A MODEL OF CHOOSING PASSENGERS' AIR FLIGHT

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The article deals with a creation of the passenger's behaviour model at a flight choice. From the variety of those different factors, which have the greatest influence on the mentioned choice, are identified. Taking them into account the original flight choice models by a passenger for one Origin-Destination those n pair of cities is developed. The simulation approach has been used for practical calculations. Simulation is carried out with MathCAD software.

***Keywords**: choice model, choice of flight, simulation approach*

1. Introduction

Choice models describe the general enough situation when it is necessary to make only one decision from the several available. In the choice models *subject* is the person who is making a decision, and *alternatives* are his possible decisions.

There are a lot of different mathematical theories describing the various choice models, for example, their great number concerned with the transport processes is possible to find at *M. Ben-Akiva* and *S. Lerman* [1].

In the Soviet Union the first choice models were developed and applied within the limits of creation the Automatic Control Systems (ACS) of Civil Aviation in the seventieth years of the last century. The first here are the *two-alternative models of a choice* by a passenger of the mode of transport (aviation or railway), offered by *J. Paramonov* [7]. The next group of such models are *three-alternative choice models* in which the third alternative designates "the refusal of a trip". The different examples concerning with the mentioned choice problem we can see at the work of *A. Andronov* [6].Modern choice models are building on a *multi-alternative basis* and have received a wide distribution at the description of the passenger behaviour at a flight choice. The similar model example creation can be found at *J. Paramonov* [8, 9, 10].

The creation of corresponding model includes two problems: firstly, it is necessary to create the model, secondly, it is necessary to estimate its parameters. But, it is essential to note, that creation of the analytical expression for multi-alternative choice models is complex enough. And for practical calculations the simulation approach is often used [4].

When choosing an air flight the passenger may take into account the number of different factors [2, 8]. For example: the cost of the air-ticket, the length of flight, the comfort of schedule (here we mean the time of the aircraft departure), how far the airport is situated from the city centre, the comfort on board, the information about potential technical problems with aircrafts of this or that airline, a potential possibility of the terrorist act in this or that airport, etc.

In this research the multifarious factors defining this choice are carefully studied. From the variety of the considered factors are identified those which have the greatest influence. These factors are listed below and the brief characteristic to them is given.

At the initial stage of simulation the different approaches and concepts of the choice models creation have been considered. Firstly, the elementary model has been created: *the model of a flight choice by passenger for a day*. In this model the choice process is considered according to the stream of passengers arrived this day. This model is the basic for construction of all subsequent models [5].

The following model simulating the choice process takes into account several days (for the certain time horizon *H*). It is the logic continuation of the previous model. But at the corresponding computer program creation we have collided with necessity of storage and recalculation of huge quantity of data by which the passengers of each day from the period of consideration *H* are characterized. However, the output data analysis has allowed to find out the basic regularities inherent in passengers of various days from the time period *H*, and to generalize their characteristics. We have come to conclusion about inexpediency of the passengers' initial characteristics storage during all period of simulation. Therefore, for the subsequent models the initial concept of model has been completely reprocessed, and having left the initial problem statement without changes, the new approach for its decision is elaborated.

Within the limits of this approach the original model considering the choice process not from the just arrived passengers, but from already existent queue of passengers who are situated in a mode of the flight expectation during some time interval $t <= h$ (in days) has been developed, where $t = 1, 2, ..., h$.

The developed model belongs to a class of multi-alternative choice models [1]. As the stochastic model corresponding to it is complex enough for the description and simulation, for practical calculations the simulation approach has been used [4]. Simulation is carried out with MathCAD software. The detailed description of model and corresponding algorithm is given below.

2. Initial Preconditions of the Model

Let us consider the following problem. There is *m* number of flights for a day for one Origin-Destination pair of cities. Each *j*-th flight, where *j* = 1, 2, ..., *m*, will be described by the following parameters:

- *the number of seats* $\mathbf{r}_1 = \left(r_1^{(1)}, r_1^{(2)}, ..., r_1^{(j)}, ..., r_1^{(m)}\right)$;
- *the cost of air-ticket* $\mathbf{r}_2 = \left(r_1^{(1)}, r_1^{(2)}, ..., r_1^{(j)}, ..., r_1^{(m)}\right)$;
- *the time of departure* $\mathbf{r}_3 = \left(r_1^{(1)}, r_1^{(2)}, ..., r_1^{(j)}, ..., r_1^{(m)}\right)$.

There is a stream of passengers wishing to depart with one of these *m* flights. It is necessary to note, that in the considered choice model the passengers' characteristics vary depending on the number of days from the *passenger's lookup horizon h* (number of days when the flight for a passenger is possible), i.e. the passengers' characteristics from the different days are not identical. The fullest extent of these characteristics belongs to the current day passengers.

It is accepted that the number of passengers for a day is a random variable N having a normal distribution with parameters μ_N and σ_N. The values $\{N_k\}$ for different days (from the *consideration horizon H*) are independent and identically distributed random variables.

It is assumed that each *current day passenger* is described by four parameters having the stochastic character:

- X_1 is *the desirable time of departure*;
- Δ_+ is *the positive passenger-flight deviation* (or *the value of maximal allowed positive deviation the actual time of flight from the desirable by passenger time of departure*, where the positive deviation is understood as the moment of departure after the specified time);
- Δ_- is *the negative passenger-flight deviation* (or *the value of maximal allowed negative deviation the actual time of flight from the desirable by passenger time of departure*, where the negative deviation is understood as the moment of departure before the specified time);
- h is *the passenger's lookup horizon* (the maximal number of days during which the passenger is ready to wait a flight).

Each of the listed parameters is a random variable and has its own distribution.

The random variable X_1 defines the desirable time of departure within a day. It is described by the corresponding density of distribution. It takes whole values from 1 up to 24 with certain probabilities which correspond to the change of intensity of demands within a day.

In our research it is accepted, that distribution of a random variable X_1 corresponds to uniform distribution in interval $t \in (7,23)$.

Obviously, that for each passenger the values Δ_+ and Δ_- have the random meanings, but in the considered model it is accepted that $\Delta_+ = \Delta_- = const$, and, moreover, these values are identical for all the passengers. The value of *h* has been taken identical for all passengers as well (*h* = *const*). It is supposed, that at the presence of the real corresponding data the fitting of the simulation model will be carried out by changing of values Δ_+, Δ_- and h.

3. Model of a Flight Choice by a Passenger for a Day

At the description of the process of a flight choice by a passenger for a day it is supposed that passenger buys the air-ticket in a day of flight. However, if there are no air-tickets suitable for any flight this day, i.e. in the day of the expected departure the passenger receives the refusal, then he transfers the air-ticket purchase the next day. If the next day he is refused also, the air-ticket purchase will be transferred the day after the next too, and so on. Thus, the flight can be postponed for some days, but no more than *h* days, after that the passenger finally cancels the trip. So the passenger can get the air-ticket during the certain time horizon *h*.

Additional remarks:

1. The time horizon *h* can accept only positive values.
2. Generally the time horizon *h* for each passenger is a random variable. For simplification of calculations it is accepted that this variable is identical for all passengers.

So, there is a stream of passengers wishing to depart by certain flight, but due to various reasons, they are compelled either to transfer a flight on other day, or some other days, but no more than *h* days, or to refuse a trip.

Thus, during the horizon of consideration H the queue of expecting passengers $\mathbf{Q} = (Q_0, Q_1, ..., Q_t, ..., Q_h)$, where Q_t is a number of the expecting t days passengers (t = 0, 1, …, h), gradually grows.

The original algorithm for decision of the task in view, as it has been already noted earlier, has been developed. Their novelty and originality consists in consideration of the simulation process not from the side of newly arrived passenger, but from the side of already existent queue of expecting passengers.

It is accepted, that the characteristics of the passengers from the every t-th day from the *passenger's lookup horizon h* are homogeneous values, but the passengers characteristics from different days differ among themselves. For example, the passengers of different days of expectation ($t \neq 0$) are characterized by different values of the flight refusals probabilities: the value t increase leads to the increase of the flight refusal probability, and reaches its maximum last day of expectation (h).

In this case, the process of choice of the flight j (j = 1, 2, ..., m) by the current day passenger i (i = 1, 2, ..., N) can be described in the following way.

From all flights m only those moments of departure $r_3^{(j)}$ are selected which are situated within the corresponding time interval $r_3^{(j)} \in \left(X_1^{(i)} - \Delta_-^{(i)}, X_1^{(i)} + \Delta_+^{(i)}\right)$. If there are some flights available then we select one with the minimal cost of the air-ticket $r_2^{(j)}$:

$$j^{(i)} = \min_j \left\{ r_2^{(j)} : r_3^{(j)} \in \left(X_1^{(i)} - \Delta_-^{(i)}, X_1^{(i)} + \Delta_+^{(i)}\right) \right\}, \tag{1}$$

i.e. we take into account two characteristics of passenger at once: the desirable time of departure and the cost of a flight. If there is no any suitable flight, the passenger passes in queue of the current day expecting passengers.

For each passenger from t-th day of expectation, where $t = 1, 2, ..., h-1$, the defining characteristic at the flight choice is the minimal cost of the air-ticket:

$$j = \min_j \left\{ r_2^{(j)} \right\}, \tag{2}$$

but if there is no any suitable flight, the passenger passes in queue of the t-th day expecting passengers.

All the passengers of h-th day of expectation receive refusal. The queue of expecting passengers for this day is cleared.

The detailed description of the process of the flight choice by a passenger for a day is given below.

3.1. Process description at a flight choice by a passenger for a day

The simulation process can be divided into two stages: *the preliminary* and *the basic* ones.

The preliminary stage of the simulation process:

1. In the beginning of a day all passengers whose expecting time has exceeded h days receive refusal.
2. Next we rewrite the expecting passengers queue, i.e. increase the expecting time (in days) for not departed passengers: $Q_{t+1} = Q_t$, where t is the day of consideration, t = 0, 1, ..., h-1.

The basic stage of the simulation process:

1. Firstly, we try to send those passengers who expected more than one day. Moreover, we try to send them in reverse order: at first Q_h passengers with "the age h", then Q_{h-1} passengers with "the age h-1", etc. The defining characteristic of a flight for passengers who are expecting more than one day is the flight cost $\mathbf{r}_2$, i.e. the passenger chooses the flight with the minimal cost $r_2^{(j)}$, here j is a number of the chosen flight, where j = 1, 2, ..., m (2).
2. Further, we generate N passengers who have arrived the current day ($t = 0$), and put them into the current day queue $Q_0 = N$. The number of the current day passengers N have the normal distribution with parameters μ_N and σ_N.
3. Next, we generate the desirable time of departure for the current day passengers $X_1^{(i)}$, where i = 1, 2, ..., N. The desirable time of departure have the uniform distribution in interval $X_1^{(i)} \in (7, 23)$.
4. After that we try to send new coming passengers Q_0 taking into account already two factors. Firstly, we consider the desirable by passenger time of departure, i.e. from all m flights we take out those which departure time $r_3^{(j)}$ get in a corresponding time interval $r_3^{(j)} \in \left(X_1^{(i)} - \Delta_-^{(i)}, X_1^{(i)} + \Delta_+^{(i)}\right)$, here j is a number of the chosen flight (j = 1, 2, ..., m), i is a number of the passengers, where

(i = 1, 2, ..., N). Secondly, we take into account the cost of a flight $r_2^{(j)}$, i.e. if there are some suitable flights we get out one of them with the minimal cost (1).

5. All current day passengers who were refused we put into the current day queue.
6. As output values we receive four ones: the new vector of expecting passenger number at the end of current day $\mathbf{Q}$, the number of satisfied claims of current day passengers $N - Q_0$, the general number of all refusals for a day *Ref*, and new vector of free seat number $\mathbf{r}_1$.

The formal description of the algorithm for a day is the following.

3.2. Algorithm of simulation for a day

Input: the number of flights *m*, the characteristics of flights $\mathbf{r}_1$, $\mathbf{r}_2$, $\mathbf{r}_3$, the parameters of the current day passenger number distribution μ_N and σ_N, the meanings of the random variables Δ_+, Δ_-, *h*, and the vector of the number of expecting passengers $\mathbf{Q}$.

Output: the new vector of expecting passenger number at the end of current day $\mathbf{Q}$, the number of satisfied claims of the passengers who came in current day $N - Q_0$, number of refusals for a day *Ref*, and a new vector of the free seats number $\mathbf{r}_1$.

Intermediate variables: the number of the current day passengers *N*; the vector of the current number of free seats $r_1^{(j)}$, where *j* is the number of current flight; *J* is the number of the chosen flight (*J* = 1, 2, …, *m*-1).

Algorithm

Begin

1. Input of the initial data: *m*, $\mathbf{r}_1$, $\mathbf{r}_2$, $\mathbf{r}_3$, μ_N, σ_N, Δ_-, Δ_+, *h*, and $\mathbf{Q} = (Q_0, Q_1, ..., Q_h)$.
2. Initialisation of the counter of the current day refusal number *Ref* ($Ref := Q_h$)
3. Identification of the variable of the available seats numbers $R_1^{(j)} := r_1^{(j)}$, where *j* = 0, 1, …, *m*-1
4. Increment of the expecting time of not departed passengers ($Q_{t+1} := Q_t$, where *t* is the day of consideration, *t* = 0, 1, …, *h*-1)
5. Begin a cycle by the consideration horizon (by the variable *t* in the back order $t = h, h-1, ..., 1$)
   - 5.1. Begin a cycle by passengers who are expecting Q_t days (by the variable *i*, where $i = 0, 1, ..., Q_t - 1$)
   - Initialisation of the variable *J* (*J* = -1, i.e. none flight is chosen)
     - 5.1.1. Begin a cycle by flights (by the variable *j*, where *j* = 0, 1, …, *m*-1)*
     - If there are available seats on the *j*-th flight ($R_1^{(j)} > 0$), then
       - Choosing of the flight $J := j$
       - Decrement of the number of the available seats on chosen flight $R_1^{(J)}$ ($R_1^{(J)} := R_1^{(J)} - 1$)
       - Decrement of the expecting passenger queue Q_t ($Q_t := Q_t - 1$)
     - End the cycle by flights
   - End the cycle by passengers
6. Generations of the current day passenger number N and the passenger characteristic X_1.
7. Placing of the new coming passengers into the current day passenger queue ($Q_0 := N$)
8. Begin a cycle by the current day passengers Q_0 (by the variable *i*, where $i = 0, 1, ..., Q_0 - 1$)
   - Initialisation of the variable $J^{(i)}$ ($J^{(i)} = -1$, i.e. none flight is chosen)
   - 8.1. Begin a cycle by flights (by the variable j, where $j = 0, 1, ..., m-1$)*
     - $J^{(i)} := \min_j \left\{ r_2^{(j)} : R_1^{(j)} > 0, r_3^{(j)} \in \left(X_1^{(i)} - \Delta_-^{(i)}, X_1^{(i)} + \Delta_+^{(i)} \right) \right\}$
     - Decrement of the number of the available seats on chosen flight $R_1^{(J)}$ ($R_1^{(J)} := R_1^{(J)} - 1$)
     - Decrement of the current day passenger queue Q_0 ($Q_0 := Q_0 - 1$)
   - End the cycle by flights

End the cycle by current day passengers

9. Calculation and output variables Q_t, where $t = 0, 1, ..., h$, $N - Q_0$, *Ref*, and $\mathbf{r}_1$

End

Comment to the algorithm: The cycles by flights (*) are organized in the way that they are looked through in the sorted order by $\mathbf{r}_2$ (the cost of air-tickets order)

4. The Model of Passenger Distribution by Flights for Several Days

4.1. The description of the simulation process

For a basis of *the model of passenger distribution by flights for several days* the previous model of a flight choice by a passenger for a day has been taken. We left all preconditions of above mentioned model, but made three essential additions in a new one:

1. The passengers of the different days of the expectation queue are characterized by the different values of the flight refusal probabilities $\mathbf{p} = (p_1, p_2, ..., p_h)$, and an increase of the value h leads to the values $\{p_i\}$ increase, where $i = 1, 2, ..., h$. This probability reaches a maximum in the last day of expectation (h).
2. Thus, not all passengers "with the age h" refuse from trip; there is very small part of passengers of this day, who, with the probability $1 - p_h$, choose this or that flight. At a choice of the flight the defining characteristic for them is the cost of flight (2).
3. The general value of the refusals of a flight consists of the sums of refusals each day from the horizon h.

Thus, the changes have taken place only in the first preliminary stage of simulated process which now is described as follows:

1. In the beginning of the day of consideration with the probability p_h all passengers whose expecting time has exceeded h days are refused.
2. Remaining passengers with "the age h" we distribute on flights. Here the defining characteristic at a flight choice is its cost $\mathbf{r}_2$, i.e. the passenger chooses the flight with the minimal cost $r_2^{(j)}$, here j is a number of the chosen flight, where $j = 1, 2, ..., m$ (2).
3. For the passenger from the t-th expectation day we introduce the value of refusals *Ref*. According to the assumption of the model, in the t-th expectation day the probability of rejection will reach the value p_t from the passenger numbers of expectation queue for t-th day, where $t = 1, 2, …, h$-1.
4. Further, as before, we rewrite the queue of expected passengers, i.e. we increase an expecting time (in day) for not departed passengers: $Q_{t+1} = Q_t$, where t is considered day, $t = 1, 2, …, h$-1.

The description of the simulating process basic stage has not suffered absolutely any changes. It is necessary to notice especially that the given model is the previous model generalization and at the following vector of the flight refusal probabilities $\mathbf{p} = (0, 0, ..., 1)$ completely describes the previous model. Changing the meanings of the flight refusal probabilities vector $\mathbf{p}$ we can simulate the huge value of different possible situations.

As output values on the end period of consideration H we obtain: the percentage of the commercial loading of flights, the average number of refusals for a day, the average number of passengers which have chosen the flight in the desirable for them time in a day, the percentage of the passengers which didn't fly in the desirable day, the average time of expecting (in days) for passengers.

The percentage of the commercial loading of j-th flights Com_j (in %), where $j = 1, 2, …, m$, can be defined in the following form:

$$Com_j = \frac{R_1^{(j)}}{r_1^{(j)}} \cdot 100\%, \qquad (3)$$

where $r_1^{(j)}$ is the number of seats on the j-th flight, $R_1^{(j)}$ is the number occupied seats on the j-th flight.

5. Numerical Example

In the considered numerical example the vector of the flight refusal probabilities $\mathbf{p}$ have the following meanings $\mathbf{p} = (0 \quad 0 \quad 0 \quad 1)^T$. At these meanings of probabilities we can simulate the following conditions: all passengers of the $t = h$ day of expectation receive the refusal, passengers of other days from the queue of expectation $0 < t < h$ are distributed on flights according to the minimal cost of the air-ticket, the current day passengers $t = 0$ are distributed on flights according to two conditions at once: the desirable time of departure and the minimal cost of the air-ticket.

There are $m = 5$ flights between one Origin-Destination pair of cities, the vectors of flight characteristics are sorted in the cost of air-tickets order. From this point of view the initial data of flight characteristics have the following meanings: the vector of seats number $\mathbf{r}_1 = (80 \quad 80 \quad 100 \quad 80 \quad 100)^T$, the vector of the air-tickets cost $\mathbf{r}_2 = (50 \quad 75 \quad 100 \quad 125 \quad 150)^T$, and the vector of the plane departure time $\mathbf{r}_3 = (21 \quad 12 \quad 9 \quad 17 \quad 19)^T$. The passenger characteristics take the following meanings: desirable departure time corresponds to the uniform distribution in interval $t \in (7,23)$, the values of the positive and negative passenger-flight deviation (further, *absolute value of passenger-flight deviation*) are identical for each passenger ($D = \Delta_- = \Delta_+$), the passenger's lookup horizon $h = 3$ is identical to all passengers, the initial queue of the expecting passengers is empty $\mathbf{Q} = (0 \quad 0 \quad 0 \quad 0)^T$, the consideration period is $H = 100$ days, and the number of passengers N from each current day ($t = 0$) from the consideration period H have the normal distribution with parameters $\mu_N = 300$ and $\sigma_N = 20$.

The main task of this example is to investigate the dependence on the percentage of the commercial loading of j-th flights Com_j (3), where $j = 1, 2, \ldots, m$, from the value of absolute passenger-flight deviation D. As we can see from the meanings of the vector $\mathbf{r}_1 = (80 \quad 80 \quad 100 \quad 80 \quad 100)^T$, the total sum of seats on flights for each current day $\sum_{j=1}^{m} r_1^{(j)} = 460$ considerably exceeds the average number of the current day passengers μ_N. It allows us to investigate the commercial loading of flights only for the current day passengers. The obtained results of the commercial loading of j-th flights Com_j (in %), where $j = 1, 2, \ldots, m$, dependence on the value of absolute passenger-flight deviation D are presented in the table 1.

Table 1. The percentages of the comercial loading for *m* flights dependence on the value *D*

***D* (hour)**	**0.50**	**0.75**	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**
Com_1 (%)	100	100	100	100	99	99	100	100	100	100	100
Com_2 (%)	49	50	55	65	82	92	97	99	100	100	100
Com_3 (%)	18	31	42	47	52	49	43	41	40	45	44
Com_4 (%)	24	37	55	68	83	92	99	99	100	100	99
Com_5 (%)	19	29	40	36	23	18	15	20	22	27	26

Other purpose of this example is the investigation of the current day passengers service quality K dependence on the value of absolute passenger-flight deviation D, where K is the number of the current day passengers who were departed during desirable time of day. Results of simulation are shown on figure 1.

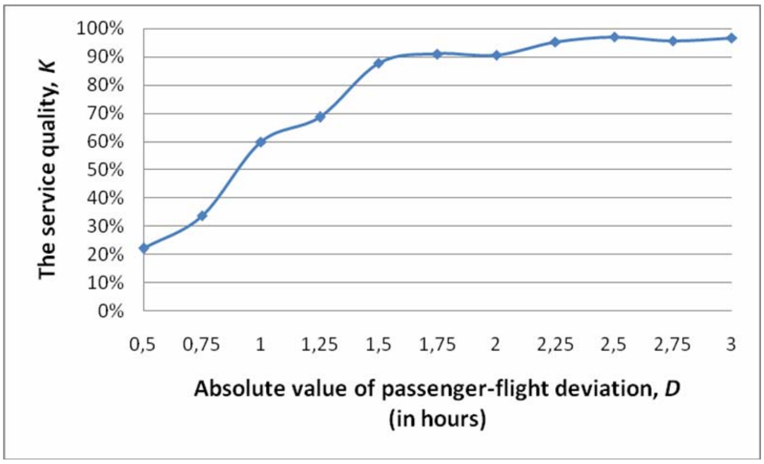

Fig. 1. *Value K dependence on value D*

Analysis of the received results

We would like to remind, that capacity of planes had only two meanings: 80 and 100 seats. The following regularity has been noted:

1. With the increase of absolute passenger-flight deviation value *D* the meaning of the quality of service *K* increases and converges to the value $\mu_N = 300$ (see fig. 1).
2. The increase of absolute passenger-flight deviation value *D* till the meaning *D* = 1 leads to the growth of all flights commercial loading, but the further increase of value *D* (*D* > 1) has shown the steady growth the commercial loading of flights only with the number of seats 80.
3. The commercial loading of flights with number of seats is equal 100 is considerably smaller and did not converge to a level of 100 %, but stabilized at levels of 40 % for the 3-rd flight and 22 % for the 5-th.

Therefore, it is possible to conclude, that results of simulation are quite adequate to the simulated process. Thus, two tendencies are detectible:

1. The less the air-ticket cost, the higher the percent of the flights commercial loading.
2. The flights filling process takes place proportionally enough, therefore, the flights with greater number of seats is characterized by not enough capacity (the less percent of the flights commercial loading for the 3-rd and the 5-th flights).

Possible recommendations: the low percentage of the commercial loading of the 3-rd flight is connected with the inconvenient moment of the flight departure for the passenger (9 PM) and with high enough cost of the air-ticket, therefore, it is necessary either to reduce the cost of the air-ticket, or to change the plane departure time, or to offer the plane with the smaller number of seats. Note, that each variant can be simulated separately for the optimum decision acceptance.

6. Conclusions

The passenger's behaviour model at a flight choice for one Origin-Destination pair of cities is created out in this research. This model taking into account three characteristics of flight: the number of seats, the cost of air-ticket and the time of departure; and four characteristics of passenger as well: the desirable time of departure, the positive and negative passenger-flight deviations, and the passenger's lookup horizon. The originality of the model consists in the choice process consideration from the side of the expecting passengers queue. For practical calculation the simulation approach has been used. Numerical example confirm the adequacy of the considered model.

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