A new aircrew-scheduling model for short-haul routes

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Abstract

The aircrew-scheduling model proposed here considers not only the performance of the crew scheduling process but also the flexibility of an irregular operation. A genetic algorithm is applied to solve this problem efficiently. In case of airline operations, with many scattered skeleton activities and frequently unexpected irregular events especially for the short-haul airlines, the method is more effective than the traditional aircrew-scheduling model. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Aircrew-scheduling problem; Genetic algorithm; Irregular operation

1. Introduction

Coleman (1997) argued that regional aviation is, by definition, short haul. The average trip length for passengers on regional airlines is 230 miles (370 km). Owing to this, aircraft in regional fleets undertake, on average, twice as many daily takeoffs and landings as long-haul aircraft operated by major carriers. Generally, aircraft in regional airline service make 8–10 daily takeoffs and landings. This makes it difficult for aircrew to switch aircraft during a day. Further, the uneven passengers’ arrival rate, the short turn-around time and changeable weather often cause disruptions to services. This phenomenon is different from that of the long-haul airlines for which many scheduling models were designed. The short-haul situation is more akin to the bus- or train-crew-scheduling problem (Kwan, 1999).

A period of duty involves a set of flights. The limited time between those flights prevents the crew from executing duties in another aircraft. The duty pairing, or rotation, is a sequence of duty periods with overnight rests in between. Each duty pairing begins and ends at the same crew base, which is the city where crews are stationed. In some cases, a duty pairing includes flights in which a crew flies as passengers, which is called a deadhead or positioning (PNC) trip. After all the required flights are covered by duty pairings, the personalized schedule is then constructed for aircrew by assigning the duty pairings to them according to a bid-line procedure or a rostering procedure.

This crew-scheduling method is effective if the skeleton activities are few and condensed. Gamache and Soumis (1998) showed that the assignment of skeleton activities, or desiderata, during optimization is substantially more cost-effective than pre-assignment. The crew assignment might fail to assign all duty pairings if the pre-assigned and scattered skeleton activities are considered. In reality, there are many reasons for the dates of skeleton activities to be predetermined. For example, the due date for visa and passport, medical check, the availability of aircraft and airport for training, the required date for administrative work and air-safety meeting, the required layoff for personal issue and so on. Besides, if the irregular operation occurred, the on-site-crew management might ruin the optimized and planned roster very much. The pairings as well as the crew schedule then need to be repaired. Again this arrangement might take a lot of human effort to adjust the planned schedule after any irregular event occurs.

Therefore, in this new model, we modify the definition of the two processes and build up a flexible and efficient crew-scheduling process for crew management without extra computation effort. We call them the duty forming and duty assignment process, respectively. The idea is that in the duty forming process, we only form the elemental duties but move the rotation construction process into the duty assignment process. That is, the rotation is constructed after the duty assignment process is completed. Thus, in the duty assignment process, we
deal with the duty but not the rotation. In this way, the duty assignment will have more flexibility than ever. The skeleton activities and the duties can also be pre-assigned without any problem because the assignment unit is smaller. The multiple crew bases problem can also be solved without any problem. The computation effort decreases in the crew pairing process but increases a bit in the crew rostering process. In the test case of a Taiwan domestic airline, we follow the framework of genetic algorithm and use a problem-suitable matrix-typed chromosome to solve this aircrew-scheduling problem efficiently.

2. Review of crew-scheduling problem

According to the flight length, the crew-scheduling problems are of two types: international (long haul) and domestic (short haul). Vance et al. (1995) have also made a classification by flight frequency—the daily problem, weekly exceptions problem, transition problem and dated weekly problem. According to Barnhart et al. (1998), the aircrew-scheduling problem is typically solved in two stages: the crew pairing and the crew rostering problems. The purpose of these problem classifications is to reduce the complexity. In this paper, we are dealing with the aircrew-scheduling problem in the short-haul markets with a weekly problem.

Crew pairing problem is to form a set of rotations in such a way that each flight segment or leg is covered at least once and that the total cost is minimized. A rotation is usually a round trip that takes a crew from its home location or base and returns right to the same place at the end of the journey (Arabeyre et al., 1969). Most current approaches to this problem center around the set partitioning problem (Baker et al., 1985; Marsten and Shepardson, 1981) as follows:

\[
\begin{align*}
\min & \quad \sum_{p \in P} c_p y_p, \\
\text{s.t.} & \quad \sum_{p \in P} y_p = 1, i \in F, \\
& \quad y_p \in \{0, 1\}, p \in P,
\end{align*}
\]

where \( y_p = 1 \) if pairing \( p \) is in the solution, and 0, otherwise. \( F \) is the set of flight segments and \( P \) is the set of pairings. A column \( p \) has 1 in row \( i \) if the flight \( i \) is flown by pairing \( p \), and \( c_p \) is the cost of pairing \( p \).

The crew rostering problem is that of constructing personalized schedules for airline crewmembers. There are two ways to do this, the Bidding System and the Equitability System. The Bidding System allows the senior crews to bid his preferred rotation to construct his personalized schedule. Bid-line procedures, one of the bidding systems, are more common among large North American airlines. Preferential bidding is variant proposed by Gamache and Soumis (1998) and Byrne (1988). Its main drawback is that some duties might fail to be assigned. But it can be repaired by preserving some extra manpower. Besides, the junior aircrew will feel frustrated, as the senior aircrew is given priority in choosing. The Equitability System is to assign aircrew the duties by following the equitability principle, trip preferences, vacation preference, crew requests, flight hours, duty days, layover days, vacation days, duty numbers, etc. The solutions include high-priority assignment, day-by-day assignment, pilot-by-pilot assignment, day-by-day and pilot-by-pilot combined assignment, generalized set partitioning problem, column generation (Marchettini, 1980; Antosik, 1978; Buhr, 1978; Byrne, 1988; Dusan and Panta, 1998, 1999; Gamache and Soumis, 1998; Gamache et al., 1999; Glanert, 1984; Morre et al., 1978; Nicoletti, 1975; Ryan, 1992; Ryan and Day, 1997).

3. A new concept for aircrew scheduling

3.1. Concept construction

To survive in a competitive domestic airline market, cost savings are as important as exploring the new market. By taking the characters of frequently irregular events in the short-haul problem, the crew management needs to be much more efficient than the long-haul problem. This leads to the creation of our idea. Kwan (1999) has also stated the differences between general airline and railway crew-scheduling problem. This short-haul problem is much closer to the railway crew-scheduling problem.

To reduce the complexity of the crew-scheduling problem, it has been separated into two sub-problems: the crew pairing and the crew rostering problems, for a very long time. The crew pairing problem is to construct a set of rotations in accordance with the collective agreement and security rules. A rotation or a duty pairing is a sequence of flight sectors on consecutive days, worked by a crew leaving and returning to the same city or base. The crew rostering problem is to assign the above rotations, rest periods or other activities to aircrew in accordance with the crew’s preferences or the company’s goal. However, to generate a rotation is technically not very difficult. To assign those rotations to a schedule with many pre-assigned and scattered skeleton activities, it will not be very easy to find the feasible solution then. This traditional procedure also prevents the possibility of quick crew management during an irregular operation.

Our aircrew scheduling idea is induced from operation control to tactical decision, bottom up, but not in the reverse direction. So we consider the needs for operation control first and then go back to think about
the way that aircrew scheduling should proceed. We bypass the rotation construction stage and assign the duties straightforwardly to the aircrew. The assignment of duties is much easier than the rotations because the length of a duty is a day. The rotation, however, varies from a day to several days. The rotations are not formed in the duty forming process, but after our duty assignment process, the rotations as well as the traditional crew pairing process can be determined. Additional benefits can be considered, such as the expected length of the rotation, multiple crew bases consideration, pre-assigned duty. The principle of base-to-base is then no longer necessary in the crew pairing process.

Fig. 1 shows the general crew-scheduling process. The first step is to examine the schedule length of aircraft. Because of the characters of short-haul flights, the schedule of aircraft might include many flights in a day as shown in Fig. 1. If the flight time of an aircraft schedule has exceeded the aircrew’s regulation, then the schedule of aircraft must be separated while constructing the duties of the crews. To shorten the potential deadhead cost of the crew assignment, usually we use the crew’s base as the cutting point of an aircraft’s schedule. In Fig. 1 we assume that TSA is the crew’s base, so we separate the schedule of Aircraft 1 into Duties A and B. The flight times of the schedule of Aircraft 2 and 3 do not exceed the aircrew’s regulation. So we transfer their schedule to Duties C and D without any partition. The final step is the rotation formation with the principle of base-to-base. Fig. 2 shows the result of the crew rostering process. If there is one crewmember who has only one day available for duty assignment, then it is impossible to assign him a 2-day rotation. The traditional model needs eight deadhead trips and three layovers to implement the schedule.

In our model, most of the deadhead costs can be removed by assigning a proper duty to a corresponding crewmember. From Fig. 3, we can see how flexible and cost-efficient it is. The total number is 3 for deadhead trips and 4 for layovers. We can take care of the multiple crew bases problem and the deadhead cost simultaneously. One’s duty can be easily switched to another crew if needed. A special duty can also be easily pre-assigned to a dedicated person but not a rotation. These issues are very difficult for the traditional scheduling process to deal with. The skeleton activity will also face the same condition with the pre-assigned duty. The only drawback of our new idea is that the operators must rely very much on the computer system (Table 1). Table 1 lists the differences between the duty assignment based crew-scheduling problem and rotation assignment based crew-scheduling problem.

### 3.2. Implementation method

The genetic algorithm (GA) is the solution algorithm of our proposed model (Holland, 1975). The algorithm we use follows the more popular methods, such as roulette wheel sampling, percentage reproduction, two-point crossover, and mutation. Only the encoding style of the chromosome needs to be clarified. Radcliffe (1997) stated that there are many GA encode styles, such as

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### Table 1: Differences between Duty Assignment and Rotation Assignment

<table>
<thead>
<tr>
<th>Duty Assignment</th>
<th>Rotation Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 deadhead trips</td>
<td>3 deadhead trips</td>
</tr>
<tr>
<td>3 layovers</td>
<td>4 layovers</td>
</tr>
</tbody>
</table>

---

Fig. 2. Rotation assignment-based crew rostering result.
as the binary string style and the tree style. Here we use a matrix representation rather than a string list representation. First, this is because of the intuitive connection between a chromosome and a roster. Second, it satisfies the flexibility requirement as we proposed the duty-based crew rostering method. Third, with the help of the powerful computing machine, we can examine the feasibility of a limited chromosome very fast. Fig. 4 shows this matrix-styled chromosome. In Fig. 4, \( p_z \) indicates the zth crew, \( d_\beta \) represents the \( \beta \)th day and \( \omega_{2\beta} \) represents a duty or a skeleton activity in the chromosome of zth crew and \( \beta \)th day. Thus, we expect that only a flight duty or a skeleton activity can be put into the cell of the chromosome. The left part of Fig. 5 shows the two-point crossover operation. The right part of Fig. 5 demonstrates the mutation operation; that is to select two different cells on the same column randomly and swap the content of those two cells.

Fig. 6 shows the solution flow of the duty forming process by following the genetic algorithm. It starts with

<table>
<thead>
<tr>
<th>Day</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot 1</td>
<td>Duty B</td>
<td>Duty D</td>
<td>Duty C</td>
<td>The base of pilot 1 is TSA, LOK is a layover at KHH, LON is a layover at TNN, PNC2 is positioning to his base after his duty.</td>
</tr>
<tr>
<td></td>
<td>LOK</td>
<td>LON</td>
<td>PNC2</td>
<td></td>
</tr>
<tr>
<td>Pilot 2</td>
<td>Duty D</td>
<td>Duty C</td>
<td>Duty B</td>
<td>The base of pilot 2 is KHH. PNC1 is positioning for Duty B.</td>
</tr>
<tr>
<td></td>
<td>LON</td>
<td></td>
<td></td>
<td>The base of pilot 3 is TSA.</td>
</tr>
<tr>
<td>Pilot 3</td>
<td>Duty A</td>
<td>Duty A</td>
<td>Duty A</td>
<td>The base of pilot 4 is KHH.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PNC1</td>
<td></td>
</tr>
<tr>
<td>Pilot 4</td>
<td>Duty C</td>
<td>Duty B</td>
<td>Duty D</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>LON</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Duty assignment-based crew rostering result.

Table 1
Comparisons between the duty assignment-based crew-scheduling problem and rotation assignment-based crew-scheduling problem

<table>
<thead>
<tr>
<th>Assignment unit</th>
<th>Items of crew scheduling process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duty-based</td>
<td></td>
</tr>
<tr>
<td>Considerations in crew pairing process</td>
<td></td>
</tr>
<tr>
<td>1. Multiple crew bases</td>
<td>1. Single crew base</td>
</tr>
<tr>
<td>2. Maximum sectors in a duty</td>
<td>2. Maximum sectors in a duty</td>
</tr>
<tr>
<td>3. Manpower allocation at different bases</td>
<td>3. MRT, official day-off, flight hours, flight duty period, etc.</td>
</tr>
<tr>
<td>4. Source from aircraft schedule or timetable</td>
<td>4. Source from time table</td>
</tr>
<tr>
<td>Considerations in crew rostering process</td>
<td></td>
</tr>
<tr>
<td>1. Equilibrium indexes</td>
<td>1. Equilibrium indexes</td>
</tr>
<tr>
<td>2. Individual crew consideration</td>
<td>2. Fixed rest time between two rotations.</td>
</tr>
<tr>
<td>3. Crews productivity</td>
<td>3. Single crew base</td>
</tr>
<tr>
<td>4. Cost calculation accuracy</td>
<td></td>
</tr>
<tr>
<td>5. Irregular operation ability</td>
<td></td>
</tr>
<tr>
<td>6. Individual position connection</td>
<td></td>
</tr>
<tr>
<td>7. Duty connection time</td>
<td></td>
</tr>
<tr>
<td>8. Flexible duty and skeleton activity management</td>
<td></td>
</tr>
<tr>
<td>9. Manpower requirement for various types of duties</td>
<td></td>
</tr>
<tr>
<td>Drawbacks</td>
<td></td>
</tr>
<tr>
<td>1. Longer duty assignment computing time</td>
<td>1. No individual crew consideration</td>
</tr>
<tr>
<td>2. Low crews productivity</td>
<td>2. Low-cost calculation accuracy</td>
</tr>
<tr>
<td>3. Low irregular operation ability</td>
<td>3. Single base limitation</td>
</tr>
</tbody>
</table>
chromosome initialization. During this process, we check the aircraft’s schedule to see if it is necessary to be separated. If it does, then two rules are applied to cut off the aircraft’s schedule. After this examination, the duty is assigned a code for later operation. After the initialization, the population of parents is generated. The following is the standard procedure for the genetic algorithm. Checking the violation of constraints, selecting the better parents to crossover and breaking the local optima by mutation. The newly generated chromosomes then replace the old chromosomes generation by generation. The algorithm stops until the score of the objective function converges. This process attempts to assemble the short flights in an aircraft’s schedule into the elementary duty according to some simple rules, such as the limit of flight sector of a duty, the percentage of daily manpower allocation for every base. It tries to shorten some potential unnecessary costs, such as PNC or layover. It happens whenever the percentage of manpower allocation at different bases does not follow the percentage of place allocation separated from the schedule of aircraft. For example, first we separate the aircraft schedule into two parts, if the number of flight sectors of an aircraft in a day is over the sector limit of a duty. The principle of cutting the aircraft schedule is at the crew’s base or at the central sector of an aircraft’s schedule. If it fails to find the central sector, i.e. the number of flight sectors of an aircraft in a day is even, then it randomly selects the cutting point around the central sector. The evaluation goal is to reduce the potential unnecessary costs. It can be implemented by making one day’s percentage of manpower allocation at different bases equal to that of the next day.

Fig. 7 shows the solution flow of duty assignment process by following the genetic algorithm. It also begins with the chromosome initialization. After the duties are generated, we have to check whether the flying time of a duty is long enough to add more crews to support this duty. Therefore the duty is duplicated if necessary. The next step is to assign all the pre-determined duties including the pre-assigned duties and the standby duties. The chromosome right now can be called a mask. It consists of the skeleton activities and pre-determined duties. They will not be changed in the later operation. The other duties are randomly assigned one by one to the remaining cells of the chromosome except the duty that is needed to assign to a crew with some special qualifications. The following also constitutes the standard procedure of genetic algorithm. This process attempts to generate a crew’s schedule to fit all constrains and the objective function. To deal with the pre-assigned duty or skeleton activities, we use a mask to filter these pre-determined duties. To speed up the search, we check the crew’s qualification before the duty can be assigned. The main flow is to generate a solution and test the solution by each constraint and the objective function. If all constraints are satisfying and the improvement of solution converges to an acceptable level, the algorithm stops.

The two problems can be classified into Constraint Satisfaction Optimization Problem (CSOP), which consists of a standard Constraint Satisfaction Problem (CSP) and an optimization function. A genetic algorithm provides the mechanism of generating the solution, testing how good it is and improving the solution generation by generation. It is straightforward to find our solution if the CSP and optimization functions have been well defined. Here we define the CSP part as the hard constraints and the optimization function as a...
combination index of several soft constraints. If the solution violates any hard constraint, then it is an infeasible solution. So our goal is to find a feasible solution, which minimizes the objective function in an acceptable period of time.

4. Test case

The density of the domestic air transportation network in Taiwan is very high. There are about 700 flights in a day. The longest flying time is approximately 50 min and the shortest flight is only for about 15 min. The average time duration between two flights is about 1.5 min. In the circumstances, any unexpected event might have a huge effect on a planned schedule, such as a late checking-in procedure, air traffic flow control, bad weather, and crew illness. A flight delayed by 5 min might cause a late departure of the next flight. So the planned schedule cannot be followed if the delay effect is enlarged. Our model is suitable for short-haul domestic airlines of the type operating in Taiwan.

4.1. Duty forming process

The goal of this process is to reduce the unnecessary PNC or layover cost caused by the improper separation of aircraft schedules. The objective function in this process focuses on the balance of one day’s percentage of manpower allocation at different bases, against the next day’s structure. All hard constraints are considered in the population initialization process, so the objective function of this process is only the linear combination of the following soft constraints:

\[
\text{Score} = \text{Cost}_{\text{DiffPlc}} + \text{Cost}_{\text{NonBaseCut}} + \text{Cost}_{\text{BaseToBase}}.
\]

Cost_{DiffPlc} represents the cost of inconsistent distribution of departure and arrival places between different day’s duties. The upper part of Fig. 8 is an example of the schedule of an aircraft. After the partition process of the aircraft’s schedules is finished, it generates elemental duties, such as M02 in Day1, M01a in Day2. The lower part is a duty set of each working day. The unbalanced distribution between one day’s arrival place and the next day’s departure place is the cost of PNC and layover. It is defined as

\[
\text{Cost}_{\text{DiffPlc}} = \sum_{d=1}^{b} \sum_{t=1}^{\beta} |BL_{1t} - BT_{12}| + \cdots + |BL_{td} - BT_{td+1}| + \cdots + |BL_{b\beta-1} - BT_{b\beta}|,
\]

where BL_{td} is the amount of duty arrivals at base t and day d, BT_{td+1} is the amount of duty departures at base t and day d + 1. There are b bases and \( \beta \) days, \( b > 1 \) and
Forexample, if therearetwocrewbases, TSA and KHH. The departure and arrival places of duties shown in the lower part of Fig. 8 are distributed as shown in Fig. 9. The objective function can be calculated as

\[ \text{Cost}_{\text{DiffPlc}} = \sum |6 - 5| + |3 - 4| + |2 - 5| + |7 - 4| + \cdots + |6 - 8| + |3 - 1| . \]  

(4)

The weight of this parameter is labeled as Manager Penalty in Fig. 11.

Cost\_NonBaseCut is the cost of not cutting the aircraft’s schedule at the crew bases, TSA and KHH. It is defined as

\[ \text{Cost}_{\text{NonBaseCut}} = \sum_{i=1}^{p} \text{NonBaseCut}_i \times W_{\text{NonBaseCut}}. \]

(5)

where NonBaseCut\(_i\) is the \(i\)th duty, 0 indicates that the cutting place is at a base, 1 otherwise. \(W_{\text{NonBaseCut}}\) is the weight for reducing the violation and is labeled as TSAKHHPenalty in Fig. 11.

Cost\_BaseToBase represents the cost whenever the departure and arrival places of a duty are not the same. For reducing the cost of PNC or layover, the principle of base-to-base still needs to be met even in the multiple crew bases problem. It is defined as

\[ \text{Cost}_{\text{BaseToBase}} = \sum_{i=1}^{p} \text{BaseToBase}_i \times W_{\text{BaseToBase}}. \]

(6)

where BaseToBase\(_i\) is the \(i\)th duty, 0 indicates the case of BaseToBase, 1 otherwise. \(W_{\text{BaseToBase}}\) is the weight for reducing its violation and is labeled as BaseToBasePenalty in Fig. 11. The termination of the optimization process is reaching the total generation number or the converging condition. The convergence is defined as

\[ \text{SCORE}_g - \text{SCORE}_{g-1} < 0.001, \]

(7)

where \(\text{SCORE}_g\) and \(\text{SCORE}_{g-1}\) are the fitness scores for current and previous generation wherever the total number of the hard constraint violations equals zero.

### 4.2. Duty assignment process

The core computation is in this process. It has to assign duties feasibly, economically and fairly. The objective function, SCORE, usually has two folds, one is the set of hard constraints including all restrictions for crew assignment, and the other set constitutes the soft constraints including operating cost and equilibrium index.

\[ \text{SCORE} = \text{Penalty\_Cons} + \text{Cost\_PNC} + \text{Cost\_LOV} + \text{Avg\_PDM} + \text{Avg\_FT} + \text{Avg\_PNC} + \text{Avg\_LOV}. \]

(8)
Penalty _Cons represents the linear combination of all hard constraints. The hard constraints considered in this paper follow the Taiwan’s CAA regulations. It is formulated as

\[
\text{Penalty}_\text{Cons} = P_{\text{Cons}24h10h} * N_{\text{Cons}24h10h} + P_{\text{Cons}7D32h} * N_{\text{Cons}7D32h} + P_{\text{Cons}7D24h} * N_{\text{Cons}7D24h} + P_{\text{ConsCLayover}} * N_{\text{ConsCLayover}} + P_{\text{ConsFDP}} * N_{\text{ConsFDP}} + P_{\text{ConsMRT}} * N_{\text{ConsMRT}} + P_{\text{ConsPNC999}} * N_{\text{ConsPNC999}},
\]

where \( P_{\text{Cons}24h10h} \) is the penalty for reducing the violation of daily flight time limit, i.e. 10 h, during the consecutive 24 h; \( N_{\text{Cons}24h10h} \) counts for each violation of this constraint. \( P_{\text{Cons}7D32h} \) is the penalty for reducing the violation of weekly flight time limit, i.e. 32 h, during 7 consecutive days; \( N_{\text{Cons}7D32h} \) is the count of each violation. \( P_{\text{Cons}7D24h} \) is the penalty for reducing the violation that crews have to take at least a break of 24 consecutive hours during 7 consecutive days; \( N_{\text{Cons}7D24h} \) counts for each violation. \( P_{\text{ConsCLayover}} \) is the penalty for reducing the violation of the limit of continuous layover days; \( N_{\text{ConsCLayover}} \) counts for each violation. \( P_{\text{ConsFDP}} \) is the penalty for reducing the violation of the maximum flight duty period; \( N_{\text{ConsFDP}} \) counts for each violation. \( P_{\text{ConsPNC999}} \) is the penalty to prevent the solution violating the position connection of two consecutive duties; \( N_{\text{ConsPNC999}} \) counts for each violation. \( P_{\text{ConsMRT}} \) is the penalty to prevent the solution violating the rule of minimum rest time; \( N_{\text{ConsMRT}} \) counts for each violation.

\[
\text{Cost}_{\text{PNC}} = W_{\text{ConsPNCop}} * N_{\text{ConsPNCop}} + W_{\text{ConsPNCp}} * N_{\text{ConsPNCp}},
\]

where \( N_{\text{ConsPNCop}} \) is the accumulated number of PNC occurred during the off-peak period, \( W_{\text{ConsPNCop}} \) the weight to reduce the number of \( N_{\text{ConsPNCop}} \). \( N_{\text{ConsPNCp}} \) is the accumulated number of PNC that occurred during the peak period, \( W_{\text{ConsPNCp}} \) is the weight to reduce the number of \( N_{\text{ConsPNCp}} \).

\[
\text{Cost}_{\text{LOV}} = W_{\text{ConsLOVop}} * N_{\text{ConsLOVop}} + W_{\text{ConsLOVp}} * N_{\text{ConsLOVp}},
\]

where \( N_{\text{ConsLOVop}} \) is the accumulated number of LOV that occurred during the off-peak period, \( W_{\text{ConsLOVop}} \) the weight to decrease the number of \( N_{\text{ConsLOVop}} \). \( N_{\text{ConsLOVp}} \) is the accumulated number of LOV that occurred during the peak period, \( W_{\text{ConsLOVp}} \) is the weight to decrease the number of \( N_{\text{ConsLOVp}} \).

Avg_PDM, Avg_FT, Avg_PNC and Avg_LOV are kinds of indices to evaluate the equilibrium level between the crew’s times of work and as such are soft constraints, where Avg_PDM represents the equilibrium level of per-diem. It is calculated as the multiplication of the unit price of per-diem and the time accumulating...
from check-in to check-out. From Fig. 10, we can see that this cost depends on whether the checking-in and checking-out is on the same day. So this index can be simplified and substituted by the amount of layovers.

Avg_FT represents the equilibrium level of flight time. It is the equilibrium index for putting different crew’s flight hours into equilibrium.

$$\text{Avg}_\text{FT} = \sum_{i=1}^{x} |\text{FT}_i - \text{AVG(FT)}_i| * W_{\text{FT}},$$  \hspace{1cm} (12)

where FT_i is the total flight time for crew i. AVG (FT_i) is the average flight time for the same class of crewmembers, i.e. \(\sum_{i=1}^{x} \text{FT}_i / x\). W_{FT} is the weight to decrease the phenomenon of unbalanced flight time.

Avg_PNC represents the equilibrium level of PNC. It is the equilibrium index for making different crew’s amount of PNC equilibrium.

$$\text{Avg}_\text{PNC} = \sum_{i=1}^{x} |\text{PNC}_i - \text{AVG(PNC)}_i| * W_{\text{PNC}},$$  \hspace{1cm} (13)

where PNC_i is the accumulated numbers of required PNC for crew i. AVG (PNC_i) is the average of all crew’s accumulated number of PNC, i.e. \(\sum_{i=1}^{x} \text{PNC}_i / x\). W_{PNC} is the weight value to decrease the in-equilibrium phenomenon of PNC.

Avg_LOV represents the equilibrium level of LOV. It is the equilibrium index for making different crew’s amount of LOV equilibrium.

$$\text{Avg}_\text{LOV} = \sum_{i=1}^{x} |\text{LOV}_i - \text{AVG(LOV)}_i| * W_{\text{LOV}},$$  \hspace{1cm} (14)

where LOV_i is the accumulated numbers of required LOV for crew i, AVG(LOV_i) is the average of all crew’s accumulated number of LOV, i.e. \(\sum_{i=1}^{x} \text{LOV}_i / x\), and W_{LOV} is the weight to decrease the unbalanced phenomenon of LOV.

A feasible result consists of only the operation cost and equilibrium index parts of the score:

$$\text{SCORE}_f = \text{Cost}_\text{PNC} + \text{Cost}_\text{LOV} + \text{Avg}_\text{PDM} + \text{Avg}_\text{FT} + \text{Avg}_\text{PNC} + \text{Avg}_\text{LOV}.$$  \hspace{1cm} (15)

4.3. Result

4.3.1. Duty forming process

Fig. 11 shows the required parameters according to our trial experience. The user parameters are as defined in Section 4.1. The system parameters are the size of the fleet (Max A.C. No., the number of aircraft’s schedule that we need to deal with) and the maximum flight sectors in aircraft’s schedules (Max Sectors No.). The GA parameters are the algorithm-related parameters. Sample space is the total number of chromosomes in one generation. Population means the size of parents. Generation means the total iteration number. Mutation(T) indicates the mutation times, while Mutation(R) the mutation rate. Fig. 12 depicts the trajectory of the penalty score of constraints with the problem size of 1400 flights in 15 days. One score of the soft constraints, Cost_BaseToBase, drops a lot after 200 generations. This will remove much of the potential operation costs. Its execution time is approximately 5 min.

4.3.2. Duty assignment process

After thorough and repeated experiments, the parameters of GA and constraints’ weight are set as shown in
Fig. 13. The hard and soft constraints are defined in Section 4.2. The left bottom part of Fig. 13 indicates the weight of PNC during the peak period, weekend holiday, PNC (WK) and the off-peak period, Monday–Friday, PNC (1–5), and the weight of layover during the peak, L/O (WK) and off-peak period, L/O (1–5). The GA’s parameters are set as below. The parent population size is 200. The offspring population size is 160. The crossover rate is 1. The mutation rate is initially set to 0.8, and then reset to 0.3 after 1000 generations. The purpose of the two-step mutation rate setting is to shorten the convergence time. The problem size is 40 crewmembers, 335 duty patterns in 15 days. Results have been recorded every 10 generations.

Fig. 14 depicts the trajectory of the violation number of all hard constraints. The generation of the violation number of those constraints decreasing to zero is as follows: CLayover is at the 780th; 24h10h is at the 1360th; MRT is at the 1360th; 7D24h is at the 620th; and P999 is at the 120th. The hard constraint, 7D32h, is only violated at the beginning and the 310th generation. The hard constraint, FDP, takes only 10 generations to decrease to zero. Therefore, a feasible solution is generated after the 1360th generation. Fig. 15 shows that the trajectory of the operation cost and the equilibrium index vary dramatically after the 1360th generation. The reason for this is that the objective function contains only the soft constraints once there is no violation of any hard constraints. The left part of Fig. 15 illustrates the required number of PNC and LOV, which is the minimum requirement for operating the aircrew’s schedule. The right part of Fig. 15 illustrates the equilibrium level of flight time, PNC and LOV, which indicates the equilibrium level between crewmembers. Fig. 16 depicts the trajectory of the value of the objective function. It took about 30 min and 2000 generations to achieve a steady state with a Pentium-III 933 personal computer. Compared with the work done by hand, the accumulated number of layovers is 126 and PNC is 74 without considering the equilibrium indexes such as flight time, Layover and PNC. In the same situation, our system generates a schedule with accumulated number of layovers, 128 and PNC, 68, which seems better than the work done by hand. If those three equilibrium indexes are considered, the accumulated number of layovers increases to 134 and PNC, 95, a little bit reasonably higher than not considering the equilibrium indexes.
5. Conclusion

For the sake of simplification, the crew-scheduling problem has often been separated into the crew pairing and the crew rostering problems. However, during an irregular operation, this framework often creates inconvenient procedures of schedule changing and inefficiency of online dispatching.

Here we have proposed a new idea of aircrew scheduling. The duty forming process forms the elementary duties according to the aircraft’s schedule and some rules, such as the maximum sectors in a duty and crew numbers for duty execution. In order to enhance the efficiency of the online crew dispatching, the duty assignment process considers all duty connection rules, such as minimum rest time and the limitation of flight hour, while assigning the duty. Since the assignment unit is a duty, crew’s duty can be changed very easily, not like the rotation generated by the traditional crew pairing method. Thus for the case of many scattered skeleton activities and the irregular events, our idea is rather important and effective for the airlines with these syndromes. This paper also presents a GA-based implementation method. All the above figures show the feasibility of our proposed approach. However, in this paper, we only use an example to show how flexible the model is. We can expect a real case test to be done in the near future to prove the efficiency of our approach during an irregular operation.

References


