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Analysis on the Service Capacity of University Canteens under the Epidemic Prevention Based on Queue Theory

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Abstract: During the epidemic period, the good service capacity of university canteens is of great significance for formulating scientific epidemic prevention and control measures and solving the phenomenon of student dining congestion. In order to solve the congestion phenomenon, during the epidemic prevention and control period, our school implemented the staggered peak dining, that is, according to different grades and different teaching buildings, the class is set at different times to reduce the queuing phenomenon. Based on this background, questionnaire survey, theoretical research and mathematical statistics are used to conduct preliminary exploration and analysis of the data, and the service time, dining time and service window of the school canteen are investigated. Based on the queuing theory, MATLAB simulation is carried out, and the canteen service system under the two modes is evaluated and analyzed by using the simulation model. Some suggestions for reasonable window opening under two modes are given.

1. Introduction

With the development of social service industry, queuing phenomenon can be seen everywhere. Queuing model is a random service system often encountered in real life. Solving the queuing problem is the focus of research in the service field. Scientific optimization of the queuing problem can not only solve the problems of limited space and facilities in the service industry, but also improve the satisfaction of the queues to the service industry. College restaurants are also part of the service industry, the school logistics catering department must provide satisfactory services for teachers and students, in order to ensure the healthy development of teachers and students. Because the class time of college students is unified and the dining time is concentrated, the queuing problem in the dining peak has always been a hot issue. Especially when students finish class at noon, there is a large flow of people entering the restaurant, and there may be a queue when entering the restaurant and eating. Students will inevitably have great emotions when they queue for a long time, resulting in many students choosing to go to off-campus restaurants, order takeout, or even replace meals with snacks, which not only cannot guarantee the food safety of students, but also has hidden dangers for their health. Affected by the epidemic since 2020, most universities have adopted closed management, and students can only choose to eat in the school cafeteria, which undoubtedly leads to more serious queuing in the restaurant during the peak period. Therefore, it is very necessary for colleges and universities to scientifically control the queuing problem in school restaurants and reduce the possibility of virus infection.

The main elements of the queuing system are the customer and the service desk, and the customer can be a person, a machine, a car, anything that needs service. A service desk can be a person, a station, a dock, a port, something that provides a service. The student canteen dining can be built into a queuing system model, in which the customer is the student dining, and the service desk is the service window, and the service rule is "first come first serve". Because students eat after class, it is easy to cause congestion, which is in line with the rules of the queuing system.

It is one of the strategies to adjust the crowding of students in the peak dining period. By dividing the flow of students in the peak dining period into different periods, the contradiction between supply and demand can be alleviated. During the epidemic period, our school implemented off-peak classes in order to alleviate the phenomenon of dining congestion. The specific method is to divide the students into two groups according to the teaching building, and the class time of each group of students is 20 minutes different. Since most students go to the restaurant after class, there is a large flow of people arriving at the restaurant during this period, so our statistical data is the number of students arriving at the restaurant 10 minutes after class. That is, the peak time for students to arrive at the restaurant is roughly 11:30-11:50 and 11:50-12:10. In normal times, students eat after class, and the peak period of students' eating is concentrated at 12:00-12:30.

Based on the existing M/M/C/K queuing theory [1] and system simulation theory[2,3], this paper analyses the phenomenon of students' dining under the two modes of epidemic prevention and control in our school and in normal times, and uses MATLAB to calculate[4], obtaining the average waiting time of students' dining under the two modes, the number of students queuing in the system, waiting time and the utilization rate of the canteen. Comparing and analyzing the crowding degree of the canteen in these two cases provides a theoretical basis for the reasonable opening of the window of the school canteen.

2. Data collection

Taking the dining hall of North campus of our university as an example, the students in dining hall were investigated and counted. The number of students eating in the canteen during two periods from 11:30-11:50 and 11:50-12:10 from Monday to Friday during the epidemic period in November 2022 was collected, and the input and output of canteen customers in each period were counted within five minutes at random, and each period was counted for 10 days (two weeks). The statistical results are shown in Figure 1 and Figure 2.

According to Figure 1, customer input in the two stages during the off-peak period are $\lambda_1 = \mathbf{1.4467}$, $\lambda_2 = \mathbf{1.5900}$ (person/min), respectively. It is preliminarily concluded that customer arrival follows Poisson distribution, and the parameters are obtained based on the principle of maximum likelihood method. And service time follows a negative exponential distribution, the parameters are $\mu_1 = \mathbf{0.3233}$, $\mu_2 = \mathbf{0.6200}$ (person/min), respectively.

In March 2023, when the epidemic prevention and control is fully opened, the school carries out normal teaching order, and selects normal time to collect the number of people who eat from 12:00 to 12:30 in April 2023, and the statistical time is also 10 days. The input and output of customers who eat in the canteen within 10 random minutes are shown in Figure 3.

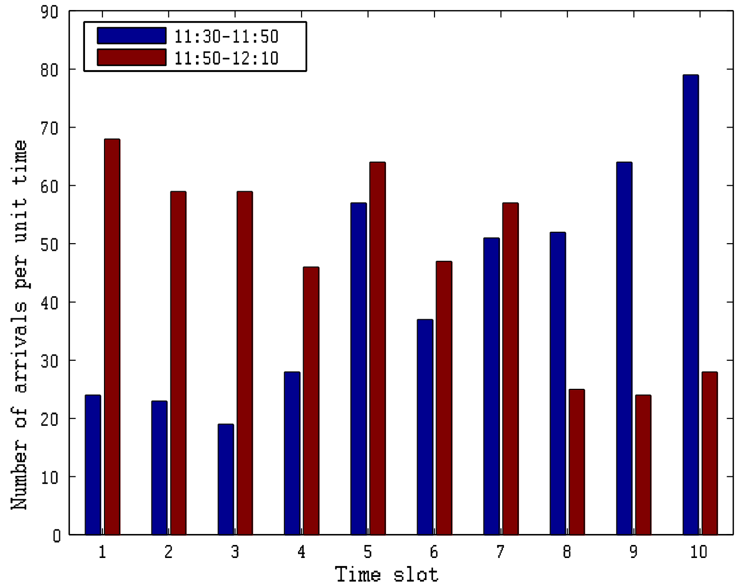

Figure 1: Customer arrival rate from Monday to Friday during off-peak periods

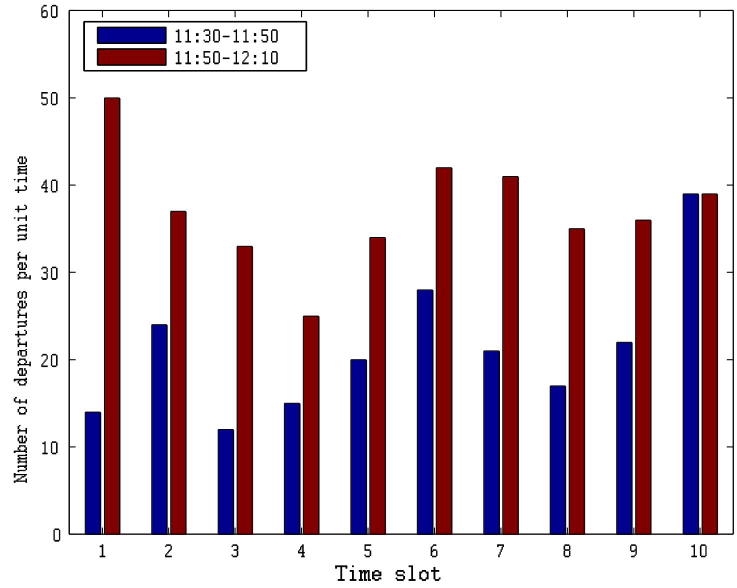

Figure 2: Service rates in different periods from Monday to Friday during peak periods

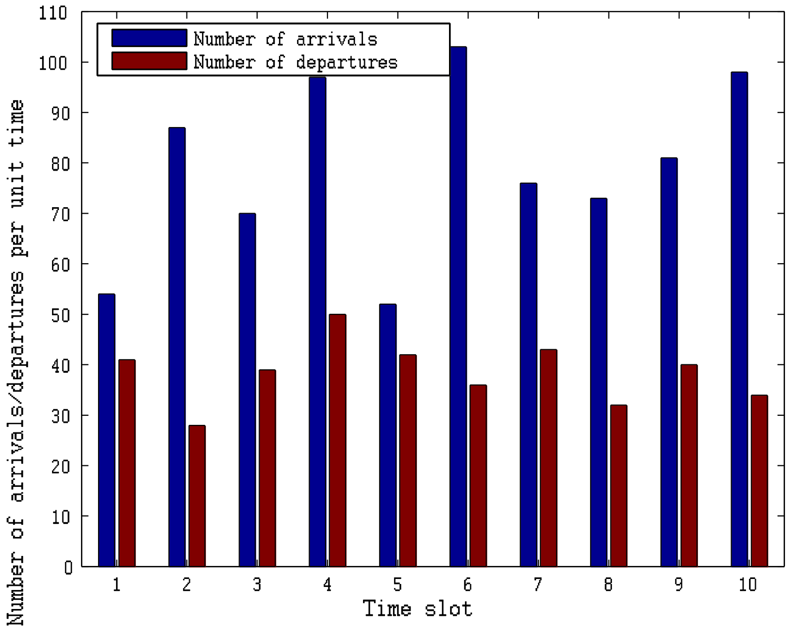

Figure 3: Customer arrival rate and service rate during the normal period Monday to Friday

Similar to the analysis of off-peak periods, it can be concluded that the customer arrival compliance parameter in normal working days is the Poisson distribution with parameter $\lambda = \mathbf{1.1150}$ (person /min), while the service time compliance parameter is the negative exponential distribution with parameter $\mu = \mathbf{0.4972}$ (person /min). According to statistical analysis, the customer arrival rate of each time period in off-peak period and normal period follows the Poisson distribution, while the service time follows the negative exponential distribution, and the results are shown in Table 1.

Table 1: Customer arrival rate and service rate in the off-peak period and normal period

	Time period	**Arrival rate**	**Service rate**
The off-peak period	11:30-11:50	1.4467	0.3533
	11:50-12:10	1.5900	0.6200
The normal period	12:00-12:30	2.6367	0.6417

As can be seen from Table 1, if the same service window is opened in all time periods, the service intensity is greater in the time period from 11:30 to 11:50 during the off-peak period. For example, only 5 Windows are opened, and the service intensity of each time period in the peak period is $\rho_1 = \mathbf{0.8189}$, $\rho_2 = \mathbf{0.5129}$ and $\rho_3 = \mathbf{0.2541}$,respectively. And the service intensity is $\rho = \mathbf{0.8218}$ in normal times.

3. Cafeteria queue model

Suppose that the customers (here refers to students) arrive at the system (canteen) in an independent way. Even if the service windows are all busy after entering the system, the customers are still willing to wait in line for their meals as long as the queue length is not large or the waiting time is not long. The queue discipline is FCFS, that is, first come, first served. Although the customer source is limited, due to the limited system space and the particularity of college canteen service (open only at specified time), the customer source can be regarded as unlimited during the period under consideration. The system only allows a limited number of customers to wait in line, and the rest of the customers have to leave and find other system services (order takeout or other ways). According to the above understanding and agreement, we establish the multi-service mixed system queuing model.

According to the above understanding and agreement, the canteen service system is M/M/C/K queuing service system[5]. In the multi-service hybrid queuing model M/M/C/K, the first M indicates that the interval time of customers arriving to the system follows the exponential distribution of parameter, that is, the arrival process of customers is Poisson distribution. The second M indicates that the service time follows the exponential distribution of the parameter. C is the number of service Windows in the service system; K is the (maximum) queue capacity in the system or the (maximum) length allowed for customers to queue in the system, including customers who are receiving services and are waiting in the queue for services. For a long time, students' choice of canteen has great stability, and the arrival rate of customers is unchanged. Because the canteen has many years of rich experience and is more skilled, the average service time will not fluctuate greatly, and the average service time is also considered to be more stable[6,7]. Assume a steady number of arrivals at each window. Due to the fixed service window of the canteen, two M/M/C/K queuing models can be built in the off-peak period, while the normal period is M/M/C/K queuing model.

Through statistics, we can measure the maximum capacity $\boldsymbol{K=165}$ .The performance the M/M/C/K queue systemas follows, where $\boldsymbol{C}$ is the number of windows opened, $\boldsymbol{\lambda}$ is the arrival rate, $\boldsymbol{\mu}$ is the service rate, $\boldsymbol{L_q}$ is the queue length (i.e., the number of queuing students), $\boldsymbol{L}$ is the number of students in the system (including queuing students and students being served), $\boldsymbol{W_q}$ is the average waiting time, $\boldsymbol{W}$ is the sojourn time (queue waiting time and receiving service time), and $\boldsymbol{\rho=\frac{\lambda}{C\mu}}$ is the service intensity (utilization rate of the system),respectively. According to M/M/C/K[8], the performance of the off-peak period and time range are shown in Table 2.

Table 2: Performance in off-peak period

Number of WindowsC	**Period of the off-peak period**							
	11:30-11:50				11:50-12:10			
	$\boldsymbol{L_q}$	$\boldsymbol{L}$	$\boldsymbol{W_q}$	$\boldsymbol{W}$	$\boldsymbol{L_q}$	$\boldsymbol{L}$	$\boldsymbol{W_q}$	$\boldsymbol{W}$
5	6.40	10.87	4.24	7.52	1.49×10^{-1}	2.714	9.40×10^{-2}	1.707
6	1.21	5.69	0.84	3.93	3.93×10^{-2}	2.604	2.48×10^{-2}	1.638
7	0.38	4.85	0.26	3.35	1.01×10^{-2}	2.575	6.38×10^{-3}	1.620
8	0.13	4.60	0.09	3.18	2.48×10^{-3}	2.567	1.56×10^{-3}	1.614
9	0.04	4.52	0.03	3.12	5.67×10^{-4}	2.565	3.57×10^{-4}	1.613
10	0.01	4.49	0.01	3.10	1.20×10^{-4}	2.564	7.61×10^{-5}	1.612

As can be seen from Table 2, if 7, 8, 9 or 10 service windows are set up, the queue length in the system during the time period from 11:30 to 11:50 is less than 1, which is unrealistic. The queue length in the second period of 5 to 10 windows is less than 1. Considering that these two service times are continuous, it is more practical to open 5 or 6 windows, and it is also necessary to analyze the service intensity and utilization rate of the system.

Table 3 shows the performance of queuing in normal times.

It can be seen from Table 2 and Table 3 that with the increase of opening windows, both the queue length $\boldsymbol{L_q}$ and the number of customers $\boldsymbol{L}$ in the system, the average waiting time $\boldsymbol{W_q}$ and the sojourn time W decrease. However, adding a window will cause a waste of resources. Table 4 shows the service intensity, idle probability and waiting probability of arriving customers with different window systems.

Table 3: Performance in normal period

Queue performance in normal period				
Number of Windows C	L_q	L	W_q	W
5	2.75232	6.86125	1.04385	2.60221
6	0.67806	4.78699	0.25716	1.81552
7	0.21453	4.32346	0.08136	1.63973
8	0.07114	4.18007	0.02698	1.58534
9	0.02329	4.13222	0.00883	1.56719
10	0.00735	4.11627	0.00278	1.56115

Table 4: Evaluation indicators of different number of windows in each period

Number of windows (C)	**The off-peak period**						**The normal period**		
	11:30-11:50			11:50-12:10			12:00-12:30		
	Service intensity	Idle probability	Waiting probability	Service intensity	Idle probability	Waiting probability	Service intensity	Idle probability	Waiting probability
5	0.89496	0.00528	0.01346	0.51290	0.07483	0.00638	0.82179	0.01090	0.01647
6	0.74580	0.00944	0.01235	0.42742	0.07645	0.00195	0.68482	0.01472	0.01051
7	0.63926	0.01075	0.00659	0.36636	0.07684	0.00053	0.58699	0.01589	0.00489
8	0.55935	0.01119	0.00293	0.32057	0.07693	0.00013	0.51362	0.01626	0.00197
9	0.49720	0.01133	0.00117	0.28494	0.07695	0.00003	0.45655	0.01638	0.00072
10	0.44748	0.01137	0.00043	0.25645	0.07696	0.00001	0.41089	0.01641	0.00026

As can be seen from Table 4, during the implementation of off-peak dining during the epidemic period, it is reasonable for the school to set up five service windows. At this time, the average probability of each window being busy in the two periods is about 89% and 51%, while the probability of being idle (system idle) is 0.5% and 7%, respectively. Students hardly need to wait. In normal times, it is more reasonable to open 7 windows, at this time the utilization rate is close to 60%, the probability that the windows are idle is about 1.5%, and students can eat almost without waiting in line, and the waiting probability is about 1.5%.

In the investigation, it was found that the school opened 8 Windows in the off-peak period, while all 10 windows were opened in normal period. Although this phenomenon reflected the care of the school in serving students, it greatly wasted resources and increased the operating cost of the canteen, which was an unreasonable way of opening.

4. Conclusion

As far as students are concerned, by increasing the number of windows, the waiting time of students can be reduced; However, from the perspective of the canteen, although increasing the number of Windows can reduce the waiting time and improve students' satisfaction with the canteen, so as to win more students to eat in the canteen, it will also increase the operating cost of the canteen. Therefore, how to balance between the two and determine the best number of windows is of great significance to both students and the canteen. This study builds a corresponding quantitative model for the window service work in the cafeteria. Starting from saving students' dining time, the paper conducts numerical simulation with MATLAB based on the queuing theory, and gives a reasonable number of open service windows, which not only ensures students' waiting time for dining is short, but also comprehensively takes into account the overall situation, which can save school resources and has certain guiding significance.

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