A Conceptual Approach for Simultaneous Flight Schedule Construction with Genetic Algorithms

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Abstract. In this paper, a new conceptual approach for flight schedule construction will be developed. Until now, the construction of a flight schedule is performed by decomposing the overall problem into subproblems and by solving these subproblems with various optimization techniques. The new approach constructs flight schedules with the help of genetic algorithms. Each individual of a population represents a complete flight schedule. This encoding avoids the artificial decomposition of the planning problem. With the help of genetic operators, flight schedule construction may be conducted simultaneously, efficiently searching for better solutions.

1 Introduction

Although positive market trends accompany the airline industry in the new millennium, ongoing deregulation continuously increases competition and rivalry within the industry. Recent developments in the commodity markets, especially the rise in oil prices, volatile demand, and extension of existing respectively new strategic alliances facilitates more effective ways of flight schedule construction.

Since every instance of a flight schedule affects the cost and revenue structure of an airline and its competitors [1], its construction is of paramount importance for every airline. The construction of a schedule is a complex planning activity. Until now, it is performed by decomposing the overall planning task into various subproblems of less complexity. Well known examples are fleet assignment or rotation building etc. [1]. Many of these subproblems are well structured and, therefore, solvable with linear optimization techniques. The subproblems will be solved sequentially where a preceding subproblem delivers the input data for the subsequent subproblems. Since the sum of partial optimal solutions does not imply an overall optimal solution, a planning methodology which facilitates a simultaneous (not sequential) optimization of flight schedules subproblems bears a high potential. This paper outlines a conceptual approach for simultaneous flight schedule construction with genetic algorithms (GA). We propose that a GA-based scheduling approach will generate better flight schedules than the sequential planning approach.

Our paper is organized as follows. The next section focuses on the traditional planning approach, e.g. the sequential optimization of flight schedules. We will briefly elaborate the subproblems and finally discuss the effectiveness of this traditional approach. In the third section, we will develop a new approach for simultaneous flight schedule construction. A coding scheme will be explicated which possesses the ability to represent real-life flight schedules. Then, genetic operators for schedule construction will be described and illustrated with examples. Finally, a concept for fitness evaluation will be stepwise modeled and exemplified. In section four, we will briefly discuss the properties of our conceptual approach and activities which help to improve the concept in the near future.

2 Traditional Schedule Construction

2.1 Sequential Planning Activities

In order to effectively develop flight schedules, it is important to represent airline operations in substantial detail. This, of course, creates complexity and leads to a large number of variables in the overall planning model. Since it is almost impossible to formulate the schedule construction problem as a mathematical optimization model in a closed form, schedule construction has been undertaken through a structured planning process which involves many activities and parts of the airline. The planning process will be decomposed into subproblems with less complexity which, in return, will be optimized sequentially.

In figure 1 an overview of the subproblems and possible aggregations to higher problem levels is illustrated [2], [3].
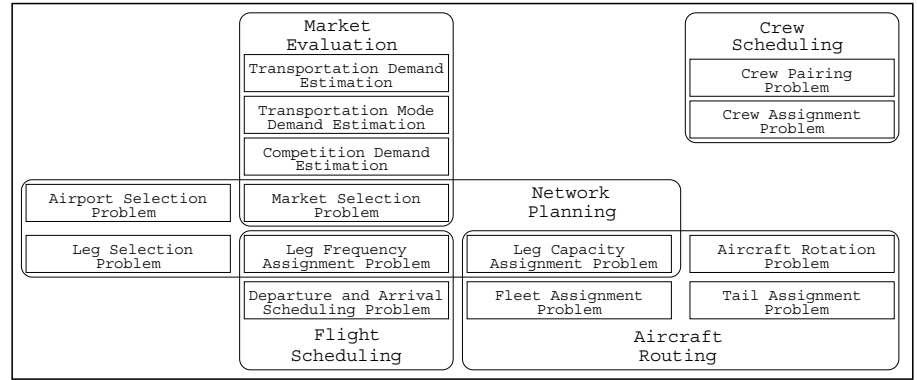

Fig. 1. Planning activities

2.2 Major Planning Activities

Market Evaluation. The quality of flight schedules is significantly influenced by the demand for flights. The estimation of the demand can be performed by

first estimating the transportation demand between an origin-destination pair (market), then splitting up this demand on different transportation modes and finally partition the demand for flight service on each airline in the market [2]. Different models exist to estimate the demand for each step. Most of these models require statistical data or facts about the socio-economic structure of the specific market. One of the most important input for demand estimation is historical data about bookings from computerized reservation systems.

Network Planning. The result of the market evaluation will allow the airline to decide which markets to serve. This may already indicate a flight network, but furthermore, a flight network is defined by its exact routes and airports. Thus, the airline has to determine which airport in a region to serve. Moreover, the airline has to select flight legs to operate in the chosen markets. This part of the network planning process is affected mostly by political strategies, geographic and socio-economic structures in the region, and ground resources of the airline.

Leg frequency assignment and leg capacity assignment are closely related. The airline needs to decide about the total number of flights on one leg for the planning period. This number influences the leg's capacity and vice versa. For some solution approaches see for example [4] and [5].

Flight Scheduling. Besides the frequency assignment in flight scheduling, the airline has to specify exact departure times for its flights. The departure times and the block time estimation (block time is the sum of flight time and the time for taxiing on the ground) determine the arrival times. However, during flight scheduling the fleet has not yet been assigned to the flights. The block time is affected by the cruising speed of an aircraft type, so as a consequence, it is unknown which block time should be taken into consideration. Thus, most approaches which determine departure times are combined with fleet assignment.

Aircraft Routing. The main tasks in aircraft routing are fleet assignment and aircraft rotation building. In fleet assignment, the airline faces the problem to assign specific aircraft types to every flight leg. After fleet assignment, flights of the same fleet are grouped into rotations of logical aircraft. A rotation is a sequence of flights which can be flown in succession by the same aircraft. Required maintenance restrictions usually are considered in this step. At the end of the aircraft routing, the airline assigns real aircraft to the rotations (tail assignment). Some approaches for this problem are proposed in [6], [7], [8], [9].

Crew Scheduling. Crew scheduling has minor influences on the schedule construction problem. In this planning step, it will be determined which crew has to operate which flight. This is done by first creating crew pairings and then assign crews to the pairings. A crew pairing is a sequence of flights originating and ending at the same crew base. See [10] for a solution approach.

2.3 Overall Assessment of Existing Flight Schedule Construction Process and Methodologies

Since researches have devoted much effort in developing optimization techniques for the subproblems illustrated, it is possible to find good subsolutions. These solutions might be (near) optimal for the subproblems, but this does not imply a good overall solution. Local optimal solutions for subproblems can turn out to be unfavorable for later planning steps. Interdependencies between the scheduling steps are cut-off, e.g. the airline may realize during crew scheduling or aircraft routing that the scheduled flights may not be carried out with the available resources. Fleet assignment models are not able to consider the number of aircraft per fleet. This problem is solved later in rotation building. Thus, it may happen that the fleet assignment has to be modified after schedule construction.

The literature provides few approaches which integrate two or more subproblems [11]. Unfortunately, there is no model that takes all subproblems for flight schedule construction into consideration. Thus, the state-of-the-art of flight schedule construction will not support the development of acceptable schedules. This might explain why many airlines - if at all - construct their schedules by trial-and-error.

3 Simultaneous Flight Schedule Construction with Genetic Algorithms

In this section, we will develop an integrated, GA-based flight schedule construction approach which simultaneously permits multiple planning activities like airport selection, leg selection, leg frequency assignment, leg capacity assignment, departure as well as arrival scheduling, aircraft rotation, and fleet assignment.

3.1 Basic Representation Concept

A flight schedule may simply be coded as a list. For example, the list [FRA0.20 AMS40 ZRH30 OSL40 ... MIL30] represents the weekly flight schedule of one single aircraft. This aircraft departs in Frankfurt (FRA) at 0.20 am to Amsterdam (AMS). Block times and minimal ground times will be stored in matrices or tables. The suffix of the city code indicates that there is an additional waiting time in AMS of 40 minutes. Thus, a flight program may be calculated as $DepTimeB = DepTimeA + FlightTimeAB + MinGroundTimeB + AdditionalWaitingTimeB$.

If the aircraft has started its service in FRA on Monday morning, it arrives in Milan (MIL) on Sunday. From MIL the aircraft will fly back to FRA in order to begin its weekly service in FRA again.

With this basic representation concept we can generate flight schedules that consist of weekly rotations only. But in reality, rotations may be longer than one week. We solve this issue by simply appending multiple week plans while introducing two markings ∘ and ∗. The symbol ∘ indicates that the rotation will

be continued. A ∗ denotes the end of a rotation. Using these two markings, we are able to represent rotations of varying length. Consider the flight schedule in figure 2.
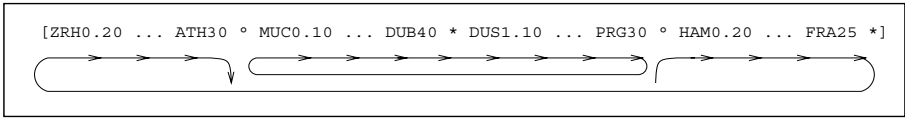

Fig. 2. Rotations

It indicates four week plans which are made up of two rotations, lasting two weeks each. The first rotation starts Monday morning with an aircraft departing from Zurich (ZRH) at 0.20 am and arriving at Athens (ATH) at the end of the week. Instead of returning to ZRH, the marking ○ indicates that it will fly to Munich (MUC) where it continues its service on Monday morning in the second week. At the end of the second week, the aircraft will arrive in Dublin (DUB) from where it will return to ZRH to end its two week rotation. The end of the rotation is symbolized by the marking ∗. The second rotation starts Monday morning in Dusseldorf (DUS). At the end of the first week, this aircraft arrives at Prague (PRG) and continues the rotation to Hamburg (HAM) on Sunday night. In the second week, this aircraft departs HAM on Monday morning on 0.20 am and completes its program in Frankfurt (FRA) where the second rotation ends.

Note that the two markings introduced represent multiple aircraft. In this example, there are four aircraft deployed in the flight schedule. The first aircraft departs ZRH Monday morning at 0.20 am, the second MUC at 0.10 am, the third DUS at 1.10 am, and the fourth HAM at 0.20 am.

The last issue to resolve is the representation of multiple aircraft types for fleet assignment. In this context the weekly plans of one aircraft type will simply be joined until the next aircraft type follows. Consider the example in figure 3 which consists of two aircraft types and two individuals.
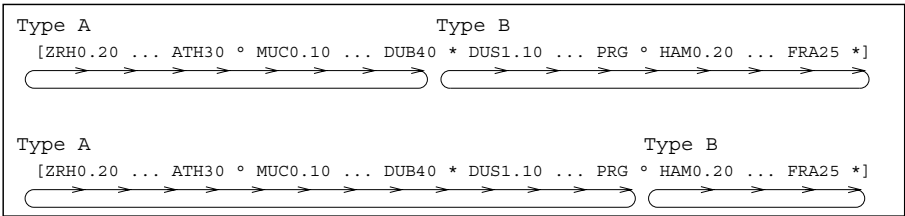

Fig. 3. Fleet assignment

Each individual represents a different flight schedule. In the first schedule, every single aircraft type has to perform a two week rotation. In the second

schedule, aircraft type A will be rotated twice whereas type B will be rotated once. The first rotation for type A has a length of one week and the second rotation one of two weeks. Note, that the various aircraft types will not be explicitly coded in the list notation. Since the number of aircraft of each type is known in advance (for example two aircraft of type A and two aircraft of type B) it is determined that the week plans for type B start after two week plans of type A.

3.2   Context Specific Genetic Operators

As we use a GA for our approach, we need recombination and mutation operators. Recombination should create individuals that inherit the properties from their parents. As the information of the schedule is mainly the order of the cities in the schedule, crossover should work well, if it preserves the order of the cities when creating an offspring. Mutation operators should in general create offspring with very similar properties as its parents. To ensure that our offspring has the desired properties, we define the genetic operators directly on the structure of the problem.

We believe that the one-point crossover is a good choice for preserving the structure of the problem. We simply need to determine the crossover site. We suggest to use the position where an exact point of time (e.g. 11.50 am) will determine the crossover site in the recombination process. As a result, we will obtain new flights at the crossover site.
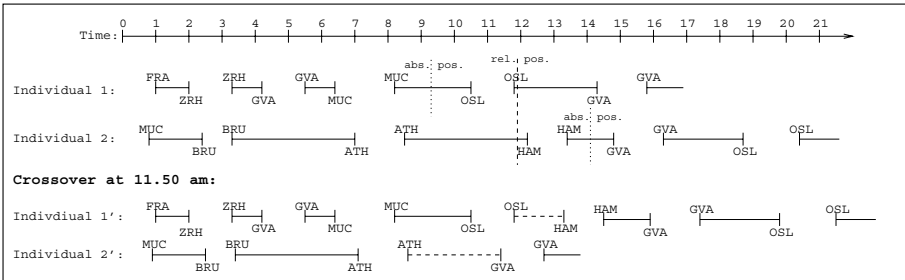

Fig. 4. One-point crossover

In our example the flights Oslo (OSL) - Geneva (GVA) and Athens (ATH) - Hamburg (HAM) will be replaced by OSL - HAM and ATH - GVA. By changing parts of individuals that contain markings of rotations this operator could produce different rotations.

Another option is the introduction of an operator which we call string crossover (see figure 5). With the help of this operator, segments of identical length may be exchanged among different week plans and will be inserted at an identical position in a week plan. The string-crossover permits the assignment of (multiple) flights to other aircraft types. Since this operator permits a better
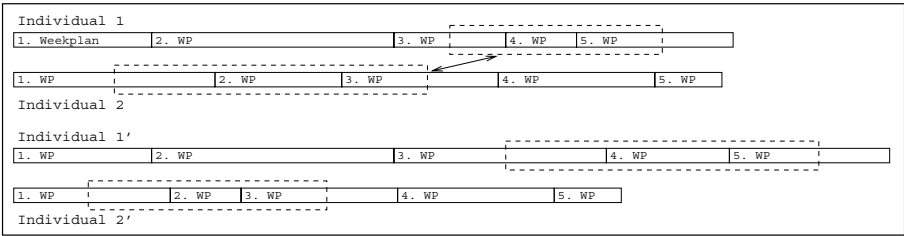
```
Individual 1
1. Weekplan      2. WP                3. WP      4. WP   5. WP

1. WP            2. WP      3. WP            4. WP         5. WP
Individual 2

Individual 1'
1. WP            2. WP             3. WP        4. WP      5. WP

1. WP            2. WP   3. WP        4. WP         5. WP
Individual 2'
```

Fig. 5. String crossover

mixing of existing solution structures while not overemphasizing the effect of a pure random search, we advocate its use for future implementation efforts.

Developing mutation operators is much more straightforward. We randomly change a city, the length of a waiting time interval, or the rotation marking. The replacement of a $*$ by a $\circ$ will change one flight. The alteration of a city will change two flights. The change of the additional waiting time will not change any destinations but rather modify the length of a flight schedule.

Since the application of the single-point crossover, the string crossover, and the mutation operator will change arrival respectively departure times of flights between child and parent individuals, a specific repair mechanism needs to be developed. This mechanism should be able to adjust the departure times in way that the differences in comparison to the parent individuals are minimized. For this reason, the additional waiting time will serve as a buffer which will gradually be shortened or prolonged through the process of time adjustment.

In some cases, this time adjustment mechanism will not permit a proper re-alignment of the flight schedule. Thus, the deletion or insertion of distinct flights is inevitable. We introduce the sum of waiting time intervals as a criterion for flight insertion/deletion. If the sum of waiting time intervals in a given planning period is low then the deletion of a flight is likely to occur. In contrast, if this sum is high then the insertion of new flights will be likely. We will model the insertion (deletion) probabilities as a (inverse) sigmoid function.

3.3   Fitness Evaluation

As the problem is quite large and difficult, approaches like GAs need a reasonable population size and run over some 50 or hundred generations. Because current, state-of-the-art flight schedule evaluation tools are very time-consuming heuristic search could only be used, if we develop a simplified model for evaluating the individuals.

Since the large time consumption of the flight schedule evaluation tools is caused by the application of an open model which considers the effects on the organization's flight schedule on its competitors and vice versa, we propose the development of a closed profit estimation model for fitness evaluation.

Since profit is defined by revenues minus cost, we need to elaborate the determination of both variables. The basis for revenue estimation is the number of

passengers or the number of seats sold. We approximate the number of passengers as following:

$$s_{ij}(t) = h_{ij}(t)^b \cdot f^{e_{ij}} \cdot p_{ij}(t) \cdot (m_{ij} + m_{j_{ik}}). \tag{1}$$

The main factor in this expression is the time-dependent attractiveness $p_{ij}(t)$ of a flight from city i to city j. It will be calculated with the help of a time-of-week curve. Since the time-of-week curve can be derived from historical data, to every flight pair in a schedule a specific attractiveness could be assigned according to the departure time. For example, if a flight is scheduled for $t =$ Monday, 4.00 pm, the time-of-week curve will deliver an attractiveness of $p_{ij}(t) = 0.1$. This indicates that this particular flight captures 10% of an airline's entire market volume m_{ij} between these two cities.

In addition, we assume that the number of connecting flights at the destination j will increase the attractiveness of a flight. Thus, we model the additional demand with the help of the variable $m_{j_{ik}}$. For $i =$ HAM, $j =$ ATH, and $k =$ OSL, $m_{j_{ik}}$ expresses the additional market size of a connecting flight from ATH to OSL if the passenger has started it's trip in HAM.

Another factor to consider is the frequency $f^{e_{ij}}$. The higher the number of flights e between two cities i and j, the more passengers per flight will be attracted.

The last factor to include is the homogeneity $h_{ij}(t)^b$. It reflects the issue whether a flight takes place daily or on special weekdays only. If it takes place every day, b would be 7. If this flight is offered only on Monday, Wednesday, and Friday, b would be 3. So each flight schedule will be inspected for recurring flights for a given t and the result will bounded to the value for variable b.

Applying this fitness function, the GA would generate flight schedules containing a high proportion of flights at peak hours. Thus, the fitness evaluation needs to be extended with regard to the following issues:

- How can we distribute the demand across conflicting flights?
- How can we model limitations in capacity?

As stated, there are flights between two cities i and j which depart close together and compete for identical passengers. Therefore, we need to develop a mechanism that distributes the overall demand in a time interval among the departing flights. We assume that the demand for one flight is described by a normal distribution. For our purpose, we model a normal distribution curve for each flight in the same market. The area below the curve corresponds to $s_{ij}(t)$. The maxima of the curves represent the departure times, the standard deviation depends on $s_{ij}(t)$. A curve has the following function:

$$f_{t_x}(t) = \frac{s_{ij}(t_x)}{\sigma_{s_{ij}(t_x)}\sqrt{2\pi}} e^{-\frac{(t-t_x)^2}{2\sigma^2_{s_{ij}(t_x)}}}, \tag{2}$$

where
- $s_{ij}(t_x)$ is the expected number of seats sold for a flight at the exact time t_x between two cities i and j,

– $\sigma_{s_{ij}(t_x)}$ is the standard deviation of the flight x with the departure time t_x and its demand $s_{ij}(t_x)$.

Depending on the departure times and the demand curve there are areas which comprise two or more flights. These areas may be separated, indicating the specific demand of a distinct flight. For example, four aircraft with identical destinations depart from the same city at $t_1 = 6.00$ am, $t_2 = 10.50$ am, $t_3 = 12.00$ pm, and at $t_4 = 12.05$ (see figure 6). Without consideration of this conflict, there would be a demand for each flight of $s(t_1) = 80$, $s(t_2) = 50$, $s(t_3) = 70$, and $s(t_4) = 69$ passengers. Unfortunately, the estimated total number of seats of 269 seems to be unrealistic since the flights at t_2, t_3, and t_4 compete for the same passengers. If we apply the function as listed above, the demand will be distributed as follows: $s(t_1) = 80$, $s(t_2) = 47.1$, $s(t_3) = 31.1$ and $s(t_4) = 29.9$.
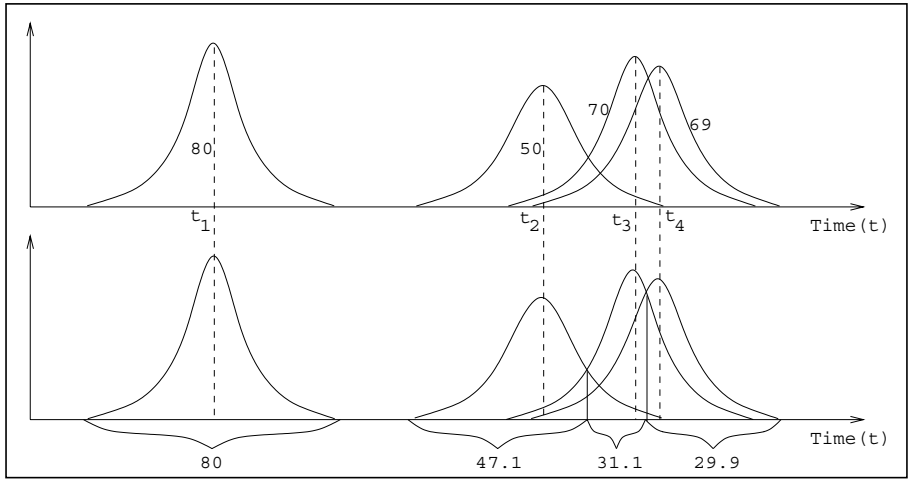
Fig. 6. Conflicting flights

This formula has the advantage that it may also be applied for modeling limited transportation capacity of an aircraft. Capacity restrictions may be represented as left and right boundaries of the area below the normal distribution curve. The demand external this area represent capacity shortages. We need to consider these shortages in order to model customer retention or compensation effects which may take place due to more than one flight. In this situation, the neighboring flights might be able to satisfy this demand peaks if they offer enough additional seats (see figure 7).

In figure 7, flight f_1 will not be able to serve all customers. This limitation is modeled with the help of the boundaries t_{1_l} and t_{1_r}. The capacity barriers of flight f_2 are modeled with the help of t_{2_l} and t_{2_r}. Since f_1 is already able to serve the demand of f_2 within the area of t_{2_l} and t_{1_r}, it will add additional capacity for f_2. This case is illustrated with the help of an area which is adjacent to the right of t_{2_r}. With out this spill-over effect, the area to the right of t_{2_r} could not be utilized.
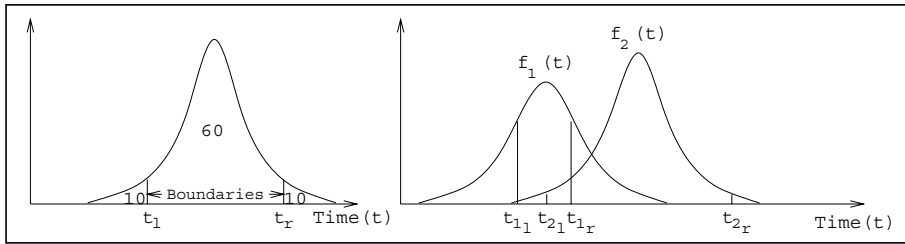
Fig. 7. Limited transportation capacity

Using these evaluation schemes, we are now able to estimate the numbers of passengers on each flight leg. Since we know the average revenue per passenger in all markets from the past, we will be able to compute the revenues induced by each flight schedule. Since the costs involved is also available from historical data, the estimated profit of each schedule can be calculated.

4   Discussion

The complexity of constructing flight schedules has led to a sequential planning process. The scheduling problem has been decomposed into numerous subproblems of less complexity. These subproblems may be solved with exact and heuristic approaches. But the optimal local solutions of the subproblems will not imply a good overall solution.

In order to achieve good results, flight schedule construction needs to be performed simultaneously. We believe that our concept sketches a promising way of doing this. In our concept, an individual in a population of a GA represents a complete flight schedule. We have defined genetic operators and derived a fast fitness evaluation method. We have not yet found similar approaches in the literature.

Since we are currently preparing the implementation of our concept, we need to define an appropriate test scenario. Within this scenario, we need to independently test the validity of our profit proxy as well as its underlying assumptions. If this proves to be applicable, we need to test our prototype against the existing planning approach. The genetic operators may be refined. If our GA-based concept will meet or exceed current standards, additional planning activities like tail assignment, crew assignment, and maintenance planning might be integrated.

References

1. Etschmaier, M. M., Mathaisel, D. F. X., *Airline Scheduling: An Overview*, in: Transportation Science, May 1985, pp. 127 - 138.
2. Suhl, L., *Computer-Aided Scheduling, An Airline Perspective*, Wiesbaden, 1995.
3. Antes, Jürgen, *Structuring the Process of Airline Scheduling*, in: Operations Research Proceedings, 1997, pp. 515 - 520.

4. Teodorovic, D., Krcmar-Nozic, E., *Multicriteria Model to Determine Flight Frequencies on an Airline Network under Competitive Conditions*, in: Transportation Science, February 1989, pp. 14 - 25.
5. Dobson, G., Lederer, P. J., *Airline Scheduling and Routing in an Hub-and-Spoke System*, in: Transportation Science, August 1993, pp. 281 - 297.
6. Desaulniers, G. et al., *Daily Aircraft Routing and Scheduling*, in: Management Science, June 1997, pp. 841 - 855.
7. Kontogiorgis, S., Acharya, S., *US Airways Automates Its Weekend Fleet Assignment*, in: Interfaces, May/June 1999, pp. 52 - 62.
8. Clarke, L. et al., *The Aircraft Rotation Problem*, in: Annals of Operations Research, No. 69, 1997, pp. 33 - 46.
9. Talluri, K. T., *The Four-Day Aircraft Maintenance Routing Problem*, in: Transportation Science, February 1998, pp. 43 - 53.
10. Mellouli, T., *Standardisierte Decision-Support-Komponenten für Ressourceneinsatzplanung und Störungsmanagement bei Bahn-, Regionalbus- und Fluggesellschaften*, Proceedings of the 3. Meistersingertreffen, November 25./26. 1999, Schloss Thurnau, Germany.
11. Barnhardt, C. et al., *Flight String Models for Aircraft Fleeting and Routing*, in: Transportation Science, August 1998, pp. 208 - 220.