Robust Optimization in Airlines' Hybrid Channels Coordination with Service-Level Constraints

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Abstract. This essay considers the influence of the service level in the research of the robust optimization of airlines' hybrid channels coordination with uncertain demands. In the essay, the service level is taken as a constraint in the model that is established based on the characteristics of channels coordination and scenario analysis. In this way, it can make the airlines' hybrid channels coordination more effectively. Then three-dimensional numerical experiments of the robust optimization model are performed and the results show that the model proposed is robust to uncertain demands and fit for airlines' hybrid channels coordination; Airlines should focus on promoting the direct channel and passengers' stickiness; agents should focus on reducing the cost of the channels, and they should carry out improve-service-level cooperation to attract passengers; airlines and agents also should cooperate with each other to obtain win-win strategies.

1. Introduction

Recently, some China's major airlines such as Air China and China Southern Airlines have a statement successively with China's third major OTA Qunar.com to suspend cooperation, it shows that the channels competition between airlines and agents has been heating up and chaotic airlines' hybrid channels need effective coordination urgently.

At home and abroad, the research of airlines' hybrid channels management and robust optimization method have achieved fruitful results. Cheng, Lee, Shomali took American airlines as the object and studied the coordination problem of Internet direct channel and traditional marketing channel of airlines under the condition of electronic market [1]. Zhang, Ding, Sun carried out the research on strategy selection of airlines' hybrid channels by using evolutionary game theory [2]. Saha [3] and David, Adida [4] studied the coordination of dual-channel supply chain on the perspective of channel structure and channel competition. Xu and Huang [5-6] established the single-objective and multi-objective robust operation model for electronic supply chain with uncertainty demand. Then Xu and Huang [7] established the multi-objective fuzzy programming model for operation of supply chain by using the fuzzy set method and robust optimization method.

Service level is widely used in the field of supply chain. Liu, Dong and Zhang discussed the single buyer's optimal purchasing decision in two-period when facing opportunity constraints of service level [8]. Sun and Zhang mainly studied the strategy for the inventory cost of the traditional channels with service-level constraint. First in connection with the characteristics of the traditional channels, they built the new inventory control model with service-level constraint considerations and then proposed the corresponding algorithm and steps for its solution [9]. Shen, Zhang and Qing considered

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a kind of supply chain system. The impacts of the service-level constraint on supply chain's profits and the effect of differentiated buy back contract were analyzed by numerical analysis [10].

These essays have conducted fruitful research on the question of airlines' hybrid marketing channel coordination and some qualitative analysis about service level and have achieved lots of useful results. However, at present, the study of management and optimization in airlines mainly focus on aviation operation problems like airlines flight schedules or airlines crew pairing, it still lack of robust optimization research on the coordination of the airlines' hybrid channels under the circumstance of fully Internet "+" and lack of the quantitative consideration of service level in the field of aviation. According to the present situation, the general scheme of this essay is as follows.

2. Modeling

2.1. Structure of channels

With the continuous development of Internet technology, the airline's hybrid channels are undergoing continuous changes. Airline's hybrid channels refer to the network marketing channels and traditional marketing channels co-existing and airlines' hybrid channels can be divided into two types of direct channels and distribution channels according to the subjects of the channel, the marketing channels that tickets are directly sold from airlines to passengers are known as direct channels; the channels that tickets are indirectly sold from ticket agents and other subjects to passengers are known as distribution channels. There are several sub-categories in direct channels and distribution channels.

The structure of channels coordination system is presented in Figure 1.

Figure 1. Airlines' hybrid channels coordination system.

2.2. Notations

The air tickets, airlines, passengers and agents in the coordination system are expressed separately with the subscripts i, j, k, l .

e_{ijk} , per unit main business income for airlines j sells air ticket i to passenger k (include the income of tickets, luggages, and other income got by airlines); $e_{l,ik}$, per unit main business income for agent l sells air ticket i to passenger k ; c_{ijk} , per unit variable cost for airlines j sells air ticket i to passenger k ; $c_{l,ij}$, per unit variable cost for airlines j copes with agent l ; $c_{l,ik}$, per unit variable cost for agent l sells air ticket i to passenger k ; r_{ij} , preparation cost for airlines j produces air ticket i ; f_{jk} , fixed cost for airlines j satisfies (some) demands of passenger k ; $f_{l,j}$, fixed cost for airlines j copes with agent l ; $f_{l,k}$, fixed cost for agent l copes with passenger k ; C_{ij} , maximum transportation capacity of air ticket i of airlines j ; T_j , total transportation capacity of airlines j ; d_{ik} , demands of air ticket i from passenger k ; q_{ik} , per unit penalty for the quantity of air ticket i does not satisfy the demands of passenger k ; x_{ijk} , quantity of air ticket i that passenger k purchases from airlines j ; $x_{l,ik}$, quantity of air ticket i that passenger k purchases from agent l ; $z_{jk} \in \{0,1\}$, if airlines j satisfies some demands of passenger k , then $z_{jk} = 1$, otherwise $z_{jk} = 0$; u_{ik} , quantity of air ticket i that does not satisfy the demands of passenger k ; $y_{ij} \in \{0,1\}$, if airlines j offers air ticket i , then $y_{ij} = 1$, otherwise $y_{ij} = 0$;

Assuming there are s kinds of possible scenarios of the passengers' uncertain demands in the coordination system which can use a set $G_s = \{1, 2, \dots, s\}$ to represent. The probability of scenario s is p_s and $\sum_{s \in G_s} p_s = 1$. The demands of air ticket i from passenger k under scenario s is d_{ik}^s . Assuming x_{ijk} , $x_{l,ik}$, z_{jk} are control variables, the other decision variables are effective for all scenarios. Under these conditions, for each scenario s , the quantity of air tickets purchased by passengers from airlines and agents and whether the airlines adopts direct selling or distribution strategy will depend on different demands of the scenario, these parameters can represent with x_{ijk}^s , $x_{l,ik}^s$ and z_{jk}^s . In addition, u_{ik}^s represents the quantity of air ticket i that does not satisfy the demands of passenger k under scenario s .

In the model, there are two factors worthy of attraction: ① Air tickets have been realized in fully electronic and open inventory to all channels, so there is no products transportation and inventory problem when air tickets in the whole coordination system; ② In this essay, the service level indicates the degree of the satisfaction with the market demands. Considering the limit, the service level of the airlines can use α ($\alpha \in [0, 1]$) to represent and the service level of the agents can use β ($\beta \in [0, 1]$).

2.3. Robust optimization model

Objective function (maximize the total profits of airlines' hybrid channels coordination):

$$\max P = \sum_{s \in G_s} p_s \left[\sum_i \sum_j \sum_k e_{ijk} x_{ijk}^s + \sum_l \sum_i \sum_k e_{l,ik} x_{l,ik}^s - \sum_i \sum_j \sum_k c_{ijk} x_{ijk}^s - \sum_l \sum_i \sum_j c_{l,ij} x_{l,ij}^s - \sum_i \sum_j t_{ij} y_{ij} - \sum_j \sum_k f_{jk} z_{jk}^s - \sum_l \sum_j f_{l,j} - \sum_l \sum_k f_{l,k} - \sum_l \sum_i \sum_k c_{l,ik} x_{l,ik}^s - \sum_i \sum_k q_{ik} u_{ik}^s \right] \quad (1)$$

In the objective function, $\sum_i \sum_j \sum_k e_{ijk} x_{ijk}^s$ represents total main business income of production for all airlines under scenario s , $\sum_l \sum_i \sum_k e_{l,ik} x_{l,ik}^s$ represents total main business income of all agents under scenario s . Other constraints are as follows.

Total capacity of i :

$$\sum_k x_{ijk}^s + \sum_l x_{l,ik}^s - y_{ij} C_{ij} \leq 0, \forall s, i, j \quad (2)$$

Total capacity of j :

$$\sum_i \sum_k x_{ijk}^s + \sum_l \sum_i \sum_k x_{l,ik}^s \leq T_j, \forall s, j \quad (3)$$

The supply of airlines does not exceed the total demands of passengers:

$$x_{ijk}^s \leq \sum_k z_{jk}^s d_{ik}^s, \forall s, i, j \quad (4)$$

The supply of agents does not exceed the total demands of passengers:

$$x_{l,ik}^s \leq \sum_k d_{ik}^s, \forall s, i, l \quad (5)$$

The bottom limit the distribution channel is t :

$$\sum_s \sum_l \sum_i \sum_k x_{l,ik}^s \geq t \left(\sum_s \sum_l \sum_k x_{ijk}^s + \sum_s \sum_l \sum_i \sum_k x_{l,ik}^s \right), \forall j \quad (6)$$

Constraint of the service level of airlines:

$$\frac{\sum_j x_{ijk}^s}{d_{ik}^s} \geq \alpha, \forall s, i, k \tag{7}$$

Constraint of the service level of agents:

$$\frac{\sum_l x_{ikl}^s}{d_{ik}^s} \geq \beta, \forall s, i, k \tag{8}$$

Because the constraints of (7) and (8) are non-linear, supposing that $b = \frac{1}{d_{ik}^s}$, and then the constraints of (7) and (8) are rewritten as linear constraints:

$$b \sum_j x_{ijk}^s \geq \alpha, \forall s, i, k \tag{9}$$

$$b \sum_l x_{ikl}^s \geq \beta, \forall s, i, k \tag{10}$$

Constraint of demand and supply:

$$\sum_j x_{ijk}^s + \sum_l x_{l,ik}^s + u_{ik}^s \geq d_{ik}^s, \forall s, i, k \tag{11}$$

3. Numerical experiments and analysis

In order to carry out the numerical experiments of the robust optimization model mentioned above more objectively, two sets of data with certain and uncertain demands are set to carry out comparative numerical analysis, so as to test the robustness of the model and find out the effect of some values changes of some parameters in the model on the results of the model.

3.1. Robustness verification

Taking the questionnaire research results of passengers’ trip purpose of Li, Zhu, and Chen as reference [11], assuming that there are 3 kinds of passengers in the system. Under the condition of uncertain demands, assuming that each kind of passengers have four kinds of demands scenarios with known probability, these scenarios and the probability of each scenario are shown in Table 1. According to the above principle and actual cost data obtained from the airlines’ marketing department, assuming that the fixed cost and per unit variable cost for airlines copes with three agents are 25 and 4, 3, 2; preparation cost of airlines is 48; maximum transportation capacity is 1100; the bottom limit of proportion of the distribution channel is 60%. The data of income is shown in Table 2 to Table 5.

Table 1. Scenarios of demands

Scenarios	Prob.	Business	Leisure	Others
1	0.1	174	160	144
2	0.2	178	195	144
3	0.3	384	355	239
4	0.4	552	471	360
Certain	1	389	350	259

Table 2. Total main business income under scenario s

	Business	Leisure	Others
Airlines	64	53	46
Agents	57	60	40

Table 3. Per unit variable cost for airlines copes with passengers

	Business	Leisure	Others
Variable cost	18	10	20
Penalty	58	30	40

Table 4. Per unit variable cost for agents cope with passengers

Agents	Business	Leisure	Others
1	27	32	38
2	28	34	30
3	23	31	25

Table 5. Fixed cost to satisfy passengers' demands

	Business	Leisure	Others
Airlines	38	30	18
Agents 1	33	25	15
Agents 2	45	33	32
Agents 3	44	34	26

By LINGO software, keeping the other parameters unchanged and taking the service level α and β as 50%, when passengers' demands are certain and uncertain, maximum total profits of the coordination system is 20125 and 21765. It can be seen from the results the deviation rate of total costs of the coordination system is 8.15%, that is, for the given uncertain demands scenarios, the optimal solution of the model is close to the optimal solution when the demands is certain. And after verification, for any demands scenario $s \in G_s$, the optimal solution is always feasible.

3.2. Numerical experiments of the proportions of distribution channel

The proportions of tickets sold from direct and distribution channel are sum up to 1. Nowadays, the proportion of the distribution channel will have a falling trend. Setting the value of t from 100% to 0% to carry out numerical experiments, remaining other values in section 3.1 to observe the trend of maximum total profits of coordination system. The results are presented in Figure 2.

From Figure 2, we can see that the deviation rates of total profits show three-stage change trend with the value of t decrease. (1) When value of t is from 100% to 95% and from 5% to 0%, the deviation rate is near to 0, that is, decrease of the proportion of distribution channel basically does not affect the robustness of coordination system. But, due to some historical reasons, the two kinds of conditions of distribution channel mentioned above basically will not appear in real airlines' hybrid channels coordination system. (2) When value of t is from 95% to 50%, the deviation rates show a rising trend and peak in 50%, that is, the robustness of coordination system shows a falling trend and the falling trend will reach the valley when the proportion of direct channel is 50%. (3) When value of t is from 50% to 5%, the deviation rates show a falling trend.

These conclusions can be seen, for airlines and agents, based on the current distribution of the status quo and the airline's drastic reduction in the proportion of distribution channels, it is recommended that agents do not over reject the airline's reduced distribution channel ratio strategy, because the appropriate reduction in the proportion of distribution channels will also give agents robust advantages, it is a better strategy for agents. Therefore, agents can work closely with airlines, "retreat in order to advance", in the "sacrifice" of the appropriate reduction of distribution channels, get common pursuit of the best strategy of robustness with airlines, access to coordinated and win-win situation.

Next, setting the value of t from 100% to 0% to carry out numerical experiments, meanwhile remaining other values unchanged in section 3.1 to observe the trend of maximum total profits and airlines' and agents' profits of coordination system under certain and uncertain demands scenarios. The results of numerical experiments are shown in Figure 3 and Figure 4.

Figure 2. Change diagram of deviation rates **Figure 3.** Change diagram of total profits. **Figure 4.** Change diagram of airlines' and agents' profits.

It can be seen from Figure 3 that when the proportion of distribution channel decreases, the maximum total profits show a continued rising trend. It can be seen from Figure 4 that when the proportion of distribution channel decreases, the airlines' profits show the same trend with the total profits and the agents' profits show a continued falling trend.

For airlines, with the falling proportion of distribution channel, the higher proportion of direct channel, the higher total profits and airlines' profits will be. Therefore, airlines are supposed to spare no effort to improve the proportion of direct sales so as to seek maximize profits. For agents, with the falling proportion of distribution channel, the higher proportion of direct channel, the higher total profits will be but the lower agents' profits will be. Therefore agents should grasp the advantage of high proportion of distribution channel.

In summary, taking both the system robustness and total profits into account, when the proportion of distribution channel is from 100% to 50%, the deviation rates show a rising trend and peak in 50% and the maximum total profits increase all the time, that is, the robustness of coordination system shows a falling trend and the profits show a rising trend. Airlines and agents needs to make a choice between the system robustness and total profits. When the proportion of distribution channel is from 50% to 0%, the deviation rates show a falling trend and the maximum total profits still increase, that is, the robustness of coordination system and profits both show a rising trend. Airlines and agents should carry out deeper cooperation with each other and jointly promote the development of aviation market.

3.3. Numerical experiments of the level of service

With the development of the market, passengers' requirements on the service level are getting higher and higher, and the service level directly affects the revenue of airlines and agents. The following examines the impact of service level on system robustness.

Setting the service level of airlines and agents from 0% to 100% to carry out numerical experiments, meanwhile remaining other values unchanged in section 3.1. The results of numerical experiments are shown in Figure 5.

Figure 5. Change diagram of deviation rates of total profits with the change of the service level.

It can be seen from Figure 5 that when the service level of airlines remains the same, the deviation rates show the trend of first falling and then rising with the increase of service level of agents and when the service level of agents remains the same, the deviation rates show the same trend of first falling and then rising with the increase of service level of airlines. And the bottom point is when the service level of airlines and agents are both 90%, that is, the robustness of channels coordination is highest at that time.

Therefore, for airlines, when their service level is less than 90%, airlines should improve the service level to raise the proportion of direct channel through providing more seats by multivariate Internet direct channels, launching preferential package tickets and other measures, as well as increasing the cost of service. When their service level is greater than 90%, airlines can reduce the cost of service and coordination of channels, strategy of putting high proportion of preferential package tickets in the sales area where the service level is high can continue to use.

For agents, the increase of the service level is a double-edged sword. On the one hand, compared to the passengers of airlines, the passengers of agents have lower loyalty of channels, hence agents should improve the service level by providing more personalized user experience than airlines at the expense of more costs. On the other hand, agents can also obtain maximum benefits to offset the cost above by putting high proportion of preferential package tickets in the sales area where the service level is high.

4. Conclusion

By performing numerical experiments of the proportions of distribution channel and the level of service, with the proportion of distribution channel continues to decrease and the level of service continues to increase, ① airlines should focus on raising the proportion of direct channel and passengers' satisfaction through multivariate service and products; ② agents should improve the service level by providing more personalized user experience than airlines at the expense of more service costs and carry out deeper cooperation with airlines; ③ airlines and agents should cooperate on service and experience and other aspects to attract passengers, and put high proportion of preferential package tickets in the sales area where the service level is high. It will help airlines' hybrid channels coordination system have higher robustness and more orderly, so as to reach win-win situation of airlines and agents.

But with the service requirements of passengers are higher and higher and the demands are increasingly diversified, how to enrich the quantification of service level are matters of concern.

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