A Coordinated Flight Scheduling Model for Allied Airlines

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Abstract: The setting of good flight schedules for allied airlines can not only enhance allied airline operating performance, but can also be a useful reference for alliance decision-making. In this research, we develop a coordinated flight scheduling model, which will help the allied airlines solve for the most satisfactory fleet routes and timetables under the alliance. We employ network flow techniques to construct the model. The model includes multiple passenger- and fleet-flow time-space networks that can formulate the flows of passengers and the allied fleet in the dimensions of time and space. A number of side constraints are set according to real operating requirements. The model is formulated as a multiple commodity network flow problem which can be solved using a mathematical programming solver. Finally, to evaluate the model, we perform a case study based on real operating data from two Taiwan airlines. The preliminary results are good, showing that the model could be useful for airline alliances.

Keywords: alliance, routing, scheduling, time-space network, multiple commodity network flow problem

1. Introduction

In recent years, major air carriers around the world have increasingly entered into alliances with other carriers as a means of forming global networks and improving operation efficiency. As of June 1996, about 171 international airlines had formed more than 380 alliances. Since 1990 more than 50 alliances have emerged yearly (Airline Business, July 1996). Obviously such alliances are a global tendency.

Much research has recently been devoted to alliance problems, by the air industry as well as in academic fields. These studies addressed various aspects of airline alliance, e.g., theoretical studies on economic issues, empirical investigations, formations and typologies, and regulatory issues. For example, Lederer (1993) presented a simple model of competition between transport firms that captured the interaction of system design, price setting, and consumer choice. Perrot (1993) surveyed the results relative to the specifics of competition when compatibility matters, in the case of substitutes or complements, with or without network externalities. Youssef and Hansen (1994) assessed the impact of the SAS-Swissair alliance on service quality, market concentration, and fares. Hannegan and Mulvey (1995) examined the impacts of code-sharing alliances on airline and consumers. Oum et al. (1996) examined the effect of code-sharing agreements on firm conduct and air fares by focusing on trans-Pacific markets. Encaoua et al. (1996) focused on network effects originating on the demand side.

Brueckner and Whalen (2000) found no statistical evidence that fares on trans-Atlantic gateway-to-gateway markets were increased by a code-sharing agreement on that market. Brueckner (2001) examined the effects of international airline code-sharing on traffic levels and welfare, and found that airline alliances and code-sharing agreements might be socially desirable by lowering prices on indirect, interline markets. Evans (2001) reviewed literature on airline alliance, explored the underlying motivations for alliance formations and presented a conceptualization of the collaborative strategy process for international airline alliances. Zhang et al. (2004) developed an oligopoly model to investigate the effect of an air cargo alliance on competition in passenger markets.

Under the growing trend of airline alliance, fleet routing and flight scheduling, which affect aircraft usage efficiency and timetables, are essential to a carrier’s profitability and its level of service in the market with alliance. In tradition, the flight scheduling process typically consists of two inter dependent phases: (a) the schedule construction phase and (b) the schedule evaluation phase. The construction phase is accomplished by drafting a timetable according to the projected demand, the market share and the available airport time slots. During the following schedule evaluation phase, the draft timetable is examined for operating feasibility, cost and performance considerations. The feasibility checks in this evaluation phase mainly include fleet routes, fleet size, crew scheduling and maintenance arrangements. Any needed improvements identified during this phase are fed back into the construction phase and the timetable is revised. The flight scheduling process iterates these two phases until a desirable timetable is obtained.

Much research has already been devoted to fleet routing and flight scheduling problems, by the air industry as well as in academic fields. For example, Abara (1989) developed an integer linear programming model for fleet assignment with fixed flight departure times, formulated as a multicommodity network flow problem. Dobson and Lederer (1993) developed a three level hierarchical process to study the competitive choice of flight schedules and airfares by airlines in a pure hub-and-spoke (with single hub) system. Hane et al. (1995) modified Abara’s model so that it could solve daily aircraft routing and scheduling problems (DARSP) without departure time windows. Clarke et al. (1996), based on Hane et al.’s basic model, tried to develop a fleet assignment model which would take aircraft maintenance and crew scheduling into consideration. Yan and Young (1996) developed a set of network models to help carriers solve for effective short term flight schedules and fleet
routs, based on a drafted timetable and all the operating constraints. Desaulniers et al. (1997) developed two integer programming models, a set partitioning type of model and a time constrained multicommodity network flow model, for solving DARSPs according to a set of flights with known departure time windows.

To improve Yan and Young’s model, Yan and Tseng (2002) developed an integrated scheduling model for multi-fleet routing and flight scheduling. The objective was to maximize the system profit, given a fixed projected passenger demand and all the operating constraints. They also developed a Lagrangian relaxation-based algorithm to efficiently solve the model. Yan et al. (2002) developed a short-term flight scheduling model and a solution method that could incorporate variable passenger demands, in order to help solve for better fleet routes and flight schedules in a competitive market. Barnhart et al. (2002) considered airline fleet assignment problems that involved the profit maximizing assignment of aircraft types to flights. They proposed a new formulation and solution approach that captured network effects and thus would generate a superior solution. Lohatepanont and Barnhart (2004) described several integrated models and solution algorithms that could simultaneously optimize the selection of flights and the assignment of aircraft types to the selected flights.

To the best of the authors’ knowledge, the airline flight scheduling literature mainly focuses on single carrier transportation, and thus may be difficult to apply to alliance airline scheduling. Therefore, in this research, we develop a coordinated flight scheduling model, designed to help the participating airlines solve for the most satisfactory fleet routes and timetables for their alliance. It is expected that such a model will be a useful tool for the allied carriers to plan the most suitable fleet routes and timetables for short-term operations.

The scope of this research is confined to the subject of fleet routing and flight scheduling operations under airline alliances, given the projected trip demand (OD), fleet size, available slots, airport quotas and related cost data. For simplicity, we focus primarily on single-fleet routing and flight scheduling but the results could be extended to multi-fleet operations. Furthermore, for simplicity of modeling, two carriers (Airlines A and B) are used as examples. Although the scheduling process is, in practice, closely related to the aircraft maintenance and the crew scheduling processes, these processes are usually separated to facilitate problem solving (Teodorovic, 1988). According to the studied Taiwan airlines, in practice, maintenance and crew constraints are rather flexible, due to their use of stand-by crews and their progressive maintenance policy. These activities are always performed after the fleet routes and flights schedules have been solved. To reduce the problem complexity, as in Yan and Young (1996) and Yan and Tseng (2002), we exclude these constraints in the modeling.

The rest of this paper is organized as follows: In Section 2, we introduce the model. In Section 3, a case study is conducted to evaluate the performance of the model. Finally, in Section 4, we offer some conclusions.

2. Modeling approach
A time-space network technique is applied to construct a coordinated fleet routing and flight scheduling model for the purpose of maximizing the carriers’ total profit. The major elements in the modeling, including the fleet-flow time-space networks, the passenger-flow time-space networks, and the mathematical formulation, are as follows.
2.1 Fleet-flow time-space networks
A time-space network, as shown in Figure 1 or 2, is established for single-fleet routing, for each airline, within the specified time period (one day in this study) and locations. The horizontal axis represents the airport locations; the vertical axis stands for the time duration. All available airports are included. The two major components in the network are “nodes” and “arcs”. Each node represents a specific airport and a specific time, while each arc represents an activity for an airplane, such as a flight, a ground holding period, or an overnight stay. The arc flows express the flow of airplanes in the network. Three types of arcs are defined below.

2.1.1 Flight arc
A flight arc represents a flight/a flight connecting two different airports. For convenience of presentation, in this paper, a flight leg is called a flight, but in practice the user can combine a set of several connected flights to form a complete flight. All possible flights between two available airports for carrier are installed into the network within a reasonable block of time, as long as time slots at the corresponding airports are available. Each flight arc contains information about the departure time, the departure airport, the arrival time, the arrival airport and the operating cost. The time block for a flight is calculated as from the time when the airplane is prepared for this flight to the time when this flight is finished. Basically, it includes the time for investigation prior to departure, fuelling, passenger/baggage boarding and getting off, and the flight time in the air. The arc cost is the operating cost of the flight. The arc flow’s upper bound is one, meaning that the flight can be served at most once. The arc flow’s lower bound is zero, implying that no airplane serves this flight. In addition, the departure interval at the same airport is adjustable; so as to meet the carrier’s operating requirements.

To design flights for parallel/complementary alliances, the following two points should also be considered.

A. Parallel alliance
A parallel alliance refers to collaboration between the two airlines with the same routes in their networks. Under a parallel alliance, both airlines provide one simultaneous flight. Therefore, a side constraint should be set for the same flight so that the arc flows associated with the same flight in the two networks are at most one. As shown in Figure 1, the thick arrows (Airline A) and the thin dotted arrows (Airline B) represent flights that connect station 1 and station 2. Similarly, as shown in Figure 2, flight arcs are designed to connect station 2 and station 1. The two types of flights have the same origin and destination but are separately distributed.

B. Complementary alliance
A complementary alliance refers to a situation where two airlines have linked their existing partial networks to form a more complete complementary network, feeding traffic to each other. In a complementary alliance, both airlines form a flight to serve a new OD demand. As shown in Figure 1, the thick arrows (Airline A) and the thin dotted arrows (Airline B) represent the flights connecting station 3 and station 5. Airline A is first (station 3 to station 4) and Airline B is second (station 4 to station 5), or Airline B is first (station 5 to station 4) and Airline A is second (station 4 to station 3). Similarly, the flight arcs in Figure 2 are designed to connect station 3 and station 5.
2.1.2 Ground arc
A ground arc represents the holding of airplanes at an airport in a time window. The arc cost, which includes the airport tax, the airport holding charge, the gate use charge and other related costs, denotes the expenses incurred for holding an airplane at an airport in the
corresponding time window. The arc flow’s upper bound is the apron capacity (or infinity, if the capacity is large), indicating the maximum number of airplanes that can be held at this airport during a specific time window. The arc flow’s lower bound is zero, implying that no airplane is held at this airport in this time window.

2.1.3 Cycle arc
A cycle arc represents the continuity between two consecutive planning periods. It connects the end of one period to the beginning of the next period for each airport. The arc cost is the cost of holding an airplane overnight, and is similar to the ground arc cost but with the addition of an overnight charge. The upper bound and lower bound of the arc flow are set the same as those of the ground arcs.

2.2. Passenger-flow time-space network
The time-space network technique is applied to indicate the passenger movement corresponding to certain times and locations, for each airline. Each passenger-flow time-space network represents a specific OD pair from the origin-destination table (known as the OD table). A set of passenger-flow time-space networks associated with the ODs are constructed for each airline. In particular, three types of passenger-flow time-space networks, with a similar time-space structure, are created for each airline, including individual, parallel alliance, complementary alliance networks, as shown in Figures 3, 4, and 5, respectively. An individual passenger-flow time-space network formulates the transportation plan of an OD’s passengers, by only its own fleet/flights in terms of time and space. A parallel alliance passenger-flow time-space network formulates the transportation plan of an OD’s passengers, by its and its allied airline’s fleets/flights, on the same route. A complementary alliance passenger-flow time-space network formulates the transportation plan of a new OD’s passengers, via its flights and its allied airline’s flights, in each existing partial network, to form a new complementary network. Such networks are designed to be symmetrical to the fleet-flow time-space networks so as to facilitate problem solving. Since the networks for Airlines A and B are similar, to save space, we only show the networks for Airline A. The horizontal and vertical axes are defined as the same as those in the fleet-flow time-space networks. Here, a node also represents an airport at a specific time; however, an arc designates an activity showing the passenger movement. In each type of passenger-flow network, there are three types of arcs altogether, which are defined below.

2.2.1 Delivery arc
A delivery arc represents the transportation of passengers from one airport to another on a flight, which is served by the original airline or its ally. The transportation time is the same as the corresponding time block for the associated flight in the fleet-flow time-space network. The arc flow’s upper bound is the aircraft capacity (maybe with a planning load factor), meaning that the maximum flow in the arc is the loading capacity of the aircraft. The arc flow’s lower bound is zero, indicating that no passenger from the corresponding OD is delivered on the associated flight. Besides the above common characteristics in the three types of passenger-flow networks have attributes that are specific to each type, described as follows:

For an individual passenger-flow time-space network, as shown in Figure 3, the arc cost is a variable cost for serving a passenger on the associated flight (e.g. the catering cost). For a parallel alliance passenger-flow time-space network, as shown in Figure 4, for a flight served by the individual airline, the associated delivery arc cost is a variable cost for serving a
passenger, while for a flight served by the allied airline, the associated delivery arc cost is the cost that the airline has to pay its ally (usually negotiated between these two airlines), to compensate for the delivery of a passenger. For a complementary alliance passenger-flow time-space network, as shown in Figure 5, the arc costs are set similar to the arc costs of a parallel passenger-flow time-space network.

2.2.2 Holding arc
A holding arc denotes a passenger stay at an airport in a time window. A waiting (or penalty) cost is the arc cost for the time window. However, if the arc just happens to connect either the departure or the arrival station of this network’s corresponding OD pair, the arc cost is then zero, because, in practice, the stay of passengers at such stations is usually not considered a scheduling decision. Nevertheless, the arc cost is adjustable. The arc flow’s upper bound is the station’s passenger service capacity, within the network’s minimum time interval, implying that the maximum number of passengers can be accommodated at this airport in the time window. The arc flow’s lower bound is zero, meaning that no passenger from the corresponding OD stays in the airport during the time window.

2.2.3 Demand arc
A demand arc connects the arrival station to the departure station of this network’s corresponding OD pair. It denotes the service demands for the OD pair that would actually be served in the network, whether by the original airline or its ally. The arc cost is the negative value of the average associated ticket fare. The arc flow’s upper bound is the projected demand for this OD pair. The aim in the model is to maximize the carrier’s profit, which means that the passengers for this OD pair will not all necessarily be served. The arc flow’s lower bound is zero, meaning that none of the OD pair’s passengers are served in the network. The trip demand for a specific OD pair can be flexibly divided into several demand arcs according to the actual demand distribution, the market characteristics, or carrier considerations. For example, the arcs could be designed to be denser for an OD pair in the peak hours that contains more commuter trips. In contrast, the arcs could be more sparsely installed into the network if the passengers are less sensitive to time, such as for leisure trips. Time intervals for the demand arcs are adjustable. If the model results are expected to have an impact on the original demand, one can change the inputs and rerun the model, until satisfactory results are acquired.

It should be mentioned that, as shown in Figure 5, since the total number of passengers from station 3 to station 5, by Airline A first (station 3 to station 4) and Airline B second (station 4 to station 5), in both networks, is constrained by the projected demand, a side constraint should be introduced so that the sum of the two demand arc flows in the two networks, associated with the same demand from station 3 to station 5, must be less than or equal to the projected trip demand. The model will decide which airline should provide which flight in order to serve this trip demand.
Figure 3 Individual passenger-flow network for Airline A (OD pair: k-1->k)

Figure 4 Parallel alliance passenger-flow network for Airline A (OD pair: 1->2)
2.3. Notations of symbols used in the model formulation

Before introducing the model formulation, we first list the symbol notations that will be used in the model formulation.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r$</td>
<td>the $r^{th}$ allied airline;</td>
</tr>
<tr>
<td>$R$</td>
<td>the set of all allied airlines. In this research, $R = {1,2}$;</td>
</tr>
<tr>
<td>$n$</td>
<td>the $n^{th}$ OD pair;</td>
</tr>
<tr>
<td>$N_r$</td>
<td>the set of all ODs for the $r^{th}$ allied airline;</td>
</tr>
<tr>
<td>$m$</td>
<td>the $m^{th}$ complementary OD pair;</td>
</tr>
<tr>
<td>$CPN$</td>
<td>the set of all complementary alliance passenger-flow networks for all allied airlines;</td>
</tr>
<tr>
<td>$A_r^r$, $NF_r^r$</td>
<td>the set of all arcs and nodes in the $r^{th}$ fleet-flow network;</td>
</tr>
<tr>
<td>$CF_r^r$</td>
<td>the set of all cycle arcs in the $r^{th}$ fleet-flow network;</td>
</tr>
<tr>
<td>$B_{nr}^r$, $NP_{nr}^r$</td>
<td>the set of all arcs and nodes in the $n^{th}$ passenger-flow network of the $r^{th}$ allied airline;</td>
</tr>
<tr>
<td>$AF_r^r$</td>
<td>the number of available airplanes for the $r^{th}$ allied airline;</td>
</tr>
<tr>
<td>$IFF_r^r$</td>
<td>the set of all flight arcs in the $r^{th}$ fleet-flow network, associated with the flights served by the airline itself;</td>
</tr>
<tr>
<td>$PFF_r^r$</td>
<td>the set of all flight arcs, associated with parallel alliance, in the $r^{th}$ fleet-flow network;</td>
</tr>
<tr>
<td>$CFF_r^r$</td>
<td>the set of all flight arcs, associated with complementary alliance, in the $r^{th}$ fleet-flow network;</td>
</tr>
<tr>
<td>$S_{rg}$</td>
<td>the set of the $r^{th}$ allied airline flight arcs that arrive at (or depart from) the $g^{th}$ station;</td>
</tr>
</tbody>
</table>
\[ Q_g^r : \text{the approved flight quota (arrivals or departures) at the } g^{th} \text{ station for the } r^{th} \text{ allied airline;} \]

\[ K : \text{the aircraft capacity (perhaps with a planning load factor);} \]

\[ SA^r : \text{the set of all stations for the } r^{th} \text{ allied airline;} \]

\[ FU_{ij}^r : \text{the arc}(i,j) \text{ flow’s upper bound in the } r^{th} \text{ fleet-flow network;} \]

\[ PN_{ij}^{nr} : \text{the arc}(i,j) \text{ flow’s upper bound in the } n^{th} \text{ passenger-flow network for the } r^{th} \text{ allied airline;} \]

\[ CPDA_{ij}^{mr} : \text{the set of the demand arcs in the } m^{th} \text{ complementary alliance passenger-flow network for the } r^{th} \text{ allied airline;} \]

\[ C_{ij}^{nr} : \text{the arc}(i,j) \text{ cost in the } r^{th} \text{ fleet-flow network;} \]

\[ T_{ij}^{nr} : \text{the arc}(i,j) \text{ cost in the } n^{th} \text{ passenger-flow network for the } r^{th} \text{ allied airline;} \]

\[ D_{ij}^{mr} : \text{the projected trip demand associated with the demand arc } (i,j) \text{ in the } m^{th} \text{ complementary alliance passenger-flow network. Note that the demand is served by complementary flights of both airlines;} \]

\[ X_{ij}^{r} : \text{the arc}(i,j) \text{ flow in the } r^{th} \text{ fleet-flow network;} \]

\[ Y_{ij}^{nr} : \text{the arc}(i,j) \text{ flow in the } n^{th} \text{ passenger-flow network for the } r^{th} \text{ allied airline;} \]

2.4 Model formulation

Besides the fleet-flow and the passenger-flow time space networks introduced above, there are several issues that need to be carefully considered in the modeling: (1) the number of required airplanes in the network should not exceed the number of available airplanes for each fleet, (2) the accumulation of flights for a certain period arriving at (or departing from) a specific airport should not exceed its available quota, (3) the number of passengers transported on a flight should never exceed the serving airplane’s capacity, (4) the combined demand served by both airlines should not exceed the projected demand, and (5) given a parallel alliance the same flight can be served at most once in both fleet-flow networks. Therefore, five corresponding types of side constraints are designed during the problem formulation: (1) the sum of the cycle arc flows in each fleet-flow network should not be greater than the number of available airplanes, (2) the sum of the flights (inflows or outflows) at each airport for each airline should not exceed its approved flight quota, (3) the sum of all delivery arc flows corresponding to the same flight should not exceed the sum of each flight arc flow multiplied by the airplane capacity, (4) the sum of the two demand arc flows in the two networks, associated with the same demand, should be less than or equal to the projected trip demand and (5) the sum of all the arc flows in the two parallel alliance fleet-flow networks, corresponding to the same flight, should be less than or equal to one.

Based on the fleet-flow and the passenger-flow time space networks, as well as the side constraints, we formulate the model as a mixed integer network flow problem. The objective of this model is to “flow” the airplanes and passengers simultaneously in all networks at a minimum cost. Since the ticket revenue from the passenger-flow networks is in the form of a negative cost, this objective is equivalent to the maximization of profit. The model is formulated as follows:

Minimize

\[ Z = \sum_r \sum_{ij \in A^r} C_{ij}^r X_{ij}^r + \sum_r \sum_{ij \in B^r} T_{ij}^{nr} Y_{ij}^{nr} \quad (1) \]
The model is formulated as a mixed integer multiple commodity network flow problem, in which the objective is to minimize the total system cost of the allied airlines. Constraints (2) and (3) ensure flow conservation at every node in each fleet/passenger-flow network. Constraint (4) denotes that the number of airplanes used in each fleet-flow network should not exceed the available number of airplanes. Constraint (5) ensures that the sum of all flights arriving at (or departing from) each station does not exceed its approved quota. Constraint (6) keeps the passenger delivery volume within the aircraft’s carrying capacity for the flights served by the airline itself. Equation (7) keeps the passenger delivery volume within the aircraft’s carrying capacity for the parallel alliance flights. Equation (8) keeps the passenger delivery volume within the aircraft’s carrying capacity for the complementary alliance flights. Constraint (9) indicates that the sum of the two demand arc flows in the two networks associated with the same demand should be less than or equal to the forecast trip demand. Constraint (10) indicates that under the parallel alliance, the allied airlines should simultaneously provide at most one flight. Constraints (11) and (12) hold all the arc flows within their bounds. Equation (13) ensures the integrality of the airplane flows.

3. Numerical Tests

To test how well the model may be applied in the real world, we performed numerical tests using operating data from two major Taiwan airlines, with reasonable assumptions. We used the C computer language, coupled with the mathematical programming solver, CPLEX 8.0, to build the model and to solve the problems. The tests were performed on a Pentium 4 – 3.2G with 1.5Gb of RAM in the environment of Microsoft Windows XP. We used the operating data to build the model, and then solved the problem.

3.1 Data analysis
Our numerical tests were mainly based on the data obtained from two major Taiwan airline’s domestic operations (Airlines A and B) during the summer of 2003, with reasonable simplifications. Eight cities were served by Airline A with a single fleet of 19 AirBus 320s aircraft, with an average of 160 seats each. Nine cities were served by Airline B with 25 MD-90 aircraft, with an average of 155 seats each. All the cost parameters and other inputs, such as the flight time, the distance between stations, the landing quota at each airport, the available time slots at each airport, and the ground handling time, were primarily based on actual operating data and Taiwan government regulations, with reasonable simplifications. In addition, the cost that the rth allied airline must pay to the other allied airline to compensate for the delivery of a passenger is set as ninety percent of the ticket fare. Note that, similar to Yan and Tseng (2002), the fixed cost (i.e. the sunk cost) and the indirect cost (for example, the capital investment, depreciation, maintenance or rental charges), which are constant in terms of short-term operations, are not included in the model. That is, the profit calculated here is the short-term “operating profit”, rather than the actual profit of the system. However, through the optimization of the short-term profit, the long-term system profit can be improved.

3.2 Test results
Table 1 shows the problem size and the test results. The term “mixed alliance” denotes the combination of both parallel and complementary alliances. OBJ represents the best feasible solution obtained. Best Node represents the best objective function value of all the unexplored nodes in the branch-and-bound tree, which serves as the lower bound of the problem. GAP represents the gap between OBJ and Best Node.

<table>
<thead>
<tr>
<th></th>
<th>Airline A</th>
<th>Airline B</th>
<th>mixed alliance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Airline A</td>
</tr>
<tr>
<td>#Variables</td>
<td>15048</td>
<td>21658</td>
<td>40284</td>
</tr>
<tr>
<td># Constrains</td>
<td>5209</td>
<td>11276</td>
<td>15982</td>
</tr>
<tr>
<td>OBJ(NT$)</td>
<td>-16890876</td>
<td>-17676897</td>
<td>-35152281</td>
</tr>
<tr>
<td>BEST NODE(NT$)</td>
<td>-16903147</td>
<td>-17973459</td>
<td>-36220794</td>
</tr>
<tr>
<td>GAP(%)</td>
<td>0.0725</td>
<td>0.165</td>
<td>2.95</td>
</tr>
<tr>
<td>Computation time (sec)</td>
<td>2.06</td>
<td>3.61</td>
<td>354.13</td>
</tr>
<tr>
<td>Fleet size</td>
<td>19</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Frequency (flights/day)</td>
<td>188</td>
<td>203</td>
<td>202</td>
</tr>
<tr>
<td>Service rate(%)</td>
<td>95.8</td>
<td>96.2</td>
<td>99.2</td>
</tr>
<tr>
<td>Average load factor (%)</td>
<td>62.081</td>
<td>65.721</td>
<td>63.858</td>
</tr>
</tbody>
</table>

As shown in Table 1, we found that compared with the individual airline’s objective values, with a mixed alliance, the objective value of Airline A increased from -16890876 to -17245584 (an improvement of 2.1%), and the objective value of Airline B increased from -17676897 to -17906697 (an improvement of 1.3%). For the service rate, Airline A had an increase from 95.8% to 99.2%, while Airline B had an increase from 96.2% to 99.4%. For the average load factor, Airline A had an increase from 62.081% to 63.858%, while Airline B had an increase from 65.721% to 66.451%. For the frequency, Airline A had an increase from 188 flights to 202 flights, and Airline B’s increased from 203 flights to 214 flights.
From the above results, we found that the mixed alliance integrated not only the parallel routes but also connected the complementary routes, which improved the operating performance. The model could help the participating airlines solve for the most satisfactory fleet routes and timetables under the alliance.

Finally, the fleet flows obtained above could not yet be directly put into practice without identifying each airplane path in the fleet-flow networks. The flow decomposition method (Yan and Young, 1996) was applied to trace the path of each airplane.

4. Conclusions
In this research, on the basis on the basis of the carrier’s perspective, we develop a coordinated flight scheduling model designed to help the participating airlines solve for the most satisfactory fleet routes and timetables under the alliance. We employ network flow techniques to construct the model. The model includes multiple passenger- and fleet-flow time-space networks that can formulate the flows of passengers and allied fleets in the dimensions of time and space. A case study, utilizing the domestic operations of two major Taiwan airlines, was conducted to show how to actually apply the model in the real world. The results show that the coordinated alliance not only reduces the operating cost but also increases profit. The model and the case study should all be useful reference material for allied airlines to determine the most optimal short-term fleet routes and flight schedules.

If there are more than two airlines with alliance, the model may be suitably modified. The extension of single-fleet routing to multi-fleet routing, and the incorporation of other objectives, operating constraints or alliance strategies involved in actual operations, could be directions for future research. Finally, although the model developed is anticipated to function as a helpful tool for allied airline scheduling practices, the applications need not be restricted to only air transport. Through partial modification, the model could be applied to other modes of transport with similar characteristics, for example, fleet routing and scheduling in marine transport and in highway passenger transport. These potential applications could presumably form future research topics.

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