Optimization of Airport Taxi Queuing System based on Queuing Theory

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Abstract: Taxi is one of the main means of transportation for passengers to and from the airport and urban areas, and optimizing the airport taxi queuing system is of great significance to improve the efficiency of riding and save the time cost of customers. To reasonable design queuing system, this paper determines the queuing mode of passengers based on the Queuing Theory. In addition, a cost decision model is established combining with the Taxi Multi-service Desk Asynchronous Vacation System to optimize the number of boarding points, make the sum of the cost of waiting time per unit time and the construction cost of a single boarding point the lowest.

1. Introduction

Taxi queuing system is an important foundation facility for airport distribution[1]. To some extent, its queuing service level affects the departure efficiency of passengers and has an important impact on the efficient and orderly operation of the airport. Therefore, optimizing the taxi queuing system can ensure the maximization of the ride efficiency and reduce the construction cost. At present, the domestic and foreign studies on the pickup system mainly focus on the waiting time of taxis, while the passengers' waiting time and the setting of the boarding points are less considered [2]. According to the above background, based on different types of Queuing Theory, this paper uses the cost decision model to optimize the number of boarding points and the queuing mode of passengers in the airport taxi queuing system.

2. Model 1:Passenger queuing mode

There are a variety of ways to line up passengers in the taxi pickup area. In this paper, according to the different ways of queuing passengers in the airport, the airport taxi queuing system is divided into two modes: single line waiting service and line up at each pickup point to form multiple queues, and a model is established to compare the advantages and disadvantages of the two modes to determine the passenger queuing type.

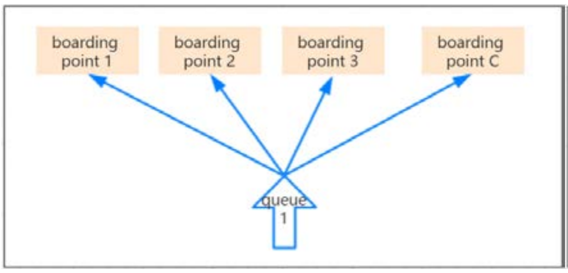

Fig. 1 queuing mode 1

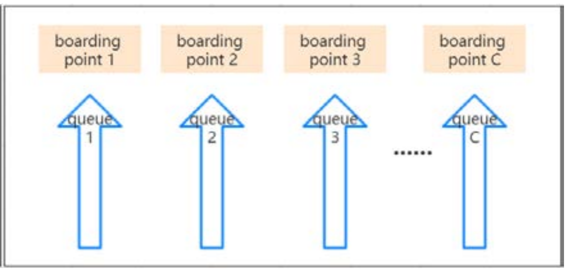

Fig. 2 Queuing mode 2

2.1 Composition and evaluation index of Queuing Theory

Queuing theory, also known as stochastic service system theory, is a major branch of operations research. It aims to solve the optimal design and optimal control of queuing system. For the airport taxi queuing system, its characteristics and indicators are as follows:

(1) Component

① Input procedure:

Passenger arrival input procedure satisfies the poisson distribution,λis the average arrival rate：

$$\lambda = \frac{\text{Number of customers in a period of time}}{\text{time}} \quad (1)$$

② Queuing rule：The queuing rules follow the FCFS (First Come First Serve) principle;

③ Service organization：The service desk is a parallel boarding point with multiple service desks, The output process satisfies an exponential distribution that obeys the average service rateμ:

$$\mu = \frac{\text{The number of customers who complete their service over a period of time}}{\text{time}} \quad (2)$$

(2) Evaluation index

① The busyness of the queuing system is expressed as the service organization's busyness rate ρ:

$$\rho = \frac{\lambda}{C\mu} \quad (3)$$

② The number of people in the queue is represented by the queue length:

$$L_s = L_q + C\rho \quad (4)$$

L_q is the average number of passengers waiting in line in the system; $C\rho$ is the sum of the number of customers being served;

③ W_q is the waiting time of the customer from entering the system to receiving the service;

④ W_s is the average time that the customer takes from entering the system to receiving the service leaving the system.

2.2 Single-queue queuing model

When passengers arrive at the boarding area, form a line and go in turn to the boarding point waiting for service. Assuming that the system capacity and customer source are infinite, this queuing mode belongs to [M/M/C] queuing service model [3]. The average arrival rate is λ_0,the average service rate is μ.The model is:

When the system reaches stability, C boarding points work independently at the same time, and the probability that the number of passengers in the system is n is[2]:

$$P_0(C) = [(\sum_{k=0}^{C-1} \frac{1}{K!}(\frac{\lambda}{\mu})^k) + \frac{1}{C!}\frac{1}{(1-\rho)}(\frac{\lambda}{\mu})^C]^{-1} \quad (5)$$

$$P_n(C) = \begin{cases} \frac{1}{n}(\frac{\lambda}{\mu})^n P_0(C), n = 1,2,3....,C \\ \frac{1}{C\mu C^{n-C}}(\frac{\lambda}{\mu})P_0(C), n = C+1 \end{cases} \quad (6)$$

Using L_s and W_s anaylyze:：

$$L_s = L_q + C\rho = \frac{1}{C!}\frac{(C\rho)^C \rho}{(1-\rho)^2} p_0 + \frac{\lambda}{\mu} \tag{7}$$

$$E(W_s) = \frac{p_n(C)}{C\mu(1-\rho)^2} = \frac{n\mu}{n!(n\mu-\lambda)^2}(\frac{\lambda}{\mu})^n P_0 \tag{8}$$

2.3 Multi-queue queuing model

If passengers form a queue at each boarding point after arriving at the boarding area, and do not leave after entering the queue, and the lines are not connected in series, then the queuing mode belongs to C [M/M/I] type services[4]:

$$P_0 = 1-\rho \tag{9}$$

$$P_n = \rho^n (1-\rho) \tag{10}$$

$$L_s = \frac{\lambda}{\mu-\lambda} \tag{11}$$

$$W_s = \frac{1}{\mu-\lambda} \tag{12}$$

2.4 Results

As a rule of thumb, λ_0=0.2 people/s as during peak hours, μ=1/18 people/s based on[5],assume C=[4,15], L_S ,W_s are calculated， as shown in the table1:

Table 1 Parameters under different queue numbers

	C	4	5	6	7	8	9	10	11
L_S /人	single-queue	10.69	4.66	3.89	3.69	3.63	3.61	3.60	3.60
	multi-queue	36.00	12.86	9.00	7.41	6.55	6.00	5.63	5.35
W_s /s	single-queue	53.45	23.28	19.47	18.46	18.14	18.04	18.01	18.00
	multi-queue	180.00	64.29	45.00	37.06	32.73	30.00	28.13	26.76

From Table 1 L_S（single-queue）< L_S（multi-queue）， W_s（single-queue）< W_s（multi-queue） Therefore, the average service time and queue length of a single-queue are smaller than that of multi-queues, so passengers should choose a single queue mode.

3. Model 2: Optimization model of the optimal number of boarding points

In order to maximize the ride efficiency, it is necessary to obtain the optimal number of boarding points. It is assumed that there are two parallel lanes in the "bus area", so the airport adopts the inner lane as the multi-point parallel boarding service type, and the outer lane plays the role of diverging and starting vehicles to reduce the interference between vehicles. Due to the use of the outer lane, the longitudinal boarding points are independent of each other, so the service type can be approximately referred to as multi-point parallel queue. Customers are passengers waiting for the taxi. According to Model 1, customers queue in a single queue mode. Customers in the front of the queue can be dispersed to the boarding points to receive services.

3.1 Taxi Multi-service Des Asynchronous Vacation System

(1) system service status:

according to the status of the customers and the service desks in the queuing system, the status can be classified into three kinds of situations[6] : 1. The busy period: there are always passengers waiting in line in the queuing system 2. Spare time: this is when the queuing system is idle and taxis are waiting for passengers 3. Leave: there is no taxi service at some pick-up points

(2) evaluation index:ρ, L_s , L_q , W_q , W_s .

(3) Multi-point vertical queue model

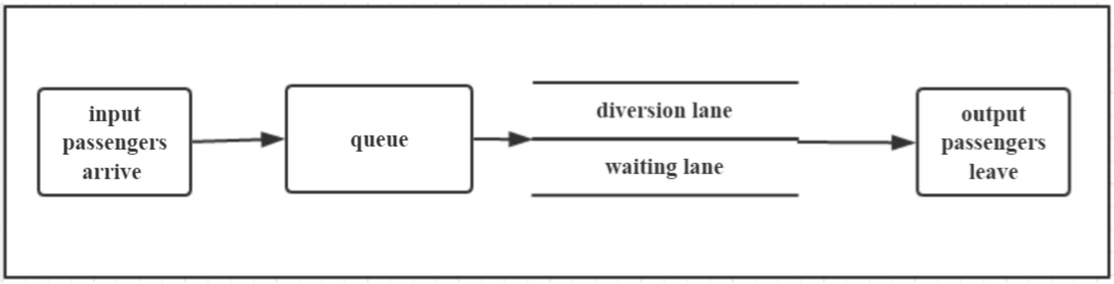

Fig. 3 Multi-point vertical queue model

As for the single-lane multi-point vertical queue model, when the bus area is in the full busy period and ρ<1, the system reaches a stable state and does not form an infinite queue. The Model is established based on this,and formula is same as(5)—(8).

3.2 Cost decision model

After the taxi queuing model is obtained, the sum of queue waiting time cost per unit time and the construction cost of single pick-up point is calculated according to the two evaluation indexes of queue length and customer's staying time, and the cost decision-making model is established to optimize the system and obtain the optimal number of pick-up points.

Assuming the total cost of queue waiting time per unit time is:

$$Z_1 = \alpha L_s \tag{13}$$

α is the time cost per passenger waiting time.

The construction cost of the boarding point per unit time is:

$$Z_2 = \beta C \tag{14}$$

β is the service time cost of a single boarding point and the construction cost of a single boarding point per unit time.

Therefore, only when the sum of the two expenses is minimized can the vehicle efficiency be maximized, so that the value of C can be obtained, which further optimizes the system[2].

$$\min Z(C) = Z_1 + Z_2 = \alpha L_s + \beta C \tag{15}$$

$$\begin{cases} Z(C) \le Z(C+1) \\ Z(C-1) \ge Z(C) \end{cases} \tag{16}$$

$$L_s(C-1) - L_s(C) \ge \frac{\beta}{\alpha} \ge L_s(C) - L_s(C+1) \tag{17}$$

3.3 Results

To solve the specific quantity of C, relevant data of Shanghai Hongqiao Airport were used to obtain the following parameters according to news reports:

Table 2 Given equation data

λ(peopel/s)	μ(peopel/s)	β/α[2]
0.2	1/18	0.002

Apply the above cost decision model and get Table3:

Table 3 The difference of L under the number of adjacent servers

L(3)-L(4)	-15.48114629	L(4)-L(5)	6.034481017
L(5)-L(6)	0.760448952	L(6)-L(7)	0.203533063
L(7)-L(8)	0.062989024	L(8)-L(9)	0.01983961
L(9)-L(10)	**0.00606878**	**L(10)-L(11)**	**0.001767435**
L(11)-L(12)	0.000486017	L(12)-L(13)	0.000125838

L(9)-L(10) $\geqq \frac{\beta}{\alpha} \geqq$ L(10)-L(11),So the best number of boarding points should be C=10.

4. Summary

In order to optimize the airport taxi queuing system, this paper takes improving the efficiency and reducing the construction cost as the primary goal. In the case of multiple service desks, determine that passengers should queue in a single queue mode.Secondly, based on the taxi multi-service desk asynchronous vacation queuing system, a multi-point vertical service type is applied to establish a cost decision model to optimize the number of boarding points, so that the sum of the queue waiting time cost per unit time and the construction cost of a single boarding point is the lowest, and the optimal number of boarding points is determined to be 10.

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