time flexibles needed to run the facility. The solution defines a permanent workforce of career employees which is difficult to increase or decrease without a structural change in the mail processing environment. Therefore, the choice of the weekly equipment schedule to use as input to the model is critical. Because mail volume fluctuates from week to week, so will the schedule. In weeks of higher than planned for volume either machine hours

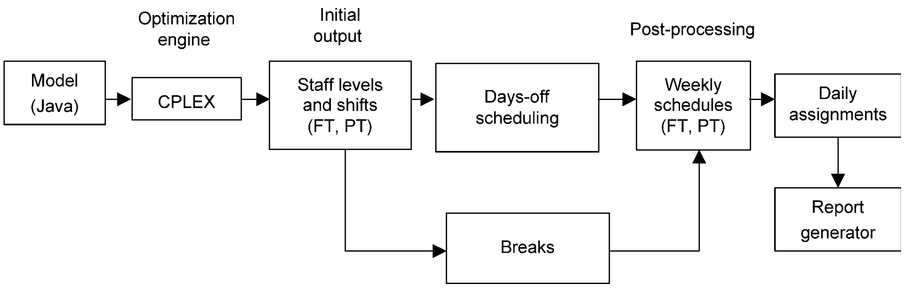

Fig. 1. Components of the scheduling optimization system.

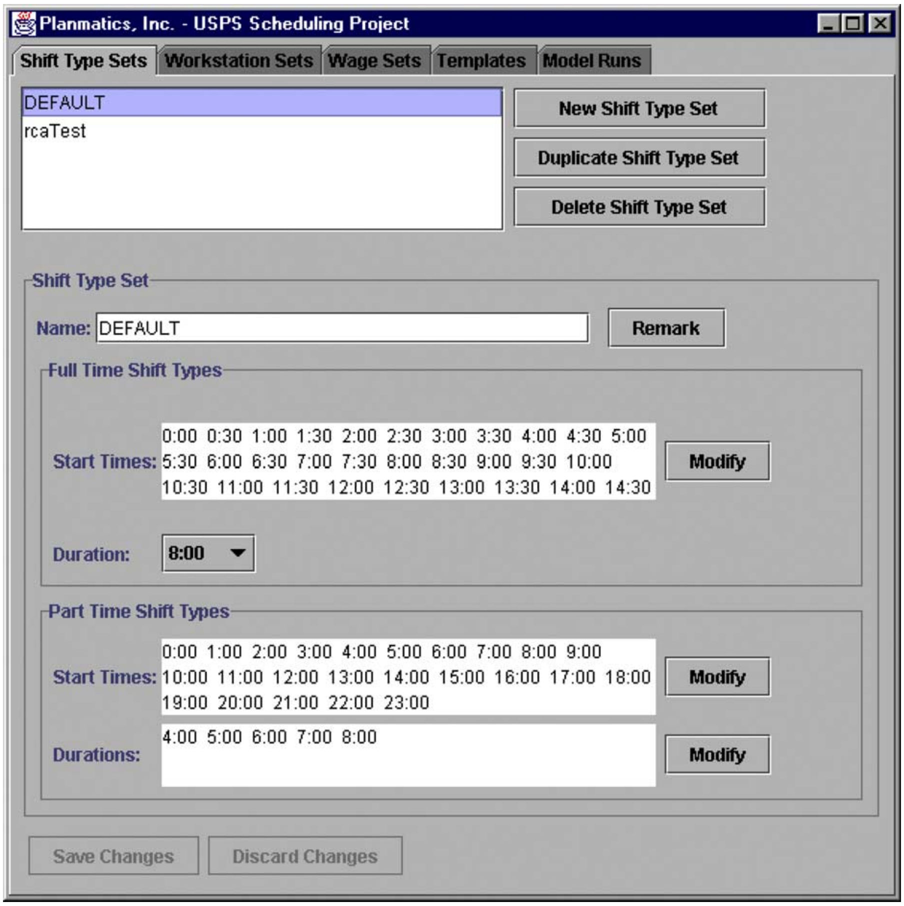

Fig. 2. Menu tabs for SOS.

must be extended or additional machines placed in operation. In weeks of lower volume, some machines may be shut down or their running times cut back. To compensate, the workforce must be adjusted within its permissible limits.

Several options exist for making these adjustments. They include an extension of part-time hours up to 39 per week for each part-time employee, the use of casuals, and the use of overtime. Each is discussed below. Nevertheless, if the size of the permanent workforce is set too low, it may not be possible to use these options to cover weeks of exceptionally high volume. On the other hand, if the permanent workforce is set too high, unnecessary labor costs will be incurred.

An additional factor that must be taken into account in structuring the permanent workforce is leave or absenteeism. For processing and distribution centers, leave due to vacations, illness, training and other causes runs between 13 and 20%. Thus on any given day, up to 1 out of 5 employees may be absent. Once again, increasing the number of part-time hours, using overtime and using casuals are the three options available to a supervisor to provide the necessary coverage. Two additional options include increasing the size of the permanent workforce and reducing the number of part-time hours or days scheduled under normal conditions. In either case, it is necessary to maintain the contractual full-time to part-time ratio.

The first step in determining the size of the permanent workforce is to specify how leave is to be handled by SOS. Once this decision is made, an analysis can be conducted to determine the 'best' week to run SOS. The best week is the one where there are just enough excess hours available from overtime, PTFs and casuals to accommodate the volume fluctuations over the year.

Remark. There is a more subtle factor from which additional hours can be drawn. This factor is an increase in productivity and has been observed when higher than expected volumes are present. In such circumstances, machine operators and mail handlers may work harder to assure that all cutoff times are met. When volumes are near or below average, their productivity returns to 'normal' or may even decrease. In other words, the amount of time it takes to do the job either expands or contracts depending on how much time is available. However, because it is a speculative proposition to treat productivity as a function of volume, this factor will not be included in the analysis. Rather, we will work with a fixed value of productivity.

5. Accommodating leave and fluctuations in demand

Large weekly fluctuations in volume coupled with leave percentages approaching 20% suggest that more than one option should be considered when planning under uncertainty. The range of possibilities is presented below. In the discussion, it is important to distinguish between hours available, H_A, and total hours associated with the permanent workforce, H_T. The two differ by the amount of leave.

5.1. Increasing the size of the permanent workforce

If a certain number of workers, say A, are needed during the week, and if on average α_{WF} percent of the workforce is on leave then the size of the permanent workforce, T, can be computed as follows

$$T - \frac{\alpha_{WF}}{100} T = A$$

so

$$T = \frac{A}{1 - \frac{\alpha_{WF}}{100}}$$

or in terms of hours

$$H_T = \frac{H_A}{1 - \frac{\alpha_{WF}}{100}} \qquad (2)$$

The value of α_{WF} is treated as a parameter allowing the user to specify the percentage of leave to be covered by increasing the permanent workforce. In SOS, when α_{WF} is set to some value other than zero, additional bid jobs and part-time schedules are created in proportion to the labor ratio parameter ρ. For the mail processing craft, this ratio is typically 4:1. The jobs created are uniformly spread over the full-time and part-time positions generated by the model. This approach is most appropriate if all employees in a particular craft are on leave about the same number of hours per year.

5.2. Decreasing the number of days worked by part-time flexibles

The general guidelines for scheduling part-time flexibles are that they can work up to 6 days a week but no more than 8 h a day and 39 h per week, excluding overtime. In SOS, schedules are constructed for PTFs by combining compatible daily shifts into weekly schedules. The goal is to give each PTF as many days of work as possible without violating the above guidelines. In some cases, this means that some PTFs may only be scheduled to work 2 or 3 days a week while others may be scheduled for 6 days. There is no requirement that a PTF work the same number of hours each day.

Part-time regulars, on the other hand, must be given a 5-day a week schedule, where it is assumed that they work the same shift type each day. Because the labor ratio is based on headcounts of full-timers and part-timers, one way to build slack into the system is to reduce the number of days PTFs are scheduled per week. This can be done in SOS by first reducing the number of PTFs scheduled to work and hold the remaining number in reserve to fill in for leave. To see how to this idea can be implemented, assume that there are no PTRs in the workforce, that the leave rate is 5% on any day, and that 100 workers are needed to run the facility. The total size of the workforce should then be approximately $100/(1-0.5)=105$. For a labor ratio $\rho=4$, these means that we will have 84 FTRs and 21 PTFs on the payroll, and on any day, approximately 80 FTRs and 20 PTFs would be in the facility. However, rather than scheduling 84 FTRs and 21 PTFs and anticipating 5 to be on leave, suppose that we produce a schedule with only 16 PTFs and hold 5 in reserve.

This cannot be done directly with SOS because the number of PTFs scheduled is not modeled as a hard constraint; it is approximated by assuming that a PTF works 5 days a week on average. This is taken into account in the labor ratio constraint

$$\sum_{f=1}^{n^F} w_f \geq \rho\left(\sum_{p=1}^{n^P}\left(v_p + \frac{1}{5}\sum_{d=1}^{7}\phi_{dp}\right)\right)$$

where ϕ_{dp} is the number of part-time shifts of type p scheduled on day d. The second term on the right corresponds to the approximation.

To implement the idea, a distinction must be made between the number of PTFs needed to meet demand in light of the labor ratio, and the number of PTFs specified by SOS. The latter will be an inflated number based on the percentage of workers on leave, α_{DAY}. To decide how much to inflate the actual number needed, let LF be the load factor defined as follows.

$$\text{LF} = 1 - \frac{\alpha_{\text{DAY}}}{\pi} \tag{3}$$

where π is the percentage of part-timers permitted; i.e. $\pi=(1/\rho+1)\times 100\%$. For example, when $\pi=20$ and $\alpha_{\text{DAY}}=5$, $\text{LF}=1-5/20=15/20=0.75$. Note that LF is between 0 and 1. When $\alpha_{\text{DAY}}=20$, $\text{LF}=0$ for $\pi=20$. When $\alpha_{\text{DAY}}=0$, $\text{LF}=1$ indicating that no adjustment should be made. In general, the largest value of α_{DAY} permitted occurs when $\text{LF}=0$ and is equal to π.

The next step is to introduce constraints in SOS that will allow us to partially control the number of part-time flexibles in the solution. Let ϕ be the approximate number of PTFs determined. The constraints are similar to (1f) and (1g) except now the load factor is present and because we do not require that PTFs work the same shifts or number of hours each day, we do not have to distinguish among shift types

$$5(\mathrm{LF})\phi \geq \sum_{p=1}^{n^P} \sum_{d=1}^{7} y_{pd} \tag{4a}$$

$$(\mathrm{LF})\phi \geq \sum_{p=1}^{n^P} y_{pd}, \quad d = 1, \ldots, 7 \tag{4b}$$

The first inequality, (4a), ensures that each PTF gets 5×LF days of work. It has the effect of increasing the number of days off from 2 when LF=1 up to 6 when LF=0.2. The second inequality, (4b), ensures that there are enough PTFs off every day to provide replacement for the specified percentage of workers on leave. For example, if LF=15/20 there would be 20−15=5 workers in reserve. However, they are really not held in reserve. All PTFs are assigned work for 3.75(=5× 15/20) days on average; i.e. SOS builds schedules for all PTFs by distributing the work load evenly over the 5×LF days. As a result, all PTFs who are assigned work have a schedule approximately (1−LF)×100% lighter than they would were leave not taken into account. When LF=0, Eq. (4a) and (b) disappear implying that no PTFs are scheduled (all are held in reserve).

5.3. Additional ways of increasing the number of available hours

For a fixed workforce, there are three ways in which additional hours can be obtained without adding career employees to the payroll. Each is described below. Note that for purposes of analysis, we will work with hours rather than headcounts, and consider one category of mail processing clerks only. The same approach is valid for all labor categories with appropriate changes in parameter values.

Overtime (OT). Rules for assigning overtime are somewhat complicated but, in general, the USPS limits it to no more than 6% of the total hours worked, which is roughly equivalent to H_A. The 6% does not refer to a maximum in any week but to an annual average. The following equations can be used to find the actual percentage

$$H_{OT} = 0.06(H_{OT} + H_A)$$

Solving for overtime hours gives

$$H_{OT} = \frac{0.06}{0.94} H_A = 0.0625 H_A \tag{5}$$

or 6.25%. A portion or all of this percentage can be applied to either leave or above average demand.

Casuals (CAS). Casual employees are those who may be called in on a daily basis but may not be assigned work in lieu of career employees. During the week, the USPS is required to make every effort to insure that qualified and available part-time flexibles are utilized at the straight time rate prior to assigning any work to casuals. The union contract states that the number of casuals may not exceed on average 5.9% of the total number of career employees (FTRs, PTRs, PTFs). Because these workers must have some skill and must be trained, this percentage is not for the year but for a short period of time, say, a week. Accordingly, we have

$$H_{CAS} = 0.059H_T \tag{6}$$

any portion of which may be used to cover above average demand during the week as long as USPS rules are followed.

Part-time hours (PT). Our experience running SOS for many different scenarios indicates that part-timers are scheduled to work about 29 h per week when the labor ratio is 4:1 (no more than 20% part-timers). This leaves approximately 10 additional hours for which they could be used to cover for leave or times when mail volumes are high. The following calculations indicate how the 10 part-time hours translates into a percentage of the permanent workforce. Assume that we start with 80 full-timers and 20 part-timers, although the actual headcount does not matter

$$\frac{\text{additional part-time hours available}}{\text{full-time hours} + \text{actual part-time hours}} = \frac{20 \times 10}{80 \times 40 + 20 \times 39} = \frac{10}{160 + 39} \cong 0.05$$

5.4. Additional part-time hours available are then approximately

$$H_{PT} = 0.05H_A \tag{7}$$

Some or all of these hours can be used to compensate either for leave or high demand. To avoid double counting, the actual number of hours available must be reduced by the fraction of PTF hours held in reserve to compensate for leave. This value is 1–LF so Eq. (7) becomes

$$H_{PT} = 0.05(\mathrm{LF})H_A \tag{8}$$

6. Selecting the 'Best' week to run SOS

The optimal composition of the workforce at a P&DC is closely linked to the equipment schedule established for processing the mail. When the latter changes so does the optimal composition of the workforce. The difficulty is that it may be desirable to change the equipment schedule regularly due to fluctuations in mail volumes but the composition of the workforce is fixed once the bid jobs are assigned. To run SOS, a 7-day equipment schedule for each craft by skill category is needed. This schedule must be derived from the mail arrival volumes and profiles for the facility. Because of the critical dependency between these two factors, not to mention the expense involved, it is critical that the week selected from which to derive a equipment schedule be chosen with care.

The USPS divides the year into 13 accounting periods (AP), 4 weeks each. Assuming for the moment that leave has been taken into account, at first glance it would seem that the equipment schedule associated with an 'average' accounting period should be chosen for SOS. The average accounting period would be the one whose monthly volume was nearest to the average volume processed by the facility over the year. Once this accounting period was identified (could be more than one), an average week could be determined by averaging the arrivals for each of the four Mondays, four Tuesdays,…, four Sundays.

Running SOS with this data would produce optimal schedules for the 'average' AP, but it is not clear that the schedule would be very good for APs whose arrival volumes were much above or below

Table 1
Total pieces handed (10^3) for the Dallas facility

AP	Weeks	TPH 1999	TPH 2000	TPH 2001
1	1	108 220.2	107 355.8	106 310.0
	2	100 163.2	105 947.5	107 773.5
	3	105 290.0	110 358.4	106 875.4
	4	113 982.9	117 655.7	113 758.6
2	5	106 055.9	108 914.9	109 334.2
	6	106 681.7	111 553.1	111 913.3
	7	105 550.0	105 850.8	107 135.6
	8	109 262.8	116 047.7	114 570.5
3	9	100 785.9	101 010.1	104 664.70
	10	105 806.2	107 565.5	116 640.30
	11	97 720.7	91 674.7	93 753.30
	12	109 050.0	107 628.9	102 962.90
4	13	119 479.3	117 379.3	124 625.5
	14	124 167.4	121 949.9	116 373.4
	15	86 571.3	102 926.7	124 409.7
	16	89 890.8	85 295.7	82 400.0
5	17	104 751.7	121 554.5	99 631.7
	18	113 673.3	112 445.5	116 416.9
	19	108 996.5	102 791.4	110 484.0
	20	119 134.1	107 624.4	113 178.5
6	21	115 284.7	117 333.6	117 451.5
	22	106 715.0	107 082.8	113 260.7
	23	96 705.4	103 882.8	109 012.0
	24	102 258.8	100 287.2	101 427.8
7	25	111 712.1	107 091.7	110 501.7
	26	104 991.3	107 936.5	112 565.1
	27	103 446.3	104 468.4	107 338.0
	28	103 803.6	103 872.4	103 069.0
8	29	104 821.1	99 248.3	108 015.2
	30	107 266.3	109 026.0	112 189.4
	31	102 831.9	105 378.9	108 316.6
	32	99 662.5	104 497.9	104 454.1
9	33	101 046.5	102 678.6	106 920.9
	34	115 380.5	116 801.5	114 062.7
	35	107 028.0	106 618.5	107 867.0
	36	105 935.0	99 628.2	105 250.2
10	37	103 561.6	96 317.6	104 146.4
	38	96 376.7	84 351.8	91 598.5
	39	103 079.7	100 919.8	106 273.5
	40	99 812.5	100 553.1	102 577.6
11	41	94 379.9	97 197.5	103 527.4
	42	104 395.2	94 446.5	101 632.1
	43	89 315.7	88 590.4	100 211.2
	44	106 497.7	103 027.1	105 738.0

(*continued on next page*)

Table 1 (*continued*)

AP	Weeks	TPH 1999	TPH 2000	TPH 2001
12	45	101 060.3	101 299.5	104 468.5
	46	101 685.0	101 229.8	103 700.1
	47	108 695.7	104 365.5	105 520.1
	48	102 179.0	102 264.3	106 299.8
13	49	97 581.9	98 457.0	102 055.2
	50	102 016.0	102 239.8	82 936.8
	51	108 417.5	99 397.1	84 373.2
	52	96 503.9	97 276.9	81 393.7
Total[a]		5 019 572	5 003 746	5 063 557
Average		104 574.45	104 244.75	105 490.84
Std. dev.		5722.94	7185.56	7886.06
Maximum		119 134.10	121 554.50	117 451.50
Minimum		89 315.70	84 351.80	81 393.70

[a] All statistics exclude AP 4.

the average. When the volume is higher than average, either PTFs must work longer hours, assuming they are not already working 8 h a day, casuals must be called in, or FTRs, PTRs, and possibly PTFs must work overtime. In this case, the facility incurs additional costs. When the volume is below the average, PTF hours are cut. This results in a cost savings for the facility.

6.1. Historical data analysis

To determine the best input data to use for deriving the equipment schedule, it is first necessary to analyze historical data to see how volume at a facility varies over the year, and perhaps to forecast volumes for the coming year by examining trends. (More sophisticated forecasting techniques are available but they require large amounts of past data, and even then the results might not be more reliable than trend analysis.) For mail processors, data in the form of total pieces handled (TPH) must be available for at least one year, and preferably several years if any forecasting is to be done. For mail handlers, this data might be sufficient if a relationship can be established between volume and mail handler productivity.

Table 1 depicts TPH (in 1000s of pieces) for the Dallas P&DC for fiscal years 1999–2001. As can be seen, volumes peak in week 14 at the height of the December holiday season. To avoid distorting the results, it is typical to exclude AP 4, which includes this week, from the analysis (an unlimited number of casuals can be hired to handle the peak demand in December). A plot of the data suggests that TPH is normally distributed over the year. This was substantiated with a chi-square goodness-of-fit test.

6.2. Management considerations

The next step in determining the best week to run the optimization model is to decide which options are to be used to compensate for leave. This decision is likely to be made at the local level, depending on the policies of the particular facility. For a leave rate of λ (percent), the options are as follows:

1. Increase the size of the workforce determined by SOS by α_{WF}, where
$$0 \leq \alpha_{\mathrm{WF}} \leq \left(\frac{\lambda}{100-\lambda}\right) \times 100\%$$
2. Select a value of α_{DAY} to reduce the number of part-time flexible days scheduled, where $0 \leq \alpha_{\mathrm{DAY}} \leq \pi$ and π is the maximum percentage of part-timers permitted. When this value is selected, the load factor LF will be calculated from Eqs. (3), (4a) and (4b) will be added to SOS.
3. Specify the percentage overtime, α_{OT}, assigned to leave, where $0 \leq \alpha_{\mathrm{OT}} \leq 6.25\%$.
4. Specify the percentage of casual hours, α_{CAS}, assigned to leave, where $0 \leq \alpha_{\mathrm{CAS}} \leq 5.9\%$.
5. Specify the percentage of PTF hours, α_{PT}, assigned to leave, where $0 \leq \alpha_{\mathrm{PT}} \leq 5(\mathrm{LF})\%$.

To account for leave, these values should be specified such that

$$\alpha_{\mathrm{WF}} + \alpha_{\mathrm{DAY}} + \alpha_{\mathrm{OT}} + \alpha_{\mathrm{CAS}} + \alpha_{\mathrm{PT}} = \left(\frac{\lambda}{100-\lambda}\right) \times 100\%$$

In all likelihood, at most one or two of these options will be used by a facility.

After making the above allocations, we must compute the overtime, casual and PTF slack that remains. The corresponding values are $\bar{\alpha}_{\mathrm{OT}} = 6.25 - \alpha_{\mathrm{OT}}$, $\bar{\alpha}_{\mathrm{CAS}} = 5.9 - \alpha_{\mathrm{CAS}}$, and $\bar{\alpha}_{\mathrm{PT}} = 5(\mathrm{LF}) - \alpha_{\mathrm{PT}}$. Note that the first two options of increasing the size of the workforce and reducing the number of PTF days are not available for the analysis to follow. The remaining slack will be spread over the year to cover the shortages in those weeks whose volumes exceed the baseline volume—the volume that can be processed by the permanent workforce determined by running SOS for the 'baseline' week. However, we must first select the baseline week before we know how much slack there is in the system. One depends on the other. To circumvent this difficulty, the following efficient trial and error procedure has proven effective. It is designed to find the week of lowest volume whose slack is sufficient to cover all weeks of greater volume without exceeding the guidelines for use of overtime, PTFs, and casuals. With respect to overtime, these guidelines are stated in terms of average usage over the year (e.g., 6% overtime) rather than maximum usage on any day or in any week. It is assumed that weekly volumes, in terms of total pieces handled, are available. The critical step is determining the productivity of the facility as measured by TPH/SOS hours, where the denominator can be derived by running SOS for an existing equipment schedule or estimated from a run of a comparable facility. This will be discussed presently. The solution will yield the week that should be used to find the minimum cost permanent workforce.

6.3. Algorithm for determining the best week

1. (Leave). Specify the leave parameters and compute the remaining slacks: $\bar{\alpha}_{\mathrm{OT}}$, $\bar{\alpha}_{\mathrm{CAS}}$ and $\bar{\alpha}_{\mathrm{PT}}$.
2. (Workforce size from SOS). Using an existing equipment schedule as input to SOS for the fiscal year being considered, compute the size and schedule of the workforce needed to process the mail for each

skill category and desired parameter settings (leave, days off, starting time flexibility, and so on). This should be done for all crafts.

3. (Convert workforce size to hours). Convert the results from SOS to hours available, H_A, and then calculate the total hours associated with the permanent workforce H_T. Recall that H_A is simply the number of hours scheduled for full-time and part-time employees by SOS without considering leave; H_T can be found from Eq. (2) once α_{WF} is specified.
4. (Productivity). Determine the productivity of the facility in terms of total pieces handled per hour:

$$\text{Prod} = \text{TPH}/H_A \tag{9}$$

The value of Prod indicates how efficient the facility would be if it were staffed at the 'optimal' level as determined by SOS for the given equipment schedule.

5. (Hours required per week). Compute the number of hours required to operate the facility in each of the other weeks of the year, excluding the weeks in AP 4, based on Prod. That is, for week i, let

$$H_i = \text{TPH}_i/\text{Prod}$$

where TPH_i is taken from Table 1 in the analysis.

6. (Slack). Calculate the number of additional hours available from overtime, use of casuals, and an extension of part-time hours. These values can be found from Eqs. (5), (6) and (8) with the following modifications.

$$H_{OT} = \bar{\alpha}_{OT} H_A/100$$

$$H_{CAS} = \bar{\alpha}_{CAS} H_T/100$$

$$H_{PT} = \bar{\alpha}_{PT} H_A/100$$

Of the additional available hours, only the hours associated with overtime, H_{OT}, can be spread over the year. The hours associated with casuals and part-timers, H_{CAS} and H_{PT}, must be used week by week; they cannot be averaged over the year.

7. (Hours due to weekly fluctuations). For the current week, calculate the number of additional hours needed during the year as follows

$$\Delta H = \sum_{i=1}^{48} \max\{0, (H_i - H_A) - H_{CAS} - H_{PT}\}$$

The summation excludes the four weeks in AP 4.

8. (Percent shortage or over-coverage). Now compute the percent difference between the slack available from overtime, H_{OT}, and ΔH:

$$\delta = \frac{48H_{OT} - \Delta H}{48H_{OT}} \times 100\%$$

Let $\varepsilon > 0$ be a 'small' number, say, 1. If $|\delta| \le \varepsilon\%$, stop; use the current week as the baseline. If $\delta > 0$, there is too much slack in the system so a week with lower volume should be selected as the baseline. If $\delta < 0$, there is not enough slack and a week with higher volume should be selected.

9. (Updating). If $|\delta| > \varepsilon\%$, set $H_{current} = H_A - (\delta/\gamma \times 100)H_A$ (where $\gamma > 0$ is a convergence parameter) and find the week whose required hours is closest to $H_{current}$. Put $H_A \leftarrow H_{current}$ (that is, update H_A by letting $H_A = H_{current}$), use Eq. (2) to compute the new value of H_T and go to Step 6.

Several points might require clarification before attempting to implement the algorithm. First, no mention is made of cost. The basic assumption is that supervisors will use the least cost method first to compensate for shortages while staying within USPS guidelines. The required order is PTFs, overtime, and casuals; however, it is recognized that particular situations might call for, say, casuals rather than the use of overtime.

Another issue relates to the choice of the parameters ε in Step 8 and γ in Step 9. In computing $H_{current}$, some trial and error is required to pick a good value of γ. This parameter was introduced after several test cases indicated slow convergence. Also, when to stop the algorithm depends on the value of ε. Similarly, some experience is needed to specify this parameter value as well. A final point is that the algorithm is not monotonic; that is, there is no guarantee that the value of δ will decrease from one iteration to the next.

6.4. Computing productivity when there is no equipment schedule

The algorithm requires that the user have a measure of productivity for the facility which can be obtained by running SOS. This value is computed at Step 5 and depends on the available hours associated with the permanent workforce, H_A. If it is not possible or practical to run SOS because no equipment schedule is available, H_A can be estimated from the results obtained for a reference facility such as Dallas. To see how to do this, let

Hours_{ref}	hours required to run the reference facility over the year
$\text{Hours}_{current}$	hours required to run current facility under investigation
TPH_{ref}	total pieces handled for the year by the reference facility
$\text{TPH}_{current}$	total pieces handled for the year by the current facility
Prod_{ref}	productivity measure computed with Eq. (9) for reference facility
$\text{Prod}_{current}$	estimated productivity of current facility derived from run of SOS for reference facility
$\text{TPH}_{current\_week}$	total pieces handled by current facility for week SOS was run for reference facility
$H_{A(current)}$	estimated available hours associated with permanent workforce for current facility

Now solve the following equation for $\text{Prod}_{current}$

$$\frac{\text{TPH}_{current}/\text{Hours}_{current}}{\text{TPH}_{ref}/\text{Hours}_{ref}} = \frac{\text{Prod}_{current}}{\text{Prod}_{ref}}$$

that is, $\text{Prod}_{current} = \text{Prod}_{ref}\,(\text{TPH}_{current}/\text{Hours}_{current}/\text{TPH}_{ref}/\text{Hours}_{ref})$.

The next step is to estimate $H_{A(current)}$ by solving

$$H_{A(current)} = \frac{\text{TPH}_{current\_week}}{\text{Prod}_{current}}$$

Knowing this value allows us to compute $H_{T(current)}$ from Eq. (2). The rest of the analysis can proceed as described above. An alternative to these calculations is to use the breakthrough productivity index

(BPI)—a productivity standard for equipment operators and mail handlers developed by the USPS several years ago.

7. Illustration of methodology

To test the methodology, we ran SOS for week 27 of fiscal year 2001. This was the week in which a equipment schedule was available for the Dallas facility. The worker category considered was all clerks in the mail processor craft, the labor ratio of full-timers to part-timers was set to 4, and the option to require two consecutive days off was not selected. Lunch breaks were excluded from the model due to the absence of their specification in the equipment schedule. Finally, wage rates were set at the national average and the leave rate of 13% was handled by increasing the size of the permanent workforce by $13/(100-13)\times 100\%=15\%$.

Table 2 displays the output of the run. For this facility, there were three different categories of mail processors listed in the first column. The total number of full-timers required was 563 and the total number of part-time flexibles was 140; no part-time regulars were permitted. The total amount of idle time over the week was 12.5% of the hours available, which is typical of this type of operation.

In accordance with this run, at Step 1 of the algorithm (implemented in Microsoft Excel), the leave parameters are set as follows: $\alpha_{WF}=15\%$ and $\alpha_{DAY}=\alpha_{OT}=\alpha_{CAS}=\alpha_{PT}=0$. At Step 3, we get the number of available hours from Table 2 to be $H_A=26\,192$, and from Eq. (2) we get the total hours to be $H_T=30\,106$. The productivity of the facility is computed at Step 4 using Eq. (9) with TPH obtained for week 27 in Table 1: $\text{Prod}=\text{TPH}/H_A=104\,468/26\,192=3.99$. The calculations of the values of H_i at Step 5 are omitted. At Step 6 we have

$$H_{OT} = \bar{\alpha}_{OT}H_A/100 = (0.06)(26\,192) = 1637$$

$$H_{CAS} = \bar{\alpha}_{CAS}H_T/100 = (0.59)(30\,106) = 1776$$

$$H_{PT} = \bar{\alpha}_{PT}H_A/100 = (0.05)(26\,192) = 1310$$

Using these values, at Steps 7 and 8, we compute $\Delta H=2121.3$ and $\delta=97.3\%$, respectively, which indicates that there is too much slack in the system. At Step 9, we get $H_{current}=26\,179$ when $\gamma=7.5$ (convergence is somewhat sensitive to γ so it was necessary to try different values). Setting $H_A=26\,179$ and returning to Step 6, the resultant computations give $\delta=94.9\%$ and $H_{current}=22\,847$. At the next

Table 2
Output of SOS run for Dallas facility—fiscal year 2001, week 27

Worker category	Idle time	Workers			Hours			Costs		
		FT	PTF	Total	FT	PTF	Total	FT	PTF	Total
P5-FSMO	7.90%	106	26	132	4240	729	4969	$126 838	$19 544	$146 382
P5-DC	13.20%	269	67	336	10 760	1630	12 390	$321 881	$43 700	$365 581
P4-MP	14.20%	188	47	235	7520	1313	8833	$211 323	$31 555	$242 878
Total	12.50%	563	140	703	22 520	3672	26 192	$660 042	$94 800	$754 841

Table 3
Results for best week algorithm

Iteration	$H_{current}$	H_{OT}	H_{CAS}	H_{PT}	ΔH	δ (%)	
1	26 192	1637	1776	1310	2121	97.3	
2	26 179	1423	1545	1139	3459	94.9	
3	22 847	1242	1348	994	60 168	−0.9	←stop

iteration, we have $\delta = -0.9\%$ which satisfies the stopping criterion when $\varepsilon = 1.0\%$. The full output is shown in Table 3.

The results indicate that SOS should be run using data from the week whose hours are closest to 22 847. Week 11, with $H_A = 22\,984$ h and TPH = 91 674.1, offers the best match. It is interesting to observe that this week is 12.1% below the average (excluding AP 4) and has the third lowest volume in the fiscal year. This corresponds to 1.75 standard deviations below the average, which for a normal distribution, means that volumes will be above this value 96% of the time. The implication is that the basic workforce should be capable of handling the load in only 2 or 3 weeks of the year, and that overtime, casuals and additional PT hours must be used in the remaining weeks.

8. Discussion

In planning for a permanent workforce there is an inherent tradeoff between hiring more career employees and the use overtime. Career employees incur fixed overhead costs associated with fringe benefits and leave regardless of the number of hours they work per week. Alternatively, using overtime to cover a fraction of the baseline demand even though it is billed at one and a half, and under some circumstances, twice the normal rate, might be more economical than hiring additional employees after overhead is taken into account. The use of casual labor is yet another option when labor agreements and company policies permit.

In this paper, we have developed a methodology for specifying the input data for a staffing model designed to optimize the permanent workforce at USPS mail processing and distribution centers. Limits on overtime, the use of part-time hours, the use of casuals, and leave were the principal factors included in the methodology. Because of the difficulty in changing the size and composition of the permanent workforce once it is specified, a careful balance must be struck between these factors. The corresponding problem is complicated by wide fluctuations in weekly demand and a formidable labor union.

The methodology was demonstrated using data obtained from the Dallas P&DC. The results showed that under an optimal staffing plan, overtime and casual labor would be needed in almost every week of the year. In contrast, the workforce existing at the time of the analysis was of sufficient size to handle the workload in the 10 lowest volume weeks of the year without the need for overtime. Resizing at the Dallas facility in 2003 led to a 10% reduction is mail processing clerks.

To date, the methodology has been implemented in 15 of the 275 P&DCs nationwide and is currently being evaluated by several European postal organizations. Other applications include express mail sorting centers (e.g. FedEx and DHL), reservation desks, and call centers.

From a research point of view, it would be interesting to consider an alternative to the deterministic approach proposed in this paper whereby demand was treated as a random variable. By specifying a representative set of scenarios and corresponding probabilities, a stochastic optimization model could be set up and solved to determine the size of the permanent workforce as well as overtime, part-time, and casual requirements. Initial attempts along these lines by Bard, Morton, and Wang (2004) have produced mixed results. The limiting factors were the acquisition of good data for more than a single week and actually solving a stochastic version of (1a)–(1h) when more than three scenarios were included in the analysis. To overcome the computational difficulties, a combination of specialized algorithms, feasibility heuristics, and some modeling compromises would seem to be necessary.

References

Alfares, H. K. (1997). An efficient two-phase algorithm for cyclic days-off scheduling. *Computers & Operations Research*, *25*, 913–923.

Aykin, T. (1996). Optimal shift scheduling with multiple break windows. *Management Science*, *42*(4), 591–602.

Bailey, J. (1985). Integrated days off and shift personnel scheduling. *Computers & Industrial Engineering*, *9*(4), 395–404.

Bard, J. F., Binici, C., & deSilva, A. H. (2003). Staff scheduling at the United States Postal Service. *Computers & Operations Research*, *30*(5), 745–771.

Bard, J. F., Morton, D. P., & Wang, Y. M. (2004). *Workforce planning at USPS mail processing and distribution centers using stochastic optimization.* Working paper. Graduate Program in Operations Research and Industrial Engineering, The University of Texas, Austin.

Beaumont, N. (1997). Using mixed integer programming to design employee rosters. *Journal of the Operational Research Society*, *48*, 585–590.

Bechtold, S. E., & Jacobs, L. W. (1990). Implicit modeling of flexible break assignments in optimal shift scheduling. *Management Science*, *36*(11), 1339–1351.

Berman, O., & Larson, R. C. (1993). Optimal workforce configuration incorporating absenteeism and daily workload variability. *Socio-economic Planning Sciences*, *27*(2), 91–96.

Brusco, M. J. (1998). Solving personnel tour scheduling problems using the dual all-integer cutting plane. *IIE Transactions on Operations Engineering*, *30*(9), 835–844.

Brusco, M. J., & Jacobs, L. W. (2000). Optimal models for meal-break and start-time flexibility in continuous tour scheduling. *Management Science*, *46*(12), 1630–1641.

Burns, R. N., & Carter, M. W. (1985). Work force size and single shift schedules with variable demands. *Management Science*, *31*(5), 599–607.

Clausen, J., Hansen, J., Larsen, J., & Larsen, A. (2001). Disruption management. *OR/MS Today*, *28*(5), 40–43.

Dawid, H., Konig, J., & Strauss, C. (2001). An enhanced rostering model for airline crews. *Computers & Operations Research*, *28*, 671–688.

Easton, F. F., & Rossin, D. F. (1997). Overtime schedules for full-time service workers. *Omega, International Journal of Management Science*, *25*(3), 285–299.

Emmons, H. (1985). Work-force scheduling with cyclic requirements and constraints on days off, weekends off, and work stretch. *IIE Transactions*, *17*(1), 8–15.

Gans, N., & Zhou, Y.-P. (2002). Managing learning and turnover in employee staffing. *Operations Research*, *50*(6), 991–1007.

Jarrah, A. I. Z., Bard, J. F., & deSilva, A. H. (1994). Solving large-scale tour scheduling problems. *Management Science*, *40*(9), 1124–1145.

Lin, C. K. Y., Lai, K. F., & Hung, S. L. (2000). Development of a workforce management system for a customer hotline service. *Computers & Operations Research*, *27*(10), 987–1004.

Malhotra, M. K., & Ritzman, L. P. (1994). Scheduling flexibility in the service sector: a postal case study. *Production and Operations Management*, *3*, 100–117.

Malhotra, M. K., Ritzman, L. P., Benton, W. C., & Leong, G. K. (1992). A model for scheduling postal distribution employees. *European Journal of Operational Research*, *58*, 374–385.

Pinker, E. R., & Larson, R. C. (2003). Optimizing the use of contingent labor when demand is uncertain. *European Journal of Operational Research*, *144*(1), 39–55.

Thengvall, B. G., Bard, J. F., & Yu, G. (2000). Balancing user preferences for aircraft schedule recovery during airline irregular operations. *IIE Transactions on Operations Engineering*, *32*(3), 181–193.