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IMPROVING PERSONNEL SCHEDULING AT AIRLINE STATIONS

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Many service organizations encounter personnel tour-scheduling problems which focus on the efficient assignment of daily shift schedules and work days to employees across a weekly planning horizon. The airline industry, in particular, faces a highly complex and difficult tour-scheduling environment for their ground station personnel. During the past twenty years, the airlines have worked to improve continuously their abilities to effectively schedule personnel working at planesides, counters, and gates in airline stations. Substantial reductions in labor costs have resulted from the use of efficient tour-scheduling methods for such workers. We report on the development and implementation of two modules designed to enhance the tour-scheduling process associated with United Airlines' *Pegasys* Manpower Planning System. The first module uses column generation to improve the selection of employee shifts. The second module, a local search heuristic based on simulated annealing, enables initial feasible tour-scheduling solutions to rapidly improve. Using data collected from all 119 United Airlines stations across the U.S., we find that the incorporation of the modules results in a potential annual cost savings of more than $8 million. We conclude with a discussion of notable implementation issues and extensions.

The airline industry is currently in a highly volatile state, and many airlines are engaged in steps to improve productivity and profitability. Customer service representatives and ramp service workers at ground stations comprise a large portion of an airline's workforce and must be present to satisfy customer demand in a timely fashion. The manpower planning process for these workers is a complex, multistage planning and control process. The process is typically initiated with a forecast of labor requirements based upon scheduled aircraft arrivals and departures plus planned passenger, baggage, and cargo volumes. The subsequent specification of personnel schedules with the objective of satisfying forecast demand is complicated by a host of environmental conditions which include:

1. a variety of allowable daily shift schedules;
2. numerous combinations of days-on/days-off each week and weekly rotations for providing intermittent recreational weekends;
3. limits on the ratio of full-time (FT) to part-time (PT) workers;
4. limits imposed on the number of allowable FT and PT shift schedules;
5. restrictions requiring that PT workers be scheduled so that their shifts are not contiguous during the day;
6. restrictions on the maximum number of personnel that can be scheduled for work within any single planning period due to equipment or space limitations;
7. limitations with regard to the allowable placement of meal and rest breaks;
8. operational days of up to 24 hours in length, wherein each hour may be subdivided into a number of planning periods;
9. extremely rapid fluctuations in the requirements for workers from one planning period to the next;
10. substantial differences in the requirement for labor, for the same daily time interval, from one day to the next;
11. operational weeks that invariably consist of seven days; and
12. cross-utilization between work groups at individual stations.

Personnel tour scheduling involves the determination of work and nonwork days during the week, as well as the associated daily shift starting and finishing times (shift schedules) for each employee. These problems have received significant attention from both researchers

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and practitioners in service operations. This is in large part due to the potential benefits of lower costs and improved productivity which can be realized from the efficient utilization of labor.

The environmental conditions present in any specific tour-scheduling application combine to create problems of such size and complexity that they become extraordinarily difficult to solve. Not surprisingly, a significant amount of prior research has focused on developing effective representation and solution approaches for personnel tour-scheduling problems in general (Baker 1976, Henderson and Berry 1976, Keith 1979, Bartholdi, Orlin and Ratliff 1980, Bartholdi 1981, Morris and Showalter 1983, Bechtold and Jacobs 1990). Bechtold, Brusco and Showalter (1991) provide a review and comparison of several prominent tour-scheduling approaches. A number of solution approaches have also been developed specifically for personnel scheduling in the transportation industry (Gaballa and Pearce 1979, Stern and Hersh 1980, Holloran and Byrn 1986, Koutsopoulos and Wilson 1987, and Schindler and Semmel 1993).

This paper, presents two modules we developed for improving personnel tour scheduling under the environmental conditions present at airline ground stations. The first module is a column-generation procedure that focuses upon the selection of FT and PT shifts. The second module addresses the improvement of an initial tour schedule through an approach based on simulated annealing. We demonstrate the efficacy of the modules using data collected from 119 United Airlines (UA) ground stations across the country. In the next section, we provide an overview of UA's *Pegasys* Manpower Planning System and describe the ground station personnel tour-scheduling problem. Section 2 describes the modules we developed and implemented. Section 3 demonstrates the improvements associated with the application of the new modules. Finally, in Section 4, we describe the successful implementation of the two modules into UA's *Pegasys* Manpower Planning System and address potential extensions of this research.

1. GROUND STATION PERSONNEL SCHEDULING AT UNITED AIRLINES

1.1. The *Pegasys* Manpower Planning System

United Airlines has focused on developing improvements to the manpower planning process since the early 1980s. Holloran and Byrn described a mainframe-based station manpower planning system (SMPS) developed for use by UA. Over time, this system proved difficult to maintain and its usage was limited to a small number of "expert" users. The system lacked interactive capabilities, and the process of actually developing personnel tour schedules was difficult and extremely time consuming. For the most part, manpower planners continued to develop expense budgets and shiftbids (tour schedules for which employees 'bid' using a seniority-based system) manually using heuristic procedures.

To provide manpower planners at both airport and staff locations with a fast, timely, user-friendly, interactive system, UA developed and implemented the *Pegasys* Manpower Planning System in 1991. *Pegasys* is configured to run on a DOS-based personal computer and is designed to provide the ability to rapidly analyze numerous what-if scheduling scenarios. SMPS could not be adapted to a personal computer environment due to its reliance upon mainframe computer-based hardware and mathematical programming software. SMPS was, however, used extensively in the *Pegasys* development project to provide assurance that the tour schedules produced by *Pegasys* were of comparable quality to those produced by SMPS.

The *Pegasys* system provides manpower planners with the ability to determine the labor costs of a specific schedule in a few minutes compared to 1 to 2 days for the system it replaced. *Pegasys* is currently used to develop staffing plans for all of UA's 119 domestic stations as well as many international locations.

Pegasys operates by first generating the requirements for labor. *Pegasys* uses the aircraft schedule plus forecasts of passenger, baggage, and cargo loads to compute labor requirements (i.e., the number of employees required) for each 15-minute period within a seven-day planning week. Various volume-based staffing formulas are used for calculation of these requirements. For example, ticket counter requirements are obtained by applying arrival curves which predict when customers will arrive at the airport based upon flight departures. Contact ratios have been defined which specify the percentage of customer arrivals that will require service at various individual ticket counter queues (e.g., baggage check-in, ticketing, first class, international, etc.). Expected service times for each type of required activity are specified within *Pegasys. Pegasys* incorporates these expected customer arrivals and expected service times into queueing models which determine the staffing levels required to meet specific service standards (e.g., 85% of passengers will be serviced within 5 minutes). The arrival curves, contact ratios, expected service times, and service standards vary by time of the day, day of the week, and type of queue. For example, processing times for international contacts are significantly longer than those for domestic passengers. *Pegasys* also generates requirements for several other functions, such as gate staffing and planeside operations.

Second, based on station-specific parameters (such as union requirements, hours of operation, individual station scheduling preferences, etc.), *Pegasys* generates personnel tour schedules that meet all labor requirements in each 15-minute period. We display the general structure of the *Pegasys* system in Figure 1.

Figure 2 provides an example of visual-based output generated by *Pegasys*. This display screen (the skyscraper) focuses on daily shift schedules and exhibits several schedule characteristics reported by the system. The skyscraper provides a visual representation of results obtained for a single day from one UA station. The

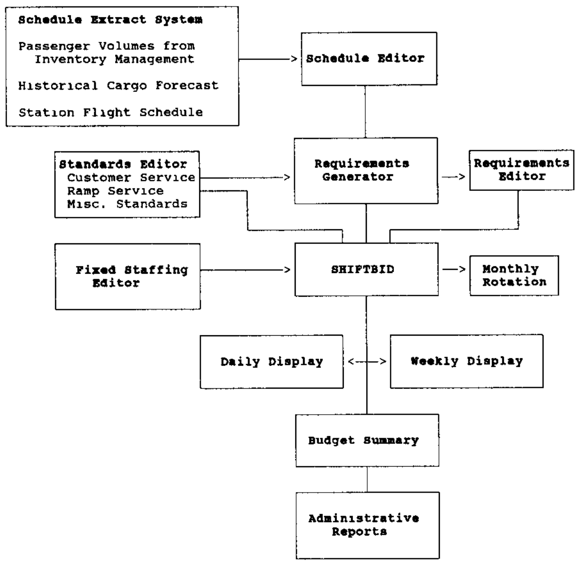

Figure 1. *Pegasys* system overview.

horizontal axis represents planning periods within a single day and the vertical axis corresponds to associated labor requirements. The solid areas of the display represent the amount of required labor generated by *Pegasys* for each 15-minute planning period during the day. The single line indicates the total labor actually scheduled by *Pegasys* for each planning period. The B's and L's indicate the appropriate placement of breaks and lunches for employees. The white space under the single line provides a visual assessment of the amount of excess labor scheduled for the day. The bracketed lines above the skyscraper show the shifts (defined by starting and ending times) and the number of workers assigned to each shift for the day. *Pegasys* also produces less detailed, visual-based output that portrays weekly tour schedules. In addition to visual-based output, *Pegasys* also produces a number of quantitative output measures associated with the shift schedules and tour schedules generated by the system.

The manpower planner may reiterate the process with adjustments to various parameter settings until satisfied with the set of tour schedules generated. The resultant staffing plans are used to develop airport expense budgets and are posted for employees to bid their preferences using a seniority-based allocation scheme. This activity is repeated several times a year for each station. Employee bids are conducted for all major schedule changes, and annual quarterly expense budgets are prepared twice each year.

1.2. The Tour-Scheduling Problem

There are a number of important tour-scheduling constraints which vary from station to station. In some instances, such as planeside operations (which include baggage handling and activities performed at the aircraft), these constraints are affected by union regulations. In other cases, constraints are imposed based upon preferences expressed by managers and workers at individual stations. In all cases, labor requirements must be satisfied by FT and/or PT employees who typically work four or five days per week with a minimum of two consecutive days off. For any given tour, the shifts are the same (i.e., have the same starting time and the same ending time) for each work day of that tour.

Nearly all stations restrict the ratio of PT employees to FT employees. The current union restrictions for planeside personnel allow the PT workforce to be no more than 20% of the FT workforce. Nonunion operations typically establish a fixed PT/FT ratio to avoid unnecessary changes in the mix of FT and PT employees.

Restrictions may also be imposed on the number and placement of FT and PT shift-starting times. These constraints often have serious implications for the efficiency of the complete tour schedule for an individual station. Under the present union restrictions, stations are limited to using only seven FT shift-starting times and two PT shift-starting times. Moreover, a separation of at least 8 ½ hours between the PT starting times is required.

Some situations also require briefing and checkout sessions for employees. Briefing periods occur at the beginning of an employee's shift and are typically 15 minutes long. Checkout periods occur at the end of the shift. During a briefing or checkout session, an employee is not able to satisfy labor requirements.

The Tour-Scheduling Model (P1)

The UA tour-scheduling problem (**P1**) can be modeled using an extension of Dantzig's (1954) modified set-covering formulation, as shown below.

Definitions

Tour. A tour is defined as an allowable work pattern for an employee. This pattern consists of a set of work days for the week, as well as the shift starting and finishing times on each work day. For any given tour, the shifts are the same (i.e., have the same starting time and the same ending time) for each work day of that tour.

Tour type. The tour type designates the length of the shifts within a tour.

Model Parameters

M = the number of 15-minute intervals in the weekly planning horizon (7 days/week × 96 intervals/day = 672);

$\mathbf{T}_f$ = the set of indices associated with the allowable FT tour types;

$\mathbf{T}_p$ = the set of indices associated with the allowable PT tour types;

$\mathbf{T} = \mathbf{T}_f \cup \mathbf{T}_p$;

C_{ij} = the cost of an employee working a tour of type j which begins in interval i;

R_k = the number of employees required to be present in 15-minute interval k;

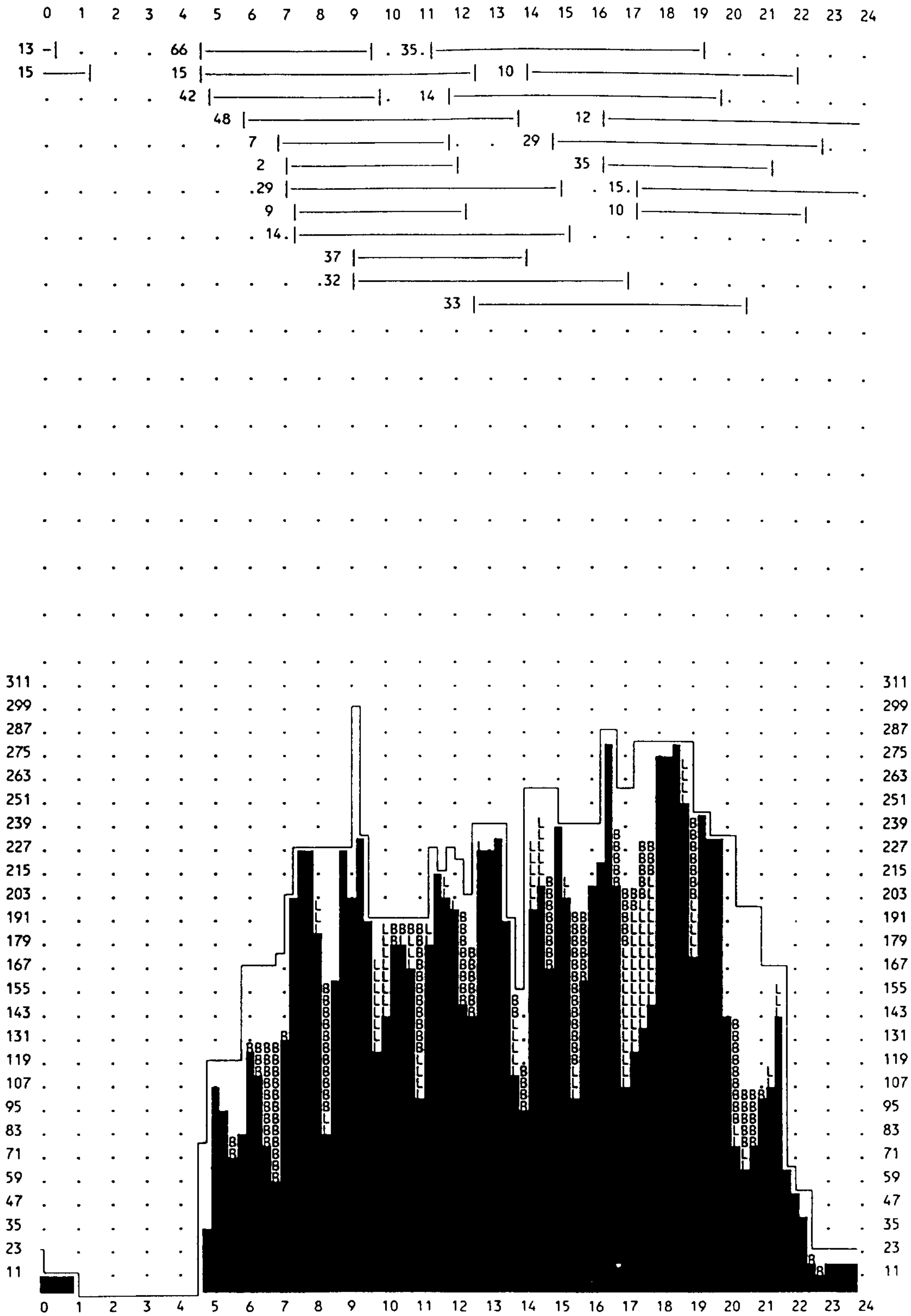

Figure 2. Example *Pegasys* system output for the skyscraper.

π = the maximum ratio of PT employees to FT employees;

Θ_f = the maximum number of starting times allowed for FT tours on any work day across the week;

Θ_p = the maximum number of starting times allowed for PT tours on any work day across the week;

ϕ = the minimum number of 15-minutes intervals which must separate the daily starting times for PT tours;

a_{ijk} = 1, if period k is a work period in a tour of type j which begins in period i, 0 otherwise;

m = a large positive number.

Decision Variables

X_{ij} = the number of employees working tour type j and beginning work in period i;
V_i = 1, if any FT employees begin work in the ith interval of the day on any day of the week, 0 otherwise;
W_i = 1, if any PT employees begin work in the ith interval of the day on any day of the week, 0 otherwise.

Tour-Scheduling Formulation

$$\text{Minimize} \quad \sum_{i=1}^{M} \sum_{j \in \mathbf{T}} C_{ij} X_{ij} \tag{1}$$

subject to

$$\sum_{i=1}^{M} \sum_{j \in \mathbf{T}} a_{ijk} X_{ij} \geq R_k \qquad \text{for } k = 1, 2, \ldots, M, \tag{2}$$

$$\pi \sum_{i=1}^{M} \sum_{j \in \mathbf{T}_f} X_{ij} - \sum_{i=1}^{M} \sum_{q \in \mathbf{T}_p} X_{iq} \geq 0, \tag{3}$$

$$X_{ij} \leq m V_h \qquad \text{for } i = 1, 2, \ldots, M \text{ and } j \in \mathbf{T}_f, \tag{4}$$

where h = modulo$_{96}(i)$ if modulo$_{96}$ $(i) \neq 0$, 96 otherwise,

$$X_{ij} \leq m W_h \qquad \text{for } i = 1, 2, \ldots, M \text{ and } j \in \mathbf{T}_p, \tag{5}$$

where h = modulo$_{96}(i)$ if modulo$_{96}$ $(i) \neq 0$, 96 otherwise,

$$\sum_{i=1}^{96} V_i \leq \Theta_f, \tag{6}$$

$$\sum_{i=1}^{96} W_i \leq \Theta_p, \tag{7}$$

$$\sum_{k=i}^{i+\phi-1} W_h \leq 1 \qquad \text{for } i = 1, 2, \ldots, 96, \tag{8}$$

where h = modulo$_{96}(k)$ if modulo$_{96}$ $(k) \neq 0$, 96 otherwise,

$$X_{ij} \in \{0, 1, 2, \ldots\} \quad \text{for } i = 1, 2, \ldots, M \text{ and } j \in \mathbf{T}, \tag{9}$$

$$V_i, W_i \in \{0, 1\} \qquad \text{for } i = 1, 2, \ldots, 96. \tag{10}$$

The objective function (1) of **P1** is intended to minimize total scheduling cost. Constraint set (2) ensures that the labor requirements are satisfied for each 15-minute planning interval, while constraint (3) imposes the limitation on the PT/FT ratio. Constraint sets (4) and (5) are designed to detect the 15-minute intervals in which FT and PT employees begin work. Constraints (6) and (7) limit the number of FT and PT starting times, respectively. Constraint set (8) ensures a separation of at least ϕ 15-minute periods between PT starting times. Constraint set (9) requires the tour assignments to be integer-valued, and constraint set (10) requires the starting time indicator variables to be 0 or 1.

The integer programming tour-scheduling model presented in (1)–(10) contains such a large number of integer decision variables that mathematical programming solution approaches require extremely long solution times even on very fast mainframe computers. Moreover, UA has found that the only way to ensure that the majority of manpower planners will use tour-scheduling software is to provide them with a tool that will run quickly on a personal computer. Thus, an additional constraint is effectively imposed by the nature of the manpower planning system at UA: the tour-scheduling procedure should run in less than 5-minutes on a personal computer. These conditions made it infeasible to make direct use of **P1** in designing a solution strategy. Instead, UA incorporated into *Pegasys* a multistage procedure (**SHIFTBID**) which first generates shifts and subsequently constructs a feasible tour-scheduling solution via a number of heuristic procedures. **SHIFTBID** generally performed quite well and had gained wide acceptance throughout the company. Nevertheless, UA believed there was room for improvement.

2. THE PERSONNEL TOUR-SCHEDULING MODULES

Our experience with **SHIFTBID** suggested two primary areas for improvement: the initial selection of shifts; and the assignment of employees to tours. In the subsections below, we outline the modules we developed to address these two issues.

2.1. Shift Generation Heuristic (SGH)

We found that **SHIFTBID** generally performed well in selecting shifts. However, in scattered instances the **SHIFTBID** shift selection was associated with a very poor final tour-scheduling solution. In several cases, we found that improvements in shift selection could result in a large reduction of full-time equivalent (FTE) workers in the final tour-scheduling solution. The cost savings associated with these large reductions provided a compelling reason to develop an automated mechanism for producing an improved set of shifts.

One approach to shift selection would be to formulate and solve the modified set-covering formulation of the shift-scheduling problem (hereafter, **P2**) associated with a "composite day" of labor requirements. We considered several options for generating the composite day including: 1) taking the day with the highest sum of demand as the composite day; 2) averaging the demand across each day of the week for each 15-minute interval; and 3) taking the maximum demand across the seven days for each 15-minute interval. We found option 3 to be the most robust; the models and results discussed hereafter are based on this convention.

The Shift-Scheduling Model (P2)

The shift-scheduling model is identical to that defined for **P1** with the following changes regarding the model parameters and decision variables.

Definitions

Shift. A shift is defined as an allowable daily work pattern for an employee. This pattern is defined by the shift starting and finishing times.

Shift type. Shift type designates the length of the shift.

Model Parameters

M = the number of 15-minute intervals in the daily planning horizon of the composite day = 96;
$\mathbf{T}_f$ = the set of indices associated with the allowable FT shift types;
$\mathbf{T}_p$ = the set of indices associated with the allowable PT shift types;
$\mathbf{T} = \mathbf{T}_f \cup \mathbf{T}_p$;
C_{ij} = the cost of an employee working shift type j which begins in interval i;
R_k = the number of employees required to be present in 15-minute interval k of the composite day;
Θ_f = the maximum number of starting times allowed for FT shifts;
Θ_p = the maximum number of starting times allowed for PT shifts;
ϕ = the minimum number of 15-minutes intervals which must separate the daily starting times for PT shifts;
a_{ijk} = 1, if period k is a work period in shift type j which begins in interval i, 0 otherwise;

Decision Variables

X_{ij} = the number of employees working shift type j and beginning work in interval i;
V_i = 1, if any FT employees begin work in the ith interval of the day, 0 otherwise;
W_i = 1, if any PT employees begin work in the ith interval of the day, 0 otherwise.

Investigation of this shift-scheduling model using the MIP branch-and-bound routines from OSL installed on an IBM 3090 computer suggested that long run-times and large memory requirements could be expected. The stipulation that the entire tour-scheduling module in *Pegasys* require less than 5 minutes of execution time on a personal computer emphasized the need for an alternative solution approach. Consequently, we developed a computational model (hereafter, **P3**) for use in generating shifts.

The Computational Shift Scheduling Model (P3)

The computational model is identical to **P2** except that constraint (9) is replaced with:

$$X_{ij} \geq 0 \qquad \text{for } i = 1, 2, \ldots, M \text{ and } j \in \mathbf{T}. \qquad (11)$$

Whereas (9) required the X_{ij}'s to be integer-valued, (11) is merely a nonnegativity constraint.

To solve **P3**, we developed a shift generation heuristic, based on column generation, for producing a set of shifts. Column generation is useful in circumstances where the linear program is too large to be conveniently solved. The procedure is iterative and operates by solving a linear program made up of a restricted set of the variables from the full problem. Dual-variable values are used to select variables from the full problem for inclusion in subsequent executions of the restricted problem. Column generation is an important element in the decomposition method (Dantzig and Wolfe 1960) and has been effective in solving the cutting-stock problem (Gilmore and Gomory 1961, 1963). Easton and Rossin (1991) make use of column generation in personnel scheduling. The shift generation heuristic we developed does not require that an optimal solution to **P3** be obtained, but is designed to identify shifts that would likely be associated with good solutions to the tour-scheduling problem (**P1**).

SGH is intended to generate a set of shifts, **S**, and the corresponding number of employees assigned to those shifts, which minimize the scheduling costs associated with satisfying the demand of the composite day. Specifically, **SGH** uses column generation to append shifts to **S** iteratively. A step-by-step overview of **SGH** is presented in Figure 3. The procedure begins in Step 0 by including only enough shifts to enable a feasible shift-scheduling solution to be obtained. For the UA scheduling problem, no more than four FT shifts are ever necessary to cover all 15-minute demand intervals.

Since **SGH** appends shifts one at a time, the PT/FT ratio in **S** is controlled outside the simplex procedure. The shift-scheduling LP problem posed by equations 1–3 and 11 is solved in Step 1 and the dual prices, Y_i^*'s, are used to guide the selection of the next shift to append. If the total number of active shifts, A, in the shift-scheduling solution is equal to $\Theta_f + \Theta_p$, then no further shifts can be added and **S** is returned as the solution to **P3**.

If $A < \Theta_f + \Theta_p$, then the set of candidate shifts for inclusion in **S** is developed in Step 2. If the number of FT (PT) shifts in **S** is less than Θ_f (Θ_p), then all FT (PT) shifts are placed in the set of candidate shifts. The candidate shifts are evaluated in Step 3 by computing a "potential benefit criterion" (P_{ij}) as follows:

$$\sum_{k=1}^{M} a_{ijk} Y_k^* + \pi Y_{M+1}^* - C_{ij}$$

$$\text{for } j \in \mathbf{T}_f \text{ and } i = 1, 2, \ldots, M$$

and

$$\sum_{k=1}^{M} a_{ijk} Y_k^* - Y_{M+1}^* - C_{ij}$$

$$\text{for } k \in \mathbf{T}_p \text{ and } i = 1, 2, \ldots, M.$$

STEP 0. Construct an initial working set, S, which will enable a feasible LP shift-scheduling solution to be obtained. The working set should use as few shifts as possible.

STEP 1. Formulate and solve the shift-scheduling problem using the simplex method. Define "active" shifts as those with $X_l > 0$. Let A = total number of active shifts. If $A = \Theta_f + \Theta_p$, then go to Step 6.

STEP 2. Determine the set of candidate shifts for potential inclusion in S.

STEP 3. Evaluate each candidate shift by computing its potential benefit criterion (P_{tl}) value.

STEP 4. If $P_{tl} \leq 0$ for all candidate shifts, then go to Step 6.

STEP 5. Append the shift with the greatest P_{tl} to S. Ties among shifts are broken arbitrarily. Return to Step 1.

STEP 6. Return S.

Figure 3. An overview of the steps of the **SGH.**

If the $P_{tl} \leq 0$ for all candidate shifts, then **S** is returned as the solution to **P3**. Otherwise, the shift with the maximum P_{tl} is appended to **S** in Step 5.

Upon completion of **SGH**, the shifts in **S**, along with the corresponding number of employees assigned to the shifts, are passed to **SHIFTBID**, which constructs an initial feasible tour-scheduling solution based on those shifts. This initial solution is subsequently passed to the local search heuristic described below.

2.2. Local Search Heuristic (LSH)

The second module we developed was designed to improve the initial tour-scheduling solutions passed from the **SHIFTBID** routine. This module is a local search heuristic (**LSH**) which examines the neighborhood of initial feasible tour-scheduling solutions for lower cost solutions. The **LSH** is based upon the simulated annealing (**SA**) algorithm which was originally developed to provide a computational model for problems in statistical mechanics (Metropolis et al. 1953). Subsequently, **SA** has been successfully applied to a number of combinatorial optimization problems in operations research (see Cerny 1985, Johnson et al. 1989, 1991, Brusco and Jacobs 1993). The **LSH** is the first extension of **SA** to an actual application in personnel tour scheduling.

The **LSH** is supplied with an initial (incumbent) tour-scheduling solution generated by **SHIFTBID**. Thereafter, the heuristic iterates between three primary phases: 1) DROP, 2) AUGMENTATION, and 3) EVALUATION. These phases are repeated until the stopping criterion is reached. The three phases, along with the stopping criterion, are described below. Figure 4 displays the general configuration of the **LSH** module.

The DROP phase begins with the random selection of the number of employees to be removed from the schedule, H. The value of H is selected from a uniform distribution on the interval of 8 to 12. Previous research has indicated that values of H in this range yield rapid improvement in solution quality (Brusco and Jacobs 1993). Initial testing revealed that this range was also appropriate for this implementation. A total of H employees are removed, one at a time, from the schedule. At each iteration, all tours assigned one or more employee are candidates for reduction. The tour for which the removal of one employee will result in the minimum understaffing (adjusted for the number of work periods in the tour) is selected for reduction.

In the AUGMENTATION phase, employees are added iteratively to return the schedule to feasibility. At each iteration, if adding a PT employee will not violate

STAGE 0. Receive a feasible tour-scheduling solution, **X**, from **SHIFTBID**. Let $f(\mathbf{X})$ = the schedule cost of **X.**

STAGE 1. DROP. In this stage, a fixed number of employees, H, are removed form solution in an iterative manner.

STAGE 2. AUGMENTATION. In this stage, employees are added to the schedule, in an iterative manner, until a new feasible neighboring solution, $\mathbf{X}'$, is created.

STAGE 3. EVALUATION. In this stage, $f(\mathbf{X}')$ is compared to $f(\mathbf{X})$ in order to determine the dispensation of $\mathbf{X}'$. The "shake-up" and termination criterion are also examined at this stage.

STAGE 4. Return the minimum cost solution, $\mathbf{X}_b$, to **SHIFTBID** for final processing.

Figure 4. An overview of the **LSH.**

the staffing-mix constraint, the set of candidate tours for augmentation is defined as the set of all tours. Otherwise, the set of candidate tours is limited to only the FT tours. The candidate tour associated with the greatest reduction in understaffing (adjusted for the number of work periods in the tour) is selected for augmentation. This procedure continues until all understaffing is eliminated.

In the EVALUATION phase, the disposition of the new feasible schedule is made. A new feasible schedule with a solution cost less than or equal to that of the incumbent schedule is accepted as the new incumbent schedule. If the new feasible schedule has a higher solution cost than the incumbent schedule, a probability distribution is used to determine if the new schedule will become the incumbent schedule. This probability distribution is a function of the difference in solution cost between the new and incumbent solutions, as well as the progress into the **LSH** heuristic.

We tested several rules for stopping the **LSH**. Experimentation revealed that improvement in solution cost was generally very rapid and thus extended run times were unnecessary. Additionally, we found that "shaking-up" the solution after a prespecified number of iterations without any improvement often enabled a lower cost solution to be identified. We incorporated the solution shake-up by increasing the number of tours removed in the DROP phase to up to 50% of the number of employees in solution.

LSH employs a shake-up after 20 iterations have elapsed without a lower cost solution being identified. Three shake-ups are permitted. After the third shake-up, the occurrence of 20 iterations without an improvement in solution cost results in termination of the **LSH**. This stopping criterion is preferable to a criterion based upon CPU time, because it is not sensitive to differences in computer hardware.

The lowest cost schedule identified during the execution of the **LSH** is stored as the best solution. This solution is subsequently passed back to **SHIFTBID** for final processing which includes the assignment of breaks, the placement of incremental days off, the elimination of shifts with utilization below a specified threshold, and the creation of tours containing shifts with multiple starting and ending times. Figure 5 displays a representation of the **SHIFTBID** segment of *Pegasys* that includes the **SGH** and **LSH** modules.

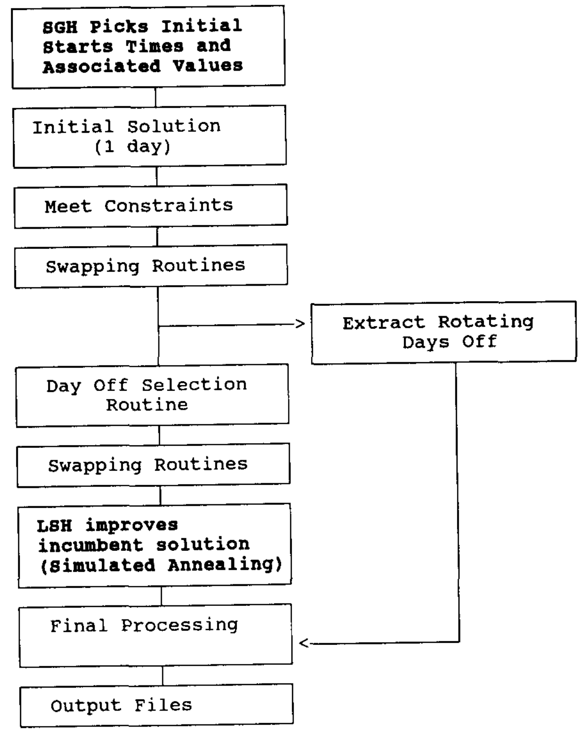

Figure 5. New **SHIFTBID** module.

3. IMPROVEMENTS IN TOUR-SCHEDULING PERFORMANCE

The **SGH** and **LSH** modules were coded in Borland C++ and installed in the *Pegasys* system. *Pegasys* was originally designed to execute in 640 Kilobytes RAM so that even modestly equipped systems could run the code. All subsequent enhancements, including this one, have been designed to maintain the 640 Kilobyte memory limitation. During the developmental stages of this project, implementations were tested on 386 and 486 microcomputers. All of the results reported herein were obtained using a 486 (66 MHz) microcomputer with 8 megabytes of RAM.

We conducted an extensive investigation of the modules using labor requirements forecasts from all of the 119 UA ground stations in the United States. These labor requirements fall into three categories: requirements for counters and gates (nonunion); requirements for planesides (nonunion); and requirements for planesides (union). Hereafter, we will refer to these three categories as CGN, PN, and PU, respectively.

We observed substantial improvements in scheduling performance due to the use of the **SGH** and **LSH** modules under each of the three labor requirements categories. To provide some assessment as to the source of the improvements, we used three test conditions: 1) **SHIFTBID** only; 2) **SHIFTBID** followed by the **LSH** (**SHIFTBID-LSH**); and 3) **SGH**, followed by **SHIFTBID**, followed by **LSH** (**SGH-SHIFTBID-LSH**). Condition 1 is a baseline which represents the **SHIFTBID** tour-scheduling procedure used by UA prior to this improvement project. Condition 2 uses **LSH** to improve the tour schedules generated by **SHIFTBID**. In condition 3, **SGH** replaces the original shift generation procedure incorporated into **SHIFTBID**, and **LSH** is subsequently used to improve the tour schedules generated.

The **SHIFTBID-LSH** test condition was designed to identify the benefits resulting from LSH alone. The **SGH-SHIFTBID-LSH** test condition was used to identify the additional benefit associated with using **SGH** to select a set of shifts which **SHIFTBID** can then use to create an

Table I
Mean Percent Reduction in FTEs Associated with the New Modules When Compared to **SHIFTBID** Alone (Condition 1): June 1993 Labor Requirements from 119 Domestic Airline Stations

Labor Requirements Category	PU	PN	CGN	Overall
June 1993 Requirements				
SHIFTBID-LSH (Condition 2)	1.51	1.80	2.06	1.78
SGH-SHIFTBID-LSH (Condition 3)	1.51	4.78	3.32	2.98

initial solution. Table I displays the results for June 1993 forecast labor requirements for the 119 domestic United Airlines stations. The results are reported as mean percent reductions of FTE's associated with test conditions 2 and 3 relative to condition 1.

Note that on average the use of the **LSH** module in conjunction with **SHIFTBID** reduced the FTE usage requirement by almost 2%. When **SGH** was installed in conjunction with both **SHIFTBID** and **LSH**, the FTE improvement over **SHIFTBID** was close to 3%. In general, the improvements associated with nonunion personnel were more than double those for union personnel. When overall workforce size and union/nonunion workforce mix is considered, along with the appropriate union and nonunion salary and benefit packages, the improvements in FTE usage that result from the use of **SGH** and **LSH** represent a potential annual cost reduction that exceeds $8 million.

To provide further assurance of cost savings, we compared the four quarterly expense budgets produced using the *new* **SHIFTBID** (i.e., **SHIFTBID** with the **SGH** and **LSH** modules incorporated) to those generated by the *old* **SHIFTBID** for all United Airlines domestic station requirement forecasts for 1995. Table II presents the mean percent reduction in FTEs associated with the new **SHIFTBID** for planeside union (PU) requirements, as well as the combination of counters and gates and planeside nonunion (CGN/PN) requirements. Across the four

Table II
Impact of the New **SHIFTBID** on the 1995 Budget: The Mean Percent Reduction in FTEs Associated with the New **SHIFTBID** in Comparison to the Old **SHIFTBID** for Each of the our 1995 Labor Requirements Forecasts

Labor Requirements Category	PU	CGN/PN	Overall
March 1995 Forecast	1.7	2.5	2.1
May 1995 Forecast	1.8	4.2	3.0
July 1995 Forecast	2.4	4.2	3.3
November 1995 Forecast	2.0	3.9	3.0
Average	2.0	3.7	2.9

sets of requirements, the mean percent reduction in FTEs for the PU requirements ranged from 1.7 to 2.4%, with an average of 2.0%. For the CGN/PN requirements, FTE savings ranged from 2.5 to 4.2%, with an average of 3.7%. The average execution time per airline station was 19 seconds using the 486 (66 MHz) microcomputer. The time required for the largest station was 104 seconds. The time required for the smallest station was 6 seconds.

4. IMPLEMENTATION AND EXTENSIONS

In this section, we describe the integration of *Pegasys* into the personnel scheduling process at UA. We subsequently explain the procedure associated with the incorporation of enhancements, such as the **SGH** and **LSH** modules, to the *Pegasys* system and the continuous improvement philosophy adopted by UA with respect to that system. We conclude with a discussion of the applicability of a *Pegasys*-type system and the column generation and local search methods presented herein to other service organizations.

4.1. Two-Phase Process for Ground Station Personnel Scheduling

Airport ground personnel are employees of the Customer Service Division of UA. United Airlines uses a two-phase process for developing personnel schedules for these workers. During the first phase, *Pegasys* is used to develop detailed customer service staffing plans for all domestic and international airports. These plans are then used to create manpower budgets for each station. A primary quarterly-based annual budget is established in November and, if necessary, a mid-year revision is prepared in May. Each station manager is responsible for the plan at his/her location. A centralized group of corporate manpower planners provides assistance and also reviews each local proposal. This review process now focuses upon the inputs and parameters used by *Pegasys*. Prior to the implementation of the *Pegasys* system, staffing reviews were far less quantitative and based, in large part, on emotion.

During the second phase, station managers use *Pegasys* to develop personnel schedules (shiftbids) which are posted and bid upon by employees. The process takes place three to four times per year and is generally tied to major changes in workload due to aircraft schedule variations or seasonal volume fluctuations. As long as the new shiftbids define staffing levels that are consistent with the budget, station managers are free to re-bid their staff. Significant variances from the budget require the approval of the corporate staff. In these cases, *Pegasys* is once again the primary vehicle for assessing the acceptability of the requested changes.

UA has increasingly integrated *Pegasys* into this two-phase personnel scheduling process over the past several years. The 1994 budget was the first annual plan that was prepared with *exclusive* use of *Pegasys* to schedule the counter, gate, planeside nonunion, and planeside nonunion personnel for all domestic and international stations. Since UA experiences enormous fluctuations in demand for service from one year to the next, it is impossible to accurately assess the cost benefit that has accrued as a result of *Pegasys*. However, there is universal agreement among all involved parties that the current planning process with *Pegasys* is far superior to its predecessor. Furthermore, productivity in the Customer Service Division, expressed as FTEs per passenger boarded, has improved by 12% since the beginning of 1992.

4.2. The Enhanced Version of *Pegasys*

The **SGH** and **LSH** modules were incorporated into the *new* **SHIFTBID** program, installed in *Pegasys*, and distributed to the corporate manpower planners for testing in November of 1993. As part of the implementation activity for this project, the *enhanced* version of *Pegasys* was evaluated during the 1994 budget process. For the most part, the *enhanced* version was not used to establish actual budgets for fiscal 1994, because this version was not yet available for use by the stations. This evaluation process, however, reinforced our earlier assessment that the *enhanced* version of *Pegasys* is capable of reducing labor costs for counter, gate, and planeside personnel by 2–3%. The results for the 1995 budget process shown in Table II confirm this assessment.

For a number of smaller international stations, the corporate manpower planners used the *enhanced* version of *Pegasys* to produce actual shiftbids during 1994. This usage resulted in significant reductions in station personnel for those stations. For example, the *enhanced Pegasys* system lowered the manpower requirements at the Buenos Aires station from 54.8 to 52.3 FTEs, a reduction of more than 4.5%. In addition, the use of the *enhanced* version to prepare a shiftbid for the Mexico City station resulted in a reduction of one FTE on a base of 26.8 FTEs, a savings of 3.7%.

The manpower planning group and UA management initiated a company-wide release of the *enhanced* version of *Pegasys* in January 1994. This enhancement to *Pegasys* was provided as part of a regular system update. UA believes that, for purposes of employee relations, it is not advantageous to widely associate software enhancements with workforce reductions. Indeed, the ongoing volatility in demand for labor effectively masks the FTE reductions that result from enhancements issued as part of regular system updates. However, our investigations demonstrate that this *enhanced Pegasys* version will provide the capability to schedule stations with substantially lower labor costs than obtainable with previous releases.

UA is committed to the philosophy of continuous improvement. Therefore, work on extensions of and enhancements to *Pegasys* is an ongoing process. Currently, a module for aircraft line maintenance is being developed. Line maintenance personnel provide assistance in aircraft guidance on the ground and station-based preventive maintenance and repair. Extension of *Pegasys* to line maintenance primarily involves the construction of functions that calculate line maintenance activities based on standards and the number and type of aircraft scheduled for service by 15-minute intervals. Given the modular design of the system, these routines can easily be integrated into *Pegasys* and immediate use can be made of the improved shiftbid program to schedule maintenance manpower. Other planned extensions include the use of *Pegasys* in scheduling cabin-cleaning crews and a number of categories of ramp personnel associated with UA's air freight operations. Our experience, particularly with the *enhanced Pegasys*, has encouraged us to anticipate that substantial cost reductions will accrue due to these extensions.

4.3. Extension to Other Service Organizations

A variety of service organizations might make productive use of a scheduling system similar to *Pegasys*. The environmental conditions we described in the Introduction are appropriate to many organizations that provide services in transportation (inter- and intracity rail, tollway), communications (telephone operator, telemarketing, messenger service), retailing (department and discount stores, restaurants), public safety (fire, police, emergency), and health care (clinics, hospitals). Effective personnel scheduling in these, and other, high customer contact segments of service organizations should be an important component of ongoing productivity improvement.

The enhancements to *Pegasys* presented in this paper should also be useful to other service organizations. The column generation procedure associated with **SGH** is very flexible in that it can be adapted to a variety of objective criteria. For example, column generation could be used to assign employees to schedules with the objective of maximizing employee scheduling preferences subject to the satisfaction of demand. The simulated annealing-based heuristic we developed was shown to produce substantial cost improvement for the UA application. Our experience with heuristics of this type suggests that they are readily adaptable to a variety of environmental conditions. Additional work in extending such heuristics to other labor scheduling applications could prove productive.

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