United Airlines Station Manpower Planning System

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United Airlines has developed and implemented a computerized station manpower planning system for scheduling shift work at its reservations offices and airports. The system utilizes integer and linear programming and network optimization techniques and encompasses the entire scheduling process from forecasting of requirements to printing employee schedule choices. Since its implementation in 1983, it has been used to develop work schedules for 4,000 employees on a regular basis and is eventually expected to schedule 10,000 employees or 20 percent of United's total work force. The system has produced direct labor cost savings of over $6 million annually while earning rave reviews from United upper management, operating managers, and affected employees.

In 1982, upper management of United Airlines initiated the station manpower planning project as part of cost-control measures associated with the airline's 1983-84 expansion. Expanded flight schedules and increased passenger volumes would require substantial planning to control labor costs and still maintain desired customer service levels.

A manpower planning group was established directly under United's senior vice-president of corporate services, Tony Chaitin. It was headed by a former airport manager with over 20 years experience and consisted of only a few scheduling analysts. The group targeted for at-

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TRANSPORTATION — AIR
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tention those airports and reservations offices where work loads would be greatly increased by expansion. In a single month of 1984, for example, United would add 67 departures to its operation at Chicago's O'Hare Airport.

Using accepted scheduling techniques, the manpower planning group found it difficult to produce future plans for all airports and reservations offices in the required time frame, and therefore they began investigating methods of automating some of the more time-consuming manual procedures. In addition, their evaluation of the way in which days off were assigned brought into question various shift scheduling strategies and raised the possibility of using optimization techniques.

It was at this point that we became involved in the effort. Beginning with a few computer programs that automated manual scheduling techniques and a simple linear programming model, we developed a Station Manpower Planning System (SMPS) by adding functions and enhancements to the system to attain specific objectives.

From mid-1982 through mid-1983 we applied management science techniques to shift scheduling at United with an overwhelming impact not only on United management and members of the manpower planning group, but also for many who had never before heard of management science or mathematical modeling.

Background

In 1984, United Airlines became the only airline with service to cities in all 50 of the United States. This resulted from ambitious expansion in 1983 and 1984 and was achieved in the face of unprecedented industry competition. United recorded net earnings of $259 million on 1984 revenues of $6.2 billion, the second highest profit in company history and more than double its 1983 earnings of $121 million. Of greater significance was the rise in operating profit in 1984 to $564 million, well above the 1983 operating profit of $160 million. Revenues in 1984 increased six percent over the previous year, while costs grew by less than two percent — a clear indication of the company's success in controlling costs.

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Cost control is essential to competing successfully in the airline industry. While 1983 and 1984 were profitable for many carriers, nearly 75 others were forced into bankruptcy. Most never flew again or flew with sharply curtailed flight schedules. Some used Chapter 11 filings to void union contracts and thereby reduce labor costs, albeit at a large price in terms of personnel relations. Addressing company managers in 1983, United Chairman Richard Ferris flatly stated that there was no room in the industry for low-cost competitors; only the "lowest" cost competitors would succeed.

United's expansion in 1983 and 1984 (serving 48 new airports, for a total of 159 airports in 139 cities) was executed in conjunction with well-conceived cost control measures. In some cases, costs were reduced directly through new union "two-tier" wage scale contracts and termination incentive plans. Other cost cutting required improvements in work scheduling and manpower utilization.

Substantial company resources had been devoted to work scheduling and manpower utilization of unionized flight crews in the past. However, nonunion and other work groups did not receive comparable attention until 1982 when United created its station manpower planning project. This was specifically directed at reservations offices and airport groups working shift schedules.

Reservations

United's 11 reservations offices employ over 4,000 reservation sales representatives (RSRs) and support personnel. Using on-line computer terminals tied into United's central Apollo reservations system, these employees book reservations, process special requests for meals and seat assignments, maintain waiting lists, and notify passengers of schedule changes.

The work force is made up of both full-time and part-time employees. Full-time shifts are eight and 10 hours in length with part-time shifts ranging from two to eight hours. Employees are allowed 30 minutes for lunch periods and receive breaks approximately every two hours.

Calls are routed to agents by automatic call distributors, which also collect numerous statistics on call volumes, length of calls, number of lost calls, and so forth, and compute service factor statistics. The level of service is commonly measured by a telephone service factor giving the percentage of calls answered within a given time interval.

Requirements for RSRs are determined by a forecasting and queueing model. Using an autoregressive moving average technique, the model forecasts call volumes based on historical trends. Employee requirements for 30-minute periods are developed with the queueing portion of the model using a waiting time distribution function to determine the number of employees necessary to provide the desired level of service. The two assumptions on which the waiting time distribution function is based (call arrivals following a Poisson distribution and service times following an exponential distribution) have proved to be valid. Monitoring the telephone service factor has shown that service factors are within one percent of the desired level.

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Airports

United employs 1,000 customer service agents (CSAs) at its 10 largest airports. They ticket passengers, check them in at the gates, and also staff such passenger service functions as lost and found.

CSAs work both full- and part-time shifts similar to those of the reservations employees. In the past, airport employees also worked split shifts in which they worked part of their shift, were off-duty for more than two hours, and then worked the remainder of the shift.

Requirements for airport CSAs are

determined separately for counters and gates. Counter employees ticket customers and check in baggage. The requirements for counter CSAs are developed in a fashion similar to those for reservations agents — passenger loads and arrival trends are used to forecast work volumes, and the same queueing model is used to determine the number of employees required to serve a given percentage of customers within a defined waiting time. Gate employees check in and board passengers at the gates. The requirements for gate agents are determined directly on the basis of the number of concurrent departures and the size of the aircraft. Requirements for both gate and counter CSAs are determined for 30-minute time intervals.

We didn't develop any sophisticated tracking mechanism for validating the accuracy of requirements determined for CSAs at airports. Feedback from station operating managers provided more than adequate validation. For many years their careers have depended on being able to judge whether they are either over- or under-staffed.

Problem Development

When we began the Station Manpower Planning Project in 1982, we defined several specific project requirements:

- To determine the needs for increased manpower,
- To identify excess manpower for reallocation,
- To reduce the time required for preparing schedules,
- To make manpower allocation more day- and time-sensitive, and
- To quantify the costs associated with scheduling.

All the project objectives revolved around developing shift schedules. The impact of expansion on work loads had to be evaluated station by station and for a variety of alternative aircraft schedules. In addition, work rule changes affected how increased work loads were handled differently for different locations. Their effects and their costs could not be accurately evaluated on a systemwide or macro-level basis.

Historically, shift schedules at airports and reservations offices were prepared by hand. The coverage for each half-hour period was based either on the shift's peak requirement during the week or on its average requirement over the week. Peak-based schedules were costly and left employees underutilized on nonpeak workdays. On the other hand, schedules based on the average failed to provide adequate coverage on peak days; over time they usually evolved into peak-based schedules. While work-load patterns differ from one day of the week to the next, both processes staffed to a "representative" day.

Some years ago a single-day staffing model was developed. However, it also used the concept of a representative day and suffered from the same drawbacks associated with average- and peak-based requirements.

Days off were assigned on a rotating basis; employees worked six days followed by two days off and received an additional day off every six weeks.

Shift scheduling problems like United's have been solved by using integer and linear programming techniques to solve single-day models [Henderson and Berry 1976; Keith 1979; and Gaballa and Pearce 1979]. Full work schedules including days off and schedule period transitions are then handled separately. This single-day approach to shift scheduling can be justified either when requirements do not vary from day to day (a representative day actually exists) or when enough scheduling flexibility is allowed that seven individual day schedules can be combined into a full week schedule. Unfortunately neither situation existed at United: requirements vary widely from day to day, and work rules require employees to have the same starting time every day and to work the same shift length every day.

It has been said that "although a complete model can be formulated, the size is too large to consider as a practical alternative" [Rubin 1975, p. 6]. Indeed, the size implications of combining daily and weekly scheduling are formidable. In average schedules, United's airports and reservations offices have combinations of shift types, starting times, lunch and break assignment times, and days off which result in an integer LP matrix containing over 20,000 activities (variables) and millions of matrix elements (coefficients). Using only IBM's MPSX and MIP/370 optimization software, the Station Manpower Planning System combines both daily and weekly scheduling into a single model.

Station Manpower Planning System (SMPS)

United's Station Manpower Planning System uses developed requirements for 30-minute intervals over a seven-day period to produce monthly shift schedules. That is, all weeks during a given schedule month are assumed to be identical. Monthly schedules are then combined into work schedules based on month-to-month transition rules and considering employee schedule preferences. Work schedules are posted without employee assignments. Employees then bid on the schedules by making an ordered list of their preferences. By processing bids in seniority order, individual employee assignments are determined and noted on the posted work schedules.

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SMPS is accessed through United's time-sharing computer system and is available at virtually all United operating locations. SMPS requires no sophisticated knowledge of computers or mathematics to operate. Local schedulers at airports, reservations offices, and field offices, as well as corporate planning groups, have been trained to use SMPS.

A basic schematic drawing of United's Station Manpower Planning System appears in Figure 1. It consists of a mixed integer linear programming model (Start Times Module), a continuous linear programming model (Scheduling Module), a heuristic rounding routine and report writer (Report Module), and a network assignment model (Day-off Pairing

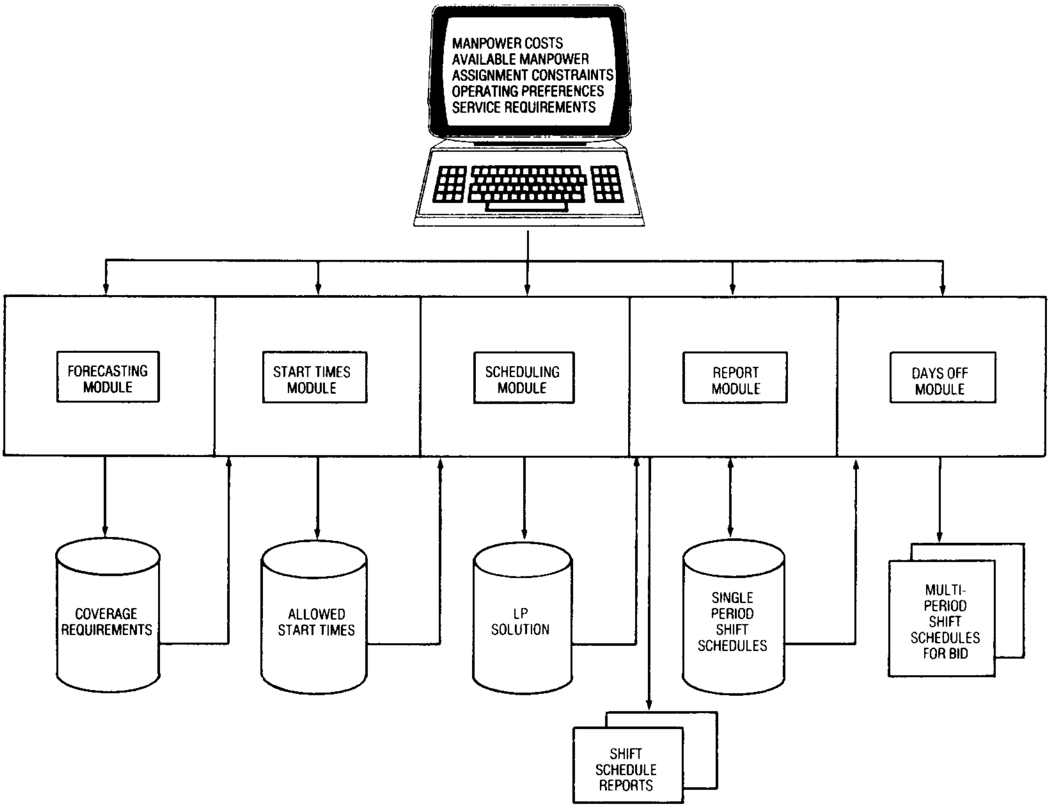

Figure 1: Station Manpower Planning System (SMPS) modeling components combine to develop complete shift schedules.

Module).

Data for the system are coverage requirements, manpower costs, definitions of shifts and their associated work hours, allowable days-off patterns, available manpower limits when they exist, and operational restrictions. Manpower costs include salary and benefit costs associated with shift alternatives as well as schedule-specific costs like starting time differentials and early or late lunch differentials. Shifts are defined by work hours, required briefing and break periods, and alternative placement times for breaks and lunches. All combinations of days off are allowed but small pseudo costs are placed on each alternative by operating managers to represent employee preferences. They drive the system to choose the preferred patterns when the minimum schedule cost is unaffected. The available manpower is sometimes limited by the total head count, the number of part-time employees, the required full-time base contingent, and so forth. Operational restrictions include constraints like maximum shift exchange percentages. The number of employees coming onto a shift and the number leaving at the same time must be controlled to avoid interruptions in service during the exchange period.

Using the various data elements, the SMPS Start Times Module, Scheduling Module, and Report Module combine to produce a monthly shift schedule which can, if desired, be manipulated and manually fine-tuned. Final monthly shift schedules are then combined into the final trimester employee work schedules by the Day-off Pairing Module.

Start Times Module

The Start Times Module is a mixed integer LP model whose sole purpose is to determine the times of day at which shifts will be allowed to start. These start times are inputs to the Scheduling Module.

In United reservations offices and airports, no limit exists on the number of starting times that can be used. However, we prefer to use no more starting times than necessary. Also, given a choice, employees and operating managers prefer some starting times over others. Therefore, the Start Times Module is used to minimize the number of starting times even when no formal restrictions exist.

Originally, the functions of the Start Times Module were contained in the SMPS Scheduling Module. The Scheduling Module contains the full shift scheduling formulation and is capable of obtaining a global optimum. The Start Times Module does not account for days-off scheduling and therefore can choose starting times which have the potential of producing a suboptimal solution. However, testing showed that choosing starting times independently in the Start Times Module provided drastic reductions in computer run times and with very little compromise of solution quality.

Scheduling Module

The Scheduling Module is the base optimization module of the system. Based on linear programming, it identifies monthly shift schedules which minimize labor cost while meeting employee and operating preferences. Taking into account a full week's coverage requirements (which repeat each week of the month), the Scheduling Module identifies the number and type of shifts required, each shift's starting time, the days off assigned, and how lunch and break assignments are to be allocated for each day of the week.

Although the Scheduling Module has an option for solving the full integer model (and this has been used for employee work groups with fewer shift alternatives), integer programming is abandoned in the case of airports and reservations offices. A heuristic rounding algorithm similar to that described in Henderson and Berry [1979] is incorporated in the Report Module and serves to convert the Scheduling Module's fractionated LP solution into a workable shift schedule.

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Users of the SMPS have gotten tremendous mileage out of the minimum manpower cost produced by the Scheduling Module. Since the model solution set is rich in alternatives, integer solutions are obtainable which do not differ much from the noninteger solutions (typically two to five percent). Therefore, the continuous solution gives manpower planners an absolute lower bound obtainable on staffing costs, serves as an indicator of what gains might be realized through manual manipulation of the schedule, and provides schedulers with a gauge to evaluate the quality of final schedules produced by the Report Module. The ability of the Scheduling Module to identify the absolute minimum manpower cost — and the comparative cost of final schedules produced after rounding a fractionated linear programming solution — was the major factor in convincing United management to support the development of SMPS.

Although the Scheduling Module in the final SMPS solves a matrix of around 5,000 columns, 1,000 rows, and 20,000 elements (and runs in less than 10 CPU minutes on an IBM 9081), original run times were excessive and required some design changes to produce a viable modeling system. The high matrix density of the scheduling model for airports and reservations offices posed a problem for solving even the continuous linear programming model. With coefficients in staffing requirements constraints for each time period worked, even a matrix with 5,000 shift alternatives could have over a million elements. Formulating the staffing requirements rows as requirements in a time period over and above those of the previous time period reduced the density by a factor of 30 to one.

The scheduling model is automatically decomposed and first solved without considering undesirable shifts and days off. Then all legal combinations are added and the model continues to the final solution. This also improved the model solution times considerably.

Testing showed that restrictions could be imposed that had little or no affect on solution quality. In the final version of the Scheduling Module, we decided to remove the integer variables associated with choosing starting times and place them in the Start Times Module independent of days-off choices. To further speed run times, we added an option to restrict the shifts in the Scheduling Module to those which had nonzero values in the Start Times Module.

Report Module

The Report Module produces monthly shift schedules and places them in an interactive database where they can be accessed by schedulers. In addition, it produces a variety of coverage and cost reports associated with each shift schedule.

A heuristic rounding algorithm is contained in the Report Module for creating full manpower work schedules from fractionated linear programming solutions. The techniques utilized in the algorithm are also available to schedulers for handling minor changes and in fine-tuning shift schedules.

Day-off Pairing Module

The Day-off Pairing Module is a network model used to combine monthly shift schedules into trimester work assignments on the basis of allowed transitions between shifts types and assigned days off in two adjoining months. Allowed transitions, for example, insure that the tour will not require working more than six days consecutively.

The Day-off Pairing Module uses an out-of-kilter algorithm to solve a simple assignment problem. Combination of shift schedules into tours is based on a set of transition costs. The costs define preferred, permitted, and forbidden transitions. A primary function of the transition cost definitions is to restrict the number of consecutive days worked during each monthly transition.

An option in the Day-off Pairing Module permits the spreading of weekend days off among employees to be maximized. In this way, weekend days off are included in as many work tour assignments as possible.

The Day-off Pairing Module is a critical link in the SMPS system. It replaces a manual function that was very time consuming. Secondly, by producing complete assignments for field offices, the credibility of the work schedules it produced was established.

Implementation

Because an effective model was urgently needed, we did not have long lead times in which to develop and refine the system. We elected to prototype a system and make ongoing refinements as we identified operational needs. Of the four modules in the final version of SMPS, only the Scheduling Module was included in the initial prototype. This rudimentary version of SMPS was used to prepare schedules for each of the 11 reservations offices in January 1983.

These first work schedules developed by SMPS were not accepted with enthusiasm. Although they were economically optimal, they did not incorporate other considerations deemed essential by reservations managers. Whether these other considerations were in fact important (and many were not) was not the point; rather, the perception that these considerations were ignored became the central issue. The cardinal rule for earning the trust and respect of operating managers and support staffs — "getting them involved in the development process" — had been violated.

Subsequent reservations work schedules were developed with substantially increased user participation, thereby overcoming this resistance. In the process we realized that SMPS needed to be more flexible. Satisfying the group culture at each office was essential in garnering field support. As a result, office-specified input variables, such as the number of start times, the preferred shift lengths, the length of breaks, preferred days off combinations, and so forth, became an integral part of SMPS. This versatility gave office managers the luxury of evaluating schedules incorporating different input parameters but identical manpower requirements.

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Airports began implementing SMPS six months after the first schedules were developed for reservations offices. The resistance encountered during our initial implementation was avoided at the airports. Several factors contributed to this success:

(1) SMPS was implemented only at the request of each airport operating manager.

(2) New implementations were limited to

one new airport per trimester bid period. The project team focused its efforts on educating the managers at a single airport, rather than trying to cover as many as 11 at once.

(3) The implementation timetable was established by airport management, rather than by corporate headquarters.

(4) Members of the project team prepared preliminary schedules that were reviewed with airport personnel during on-site visits well in advance of implementation.

United's Station Manpower Planning System was completed in June of 1983. Between June of 1983 and October of 1984, SMPS was implemented at United's nine largest airport operations. The flexibility built into SMPS for the reservations offices permitted an easy transition to scheduling of airport CSAs.

An unexpected SMPS application surfaced in the fall of 1983. As mentioned above, the system's flexibility permitted the office managers to analyze various scheduling parameters and compare the resulting schedules. United's industrial relations staff, responsible for negotiating the company's union contracts, expanded this concept. Using SMPS as a spreadsheet, the IR staff conducted exhaustive analyses of alternative contract scenarios. The comprehensive nature of this analysis required that each scenario, representing various potential contract obligations, be applied to each of the company's five largest airport operations. Furthermore, work rule differences between union and nonunion employees required new constraints and flexibility within SMPS. A number of the functions and capabilities in the final version of SMPS resulted from the needs of this analysis.

Benefits

The SMPS has been an overwhelming success at United. Benefits it has provided include

— Significant labor cost savings,
— Improved customer service,
— Improved employee schedules, and
— Quantified manpower planning and evaluation.

Our primary objective in developing SMPS was to reduce labor costs through efficient manpower scheduling. Since 1983, SMPS has provided staffing plans that have decreased manpower coverage requirements in United's reservations offices and larger airports by an average of six percent. We have realized savings in direct salary and benefit costs of $6 million annually. Unquantified capital benefits include

— Additional revenue generated by improved service,
— Benefits from the use of SMPS in contract negotiations,
— Savings from reduced support staff requirements,
— Savings from reduced manual scheduling efforts,
— Cost reductions from additional smaller work groups, and
— Reduced training requirements.

In addition, while SMPS is currently used to schedule around 4,000 employees on a regular basis, it will eventually be used to

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schedule up to 10,000 employees (20 percent of United's work force).

United's key operations managers believe that the intangible benefits of SMPS may outweigh the tangible cost savings. This is particulary apparent in the area of improved customer service. Recently, at United's eastern regional station manager's meeting, one manager described the model to the gathering as

> magical, . . . just as the (customer) lines begin to build, someone shows up for work; and just as you begin to think you're overstaffed, people start going home.

Typical of other station managers comments are the following:

> When I took over this (airport) operation, we had never had a 10:30 AM shift. Looking at my requirements, I thought a 10:30 shift was needed, but my scheduler disagreed. Sure enough, the first (SMPS) run gave me a 10:30 shift. I knew I needed it!

> We've never had a 17:30 start time. I don't know why. It really solved our overnight scheduling problem.

"Just as the lines begin to build, someone shows up for work."

Operating managers and United's stockholders are not the only ones to benefit from the SMPS. Many employees want part-time work in reservations offices and airports and prefer to work less hours than had usually been required by the manually developed schedules. New short tours were scheduled by SMPS and, in combination with United's 1983-84 expansion, the result was that all labor cost savings were attained without layoffs or other forced employee reductions.

The employees whose work schedules were developed by SMPS became its strongest proponents. Employee schedules were tailored to employee likes and dislikes by location whenever that was possible without sacrificing coverage or cost. In addition, the change from rotating days off to fixed days off with transitions gave employees more choices of schedules. With SMPS implementation, some 40 percent of San Francisco CSAs received their first choice of duty tour. One employee was ecstatic about receiving a schedule containing weekends off only when the 49ers were in town. Another airport was well known for operating with minimum manpower and maximum coverage. However, to make it work, its employees were required to work split shifts and often undesirable schedules. The schedules produced by SMPS did not reduce manpower costs at the airport, but they were able to completely eliminate split shifts and to provide more amenable schedules at the same cost and with equal or better coverage.

SMPS has provided United with a valuable planning and evaluation tool. The spreadsheet application of SMPS, pioneered in response to United's industrial relations staff requests, has been used to identify relative costs of various contractual obligations. At an operating level, managers have used the model to judge the subjective quality of a schedule versus the costs of additional scheduling constraints.

In the course of 18 months, use of SMPS has "completely changed United's perception and approach to scheduling manpower. SMPS has introduced new scheduling practices at airports and reservations offices without disrupting operations or personnel relations." This comment from Walt Benin, the corporate manager of manpower planning, effectively summarizes the overall impact of SMPS at United Airlines.

Acknowledgments

The success of SMPS at United Airlines is not due solely to the efforts of corporate management and the SMPS project team. Without the support of operational managers and their staffs, SMPS could not have succeeded. Moreover, the willingness of the employees themselves to accept changes benefiting United Airlines played an invaluable role in achieving final results.

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