Yield Management Method Focused on Discount Ticket Sales Quota

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One approach for increasing the revenue of railway undertakings is to adopt yield management techniques, by setting quotas for discount ticket sales of reserved seats on express trains. We developed a method to calculate the optimum sales quota, incorporating estimations for the demand of various discount tickets and purchase behavior of passengers with the next-best-option when they were not able to buy their desired ticket. We conducted a trial sale by applying the calculated sales quota into the actual seat reservation system and confirmed that the method can increase revenues and facilitate decision-making for setting sales quotas.

Keywords: yield management, discount ticket, revenue, sales quota, reserved seat

1. Introduction

In Japan, railway passengers are supposed to decrease due to population decline. Since railway operators have self-supporting accounting systems, the expected fall in demand poses a serious issue. Maintaining current levels or increasing revenue has become a key priority.

Applying a yield management method (abbreviated “YMM” hereafter) could be a solution to this problem. YMM is a “practice of controlling the availability and/or pricing of products or services with the goal of maximizing expected revenues,” [1] and is especially advanced in the airline and hotel industries. YMM is a sales method which can be applied when the target product or service is fixed in supply and becomes worthless after a certain fixed time. Japanese trains with reserved seats or whose seating capacity is limited satisfy these conditions, therefore, YMM can be applied. One of the approaches to applying YMM is to set and control a maximum sales volume (quota) for certain types of ticket, for seats that are sold at different prices.

We developed a method to calculate the optimum discount ticket sales quota (abbreviated “DTSQ” hereafter) which is expected to maximize revenue. We conducted a trial sale by applying the calculated DTSQ to the actual seat reservation system and confirmed that the method could increase revenues and facilitate decision-making for setting DTSQ.

2. Yield management on airlines and issues to apply it to Japanese railways

Since the early 1970s, airlines in Europe and the USA have been providing ‘early bird’ discount tickets [1], and this is said to be the origin of YMM. The deregulation of Japanese domestic airlines in the late 1990s made it possible to introduce various discount fares [2]. Today, prices

for most Japanese airline tickets are not fixed: their prices vary depending on past or forecast sales. The prices of discount tickets are set at several levels, each with a fixed sales quota. When the number of sales at a specific level reaches the sales quota, the sale of tickets in the next price band starts. Airlines can control the size of the quotas and/or price bands even after tickets have been released for sale, according to actual and predicted sales, in order to maximize revenues.

While the YMM on airlines is highly advanced as described above, it is difficult to transpose an identical system to Japanese railways, because there are some issues, which are listed in Table 1.

- (1) Railway passengers can get on and off a train at any station on the way, while airline passengers cannot. Therefore, the balance between long-distance passengers who pay more as a whole, and short-distance travelers whose fares per kilometer are relatively high, should be considered.
- (2) On most express trains there are non-reserved seats. Since non-reserved seat tickets can be used on any train, it is difficult to know and control exactly the demand for each train.
- (3) Although appropriate overbooking is effective for revenue growth, it cannot be applied to reserved seats on Japanese trains because tickets are sold with designated seats (with few exceptions).
- (4) In Japan, train fares and surcharges for Shinkansen trains are determined within a maximum price framework approved by the government. Therefore, the price of railway tickets cannot rise beyond a certain level, even when demand is high. Airlines, on the other hand, have more flexibility, since they can raise domestic airfares if they notify the government.
- (5) It is difficult to accurately calculate the revenue earned from each train, because the fare is calculated on the basis of journey segments used by each passenger, even if he/she transfers between multiple trains

Table 1 Issues in applying airline YMM to Japanese railways

Issues related to nature of railway journeys	(1) Passengers may travel different journey segments. (2) Some tickets can be sold without seat reservation.
Issues on booking	(3) Overbooking is not allowed.
Issues on fares	(4) Maximum prices must be approved by the government. (5) Revenue earned from each train is difficult to calculate.
Issues related to reservation system	(6) Changing sales quotas and prices is complicated.

operated by same operator. This, however, does not apply to discount tickets valid only on specific express trains, which have increased in recent years.

- (6) Depending on the specification of the seat reservation system, it is complicated and not practical to change sales quotas and prices of railway tickets after sales have begun.

Furthermore, how YMM is actually applied to sales is often kept secret, because it forms a central part of a company's competitive sales strategy to beat competitors. Previous work has remained at theoretical level [3]. As such, there are few references for advanced know-how about how airlines and other industries apply YMM, which is another issue for Japanese railways hoping to apply YMM.

Nevertheless, European intercity trains have been pioneers in adapting YMM to the railways. For example, TGV, the high-speed railway service in France, introduced YMM in 1993 [4]. They offer several different types of ticket at different prices, and prices may change based on actual sales. However, since seat reservation schemes and fare policies differ between Europe and Japan and some of the issues described above do not apply Europe, if YMM is adopted for Japanese railways, it would have to be designed to meet Japan's specific needs.

3. Target yield management method

As explained in Chapter 2, a YMM with raising prices would be hard to apply on Japanese railways. As such, the target for the railways is to design a discount ticket sales strategy which can increase revenue. As illustrated by Table 2, there are numerous controllable elements in YMM. Of these elements, transportation capacity is difficult to modify frequently, because crew and vehicle schedules have to be changed, as are terms of use and sales periods, because changes must be announced to the public. Furthermore, selling many kinds of tickets can be a solution for the company, but it is complicated for customers. On the basis of these considerations, we decided to focus on YMM, controlling DTSQ. Some railway operators already control DTSQ, but it is determined empirically, so there is room to improve YMM with DTSQ.

YMM through DTSQ for the purposes of this study can be defined as follows: while discount tickets can increase the number of passengers, if they are unlimited, passengers who would normally be willing to pay a higher price to travel will also buy them leading to a loss of revenue.

Table 2 Elements of YMM which can be controlled in the case of railways

Transport capacity	- Train operation schedule (timetable and operational plan of extra trains) - Train set and capacity - Allocation of reserved/non-reserved seats
Fare	- Difference depending on date of operation and train - Change based on past sales (dynamic pricing)
Terms of use of ticket	- Booking/purchasing deadlines - Cancellation and change policy (handling fee) - Restrictions on valid days and trains - Restrictions on payment method (e.g. credit card only)
Terms of sales of ticket	- Sales quota (DTSQ) - Period during which discount is available - Changes based on actual sales

Therefore, DTSQ must be determined to prevent excessive discount. On the other hand, a DTSQ which is too limited, can cause a loss of passengers, because some customers unable to buy discount tickets may give up traveling by train, and this also leads to loss of revenue. Consequently, DTSQ should neither be too generous nor too limited. Striking the right DTSQ balance should maximize revenue.

4. Yield management method with discount ticket sales quota

4.1 Outline of the method

A method was designed to calculate DTSQ to maximize expected revenue based on the following assumptions:

- (1) List of tickets, prices and terms of use of each ticket are a given: these were beyond the scope of the study. Price and terms of use for each ticket are same on any day, train and time of booking.
- (2) The method is applied to decide DTSQ before the date on which tickets are released. To adjust DTSQ based on actual sales was beyond the scope of the study.
- (3) The sale of tickets for some specific trains is allowed: for example, discount tickets for early morning or slower trains can exist. Note that the target trains of each ticket are given.
- (4) For some tickets, the sales deadline is set to some days before the day of travel: even if seats are still available on the day, passengers cannot book them because the deadline has passed.
- (5) DTSQ may be different between trains and tickets.
- (6) All tickets are sold on a first-come, first-served basis. In other words, when a passenger requests to book an available ticket, it should always be booked.
- (7) Passengers do not cancel nor change their ticket after booking.

The outline of our method is shown in Fig. 1. This method is used to calculate the DTSQ which will maximize total revenue from reserved seats on all outbound or in-

Fig. 1 Outline of method to calculate DTSQ

bound trains on a specific express line operated on a specific day. First, passenger demand for the target date and each train are estimated for each journey segment, type of ticket and time of booking. Then it is assumed that the estimated number of passengers will try to book their desired ticket. However, sometimes the desired ticket is not available because of the DTSQ or because all the tickets have been bought. In such situation, passengers must change their selection: they may choose a different train, a different type of ticket or not take the train. Based on this selection behavior, sales volume and revenue for each ticket type are determined. Consequently, we can say that by controlling ticket availability, DTSQ affects total revenue. On the basis of these points, our method can calculate optimal DTSQ by solving a mathematical optimization problem whose objective variable is revenue and control variables are the DTSQ.

In order to be able to build this method, it is necessary to develop ways to estimate demand and to quantify passengers' choice of next-best-option, which are described in 4.2 and 4.3.

4.2 Demand estimation method

As described in 4.1, passenger demand for tickets on the target date and for each train, needs to be determined per journey segment. The type of ticket and time of booking must also be considered because tickets are sold on a first-come, first-served basis and the period of availability of some tickets is limited. Examples of estimated demand are shown in Table 3. We developed a method to estimate such demand by utilizing the demand estimation method to which independent component analysis is applied, described in [5]. Independent component analysis is a computational method for separating a superposition of multiple waves into original waves, which is utilized for finding out hidden factors or components from multivariate data. In

[5], the authors treat the variation of demand over time as waves and apply FastICA (an efficient algorithm for independent component analysis) to the waves corresponding to multiple days. It enables simultaneous estimation of independent components and mixing coefficients. To get a regression equation which explains these mixing coefficients with calendar days (e.g. month, day of the week and consecutive holidays) makes it possible to estimate demand on a specific day. This method is illustrated in Fig. 2. The outline of our method based on this is as follows:

(1) The demand on a target date is estimated per time of travel, journey segment and booking time by applying independent component analysis. The booking time which runs from the date on which tickets are released (a month before the service) to the date of travel, is divided into six periods: up to 21 days prior to the journey, then, 20 to 14 days, 13 to 7 days, 6 to 3 days, 2 days and 1 day prior to the date of travel and finally the actual date of travel.

(2) The demand obtained in (1) is allocated to each train operated in same time band according to a ratio calculated from past sales records. First, trains are categorized according to their properties, such as service sections and the number of stops. Next, an average of past sales is calculated per time band, category of train, journey segment and booking time. These averages are then associated to each train and the demand is allocated according to the ratio of associated averages.

(3) The demand obtained in (2) is allocated to each type of ticket to obtain the estimated demand. This allocation is based on past sales, as described in (2).

We verified the accuracy of our method using actual data. The target of the estimations was a certain express railway operated in February and early March 2017, and the number of passengers whose journey segments consisted of movements between major cities where many early bird discount tickets were available. We used sales records for the express trains, from mid-March 2015 to January 2017, to obtain the parameters needed for the estimation. Note that special days were excluded, such as long holidays, large events and accidents. As a result, 72% of the target (57859 out of 80507 data) was estimated within an error of one-person, as shown in Fig. 3. The correlation coefficient between estimated demand and actual sales was $R=0.71$, which demonstrated that our estimation was valid.

4.3 Next-best-option selection model

We developed a selection model for passengers who were unable to book their desired ticket. We assumed that there are four choices: book a ticket for earlier train (e), book a later train (l), book a higher-priced ticket (f) and not take the train. The developed model gives the probability each alternative to be selected, depending on time interval with earlier/later train (E/L) and price difference with

Table 3 Examples of estimated demand

Date of operation	Train	Journey segment	Type of ticket	Time of booking (a)	Demand
//2020	Train No.*	St. A -> B	Discount ticket X	Up to 21 days	10 seats
//2020	Train No.*	St. A -> B	Discount ticket X	20-14 days	6 seats
...	...	...	...	...	...

(a) The number of days until date of travel.

Fig. 2 An example of demand estimation with independent component analysis

Fig. 3 Estimation error in demand

higher-priced tickets (F). We conducted an online survey to construct this model, because this type of selection behavior does not appear in actual sales data. The survey was conducted among passengers who had taken express trains with discount tickets. We asked them how they would have behaved if they could have not booked their desired discount ticket. For respondents who had chosen to take other trains, we additionally asked how much they can bring forward or put off their time of travel. Using 93 responses to the survey, in relation to a certain section between major cities, we conducted maximum likelihood estimation with a logit model, whose explanatory variables were E (minutes), L (minutes) and F (Yen). The model is described by (1) and (2).

$$P_c = \frac{\exp(V_c)}{\exp(V_e) + \exp(V_l) + \exp(V_f)} \quad (1)$$

$$V_e = \beta_e E, \quad V_l = \beta_l L, \quad V_f = \beta_f F \quad (2)$$

where

P_c : probability that option $c \in \{e, l, f\}$ is selected from choices e, l and f .

V_e, V_l, V_f : deterministic term of utility for choices e, l and f .

$\beta_e, \beta_l, \beta_f$: coefficients.

The estimated parameters are shown in Table 4. All

Table 4 Estimated parameters of the next-best-option selection

Variable	Coefficient	t-value
E : Time interval with earlier train in minutes (β_e)	$-3.874 \times 10^{-2} **$	-14.02
L : Time interval with later train in minutes (β_l)	$-4.302 \times 10^{-2} **$	-14.02
F : Price difference with higher-priced ticket in yen (β_f)	$-5.082 \times 10^{-3} **$	-13.76
Number of data	744	
Final log-likelihood	-302.5	
Adjusted likelihood ratio ($\bar{\rho}^2$)	0.408	

** = statistically significant with significance level 1%.

of them are significant with a significance level of 1% and adjusted likelihood ratio is 0.408, which suggests that the obtained model is reasonable. Furthermore, it is natural that all coefficients should have negative value.

It should be noted that the probability of selecting the option “not take the train” was fixed at 25%, on the basis of the results of the survey that was carried out. The remaining 75% was divided between the three choices by the obtained model. In our calculation, passengers who need to select the next-best-option are allocated according to these ratios.

5. Trial sale of express train tickets in practice

A DTSQ optimization system was developed using the methods described above. Figure 4 is a screenshot of the system showing the calculated optimum DTSQ for all tickets sold for certain trains. The total revenue from all target trains which had to be maximized, is also displayed. To solve mathematical optimization, the system uses OR-Tools [6] developed by Google LLC so that it works on general purpose computers.

We conducted a trial sale by applying the calculated

Optimization System for Discount Ticket Sales Quota

Calculated DTSQ (per train)

Date of operation: **/** 2020

Train: Outbound ☒ Train No.*

	Ticket type X	Ticket type Y	Ticket type Z
Station A -> B	2 tickets	7 tickets	10 tickets
Station B -> C	5 tickets	12 tickets	21 tickets

Total revenue: ***** Yen

DTSQ for each ticket

Total revenue from all trains

Fig. 4 Example calculation of DTSQ applying developed system

DTSQ to an actual seat reservation system and compared the revenue calculated from sales, with past sales records and assumed sales results, to consider the effect of our method on revenue.

5.1 Target used for trial sale

The target used for the trial sale was a certain express line operated during a certain three-day holiday in FY2018. During these three days, there was no large event that would have created special demand, and operations were normal. On this express line, some discount tickets with a sales quota were sold for the sections between major cities along the line (these sections are described “sections X” hereafter). We tried to optimize DTSQ for these tickets.

The premises of the trial were as follows.

- (1) The goal was to maximize total revenue from passengers traveling along sections X with reserved seats.
- (2) Demand of passengers boarding in other sections and party travelers who would not be influenced by discounted tickets, were included in the estimation because it was necessary to take into account the influence of full capacity. However, revenue from these groups was not considered.
- (3) Discount tickets with no sales quota were not distinguished from normal tickets. They remained on sale unless full occupancy was reached.
- (4) Adults and children were not distinguished. All passengers were treated as adults for calculating revenue.
- (5) Non-reserved seats and green cars (first-class cars), were not considered.
- (6) DTSQ had to be more than certain number, because tickets announced to be sold had to be sold.

5.2 Comparison with past sales

Revenues calculated from sales recorded in the trial were compared with those of the previous two years: FY2016 and FY2017. Sales were based on the average of

Fig. 5 Revenue growth rates during trial sale compared with past sales

five three-day holidays in FY2016. For FY2017, sales recorded during the same three-day holiday the year before were used, although sales on the 3rd day of the holiday were removed from the comparison because a special event had an impact on demand on that day.

Figure 5 shows the results. Revenues were compared day by day, and by direction of travel: e.g., the leftmost bar shows that revenue from outbound trains on the 1st day of the trial was 32% more than the average revenues from outbound trains in a five-day period (each day being the first day of the five three-day holidays described for FY2016 mentioned above).

Regarding the comparison with FY2016, revenue growth rates ranged between 17-37% and 29% on average. In particular, revenue from outbound trains on the 1st day of the trial reached almost the same as that in busy seasons in FY2016 such as new year holidays. Revenue growth rates compared with FY2017 ranged between 6-16% and 9% on average. According to railway operator statements, it is estimated that the demand for tickets on the target express line increased about 7% from FY2016 to FY2018. Even though this impacts our results, we could say that our method could increase revenues even this effect was subtracted.

5.3 Comparison with assumed sales results

To evaluate the pure effect of our method, it would be necessary to compare sales with a DTSQ calculated using our method, and those on for the same days and trains using a DTSQ determined without our method. However, it is unrealistic to apply two different DTSQs to a real sales system simultaneously. It therefore seemed more reasonable to estimate the sales that would be generated using a DTSQ determined without our method, and to compare this outcome with the sales results obtained from the trial sale. As such, sales using another DTSQ were estimated for the same days as in the trial sale under the assumption that demand was same as for the sales on the days. The revenue from these estimated sales was calculated and compared the results of the trial sale. Figure 6 shows that the effect of our method was estimated to give growth in revenue of around 5-11% or 8% on average. It should be noted that the assumptions described above are generally considered to lead to overestimations. This is because some demand may actually have been lost during the trial sale,

Fig. 6 Revenue growth during trial sale compared with estimated sales results

which is not reflected in the assumptions. This leads to underestimation of demand and estimated sales results.

6. Conclusions

We developed a yield management method which controls discount ticket sales quotas. A trial sale was conducted by applying a discount ticket sales quota set using our method, to an actual seat reservation system. The revenue growth rate during the trial sale was calculated to be 29% in relation to revenue two years before, and 9% from the previous year. These results confirmed that our method can contribute to revenue growth and facilitate decision-making for setting the sales quotas.

As described in 5.3, to evaluate the pure effect of our method is a future issue. It depends on achieving more accurate estimates of demand and next-best-option selection behavior. One solution could be to develop a demand estimation method based not only on actual demand but also on past lost demand, and to improve the next-best-selection model by considering the terms of use of tickets.

Furthermore, consider the other features described in Table 2 could enhance the effect of the yield management method. Future work will also seek to improve this new method to optimize ticket features, transport capacity, dynamic pricing, inter alia.

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