

Optimizing Pilot Planning and Training for Continental Airlines

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The Crew ResourceSolver decision-support system employs advanced optimization modeling and solution techniques to solve complex, large-scale pilot staffing and training problems at Continental Airlines. The system determines optimal pilot transitions and efficiently allocates and schedules training resources. The results are improved staffing levels and substantial cost savings through reduced staffing, hiring, and training costs. Continental has estimated savings of over \$10 million per year using the system.

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Continental Airlines, headquartered in Houston, Texas, is the fifth largest US airline based on passenger volume and employs 44,000 people worldwide. Continental provides service to five continents with over 1,100 daily flights operating 345 aircraft of four different fleet types. The airline's 4,500 pilots are stationed at three continental US crew bases (Houston, Newark, and Cleveland) and one mid-Pacific crew base (Guam).

Pilot staffing and training is one of the most complex and costly problems facing major airlines. If an airline does not manage the problem effectively, it cannot survive, not to mention profit, in the competitive air transportation market. To solve the pilot staffing and training problem, an airline determines the number of pilots needed to fly its flight schedule and builds a training plan that achieves the desired staffing levels. The large number of variables involved in these decisions makes this problem very difficult to solve in a timely and cost-effective manner. In the past, manpower planners at Continental gathered data from several disjoint database systems that were developed 10 to 20 years ago and built these training plans using spreadsheets. These aging database systems were no longer able to support the evolving manpower needs of the airline, and the manual process of putting together each training plan was convoluted and time consuming.

Navitaire (formerly CALEB Technologies Corp.) has developed the Crew ResourceSolver integrated decision-support system to help Continental solve this problem. The system represents a significant investment and upgrade in managing Continental's manpower-planning needs. It manages large volumes of data and employs state-of-the-art optimization modeling and solution techniques to efficiently allocate crew and training resources and to improve operational and financial performance. It has replaced the following systems at Continental: (1) the seniority-management system, the system that tracks the longevity of pilots at the airline, (2) the training-scheduling system, the system that tracks the training resources and the pilots scheduled for training, and (3) the crew-records system, the system that stores each pilot's work history and contact information. In addition, many spreadsheet-based and manual procedures have been automated and brought into this new decision-support system. These include the calculation of pilot-pay guarantees, the calculation of monthly staffing levels, the allocation of yearly and monthly vacation, and the construction of training-class rosters and training-device schedules. The integration of these existing systems and procedures improves the airline's processes by increasing information sharing within the organization and by simplifying system maintenance. Eliminating duplicate data

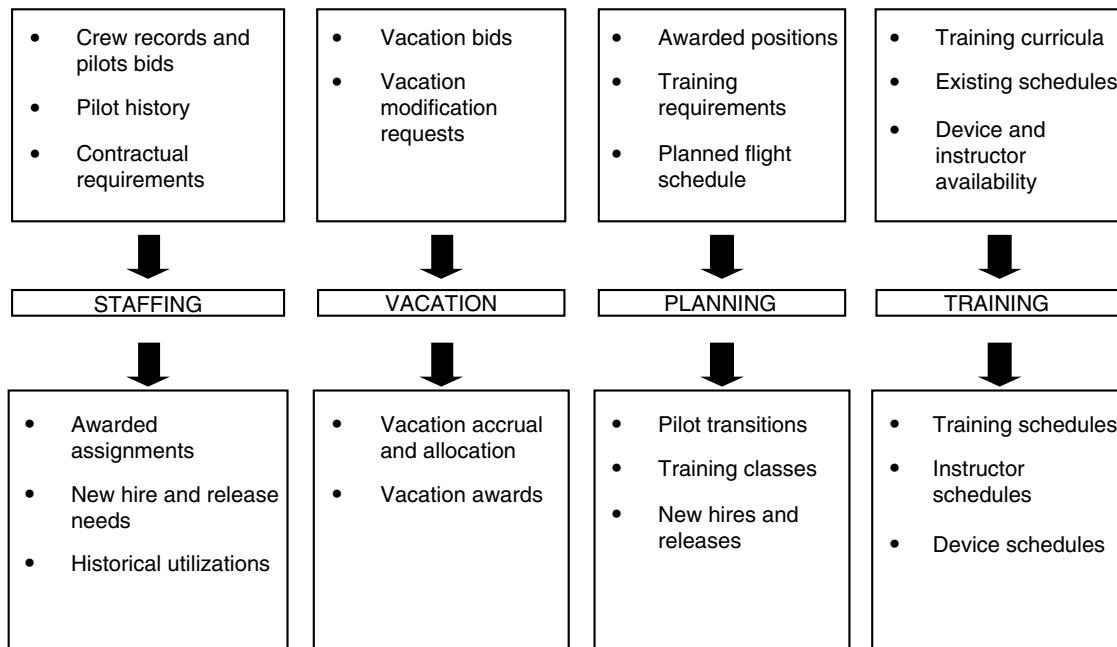


Figure 1: The Crew ResourceSolver system contains four main modules to handle staffing, vacation, planning, and training. The staffing and vacation modules maintain crew records, including all current and past assignments, absences, and training. The planning and training modules provide pilot-planning and training functions.

storage and automating processes also enhances data integrity.

The new system is composed of two administrative modules and two optimization modules (Figure 1). The staffing and vacation modules maintain crew records, including all current and past assignments, absences, and training. These modules calculate and maintain seniority information, pay information, awarded assignments, new-hire and release needs, vacation accrual and allocation, and historical pilot-utilization rates. They also support the allocation of pilot hires, releases, and assignments as well as vacations based on pilot bids, requests, and contractual obligations. Manpower planners interact with these administration modules through a graphical user interface that provides the data visibility they need to manage pilot-staffing and vacation decisions efficiently and to ensure that the data is valid and consistent.

The optimization modules provide both pilot-planning and training functions. The pilot-planning function determines the quantity and timing of training classes and pilot new hires and releases and assigns pilots optimally based on the planned flight schedule, awarded pilot assignments, and each pilot's training requirements. The training function includes building optimized training and instructor schedules and using training resources efficiently based on the training curricula, existing schedules, and device and instructor availability. It maintains schedules for

training resources, students, and classes and tracks resource utilization and each pilot's progress in training.

Staffing-Administration Module

Based on the planned flight schedule and the airline's current staffing, planned transitions, and attrition over time, the staffing-administration module identifies shortages and surpluses. Shortages in some assignments may be filled by transferring surplus pilots from other assignments. Airlines manage such transitions differently, but most use an award process in which they notify pilots of their needs and give them the opportunity to bid on these new openings. If the openings create enough demand, the airline will fill the openings based on seniority; otherwise they will fill the assignments in reverse-seniority order. If shortages across the airline are greater than surpluses, the airline will need a combination of transitions and new hires to alleviate the shortages. If surpluses across the airline are greater than shortages, it will combine transitions and pilot releases, releasing pilots in reverse-seniority order.

The airline also uses the staffing-administration module to determine how much work to assign to pilots. Contractual and governmental work rules give airlines some flexibility in scheduling monthly work for their pilots. Based on current staffing levels, the planned flight schedule, and known and predicted

absences, airlines use the staffing-administration module to decide how much work to assign pilots in each position each month. They will assign pilots more hours each month in understaffed positions and fewer hours in overstaffed positions.

Vacation-Administration Module

The vacation-administration module plans and proposes the vacation periods on which pilots are to bid. Airlines must allocate vacations to pilots carefully to avoid staffing shortfalls. The vacation-administration module avoids manpower shortages during peak demand seasons by offering more blocks of vacation time during seasons with fewer planned flights. Airlines may offer vacations to pilots annually or monthly or in combination.

Planning-Optimization Module

Once the airline has awarded pilot transitions and determined its need for new hires, pilot releases, or both, it must determine their timing. All new hires and most pilots making transitions to different positions require training to qualify for their new duties. The planning-optimization module determines the timing of all transitions, new hires, and releases to best match pilot availability with the airline's needs at each position. The planning-optimization module is constrained by the available training resources, the training requirements for each pilot, and by restrictions on pilot availability such as vacations. This module works in conjunction with the training-optimization module to determine the availability of training resources and to establish the timing of training classes for new hires and pilots making transitions.

Training-Optimization Module

The training-optimization module manages all training resources, instructors, and schedules. Given class rosters and approximate start dates for those classes, training curricula, and each pilot's qualification, the training-optimization module schedules the classes, assigning training resources and instructors to each class.

All airlines have some means of managing their manpower planning. Most airlines employ some combination of legacy database applications, spreadsheet applications, and paper-based record keeping similar to Continental's previous system. For many years, operations research and information technology professionals have envisioned an advanced decision-support system to deal with airlines' manpower-planning problems. Verbeek (1991) provides a framework for a pilot-manpower planning decision-support system and describes some of the complexities of such a system. Yu et al. (1998)

describe the initial ideas and an early prototype for the development of the manpower optimization system at Continental. Haase et al. (1999) describe a related application, a decision-support system for course scheduling developed for Lufthansa German Airlines.

The application of manpower-planning optimization models has also been considered in such areas as military planning (Grinold and Marshall 1977), naval planning and training scheduling (Yu et al. 1996), and manufacturing scheduling (Faaland and Schmitt 1993, Treleven and Elvers 1985, Park and Bobrowski 1989). The problem of scheduling pilot-training classes is similar to the problem of course-timetabling to assign students and teachers to classes and then assign the classes to rooms and weekly time slots (Fizzano and Swanson 2000, Glassey and Mizrach 1986, Schrage 1968).

Problem Description

A pilot position is described by the triple (base, fleet, and seat). Base refers to the geographical location where a pilot starts and ends trips; fleet refers to the type of aircraft the pilot flies (for example, 737, 777, DC-10); and seat refers to the status of the pilot in the cockpit (captain, first officer, or second officer). An airline constantly adjusts its need for pilots in different positions in response to new market opportunities, changing passenger demand, acquisition and retirement of aircraft and training resources, crew bases opening and closing, and evolving economic conditions. From a manpower-planning point of view, these factors feed into the flight schedule. This flight schedule can be translated into block hours (the flight hours to be staffed at each position over the planning horizon).

Most pilots change positions many times during their careers. Pilots want to move from smaller to larger fleets and from the first-officer seat to the captain seat to increase their pay and responsibility, and from base to base to work in preferred locations. Each active pilot has a unique seniority number relative to all other active pilots based on length of service with the airline.

The process for resolving the airline's changing staffing needs at different positions and pilot's requests to change positions is called the system bid award. The system-bid-award process, which the pilot contract requires at least twice a year, provides pilots an opportunity to change positions and the airline a way to adjust staffing levels in response to changes in its flight schedule, retirements, and attrition. The airline offers positions to the pilots based on its forecasted needs, and the pilots bid for the positions they desire. The airline then awards positions to the pilots following seniority-based rules. If the airline

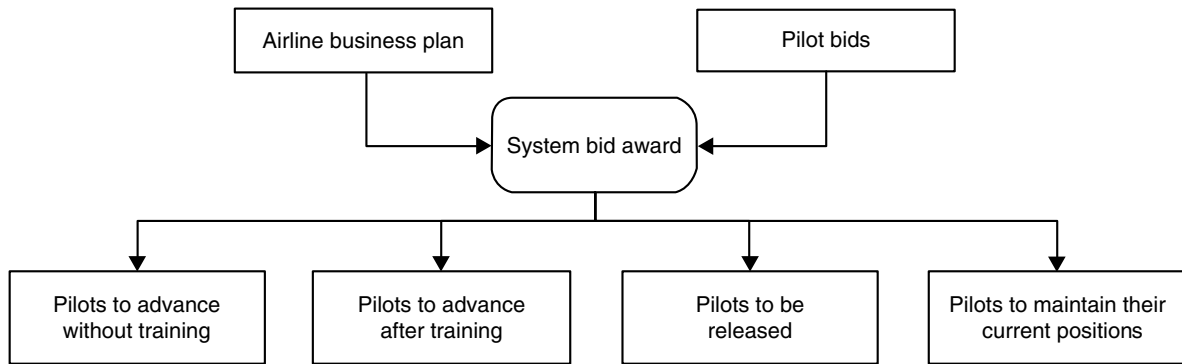


Figure 2: The system bid process, which occurs at least twice a year, combines Continental's business needs with pilot desires for new positions. All pilots receive an award with each pilot falling into one of the four cases shown.

offers more positions than it has pilots, it will hire additional pilots. Conversely, if the pilots outnumber the positions offered, the airline will release, or furlough, the pilots with the least seniority (for example, the decrease in business following the events of September 11, 2001 drove many airlines to reduce capacity by as much as 20 percent, resulting in pilot furloughs). Each award has an effective date, generally 12 months after the award date, on or before which all pilots receiving awards are to be advanced to their new positions. The advancement date for a pilot is the date on which the pilot starts working in the new position.

After a system bid award, all pilots can be separated into the following groups (Figure 2): pilots to advance without training, pilots to advance after training, pilots to be released, and pilots to maintain their current positions. Pilots to advance without training include those moving to a new base while maintaining the same fleet and seat, and those changing position that are already qualified for their new positions. All other pilots changing positions will require some training based on their previous experience and their awarded positions. Pilots who do not receive a position will be released from the airline. They may be pilots over age 60 who, by FAA regulation, must fly in the second-officer seat but do not have enough seniority to hold a second-officer position, or pilots furloughed because the airline has reduced the number of pilots it needs. The remaining pilots maintain their current positions as a result of the system bid award.

In an average system bid award, 15 to 20 percent of the airline's pilots receive new positions. In response to a system bid award, the decision-support system builds a training plan that establishes the timing of training, advancements, releases, and new pilot hires. The training plan also includes detailed training schedules composed of all training events for

each student and each training resource. Training resources include briefing rooms, classrooms, flight-training devices, cockpit trainers, and flight simulators. The training plan determines pilots' transitions across positions and it ensures adequate staffing levels, minimum cost, and efficient utilization of training resources.

Before deploying the new system, Continental's manpower planners and training schedulers worked together to build a training plan to be used after the airline awarded each system bid. Manpower planners with expert knowledge took more than two weeks to manually determine the pilot-transition part of the training plan. This part of the plan includes when pilots should go to training classes, be advanced, be hired, or be released. The training schedulers worked month by month on the second part of the training plan, scheduling the corresponding training classes. Using this manual approach, the planners and schedulers created a single, partial, suboptimal training plan that best met required staffing levels with no detailed consideration of costs. Computing the cost of a training plan is complicated, and the planners did not consider cost in building plans manually.

Now using the decision-support system, planners obtain within an hour a complete, optimized training plan that includes both the pilot transitions and the training class schedules. By exercising different options, users can replace the single manual solution with multiple high-quality solutions that they can examine carefully before choosing the most suitable one. The savings in time, however, are dwarfed by the savings derived from implementing an optimized solution that provides better coverage of the block hours and by the dollar savings from reducing staffing, pilot-pay guarantees, and training costs.

The scheduling group defines the block hours for each position each month. The primary objective of

Continental's planners in constructing a training plan is to ensure that it will have pilots in place at each position to meet these block hours. The airline must move pilots through training to their new positions in such a way that it covers as many block hours as possible.

Secondary objectives in constructing a training plan include minimizing the costs of pilot-pay guarantees and of hiring, releasing, and training pilots. The airline pays a pilot-pay guarantee, or pay-protection cost, to the pilot with higher seniority if it awards two pilots the same position on the same system bid award, and advances the pilot with lower seniority to the new position first. In such cases, the airline starts paying the senior pilot the new position rate when it advances the junior pilot. Pay protection is also invoked if the airline does not advance a pilot by the effective date of the system bid award. Delayed hiring and accelerated furloughing are desirable from a cost standpoint given that the airline incurs pilot payroll costs once it hires pilots and until it releases them. The airline treats training resources as a fixed cost; however, it pays a pilot payroll cost for each day a pilot spends in training. A lesser objective in scheduling training is to assign pilots to preferred training devices on training days when more than one device is acceptable. Thus, the cost of training is measured primarily by the amount of time pilots spend in training and secondarily by the favorable assignment of training resources.

Many constraints must be considered in building a training plan:

(1) Planners must observe pilot vacations and absences. They cannot assign pilots training during their vacations or other scheduled absences.

(2) The airline must release pilots being furloughed in reverse-seniority order systemwide. A pilot may not be released before another pilot who has less seniority.

(3) Planners must assign pilots to training and advancement. The pilots must complete specific curricula to qualify. The two basic types of curricula for each fleet are a primary systems course and a requalification course. Primary systems courses take five to eight weeks and are required for pilots new to a fleet. Requalification courses last from two days to a couple of weeks and are necessary for pilots who previously qualified but have been inactive for a period of time. Each curriculum may include defined days off, and all training schedules must include a contractual minimum of one day off during every seven calendar days in training and four days off during every 14 days.

(4) Training resources are limited. These resources include instructors, classrooms, briefing rooms, flight-training devices, cockpit trainers, and flight simulators for each fleet. Because resources are limited, class

starts each month for each fleet and types of training are limited.

(5) Planners can schedule training in flight-training devices, cockpit trainers, and flight simulators in one of four predefined periods each day called device periods. Once a year all of the airline's pilots must complete recurrent training that includes time in some of these device periods. The training schedule must include these one- or two-day training classes and enough training resources to schedule this recurrent training for each fleet.

(6) Device period constraints include assigning pilots to device periods, assigning each device period only once, and ensuring that pilots are scheduled in the same or a later device period on consecutive days.

The pilot-training-plan problem is a very large, NP-hard problem. Additional complexity for this problem comes from the following:

(1) The staffing levels for all bases, fleets, and seats are interdependent. Aside from hiring new pilots, to increase the staffing in one position, the airline must decrease its staffing in another position. If it does not furlough pilots, to decrease the staffing in one position, the airline must increase its staffing in another position.

(2) The timing and number of training classes is variable.

(3) The planners must create minimal-length pilot-training schedules using limited resources.

(4) Planners must consider complicated business rules related to each pilot's seniority, flight history, and current and future positions.

In addition to using the system to construct a training plan in response to a system bid award, the airline can use the system to reoptimize the training plan at any time. Manpower planners can gauge what impact various management decisions made between system bids might have on pilot staffing and training. The planners use an existing training plan as a base from which they create a modified plan. They do not change the objective or constraints of the original problem and add only a constraint that limits the allowed deviation from the base plan. This functionality is very useful in practice. After the planners establish an initial training plan, such factors as new market opportunities, the airline's acquisition and retirement of aircraft and training resources, its opening and closing of subbases, and changes in the number of hours to be flown for different pilot positions can lead to changes in the training plan each month. When such changes occur, planners can make selective and intelligent adjustments to the current plan without disrupting a large number of pilots.

Planners can also use the system to customize training plans by adjusting objectives and setting options. For example, they can change the weightings on

cost factors, just-in-time training, and new-hire minimums and maximums. They can fix the training and advancement dates for a group of pilots, and they can limit the block-hour shortages for specific positions in specific time periods. They can run what-if scenarios and establish the impact of assigning pilots their preferences, limiting the number of new hires, and so on for a given training plan.

Solution Methodology

To solve the pilot-training problem, we developed a two-phase solution methodology, breaking the problem into a pilot-transitioning phase and a training-class-scheduling phase. In the pilot-transitioning phase, the timing of pilot transitions is determined using limited information about training capacities to restrict the number of pilots assigned to training. This ensures that a feasible solution will exist in the second phase. The training-class-scheduling phase constructs the detailed training schedule taking as input the solution from the first phase. The combination of results from the two phases forms an overall training-plan solution.

While this approach does not guarantee an overall optimal training plan, we have found that it consistently provides high-quality solutions in a fraction of the time it takes to construct manual solutions. We have shown empirically that these solutions meet more block hours and cost less to implement than solutions generated manually.

The Pilot-Transitioning Phase

We represent the pilot-transitioning phase with a mixed-integer program (MIP). We solve the phase using a two-part approach in which we first solve the linear programming (LP) relaxation of the MIP with a high block-hour shortage penalty to determine the appropriate trade-off between block-hour shortage and dollar-cost components in the objective. The airline's primary concern is the block-hour shortage, and the model should aim to minimize it. The LP relaxation gives an estimate of the best block-hour shortages the airline can achieve, and the associated cost coefficient that must be used in the objective function of the MIP model to ensure block-hour shortages near this minimum. With these objective coefficients set, we solve the MIP model using commercial software libraries with predetermined ordering to direct the MIP branching.

The pilot-transitioning phase takes as input current pilot positions, awarded pilot positions, block hours, costs, new-hire limits, average pilot-utilization rates per position, and user preferences. By adjusting these preferences to emphasize different solution attributes, the planners can obtain various solutions. The solutions provide training requirements, vacations, and

absences for pilots who require training. The output of this phase is the training and advancement dates for all pilots with new positions, the timing and number of new hires, the release dates for pilots being furloughed, the number of training-class starts, and the training-class rosters.

The MIP model (appendix) for the pilot-transitioning phase takes the following form:

minimize cost:

block-hour shortages + pay protection
+ hiring + releasing

subject to

pilot vacations and absences,
releasing pilots in seniority order,
assigning pilots to training and advancement,
capacity of training resources,
block-hour shortage tracking,
pay-protection tracking.

The Training-Class-Scheduling Phase

The input for the training-class-scheduling phase consists of the classes to be scheduled, the pilots in each class, and their associated training curricula (all from the pilot-transitioning phase) and the available training resources. With the timing of pilot transitions fixed, we now solve the class-scheduling problem independently for each fleet. Given the training classes to schedule, we need to determine the start and end dates and a detailed daily training schedule for each class (Figure 3).

We solve the training-class-scheduling phase for each fleet in two parts. First, we use a branch-and-bound procedure to define training-class start dates and daily training-resource usage. Then, we solve an assignment problem to obtain the detailed hourly schedule of individual training resources for groups of one or more pilots.

The branch-and-bound procedure considers a subset of classes in each branch-and-bound tree and implements a rolling-horizon approach to cover all of the classes for each fleet. For example, if we have 10 classes to schedule, we can schedule the first three classes together. Then, we can fix the schedule of the first class and schedule classes two through four together. We repeat this process until all 10 classes are scheduled.

Each branch-and-bound tree schedules daily activities for a group of classes, minimizing the length of time the pilots spend in training. Each branch-and-bound tree begins from a root node in which day $t = 0$ and none of the classes to be scheduled by this tree

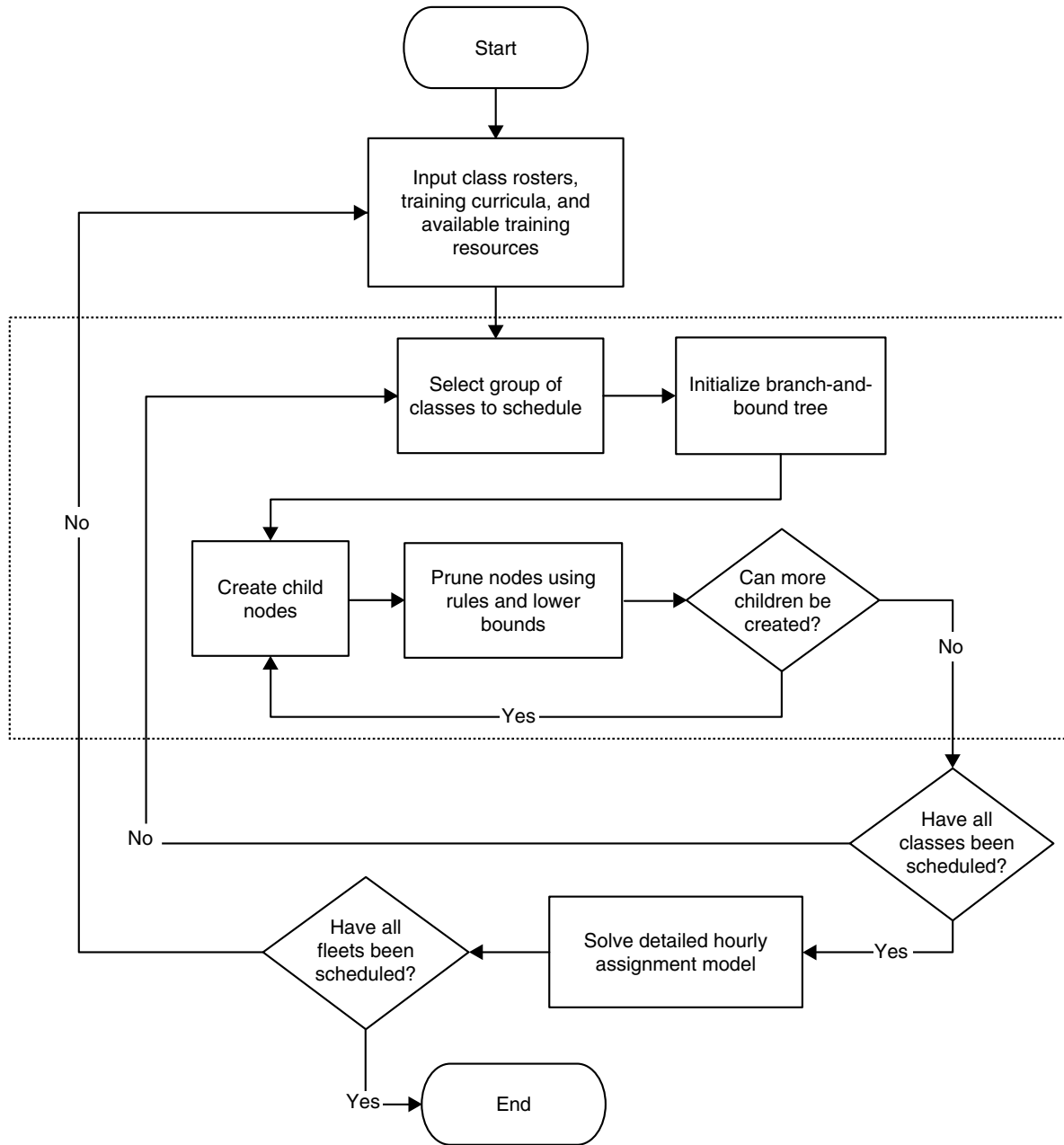


Figure 3: Given the classes that need to be scheduled, training curricula, and available training resources, a branch-and-bound procedure is used to create class schedules considering only a subset of the classes in each pass. Once all classes have been scheduled detailed hourly assignments are made. This process is repeated for each fleet.

have begun. We implement a depth-first approach to search the entire tree. Each level in the tree represents a calendar day t , and each node D represents a partial schedule PS_t through the current day, that is, the schedule for all classes from day 1 to day t . For each node D , a child node D' can be reached by scheduling a training day or a day off for each class. The current day for node D' is then $t + 1$. The new partial schedule PS_{t+1} contains the same schedule from day 1 to day t as node D plus one additional day.

We implement a node-elimination rule and a lower-bound calculation to cut off branches of the tree to increase the speed of the search procedure and eliminate infeasible schedules. The construction of the tree is constrained both by the capacity of available training resources and by contractual restrictions. An example involving the capacity of available training resources is a node representing training for multiple classes that violates the number of resources available on a given day. An example involving a contractual

restriction is a node representing the n th calendar day in training with only m days off when $m + 1$ days off are required every n calendar days. The objective function used in the branch-and-bound algorithm is the number of days pilots spend in training for all classes being scheduled. Based on the history of training days and days off at the current node, and the required training days remaining, we can compute a lower bound for each node that we can use to eliminate some child nodes once we find a feasible solution. Qi et al. (2001) give a more detailed description of the branch-and-bound framework and the rolling-horizon approach applied to this training-scheduling problem.

We then solve an assignment model with additional side constraints, transforming the branch-and-bound procedure solution that has daily activity information for each class to a detailed hourly assignment of training resources to pilots. In some cases, schedulers can use more than one training resource to achieve the desired training, but one is often preferable. The objective of the model captures this lesser factor in the training cost, the favorable assignment of training resources in the presence of multiple options. The MIP model (appendix) for the detailed hourly assignment of training resources to pilots takes the following form:

minimize cost:

assignments of pilots to training
resources,

subject to

assigning pilots to the device
periods required for training,

assigning each device period
only once,

consecutive day rules for device
periods,

device period needs for recurrent
training.

Implementation

A dedicated team of operations research and software professionals, including specialists in large-scale optimization, databases, C++, Visual Basic, and quality assurance from Navitaire as well as manpower planners, training schedulers, managers, and information technology professionals from Continental Airlines, worked together on this project for over two years. After a preliminary study conducted between April 1997 and June 1999, the project began in November 1999. The team finished gathering requirements and developed an advanced optimization prototype by

January 2000. Continental Airlines used this prototype to produce training plans for the January 2001 and July 2001 system bid awards. These training plans provided returns on Continental's investment before the production system was in place. We deployed the production system at Continental to train users and gain acceptance in February 2002.

Impact

Overall, Continental has estimated savings in excess of \$10 million annually from using the system to create training plans. The cost of a training-plan solution can be broken into a number of components. The training-cost portion is based on the number of days pilots spend in training. This cost can be reduced by scheduling training classes more efficiently and reducing the number of pilots sent to training. The airline can reduce pay-protection costs by advancing pilots to their new positions in seniority order. It can reduce payroll costs by using existing pilots more efficiently so that it hires fewer new pilots and hires new pilots later. Releasing pilots to be furloughed quickly also saves payroll cost. A common means of addressing block-hour shortages in a particular position for a particular month is to raise the number of hours pilots work in that position that month to cover the shortage. To estimate a dollar cost for block-hour shortages, we multiply an average hourly pilot wage (\$140) by the shortage hours. The airline cannot obtain a corresponding savings in overstaffed situations because of minimum-pay guarantees for pilots.

The potential sources of savings vary, and they are different on different system bids. Bids differ in the initial staffing levels, number of new hires, number of pilot transitions, number of training cycles, and number of pilot releases. A bid that requires no new hires and no pilot releases will have no cost components associated with those activities. Also the dollar costs of a training plan for a particular system bid are inter-related. For example, the airline may reduce a shortage of block hours by paying more pay protection and increasing new hires.

The airline can make a trade-off between block-hour shortages and other costs, as it did with training plans created for the July 2001 system bid award (Table 1). In the July 2001 bid, 806 pilots were assigned different positions. Of these pilots, 740 needed training to qualify for their new assignments, 79 pilots over age 60 did not receive an award and needed to be furloughed, and 238 new hires were projected. The airline gained tremendous cost savings by using an optimized plan rather than a manual solution.

Of two optimized plans, training plan 1 had the fewest block-hour shortages while training plan 2

Attribute	Manual	Training plan 1	Training plan 2
Training cost	\$29.8 M	\$27.1 M	\$26.5 M
Pay protection	\$2.3 M	\$4.2 M	\$0.2 M
New hires	\$2.2 M	\$2.5 M	\$0.5 M
Cost without block hours	\$34.3 M	\$33.8 M	\$27.2 M
Block-hour shortage	80,000 hrs	27,000 hrs	77,000 hrs
Block-hour-shortage cost	\$11.2 M	\$3.8 M	\$10.8 M
Total cost	\$45.5 M	\$37.6 M	\$38.0 M

Table 1: This cost comparison between Continental's manual solution and manpower system solutions shows statistics associated with two training plans built by the decision-support system for the system bid award along with statistics for the manual plan constructed by Continental manpower planners. The table illustrates the interrelated nature of different solution aspects.

minimized pay protection, new hires, and training costs. To achieve fewer block-hour shortages, training plan 1 maintained crews at their current positions until they were absolutely necessary to cover shortages in their awarded positions, and it hired pilots earlier than training plan 2 to prevent shortages. Training plan 2 moved senior crews earlier than needed to reduce the total number of crews with pay protection and hired later in the planning horizon to reduce overall hiring costs, which minimized costs but increased shortages. The training cost in training plan 1 was higher than that in plan 2 because it called for a more congested training schedule that increased the number of days in training for some crews. Both plans created by the decision-support system had lower costs and fewer block-hour shortages than the manual plan. Continental Airlines implemented training plan 1 for the July 2001 bid award.

Conclusions

Effective manpower planning is a key element for success in the airline business. The Crew Resource-Solver system is the first decision-support system in the airline industry that considers the entire spectrum of hiring, staffing, transition, training, and absence management.

This integrated system has driven process improvement and improved data integrity, and it is easier to maintain than the myriad legacy systems and spreadsheet applications it replaced. The system also brings tremendous savings in time and costs to Continental by optimizing its pilot-transition and training plans.

The system has changed the way Continental Airlines plans pilot staffing and training, producing legal, cost-effective staffing and training solutions from which expert, experienced planners choose the best possible solution for a given situation.

Future work to be pursued in manpower planning includes planning and scheduling recurrent training,

developing tools for rescheduling classes disrupted during training, scheduling training instructors and initial operating experience, and selling excess flight simulator time outside the airline.

Appendix

The Pilot-Transitioning Model

Indices

- i Pilots.
- f Fleets.
- h Positions.
- t Time periods (in months).
- c Curricula.

Sets

- $\phi(i)$ Time periods in which pilot i can complete training.
- $\varphi(c, t)$ Pilots that can start training curriculum c in the time period t .
- λ Set of pilots that need to be trained or advanced.
- λ_{train} Set of pilots that need to be trained.
- λ_{noaward} Set of pilots with no award who will turn age 60 between now and the effective date of the system bid award. This set is sorted in reverse-seniority order.
- $\lambda_{\text{furlough}}$ Set of furloughed no-award pilots. This set is sorted in reverse-seniority order.
- $H(h)$ Pilots whose initial position is h (including advancements, releases, and training pilots).
- $H'(h)$ Pilots whose future position is h (including new hires, advancements, and training pilots).
- $\text{NH}(c)$ New-hire positions that require training in curriculum c .

Parameters

- N Length of planning horizon in months (often 12 in practice).
- $L(i)$ Length of training for pilot i .
- CAP_{ct} Maximum number of students that can start training for curriculum c in period t .
- Initial_h Initial number of block hours staffed for position h .
- p_i Pay protection cost paid to pilot i per period.
- uti_{ht} Utilization per position h per period t .
- BHC Cost per block-hour shortage.
- NHC_{ht} Cost per new-hire pilot advanced to position h in period t .
- NAC_{it} Cost if pilot $i \in \lambda_{\text{noaward}}$ is released in period t .
- FC_{it} Cost if pilot $i \in \lambda_{\text{furlough}}$ is released in period t .
- Blockhrs_{ht} Block hours for position h in period t .

Variables

$$y_{it} = \begin{cases} 1 & \text{if pilot } i \text{ is advanced in period } t \\ & \forall i \in \lambda_{\text{train}}, \\ 0 & \text{otherwise.} \end{cases}$$

$$y_{NAit} = \begin{cases} 1 & \text{if pilot } i \text{ is released in period } t \\ & \forall i \in \lambda_{\text{noaward}}, \\ 0 & \text{otherwise.} \end{cases}$$

$$y_{Fit} = \begin{cases} 1 & \text{if pilot } i \text{ is released in period } t \\ & \forall i \in \lambda_{\text{furlough}}, \\ 0 & \text{otherwise.} \end{cases}$$

y_{NHht} Number of new hires advanced to position h in period t .

S_{ht} Number of block hours short for position h in period t .

R_i Number of months in pay protection paid to pilot $i \in \lambda$.

Model

Minimize cost:

$$\begin{aligned} & \sum_t \sum_h \text{NHC}_{ht} y_{NHht} + \sum_t \sum_{i \in \lambda_{\text{noaward}}} \text{NAC}_{it} y_{it} \\ & + \sum_t \sum_{i \in \lambda_{\text{furlough}}} \text{FC}_{it} y_{it} + \sum_{i \in \lambda} p_i R_i + \text{BHC} \sum_h \sum_t S_{ht} \quad (1) \end{aligned}$$

subject to

(2) Pilot vacations and absences:

Y_{it} variables are defined only for periods not conflicting with absences and vacations.

(3) Release pilots in seniority order:

$$\sum_t y_{NAit} = 1 \quad \forall i \in \lambda_{\text{noaward}},$$

$$\sum_t y_{Fit} = 1 \quad \forall i \in \lambda_{\text{furlough}},$$

$$\sum_{t=k}^N y_{NAit} - \sum_{t=k}^N y_{NAi-1t} \geq 0 \quad \forall i \in \lambda_{\text{noaward}}, k \in \{1, \dots, N\},$$

$$\sum_{t=k}^N y_{Fit} - \sum_{t=k}^N y_{Fi-1t} \geq 0 \quad \forall i \in \lambda_{\text{furlough}}, k \in \{1, \dots, N\}.$$

(4) Assign pilots to training and advancement:

$$\sum_{t \in \phi(i)} y_{it} = 1 \quad \forall i \in \lambda_{\text{train}}.$$

(5) Capacity of training resources:

$$\sum_{i \in \phi(c, t)} y_{i, t+L(i)} + \sum_{h \in \text{NH}(c)} y_{NHht} \leq \text{CAP}_{ct} \quad \forall c, t.$$

(6) Block-hour shortage tracking:

$$\begin{aligned} & \left(\sum_{i \in H(h), k \leq t} y_{ik} * \text{uti}_{hk} - \sum_{i \in H'(h), k \leq t} y_{ik} * \text{uti}_{hk} \right) - S_{ht} \\ & \leq (\text{Initial}_h - \text{Blockhrs}_{ht}) \quad \forall (h, t). \end{aligned}$$

(7) Pay-protection tracking:

$$R_i \geq \left(\sum_{t \in \phi(i)} t y_{it} - \sum_{t \in \phi(j)} t y_{jt} \right) \quad \forall (i, j) \in \lambda, \text{ where pilot } j \text{ may pay protect pilot } i.$$

(8) Nonnegativity constraints:

$$R_i \geq 0 \quad \forall i \in \lambda_{\text{train}},$$

$$S_{ht} \geq 0 \quad \forall (h, t),$$

$$y_{ht} \geq 0 \quad \forall (h, t).$$

The objective function (1) minimizes the cost of the model solution by penalizing block-hour shortages and tracking the cost of pilot transitions.

Constraint (2) indicates that variables are defined only during periods in which pilots are eligible for transition. The set of constraints (3) ensures that all pilots to be released are released and that releases takes place in reverse-seniority order. Constraint (4) ensures that all pilots are assigned to training or advancement, and constraint (5), that only the training resources available are used. Block-hour shortages are tracked in constraint (6), and pay protection costs are captured by constraint (7).

The Detailed Assignment of Training Resources to Pilots Model**Indices and Sets**

I Class group days (CGD)—the set of all groups from all classes on all days in the training horizon that require device period assignments.

J Device period days (DPD)—the set of all available device periods for all devices on all days in the training horizon.

K Set of four device periods each day, labeled 1, 2, 3, and 4.

$j \in E(i)$ Set of DPD j that can be assigned to CGD i .

$i \in E(j)$ Set of CGD i that DPD j can serve.

$j \in P_1(i, k)$ Set of DPD j that can be assigned to CGD i in device period k .

$j \in P_2(i, k)$ Set of DPD j that can be assigned to the same class group represented by CGD i on the following training day if the two days are scheduled on consecutive calendar days and CGD i is assigned in device period k .

Parameters

C_{ij} Cost of assignment of CGD i to DPD j .

Variables

x_{ij} Binary variable: 1 if DPD j is assigned to CGD i , 0 otherwise.

Model

Minimize cost:

$$\sum_{i \in I, j \in J} C_{ij} x_{ij} \quad (9)$$

subject to

(10) Setting aside device periods for recurrent training capacity:

$$\sum_{j \in E(i)} x_{ij} \leq 1 \quad \forall i \mid i \text{ corresponds to a recurrent training assignment.}$$

(11) Assigning pilots to device periods:

$$\sum_{j \in E(i)} x_{ij} = 1 \quad \forall i \mid i \text{ corresponds to a class assignment.}$$

(12) Assigning each device period only once:

$$\sum_{i \in E(j)} x_{ij} \leq 1 \quad \forall j.$$

(13) Pilots following device period rules on consecutive training days:

$$\sum_{j \in P_1(i, k)} x_{ij} - \sum_{j \in P_2(i, k)} x_{ij} \leq 0 \quad \forall i, k \mid \text{CGD } i \text{ needs a DPD on the following day.}$$

The objective function (9) minimizes the cost of the model solution by using the most preferred training devices and device periods for each student and by providing the most device times for recurrent training assignments. When alternate device-device period combinations can be used, the assignment of a more preferred device-device period combination has a lower cost C_{ij} than a less preferred combination. The cost of a recurrent training assignment has a small negative cost C_{ij} , thus encouraging the assignment of as many device periods for recurrent training as possible.

Constraint (10) forces the assignment of a DPD j to each CGD i . Constraint (11) allows assignment of a DPD j to recurrent training CGD i . Constraint (12) ensures that no DPD j is assigned to more than one CGD i . Constraint (13) ensures that on consecutive device days, class groups are assigned to legal device periods. Due to contractual obligations, pilots can train only in the same device period or the following device period on two consecutive training days.

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Darryl Chandler, Director of Crew Resources and Administration, Continental Airlines, 1600 Smith Street, Houston, Texas 77002, sent the following information in support of this paper: “CALEB has developed the ManpowerSolver system to assist us in taking a process which was taking two weeks to produce a training plan to virtually hours to develop the plan. ManpowerSolver also provides the opportunity to run numerous scenarios to select the optimal plan that will meet the airline's flying requirements.

“We can now review various alternatives and very quickly determine the costs of training plans and also

determine where there may be shortages or overages in staffing. Once we are satisfied with the results we can either accept the plan in whole or part. A training plan can then be locked in for the near future but be left subject to change for months in order to review changes to the business flying hours.

“ManpowerSolver can be used to review what ifs for future flying requirements and can provide better pilot staffing capability and cost information for future changes to the flying schedule. We can now better react to future flying requirements with minimal disruption to the training plan.

“We have only begun to scratch the surface on the capabilities of this system. We will be able to forecast future simulator needs, as well as better manage instructor requirements, and maximize Contract Training revenues. The system will be interfaced with our Electronic Training Records system providing the

ability to maximize credit for previous training and therefore improving the efficiency of our training programs.

“The system was used to help determine the furlough of 175 pilots in May of 2003. Because of the results that we obtained from our Solver solutions we were able to increase the furlough numbers from 150 to 175 pilots, therefore saving the company approximately an additional \$1.5 million. During the next five years the airline will experience approximately 1,100 pilot retirements. These retirements along with additional flying requirements will make staffing and training pilots more challenging as we recall pilots from furlough and hire new pilots to meet these demands. The ManpowerSolver system will be an invaluable tool that will help us maintain pilot productivity as we manage our business in the future.”