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THE PARTNER CONNECTION SELECTION MODEL FOR INTERNATIONAL AIR ROUTES UNDER MULTI-HUB SCENARIOS

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Abstract: When the beyond network can be developed through more than one hub, partner selection is no longer only a question of who operates the connecting segment: the hub, the carrier and the beyond path have to be settled together. Building on the single-hub model, the path selection variable gains a partner subscript, a base parameter ties each carrier to the hubs it can serve from, a passenger threshold screens out cooperation too small to pay for its own opening cost, and the share forecast by the quality of service index (QSI) sets the demand ceiling on each path; the result is a mixed integer program for joint carrier-hub-path selection. A large Chinese carrier radiating beyond points from several European hubs provides the case. Solved with CPLEX in AIMMS, the model returns an optimized total revenue of 87.66 million CNY. Most paths go to the carrier based at the corresponding hub, which matches how such markets actually operate, and changes in fares, QSI values and market demand move the selection.
Keywords: Air transportation; Airline alliance; Partner selection; Hub network; Quality of service index; Mixed integer programming

1 INTRODUCTION

The onward market behind an international route is rarely covered by a single hub. A Chinese carrier entering the beyond market through European gateways can send passengers to British and Irish beyond points through Heathrow, or to the beyond points of western and northern Europe through Amsterdam, Paris or Frankfurt. Different hubs come with different partners and different reachable beyond points: a hub may be the base of one carrier only, while another carrier centres its network on a different hub. Partner selection therefore stops being a single-point question of who takes the segment and becomes a three-dimensional one: through which hub, with which carrier, and along which beyond path.

What makes the three-dimensional decision hard is that complementarity and competition between networks appear at the same time. One beyond path may be covered by two hubs at once, in which case the two partners offer substitutes for each other; on thin paths cooperation is not necessarily economic, because opening a joint product carries a fixed outlay and below some passenger volume the revenue does not cover that outlay. Decide the three layers separately and the plan easily ends up with every path reasonable on its own while the network as a whole is duplicated. These factors therefore have to enter one model and be weighed against a single revenue objective.

Work on single-hub partner selection already offers a workable modelling route [1], but the multi-hub case is left open: hub-network studies usually stop at location and flow allocation and take the partner as a given set of alliance members [2-4], while alliance studies look at the terms and stability among members [5-8] and seldom solve “with whom” and “through which hub” together. The point where the two meet — share determined by product attributes as a constraint, revenue as the objective, and 0-1 choices made at once across carrier, hub and path — has not been worked out.

This paper carries out that extension on top of the single-hub model: the subscript of the path selection variable moves from the path to the partner-hub-beyond point, a base parameter describes how a carrier is tied to its hub, a passenger threshold removes cooperation that does not pay, and the post-cooperation share forecast by QSI becomes the demand ceiling of each path. The model is solved with CPLEX on AIMMS; the case gives an optimized total revenue of 87.66 million CNY and shows most paths carried by the base carrier. Section 2 reviews the related work, Section 3 sets out the problem and the model, Section 4 reports the case, and Section 5 concludes.

2 LITERATURE REVIEW

Three strands of work bear on the problem: the economic effects and stability of alliance cooperation, methods of forecasting market share, and hub networks together with path optimization.

Alliance studies answer why carriers cooperate and how cooperation holds. Oum and Park surveyed the forms, policy issues and direction of alliances and described them as a long-term arrangement that links continental markets through super-hubs [5]; Brueckner started from the economics of code sharing and showed that the gains come from complementary segments and product integration, and discussed the effect on fares and welfare [6]. Chinese work sits more at the level of mechanism: Zheng and Wang described alliance stability as a dynamic cooperative game and argued that a member stays or leaves according to the allocation rule [7]; Cong et al. studied network decisions under

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revenue sharing and linked network design to revenue distribution [8]; Mi classified the organizational forms of international route joint ventures and the conditions for them [9]. The object of this strand is the inside of the alliance, and the choice a member faces between an inside and an outside partner is rarely treated.

Share forecasting answers how many passengers cooperation brings. The quality of service index (QSI) is the most widely used tool: it scores product attributes — sales network, frequent flyer programme, transfer service and airport coordination — and converts the weighted score into a share. Zhao et al. adapted QSI forecasting to the alliance setting and brought alliance-induced attribute changes into the prediction [1]; Hu et al. proposed a multi-layer QSI for alliance network optimization [10]; Chen et al. and Deng et al. improved accuracy with a PSO-BP network and a long short-term memory network respectively [11-12]; Chen and Xu discussed the composition of route share and the factors behind it at an early stage [13]. This strand delivers reliable share forecasts, but the forecast usually stays an evaluation result and seldom enters a selection model as a constraint or a parameter.

Hub network and path studies supply the modelling tools. O'Kelly's quadratic integer programme put hub location and flow allocation into one formulation [2]; Ernst and Krishnamoorthy gave a mixed integer linear formulation and exact algorithms for the multiple allocation p-hub median problem [3]; Alumur and Kara reviewed the family of hub location models [4]. In China, Yan and Ma optimized aircraft routes based on transshipment under route joint ventures [14]. The objective in this strand is usually network cost or fleet operating cost; product attributes do not enter the share, and "with whom to cooperate" is not a decision dimension of its own.

Taken together, the gap is this: share forecasting says how many passengers can be won, network models say where to place capacity and how to allocate flows, but no framework carries both into partner selection at once. Using the QSI-forecast share as a demand ceiling, putting partner, hub and beyond point into one set of 0-1 variables, and expressing base affiliation and the passenger threshold as constraints is the response to that gap.

3 JOINT SELECTION MODEL FOR ONWARD CONNECTING CARRIER AND HUB BEYOND MULTIPLE HUBS

3.1 Problem Description

A carrier choosing a partner has to weigh the return on the onward connecting flight so that the OD path is complete. In this case the feeder flight and the target segment are both assumed to be flown by a large Chinese carrier, and the onward connecting flight by another carrier. Such carriers fall into alliance members and non-members (including independent carriers), and the difference shows up in the sales network, the frequent flyer programme, transfer service and airport coordination. QSI share forecasting makes the effect of a change in product attributes — alliance or not — on share measurable, and on that basis the attributes of the target route can be optimized to raise its share and improve the position of the routes that matter.

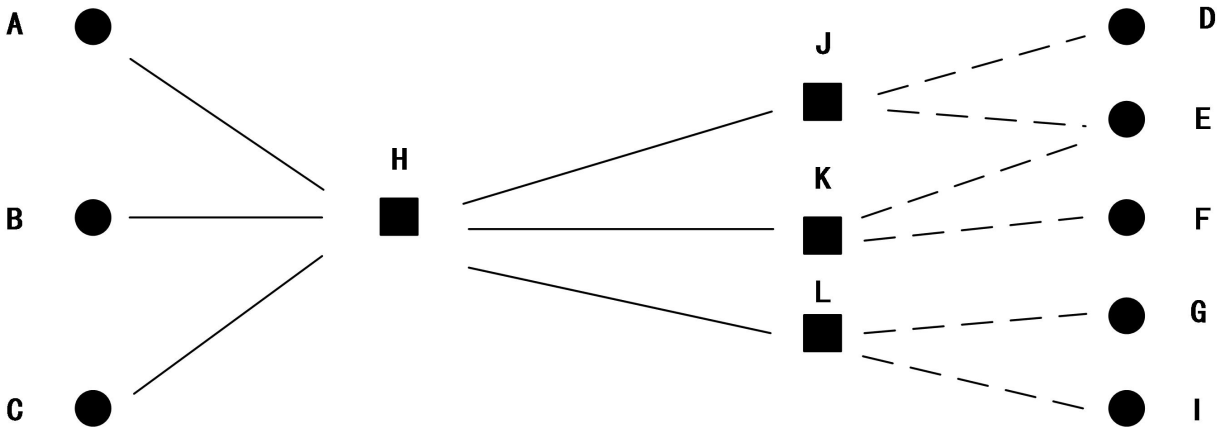


Figure 1 Schematic Structure of the Cooperative Network beyond Multiple Hubs

The model concentrates on the carrier of the onward flight, the hub and the path. The carrier is assumed to have completed the feeder flight and the target route (the solid lines in Figure 1), and what remains is to choose the carrier and the beyond points for the onward market (the dashed lines in Figure 1), still under a revenue-maximizing objective.

The difference from the conventional single-hub network problem is that the onward network differs from carrier to carrier. Hub J, for instance, may be the base of carrier B only, while carrier C is based at K. Partners therefore have to be distinguished, since a different partner brings a different connecting network; only then can one optimize which hub and which beyond points to develop for one partner or for several.

Figure 1 shows that the networks available differ by partner. For an airline using H as its hub, cooperation with different partners in different OD markets is therefore the natural arrangement, and these networks are complementary and competing at once, which is why the path selection variable has to carry a partner subscript. The difficulty is to decide the carrier, the hub and the path at the same time.

3.2 Parameters and Decision Variables

The model takes the flights on the target route of the onward market as the target flight and, with the alliance carriers B1, B2, … and the non-alliance carriers C1, C2, …, builds a route product optimization model with revenue maximization as its aim.

3.2.1 Model parameters

B: set of alliance carriers, $i \in A$; in the case, B1 and B2 both belong to B;
C: set of non-alliance carriers; in the case, C1 and C2 both belong to C;
A: set of all carriers, covering alliance carriers and independent carriers, that is, the sets B and C above;
H: set of candidate hubs; a hub here is not a conventional hub but a point at which onward cooperation can be opened, such as J, K and L in Figure 1;
D: set of candidate beyond points, that is, the beyond points that the candidate partners can reach from the hubs above, such as D, E, F, G and I in Figure 1;
OD: set of hub–beyond point pairs that can be connected nonstop. For elements $h \in H, d \in D$, if h and d are connected nonstop then $hd \in OD$.
$W_{i,j}$: candidate hub parameter, taking the value 0 or 1, where $i \in H$ and $j \in C$. $W(i,j) = 1$ means that i is the hub of partner j, and $W(i,j) = 0$ means that i is not the hub of partner j;
$OpenCost_{h,d,c}$: opening cost for the onward carrier c to open path h–d;
$Fare_{h,d,c}$: fare per passenger on the joint product segment when cooperating with carrier c on onward path h–d;
$Cost_{h,d,c}$: cost per passenger on the joint product segment when cooperating with carrier c on onward path h–d;
$QSI_{h,d,c}$: QSI value of carrier c on path h–d;
$demand_{h,d}$: passenger demand on onward path h–d;
N: the minimum number of passengers on a path if the joint product with a candidate carrier on an onward path is to qualify for opening.
WeightS: coefficient of the sales network in the QSI; WeightT: coefficient of transfer service; WeightA: coefficient of airport coordination; WeightF: coefficient of the frequent flyer programme;
M: a sufficiently large number;
Seat: number of seats of the aircraft type currently used on the target flight.

3.2.2 Decision variables

$x_{h,d,c} = \begin{cases} 1\ , & cooperate\ with\ partner\ c\ on\ h-d \\ 0\ , & no\ cooperation\ with\ partner\ c\ on\ h-d \end{cases}$. One path may carry several joint flight products, but on a single path cooperation may only be opened with one partner c. The decision variable of this model is therefore defined per path, $x_{h,d,c}$, and not for each flight combination.

$ODinc_{h,d,c}$: the number of passengers expected to be won by all joint products on onward path h–d when cooperating with carrier c after optimization; $NewQSI_{h,d,c}$: the QSI value of carrier c on path h–d after optimisation, given by $NewQSI_{h,d,c} = QSI_{h,d,c} + x_{h,d,c} \times (WeightS \times SaleNet_c + WeightT \times TransferSV_c + WeightF \times FFP_c + WeightA \times AptCo_c)$.

With the parameters and variables above, the alliance partner selection model is built with total revenue as the objective:

$$max\ Revenue = \sum_{c \in C}^{for\ all\ OD} [ODinc_{d,h,c} \times (Fare_{d,h,c} - Cost_{d,h,c}) - OpenCost_{d,h,c}] \quad (1)$$

$$\text{s.t } x_{h,d,c} \le W_{h,c} \quad \text{for} \quad h \in H, d \in D, c \in C \quad (2)$$

$$demand_{h,d} \times NewQSI_{h,d,c} / \sum_{c \in C} NewQSI_{h,d,c} \ge ODinc_{h,d,c} \quad \text{for} \quad hd \in OD, c \in C \quad (3)$$

$$\sum_{c \in C}^{n} ODinc_{h,d,c} \le demand_{h,d} \quad \text{for} \quad hd \in OD \quad (4)$$

$$ODinc_{h,d,c} \le M \times x_{h,d,c} \quad \text{for} \quad hd \in OD,\ c \in C \quad (5)$$

$$N - ODinc_{h,d,c} \le M \times (1 - x_{h,d,c}) \quad \text{for} \quad hd \in OD, c \in C \quad (6)$$

$$\sum_{c \in C} x_{h,d,c} \le 1 \quad \text{for} \quad h \in H, d \in D \quad (7)$$

$$OD_{h,d,c} \le Seat \quad (8)$$

$$ODinc_{h,d,c} \ge 0, x_{h,d,c} = \quad 0 \text{ or } 1 \quad (9)$$

Objective (1) maximizes total revenue, the difference between fare revenue and transport cost. Constraint (2) states that carrier c may serve path h–d only when hub h is the base of carrier c; if this condition is not required, replace it with $x_{h,d,c} \le 1$. Constraint (3) keeps the passengers carried by carrier c on h–d no larger than the QSI-predicted number of passengers who would fly with carrier c on path h–d; (4) keeps the total passengers carried on h–d no larger than the QSI-predicted demand; (5) sets the passengers carried by carrier c on h–d to zero when carrier c does not serve that path; (6) states that when cooperation with partner c on path h–d cannot bring the total passengers of all products up to the threshold N, cooperation with c on that path is given up; (7) guarantees that on path h–d at most one carrier is cooperating; (8) is the capacity constraint, keeping the passengers carried by a single flight after optimization no larger than the seats offered.

4 CASE STUDY

4.1 Case Data

The time frame of the data needs a word. After 2019 the air transport market absorbed a series of external shocks, and capacity, fares and demand became far more volatile, so recent cross-sectional data no longer describe a stable product competition; to keep the model inputs representative of normal conditions, historical data from before 2019 are used.
Seat cost is set at roughly CNY 0.3–0.7 per kilometer in line with practice, lower for larger aircraft and longer stages. All stages here are within 2,000 km and mostly C-class aircraft are flown, so the aircraft is fixed at 100 seats and the monthly frequency at 15, giving about 1,500 seats a month. The value of WeightS is -0.050; WeightT is 0.035; WeightA is 0.029; WeightS is -0.00041. Space limits the full data that can be shown; the other target-flight data required by the optimization are given in Table 1.

Table 1 Data of the Onward Connecting Partners

Hub airport	Beyond point	Partner	Seat cost (CNY)	Average fare (CNY)	QSI value
LHR	GLA	BA	833	3400	0.67
AMS	GLA	AF	720	1900	0.2
AMS	GLA	KL	720	2800	0.27
AMS	GLA	BA	720	1700	0.1
LHR	MAN	KL	575	3025	0.29
LHR	MAN	BA	575	1800	0.34
CDG	MAN	AF	1200	2500	0.24
CDG	MAN	BA	1200	2000	0.21
FRA	MAN	BA	840	3580	0.15
FRA	MAN	LH	840	4080	0.15
FRA	MAN	AB	840	2800	0.1
FRA	MAN	IB	840	3200	0.1
AMS	MAN	KL	400	800	0.6
ARN	MAN	KL	1400	2500	0.2
ARN	MAN	BA	1400	2300	0.1
ARN	MAN	LH	1400	2700	0.1
ARN	MAN	AY	1400	3300	0.1
ARN	MAN	SK	1400	3100	0.1
LHR	MUC	BA	866	3800	0.43
LHR	MUC	LH	866	3330	0.34
LHR	MUC	AB	866	2600	0.11
FRA	MUC	KL	300	2500	0.1
FRA	MUC	LH	300	2110	0.3
MAD	MUC	LH	1200	1500	0.18
MAD	MUC	UX	1200	1800	0.09
MAD	MUC	AB	1200	1800	0.1
MAD	MUC	LX	1200	1600	0.13
MAD	MUC	IB	1200	1700	0.1
SVO	MUC	AF	1800	2800	0.21
SVO	MUC	KL	1800	3200	0.17
SVO	MUC	SU	1800	2700	0.15
AMS	MUC	KL	660	1400	0.33
AMS	MUC	LH	660	1500	0.25
ARN	MUC	LH	1300	3000	0.2
ARN	MUC	AY	1300	3100	0.1
ARN	MUC	AB	1300	2400	0.1
ARN	MUC	SK	1300	5200	0.1
LHR	HAJ	AF	600	1900	0.19
LHR	HAJ	KL	600	2290	0.28
LHR	HAJ	BA	600	2260	0.11
LHR	HAJ	LH	600	2500	0.21
FRA	HAJ	KL	280	3990	0.15
FRA	HAJ	LH	280	2110	0.25
SVO	HAJ	AF	1800	3400	0.21
SVO	HAJ	KL	1800	4200	0.17
SVO	HAJ	SU	1800	5300	0.15
AMS	HAJ	AF	350	1700	0.2
AMS	HAJ	KL	350	2200	0.34
AMS	HAJ	LH	350	2200	0.11

Table 2 gives the path demand, that is, the monthly passengers from the hub airport to the beyond point. Only part of the software data is listed, so the figures may differ slightly from practice and can be adjusted in the software as required.

Table 2 Path Demand Data

Hub airport	Beyond point	Market demand (passengers)
AMS	MAN	7561
FRA	MUC	7374
FRA	HAM	6887
FRA	HAJ	5803
CDG	MAN	5689
LHR	MAN	5500
SVO	WAW	5475
CDG	FLR	4921
AMS	DUS	4758
FRA	FLR	4518
SVO	MUC	4450
SVO	DUS	4193
FRA	MAN	4100
AMS	HAM	3990
CDG	DUS	3808
CDG	MRS	3439
CDG	MUC	3369
AMS	HAJ	3255
AMS	MUC	3053
CDG	WAW	2942
AMS	WAW	2797
AMS	FLR	2785
CDG	HAM	2762
CDG	HAJ	2444
LHR	GLA	2100
AMS	GLA	1913
FRA	WAW	1903
LHR	DUB	1843
SVO	HAM	1676
LHR	NCL	1560
FRA	BSL	1203

4.2 Solution Results

The model was solved on the AIMMS optimization platform with CPLEX 12.5 as the solver, on a CPU of Intel(R) Core(TM) i7-6660 with 8 GB of memory. Optimized total revenue is CNY 87.66 million; part of the solution is reported in Table 3.

Table 3 Optimisation Results for the Onward Connecting Partners

Hub airport	Beyond point	Partner	Selected (1 = yes, 0 = no)	Passengers carried
MAD	MUC	AB	1	95
LHR	BSL	AF	1	112
CDG	DUS	AF	1	1196
CDG	FLR	AF	1	1500
AMS	HAM	AF	1	1173
CDG	HAM	AF	1	785
CDG	LUX	AF	1	257
CDG	MAN	AF	1	1500
CDG	MRS	AF	1	1500
CDG	NAP	AF	1	198
CDG	RNS	AF	1	489
CDG	WAW	AF	1	859
FCO	NAP	AZ	1	73
FCO	PSA	AZ	1	60
LHR	DUB	BA	1	1330
LHR	GLA	BA	1	1500
LHR	MUC	BA	1	272
LHR	NCL	BA	1	1282
AMS	BSL	KL	1	212
AMS	DUS	KL	1	1500
AMS	FLR	KL	1	1097
AMS	GLA	KL	1	696
AMS	HAJ	KL	1	1413

In the selection column, 1 means the partner is chosen and 0 means it is not; AIMMS displays only the partners that were selected. Table 3 shows that on most paths the carrier based at that hub airport is chosen, which agrees with practice. When the fares and QSI values in Table 1 or the market demand in Table 2 change, the results in Table 3 change as well.

5 CONCLUSIONS

This paper has moved partner selection in the onward market from two dimensions, carrier and path, to three: the subscript of the path selection variable carries the partner, so options through different hubs on the same beyond path can be compared inside one model; the base parameter keeps a carrier to the hubs it is based at; and the passenger threshold removes cooperation too small to cover its opening cost. With the QSI-forecast share as the demand ceiling, the model stays a linear integer program that general-purpose solvers can take directly.

The case, solved with CPLEX on AIMMS, returns an optimized total revenue of CNY 87.66 million. Across the 23 paths listed, most are carried by the carrier based at the corresponding hub, which matches how these markets operate: a base carrier knows the transfer process, the slot connections and the sales network at its own airport better, and its native attributes dominate on the onward segment. The results also show what the threshold and the capacity constraint do — on paths with high seat cost and thin demand, whether cooperation opens depends on passengers clearing the threshold, while on paths where demand is concentrated the 1,500-seat monthly capacity becomes the binding constraint.

The sensitivity comes from three inputs: fares, QSI values and market demand. A change in any one of them can alter the selection, which the case bears out and which suggests that in practice these three should be rolled forward as inputs rather than fixed once as constants.

Limits remain. Demand is treated as deterministic, so fluctuation is not represented. Attribute scores and weights depend on expert judgement and an existing fit, and their currency is limited. Cooperation is limited to one carrier per path, so competition and synergy among several partners at the same hub are left out. Revenue sharing is not in the model either, and the division of the cooperative surplus still has to be settled by negotiation outside it.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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