Managing Operations in the Time-Shared Jet Business [1]

1 Company and business overview

Jet-Share Co. is a new company which manages a fleet of business jets. Company chairman Mr. Goodwin started Jet-Share *fractional aircraft ownership program* with the purchase of 4 Lear 30 and 3 Lear 60 type of aircraft. The company targets to double its business every year for the next three years, and plans to increase its fleet size to 17 Lear 30 jets and 8 Lear 60 jets.

Under the Jet-Share concept, a fractional owner purchases a portion of a specific aircraft based on the number of actual flight hours needed annually and contracts with Jet-Share Co. to manage the aircraft [5] [11] (see box for leading fractional jet ownership programs). For example, one-eight-share owners get 100 hours flying time per year, while one-quarter-share owners are entitled to 200 hours. To book a flight, an owner calls Jet-Share Co. and specifies the departure time, departure location and destination. Within the U.S., Jet-Share Co. guarantees the availability of a jet to an owner within 5 hours after it is ordered. Jet-Share Co. charges the owners only for actual flight time, in contrast to some aircraft charter companies which would charge their customers for the time it takes the plane to reach the customer for pickup and to return to its base after drop-off.

A partial owner pays three separate fees for this program:

- a one-time purchase price for the fractional interest in the plane,
- a monthly management fee, which covers maintenance, insurance, administrative and pilot expenses, and
- an hourly fee for the time the jet is used.

The purchase price of one-eight-share is $1.2 million for Lear 30 jets and $1.5 million for Lear 60 jets. Ownership rights expire after 5 years. Like full ownership, fractional ownership provides tax benefits to the buyer and can usually be sold back after a few years. The monthly fees are $5,000 for Lear 30 and $6,500 for Lear 60 jets. The hourly fees are $1,800 for Lear 30 and $2,200 for Lear 60 jets. (The purchase prices of Lear 30 and Lear 60 jets are $8 million and $11 million, respectively.)

The program has its widest appeal among small to midsize private companies who have business travel requirements, but cannot justify the cost of an entire aircraft [4]. Through the sharing of aircraft, customers avoid the high cost of ownership and other associated overheads of establishing a corporate flight department with its own maintenance staff and pilots. Other owners include private individuals, celebrities, retired top executives or corporations looking to supplement their corporate flight departments' requirements.

[1] This case is prepared by Professor Pinar Keskinocak from Georgia Institute of Technology and Professor Sridhar Tayur from Carnegie Mellon University

Leading fractional jet ownership programs

Fractional jet ownership programs are relatively new, but are growing at a fast pace [6]. Among the leading fractional jet ownership programs are

- NetJets (operated by Executive Jet Aviation, http://www.netjets.com),
- Flexjet (operated by Bombardier Business JetSolutions, http://www.aero.bombardier.com/htmen/A7.htm), and
- Raytheon Travel Air (a subsidiary of Raytheon Aircraft, http://www.raytheon.com/rac/travelair/).

NetJets, which has the largest market share, offers up to 12 different aircraft types, including Cessna Citation, Raytheon, Gulfstream and Boeing jets (Zagorin 1999). Executive Jet Aviation revenues were projected at $900 million for 1998 and climbing at an average rate of 35% annually. Introduced in May 1995, the Flexjet program offers Learjet 31A, Learjet 60 and Challenger aircraft. FlexJet has over 350 clients, and its current growth rate is estimated at 100 new fractional owners per year. Raytheon Travel Air program, which was started in 1997 and currently serving over 300 fractional owners, features three of the aircraft in the Raytheon Aircraft product line: Beech King Air B200, Beechjet 400A, and Hawker 800XP.

2 Problems with commercial airlines and motivation for jet sharing

The first commercial flight in the United States occurred in Florida on Jan 1, 1914, when Tony Jannus flew A. C. Pheil the 21 miles across the Bay from St. Petersburg to Tampa in a two seat Benoist at an altitude of 15 feet. These days the average trip is 983 miles and in 1994 United States carriers flew more than 1.4 million passengers, 48 percent of whom were business travelers. The air travel is so much a part of the fabric of American life, in 1995 the 10 billionth passenger flew on a United States plane [7] and a record 581.2 million passengers flew in 1997. Carriers are flying an all-time high number of passengers, a record 69.3 percent of seats on planes were occupied by paying passengers in 1996 (this figure is known as the load factor). Load factors were below 60 percent 15 years ago.

With the increasing number of passengers every year, traveler face an increasing number of problems while using a commercial flight, such as no scheduled flights at the desired time of travel, delays, cancelled flights, being “bumped” from a flight or downgraded due to overbooking, no (direct) flights between certain cities (especially small cities), long connection times, long check in times, misplaced baggage, not enough first class or business class seats, and no privacy.

In January 1996, only 62.7 percent of all domestic flights by 10 major airlines were reported on time, that is, on the ground within 15 minutes of their schedule. Late arrivals meant late departures and delays for later flights at other airports [9].

Airlines are making great efforts to fill the seats and it is common practice by airlines to “overbook” seats. But in some cases (especially during business hours), more passengers can show up than seats available in a flight. According to figures reported to the Department of Transportation, the nine major domestic airlines “bought out” 757,000 volunteers in 1994; 52,000 other passengers on these airlines were listed as “bumped”, or involuntarily denied boarding [8]. Another problem the business travelers face is that there are still too few first class or business class seats on many domestic flights. This means that some business travelers either cannot book a first class seat (since most business travelers fly on short notice in the middle of the week, when the load is highest) or they purchase a first class ticket but end up staying in coach (i.e. being downgraded) due to overbooking.

There are thousands of flights every day in the U.S. But for travel between relatively small (or remote) cities, it may be difficult to find a flight, let alone a direct flight which is scheduled at the time one prefers to travel. For example, flying from a city like Rochester to a city like Wilmington, Del. on a commercial airline may take 10 hours with connections (but less than 2 hours on a private jet). In some cases, the trip between small cities may even be ”intermodal,” which means that although the airline ticket covers the whole distance, part of the trip is traveled by bus [10].

Among other problems the travelers face are long check in times and misplaced baggage (luggage that has been lost, stolen, delayed or damaged). For short haul flights in Europe between major hubs, actual flying time can be as little as 20 percent of total travel time from door to door [3]. In 1996 the 10 biggest U.S. airlines reported almost 2.4 million complaints over misplaced baggage, an average of 5.3 for every 1,000 passengers.

Private planes can save huge amounts of time, as well as providing comfort, convenience and privacy. “Without a private jet, my travel schedule would be impossible,” says Shugart, CEO of 8.5 billion Seagate Technology, who spends some 180 days a year on the “road” in a private jet [1]. But due to its high cost, operation and maintenance expenses, a private jet isn’t for everyone. Jet-Share Co.’s fractional ownership program offers a cost-effective way to gain access to private air travel, without the high cost of complete ownership and without the headache of maintaining a corporate flight department with its own maintenance staff and pilots.

3 Operations at Jet-Share Co.

To achieve the ambitious goals of the company about growth, profitability and customer satisfaction, Mr. Goodwin knew the importance of managing operations in an efficient way. Unfortunately, during the first 6 months after the company signed contracts with its first customers, things have not been running that smoothly. Every day, the operations team put a tremendous effort for creating aircraft and crew schedules, to satisfy customer demand on time. But despite these efforts and several sleepless nights, during the first 6 months they were late to pickup customers 7 times, and had to subcontract more than 10 trips. It seemed like they never had the aircraft at the right place at the right time. Mr. Goodwin and the operations team were (realistically) worried that the situation would get worse when the company would grow as planned within the next 3 years.

Scheduling aircraft to trips. On a day-to-day basis, the schedulers face an aircraft routing/scheduling problem as follows. At any time, the aircraft are at different locations or are serving a customer. New customer requests arrive over time, each consisting of a departure location, departure time and destination. Usually, it is necessary to relocate an aircraft from its current location (which may be the destination of the previous trip) to the departure location of the next trip it will serve. These flights are called "positioning legs" or "empty flights". Every customer request must be satisfied on time, possibly by subcontracting extra aircraft. Jet Shares Co. experienced that subcontracting is always possible, but usually at a very high cost. They estimate that the cost of subcontracting an aircraft for one hour is about ten times the cost of flying an aircraft which is in their fleet.

For Jet-Share Co., there are two major types of costs: operating costs (fuel, maintenance, etc.) for flying the aircraft and the penalty costs for not being able to meet some customer requests without subcontracting extra aircraft. The schedulers at Jet-Share Co. try to create a flight schedule for the fleet to satisfy the customer requests (by subcontracting extra aircraft if necessary) at minimum cost under additional constraints of maintenance requirements and previously scheduled trips. Since customers only pay for actual hours flown, minimizing the number of empty flight hours and subcontracted hours (keeping in mind that each subcontracted hour is equivalent to 10 empty flight hours) is the main objective for the company.

Each aircraft has to go to maintenance periodically. When an aircraft comes out of maintenance, it can fly only a limited number of hours before its next maintenance, so the schedulers have to make sure that the available flight hours of the aircraft are not exceeded in any schedule. Similarly each aircraft can do only a limited number of landings before its next maintenance. These are called the *maintenance constraints.*

There may be some trips which are previously assigned to some aircraft, and these schedules should not be changed while creating a new schedule. These restrictions are called the *pre-scheduled trip constraints.* There are several reasons for the pre-scheduled trip constraints. For example, a pre-scheduled trip may actually be a scheduled maintenance. Maintenance is done only at certain locations, and if an aircraft is scheduled for maintenance at a certain location at a certain time, the schedulers should make sure there it will be there on time. Also, there may be restrictions due to crew scheduling, which may require the scheduling of a particular aircraft to a particular trip.

While creating flight schedules for the aircraft, the schedulers consider a predetermined time period (usually one to three days) and do the scheduling for that time period, which they call the "scheduling horizon". Since most customers book their trips at least a few days in advance, the demand is usually known for the next three days. The schedule is updated twice daily, based on new information about demand, aircraft locations and maintenance information of the aircraft. Since customers become partial owners of either a Lear 30 or a Lear 60 jet, the schedules for these two types of aircraft are generated separately.

As an example, the information about the aircraft and requested trips for a given day is as follows.

Lear 30 aircraft (numbered as) 1, 2, 3, 4 are currently in locations 6, 7, 2, 4, respectively (cities are also enumerated). There are 8 trips to be served.

The information about the trips is given in the Table 1. The departure time is given in minutes, assuming that the current time is zero. The flight times and total travel times are also given in minutes. There are two trips, 1 and 2, which are previously scheduled to aircraft 3 and 2, respectively. Only aircraft 1 has maintenance restrictions during the scheduling horizon: it can fly at most 337 minutes and land at most 9 times before its next maintenance. Furthermore, aircraft 1 is not available for scheduling after 630 minutes.

Table 1: Trip information

Trip j	Departure location $\alpha(j)$	Destination $\beta(j)$	Departure time $dtime(j)$	Flight time $fly(j)$	Total time $tt(j)$	No. of landings $land(j)$	Scheduled aircraft $sch(j)$
1	2	2	210	220	250	1	3
2	3	7	650	90	120	1	2
3	9	5	298	120	150	1	0
4	6	8	35	150	180	1	0
5	8	5	293	258	288	1	0
6	8	10	385	141	411	2	0
7	4	1	14	201	231	1	0
8	6	6	188	120	150	1	0

Figure 1 displays the departure locations, destinations and total travel times of the trips.

Table 2 displays the flight times between every pair of locations for possible positioning legs. Table 3 displays the number of landings between every pair of locations.

To construct a feasible schedule, a natural question to answer is “Which trips can be served by each aircraft?”.

Question 1 *To create a feasible schedule, what other natural question needs to be answered? Note that an aircraft can serve more than one trip during the planning horizon.*

To summarize the information needed for creating feasible schedules, the schedulers create two matrices called AT (‘A’ for aircraft and ‘T’ for trip) and TT (with elements either zero or one). The matrix AT has a row for each aircraft and a column for each trip. The matrix TT has a row and column for each trip. So, they set

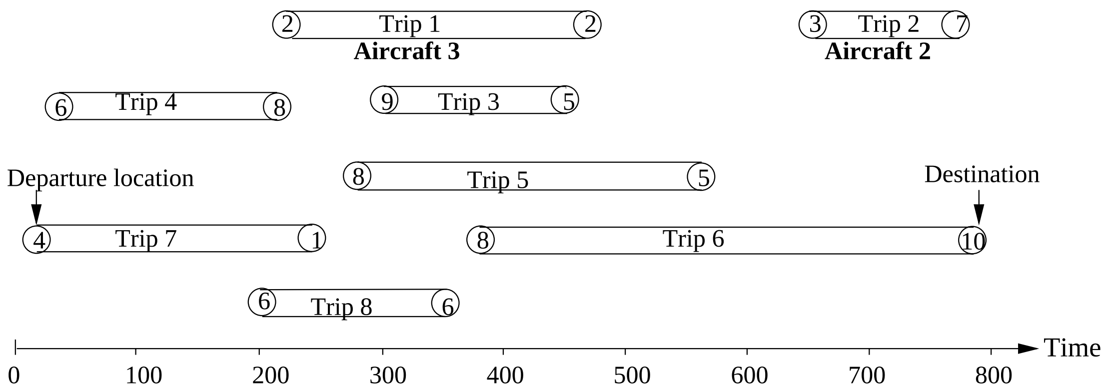

Figure 1: Trips

Table 2: Flight times (in minutes)

City	1	2	3	4	5	6	7	8	9	10
1	0	150	190	201	108	95	108	124	67	134
2	150	0	277	342	258	242	190	228	175	30
3	190	277	0	150	192	212	90	67	124	247
4	201	342	150	0	120	150	175	134	170	319
5	108	258	192	120	0	30	153	134	120	242
6	95	242	212	150	30	0	162	150	124	228
7	108	190	90	175	153	162	0	42	42	162
8	124	228	67	134	134	150	42	0	60	201
9	67	175	124	170	120	124	42	60	0	150
10	134	30	247	319	242	228	162	201	150	0

$\mathrm{AT}(i,j) = 1$, if aircraft i can serve trip j, and
$\mathrm{TT}(j,k) = 1$, if trip k can be served immediately after trip j by the same aircraft.

Based on trip, aircraft and positioning leg information, they created the two matrices AT and TT as follows:

$$\mathrm{AT} = \begin{bmatrix} 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \end{bmatrix} \qquad \mathrm{TT} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Question 2 *Explain why $AT(2,4) = 0$ and $AT(1,4) = 1$. Explain why $TT(1,3)$, $TT(7,5)$*

Table 3: Number of landings

City	1	2	3	4	5	6	7	8	9	10
1	0	1	1	1	1	1	1	1	1	1
2	1	0	2	2	1	1	1	1	1	1
3	1	2	0	1	1	1	1	1	1	1
4	1	2	1	0	1	1	1	1	1	2
5	1	1	1	1	0	1	1	1	1	1
6	1	1	1	1	1	0	1	1	1	1
7	1	1	1	1	1	1	0	1	1	1
8	1	1	1	1	1	1	1	0	1	1
9	1	1	1	1	1	1	1	1	0	1
10	1	1	1	2	1	1	1	1	1	0

and $TT(5,2)$ *are zero.*

4 How to create a good flight schedule?

Currently, schedulers create the daily flight schedules manually, using magnets on a board, by trial and error. This process takes a lot of time, since there are many alternatives to consider, and most of the time they cannot generate a satisfactory schedule.

Once generated, a schedule contains the sequence of flights to be flown by each aircraft. For this particular day, the team created the following schedule, which requires subcontracting trip 5:

Aircraft	Trips
1	4,3
2	8,2
3	1
4	7, 6

Question 3 *Is this schedule feasible? Suggest an alternative feasible schedule.*

Question 4 *The schedulers are upset that even the best schedule they generated for this instance requires subcontracting. Do you think it is possible to satisfy all the trip requests without subcontracting extra aircraft in this case? Why?*

Question 5 *Propose a heuristic that would take a feasible schedule as input and modify it to improve its quality.*

The company invested in a new data management system with the following features: data entry and display (to enter incoming requests, to update the remaining flight hours of each customer etc.), flight time calculator, and schedule display. With the help of this system, the company has instant access to up-to-date data, but unfortunately the sytem does not offer any assistance in creating flight schedules.

Question 6 *What kind of data would you need for creating a feasible and "good" schedule for the aircraft? Do you think there would be any problems in obtaining the data or in its accuracy?*

Mr. Goodwin heard that some other competitors use mathematical programming and optimization tools to help them solve their operations problems. He suggested his operations team to find about these techniques and develop robust solution methods which could generate good solutions quickly.

One of the possibilities the operations team wants to consider is to model the problem as a linear (integer) program and to solve it using a commercial tool available in the market. This would minimize the amount of effort the team needs to put into developing and coding special-purpose algorithms. The team also believes that using this approach would give them the flexibility to change their model, should the constraints or the way the business is run changes over time. Unfortunately, none of the team members has enough knowledge on linear/integer programming, and even after spending a week, they still could not figure out how to model the flight scheduling problem. So, they ask for your help.

Question 7 *How could you model the aircraft scheduling problem as a linear integer program?*

Hint: Use the following variables:

$$S_j = \begin{cases} 1, & \text{if trip } j \text{ is subcontracted} \\ 0, & \text{otherwise} \end{cases} \qquad j = 1, \dots, m$$

$$Z_{ijk} = \begin{cases} 1, & \text{if aircraft } i \text{ serves trip } j \text{ just before trip } k \\ 0, & \text{otherwise} \end{cases} \qquad \begin{array}{r} \text{AT}(i,j) = 1, \;\; \text{AT}(i,k) = 1 \\ \text{TT}(j,k) = 1 \end{array}$$

In general, the total travel time between a pair of locations is longer than the flight time (due to landing delays etc.), but for simplicity you may assume that the flight times for positioning legs are equal to the total travel times.

Question 8 *If the aircraft did not have any maintenance restrictions or pre-scheduled trips, how would you solve this problem?*

Hint: Model it as a minimum cost flow problem.

Question 9 *Comment on the benefits and drawbacks of using integer programming to solve the aircraft scheduling problem. Propose an alternative "heuristic" solution method. For example, you could modify a solution to the problem without pre-scheduled trips and maintenance restrictions to construct a solution for the original problem. Use the heuristic method(s) you proposed to construct alternative solutions to the example and compare them with the integer programming solution. For what kind of problem instances do you think your heuristic would work best/worst?*

The solution approaches discussed so far will work well as long as there are no exceptions, such as last minute travel requests or cancellations, delays due to maintenance problems or weather conditions, or changes in the availability of crew. But it is inevitable that such exceptions will occur from time to time, and the company needs to be prepared to handle them efficiently to meet its goals on customer satisfaction. One approach for coping with exceptions is to create "robust" schedules, which will still work fine even in case of unexpected events. Another approach is to modify or repair the current schedule to construct another schedule which is still feasible and good under the new circumstances.

Question 10 *How could you measure the robustness of a schedule? We call a schedule robust if it remains a good and feasible schedule even if some of the initial conditions (i.e., input data) used while creating it change. Propose approaches for creating robust aircraft schedules. Some of these approaches could be slight modifications of the methods you proposed earlier.*

Question 11 *Propose a heuristic that takes a feasible schedule as input and modifies it to accomodate a new trip request.*

It is important to note that the aircraft cannot fly by themselves, they need crew. Hence, aircraft schedules also have to be coordinated with crew schedules. Two crew members are required to fly an aircraft in the company's fleet and at least one of them should be qualified as a "pilot" for that type of aircraft. Each crew member is qualified to fly only certain types of aircraft, either as a pilot or as a co-pilot. For example, the most experienced crew members employed by the company can fly both types of aircraft (Lear 30 and Lear 60) as a pilot, whereas some of the other crew members are only qualified to fly Lear 30 aircraft as a co-pilot. If a person is qualified to fly an aircraft as a pilot, he is also qualified to fly it as a co-pilot.

Each crew member is either "on-duty" or "off-duty" on a given day. There are several restrictions about the assignment of on-duty and off-duty days, as well as the number of consecutive hours a crew member can fly and the minimum rest periods, based on Federal Aviation Administration (FAA) regulations and contractual agreements. Currently, each crew member must be assigned at least three off-duty days following a duty period of at most seven days. A duty roster is created quarterly and the pilots are assigned on-duty and off-duty days in advance, before the actual trip requests arrive.

Related to the problem of creating flexible crew workday schedules is the strategic question of how many crew members with each possible set of qualifications is needed, and how much the company has to invest for training the existing crew members to attain additional qualifications. In terms of operational flexibility, it is advantageous to have crew members who are qualified to perform more than one task. However, training is costly and with each additional qualification, the salary of a crew member, as well as his likelihood of leaving the company for a job elsewhere, also increases.

At the strategic level, capital investments for growing the fleet also have to be made carefully, since aircraft are very expensive to purchase and to maintain.

Question 12 *What other strategic or operational problems do you think this company needs to address? What kind of data would you need to analyze these problems and how would you approach solving them?*

Question 13 *How would you compare the flight scheduling problem of this company to those of major commercial airlines? What are the similarities/differences?*

References

[1] G. Baum, The Essential Capitalist Tool, *Forbes*, February 27, 1997.

[2] L. Bodin, B. Golden, A. Assad, and M. Ball (1983), Routing and Scheduling of Vehicles and Crews: The State of the Art, *Computers and Operations Research*, Vol. 10, 63-211.

[3] R. Collis, "Practical Traveler", *The New York Times*, October 26, 1997.

[4] C. Del Valle, "Can't Afford a Lear? Buy a Piece of One," *Business Week,* September 11, 1995.

[5] J.L. Levere, "Buying a Share of a Private Jet," *The New York Times*, July 21, 1996.

[6] A. Levin and D. Field, "Use of Private and Time-share Jets on the Rise," *USA Today*, November 8, 1999.

[7] E. McDowell, "Business Traveler", *The New York Times*, June 7, 1995.

[8] B. Wade, "Passengers Play the Airlines' Bumping Game," *The New York Times*, May 21, 1995.

[9] B. Wade, "When a Storm Cancels a Flight", *The New York Times*, April 7, 1996.

[10] B.Wade, "When the Plane is Really Bus," *The New York Times*, December 14, 1997.

[11] A. Zagorin, "Rent-a-Jet Cachet," *Time Magazine*, September 13, 1999.