厦門大學

Management System Simulation Report

A Single-Server Queueing System

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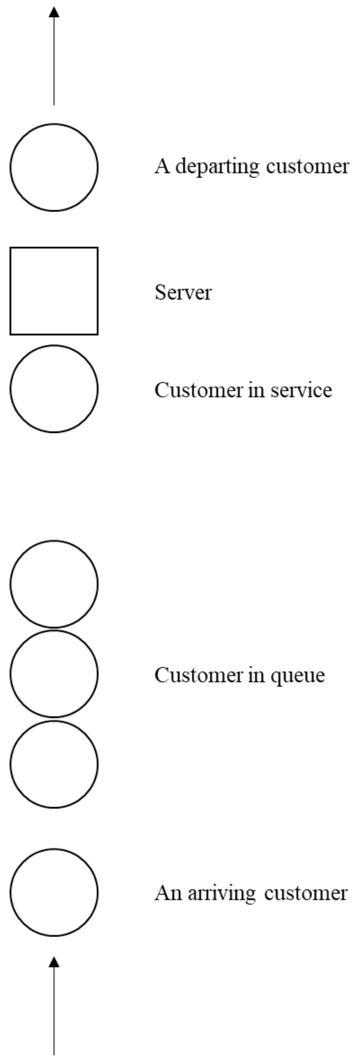
Catalogue

1.Problem Description

1.1 Problem Background

This is a single-server queueing system such as a one-operator barbershop, for which the interarrival times $A_1,A_2,\ldots$ are *independent and identically distributed* (IID) random variables. A customer who arrives and finds the server idle enters service immediately, and the service times $S_1,S_2,\ldots$ of the successive customers are IID random variables that are independent of the interarrival times. A customer who arrives and finds the server busy joins the end of a single queue. Upon completing service for a customer, the server chooses a customer from the queue (if any) in a first-in, first-out (FIFO) manner.

Fig 1.1 A single-server queueing system



1.2 The Simulation Variables

Table 2.1 Input variables

Input		
Data Type	**Name**	**Description**
float	*m_mean_interarrival*	Mean interarrival time
float	*m_mean_service*	Mean service time
int	*m_num_delays_required*	Number of customers
float	*m_delay_threshold*	Excessing delay time
float	*m_limit_num_in_q*	Queue length
float	*m_time_limit*	Limited opening time
float	*m_time_operation*	Limited operation time
float	*m_seed*	The seed number

Table 1.2 Output variables

Output		
Data Type	**Expressions**	**Description**
int	*seed[100]*	Seed numbers
float	*total_of_delays / num_custs_delayed*	Average delay in queue
float	*area_num_in_q / sim_time*	Average number in queue
float	*area_server_status / sim_time*	Server utilization
float	*total_of_delays / num_custs_delayed + area_server_status / sim_time*	Average delay in queue system
float	*area_num_in_q / sim_time + area_server_status / sim_time*	Average number in system
int	*max_queue_length*	Maximum queue length
float	*max_delay_time*	Maximum delay in queue
float	*max_sys_delay_time*	Maximum time in system
float	*1.0 * num_over_delay /*	Proportion of customers

	num_custs_delayed	delay in queue over 1 minute
float	*sim_time*	Time of simulation

Table 3.3 State variables

State		
Data Type	**Name**	**Description**
int	*server_status*	Statues of the server
int	*num_custs_delayed*	The number of customers in the queue
float	*time_arrival[Q_LIMIT + 1]*	The time of arrival of each customer currently in the queue
float	*time_last_event*	Time of last event

2.Program Organization and Logic

2.1 Model description

1.The simulation will end when n=1000 delays in queue have been completed in order to collect more data.

2.The interarrival and service times will be modeled as independent random variables from exponential distributions with mean 1 minute for the interarrival times and mean 0.5 minute for the service times.

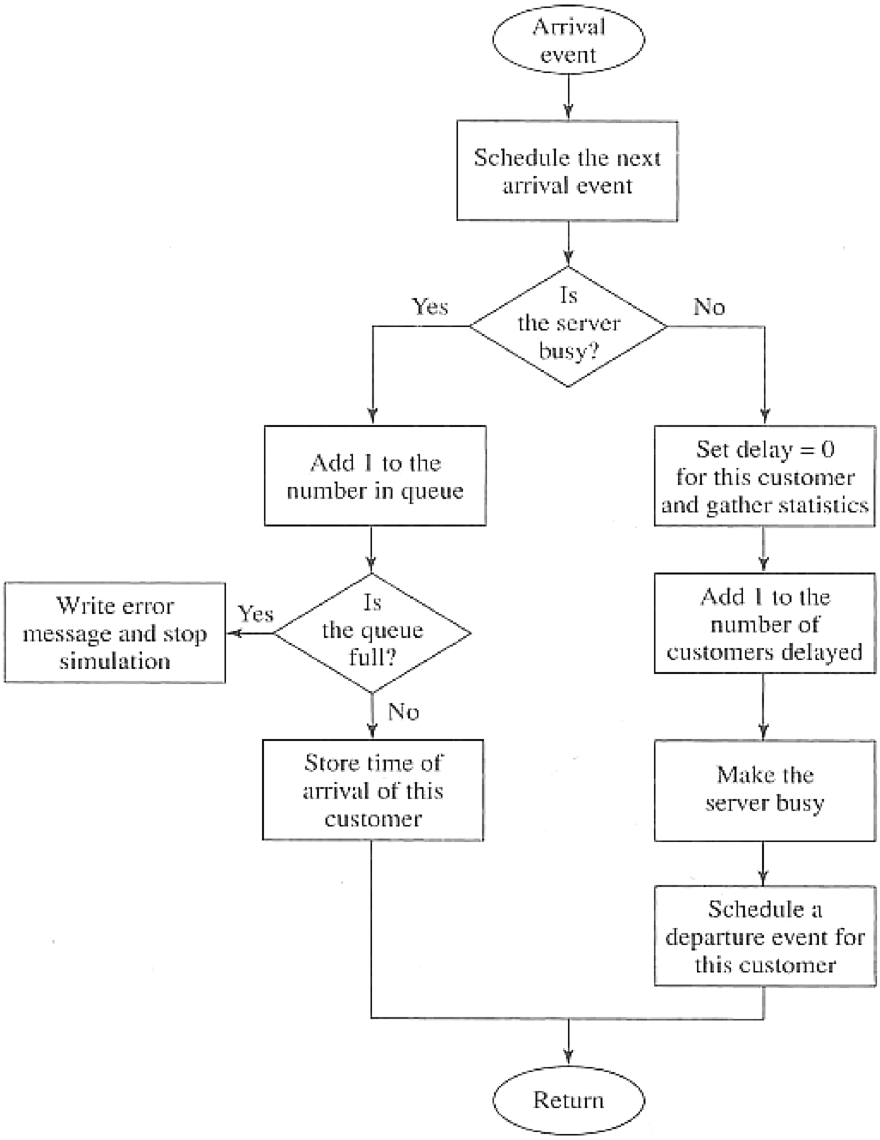
3.The single-server queue with exponential interarrival and service times is commonly called the M/M/1 queue.

4. To simulate this model, we need a way to generate random variates from an exponential distribution.

2.2 The Logic of the Arrival Event

2.2.1 Flowchart

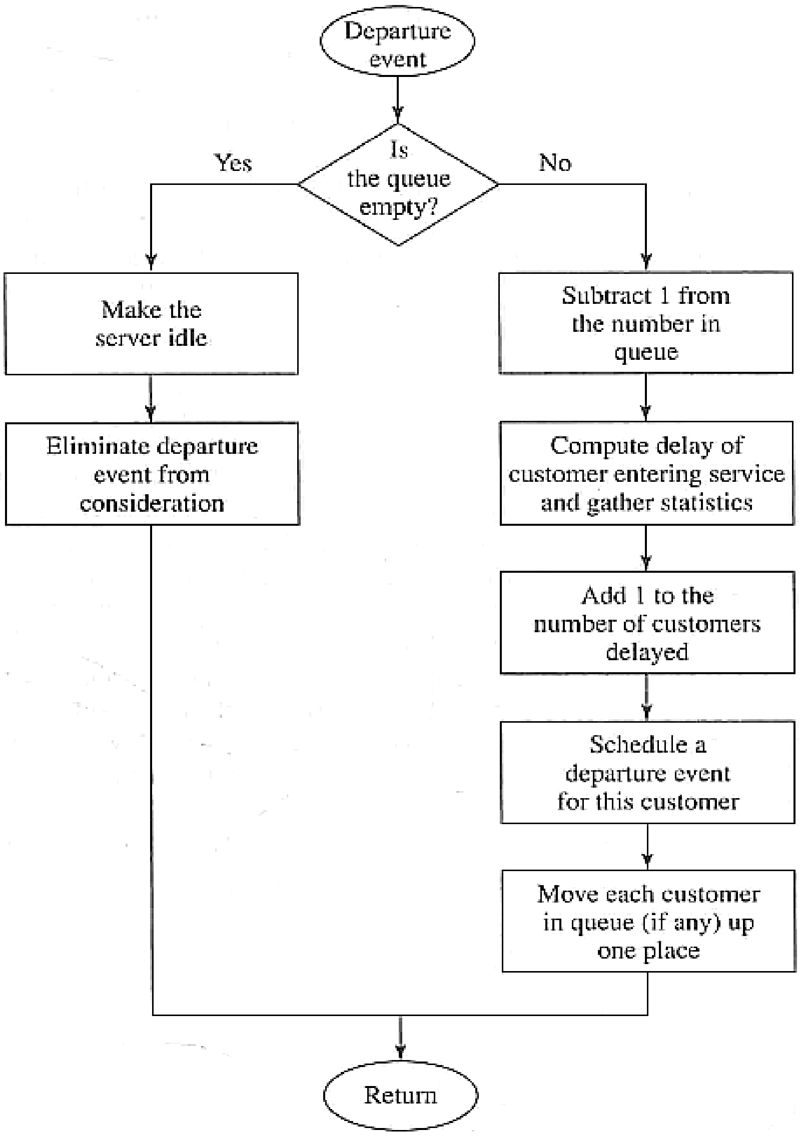
Fig 2.1 Arrival Event



2.3 The Logic of the Departure Event

2.3.1 Flowchart

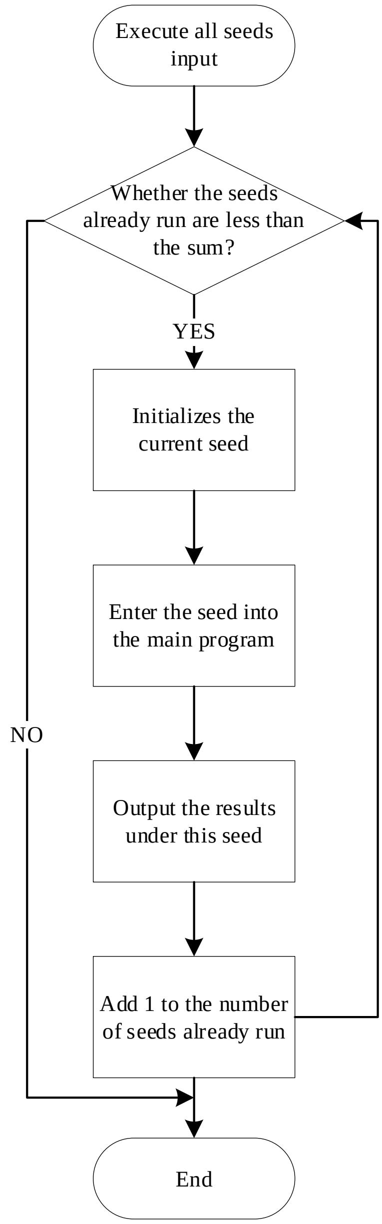
Fig 2.2 Departure Event



2.4 The Seed Number Control

2.3.1 Flowchart

Fig 2.3 The Seed Number Control



2.5 The Measures of Performance

We measure the performance of the queuing system by the following indicators:

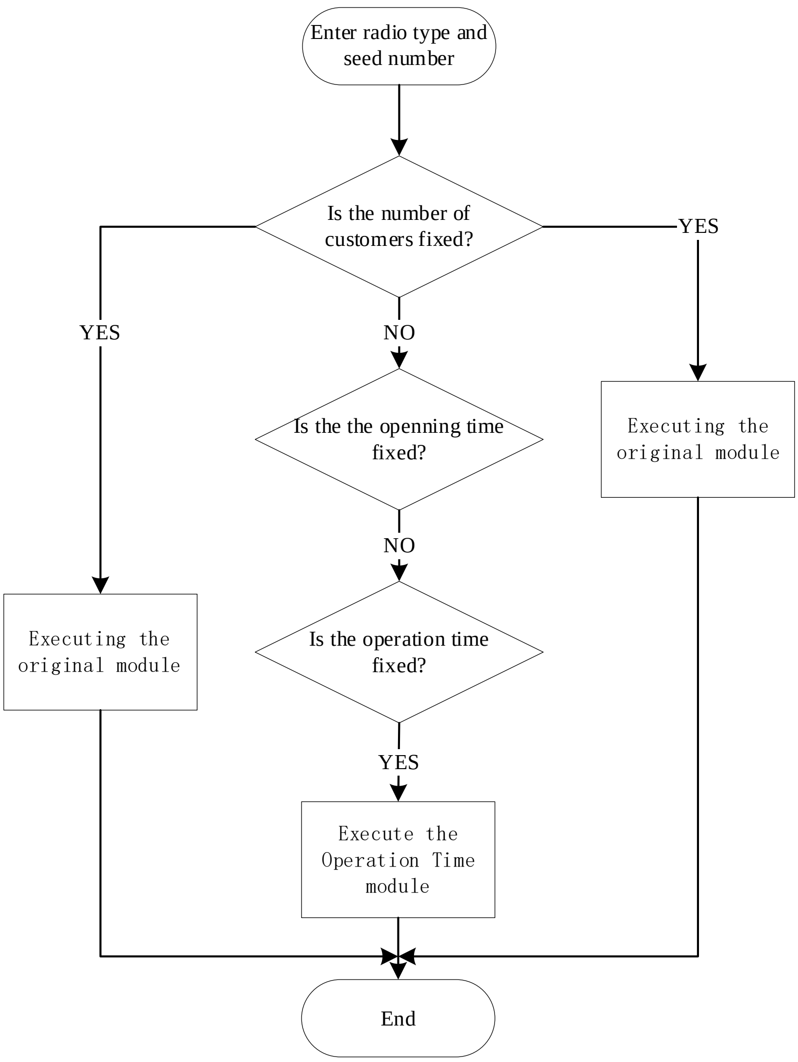
1. Average queue waiting time = total waiting time/total number of customers
2. Average queue length = integral under queue length/simulated time
3. Utilization = integral under service/simulated time

4. Time-average number in the system=Average queue length + Average number of customers served
5. Average total time in the system of customers= Average queue wait time+ Average service time
6. Maximum queue length = max_queue_length
7. Maximum queue wait time = max_delay_time
8. Maximum system wait time = max_sys_delay_time
9. Percentage of queuing for more than a minute = 1.0 * num_over_delay / num_custs_delayed

2.6 The Logic of The Main Function

2.3.1 Flowchart

Fig 2.4 Main Function



3.Output of Experiments

3.1 Original Problem Output

3.1.1 Original Output

Table3.1 Original Problem with 1000 Customers

Input	
Mean interarrival time	1.000 minutes
Mean service time	0.5 minutes
Number of customers	1000

Output	
Average delay in queue	0.430 minutes
Average number in queue	0.418
Server utilization	0.460
Time simulation ended	1027.915

3.1.2 Output with 10000 Customers

Table3.2 Original Problem with 10000 Customers

Input	
Mean interarrival time	1.000 minutes
Mean service time	0.5 minutes
Number of customers	10000

Output	
Average delay in queue	0.4547 minutes
Average number in queue	0.4519
Server utilization	0.4864
Time simulation ended	1062.1396

3.2 Changing The Seed of RNG

3.2.1 Different Seed's Output with 1000 Customers

Table3.3 Different Seed's Output with 1000 Customers

Simulation	Seed	Average delay in queue	Average number in queue	Server utilization	Time of simulation
1	1	0.43	0.4183	0.46	1027.915
2	2	0.5238	0.5519	0.5327	949.0419
3	3	0.5486	0.545	0.5276	1006.637
4	4	0.4628	0.4637	0.4841	997.942
5	5	0.5229	0.5392	0.51	969.7444
6	6	0.3961	0.3947	0.4776	1003.522
7	7	0.552	0.5794	0.5225	952.8242
8	8	0.4656	0.4429	0.4909	1051.163
9	9	0.4583	0.4624	0.4911	991.1072
10	10	0.4149	0.4211	0.49	985.0843

3.2.2 Different Seed's Output with 10000 Customers

Table3.4 Different Seed's Output with 10000 Customers

Simulation	Seed	Average delay in queue	Average number in queue	Server utilization	Time of simulation
1	1	0.4547	0.4519	0.4864	10062.1396
2	2	0.4951	0.49	0.4996	10104.1807
3	3	0.5237	0.5291	0.509	9898.1143
4	4	0.4925	0.4937	0.4975	9975.5859
5	5	0.4946	0.4955	0.501	10001.1748
6	6	0.432	0.4322	0.4892	9995.3945

7	7	0.4902	0.4861	0.4947	10084.5684
8	8	0.473	0.4635	0.4948	10206.8076
9	9	0.4806	0.4788	0.497	10038.7627
10	10	0.5289	0.534	0.4983	9916.8076

3.3 Performance of Original Problem

3.3.1 Performance with 1000 Customers

Table3.5 Performance of Original Problem with 1000 Customers

Average number in queue system	**Average delay in system**	**Maximum queue length**	**Maximum delay time in queue**	**Maximum delay time in system**	**Proportion of customers delay in queue over 1 minute**
0.8784	0.89	11	4.1275	4.5488	0.162
1.0846	1.0565	7	4.4893	5.7925	0.202
1.0726	1.0762	7	4.7554	5.8823	0.213
0.9479	0.9469	8	4.1909	4.8209	0.191
1.0491	1.0328	8	4.283	5.2499	0.196
0.8723	0.8737	6	3.6918	4.2554	0.154
1.1019	1.0745	8	4.6098	5.5253	0.209
0.9339	0.9566	7	4.0807	4.8921	0.177
0.9535	0.9494	8	4.6813	4.9998	0.175
0.9112	0.9049	9	4.5392	5.1844	0.145

3.3.2 Performance with 10000 Customers

Table3.6 Performance of Original Problem with 10000 Customers

Average number in queue system	Average delay in system	Maximum queue length	Maximum delay time in queue	Maximum delay time in system	Proportion of customers delay in queue over 1 minute
0.9383	0.9411	12	7.9819	8.5693	0.1656
0.9896	0.9947	14	9.3242	9.8809	0.1806
1.0381	1.0327	13	9.043	9.4658	0.1895
0.9911	0.9899	12	8.0918	8.249	0.1798
0.9966	0.9956	12	8.1914	9.5664	0.181
0.9214	0.9212	8	6.0137	6.6553	0.1599
0.9809	0.985	11	7.2242	7.3346	0.1817
0.9582	0.9678	11	5.507	6.7178	0.1778
0.9758	0.9777	12	8.2877	8.7292	0.1684
1.0323	1.0272	12	7.9785	8.5088	0.1909

3.4 Performance of Limited Opening Time

Table3.7 Performance of Limited Opening Time with 10000 Customers

Seed	Average delay in queue	Average number in queue	Server utilization	Average number in queue system	Average delay in system
1	0.3986	0.3944	0.4644	0.8588	0.863
2	0.5398	0.5612	0.5337	1.0949	1.0736
3	0.6198	0.6194	0.5389	1.1583	1.1587

4	0.4776	0.4923	0.5104	1.0027	0.988
5	0.4731	0.4692	0.4919	0.9611	0.965
6	0.4806	0.5185	0.5345	1.053	1.0152
7	0.5687	0.5847	0.5242	1.1089	1.0929
8	0.3714	0.3481	0.4694	0.8175	0.8408
9	0.4415	0.4424	0.4766	0.9191	0.9182
10	0.3343	0.3301	0.4658	0.7959	0.8001

Table3.8 Performance of Limited Opening Time with 10000 Customers

Seed	**Maximum queue length**	**Maximum delay time in queue**	**Maximum delay time in system**	**Proportion of customers delay in queue over 1 minute**	**Time of simulation**
1	6	3.4402	4.3016	0.1495	480
2	7	3.8298	4.1371	0.2064	480
3	7	4.7544	4.9879	0.25	480
4	7	4.1909	4.8209	0.2101	480
5	6	3.8785	4.2961	0.187	480
6	6	3.0694	3.7982	0.2143	480
7	8	4.1557	5.5253	0.2328	480
8	5	4.0501	4.7881	0.1422	480
9	6	4.2626	4.9998	0.1788	480
10	3	4.5392	5.1844	0.1245	480

3.5 Performance of Limited Operation Time

Table3.9 Performance of Limited Operation Time with 10000 Customers

Seed	Average delay in queue	Average number in queue	Server utilization	Average number in queue system	Average delay in system
1	0.2875	0.2677	0.4418	0.7095	0.7293
2	0.3107	0.292	0.4849	0.7768	0.7956
3	0.2885	0.2708	0.4658	0.7366	0.7542
4	0.2687	0.2463	0.4264	0.6728	0.6951
5	0.2467	0.2266	0.4357	0.6623	0.6823
6	0.3015	0.2895	0.452	0.7415	0.7534
7	0.2959	0.2817	0.487	0.7687	0.7829
8	0.2821	0.2609	0.4807	0.7416	0.7628
9	0.2576	0.2383	0.4281	0.6664	0.6857
10	0.2283	0.2145	0.4398	0.6543	0.6681

Table3.10 Performance of Limited Operation Time with 10000 Customers

Seed	Maximum queue length	Maximum delay time in queue	Maximum delay time in system	Proportion of customers delay in queue over 1 minute	Balk
1	2	3.8765	4.9404	0.0895	32
2	2	3.0281	4.1371	0.0998	42
3	2	3.8141	4.9007	0.0884	30
4	2	2.8895	3.3179	0.0955	32
5	2	2.6562	3.4777	0.0839	28

6	2	3.2359	3.3792	0.1215	44
7	2	3.0336	4.5199	0.1096	39
8	2	3.3018	3.7302	0.0991	20
9	2	3.9488	4.6071	0.0901	17
10	2	1.9723	3.5988	0.0732	20

4.Analysis of Output

4.1 Analysis of Question 1

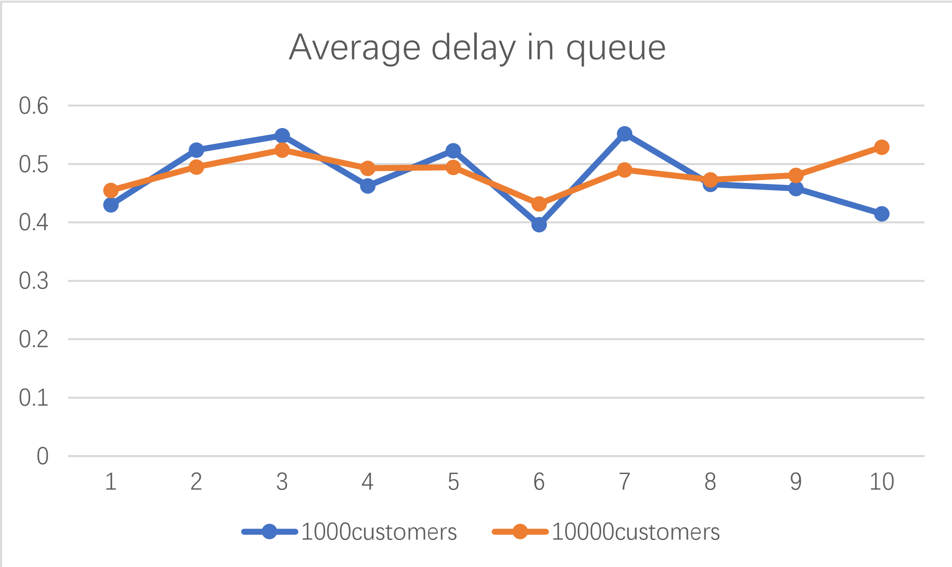
The simulation result of the number of 10,000 customers is closer to the steady state, so we use this result as the basis for our result analysis.

As can be seen from the results of the original question, the average waiting time of customers in the queue is 0.4547 minutes, the average number of queuing people per minute is 0.4519, and the service efficiency is only 0.4864.So in this case, the service efficiency is not high. However, since this result is only obtained by repeating one seed number, we will compare the different customer numbers after changing the seed number.

4.2 Analysis of Different Situations' Performance

4.2.1 The steady state

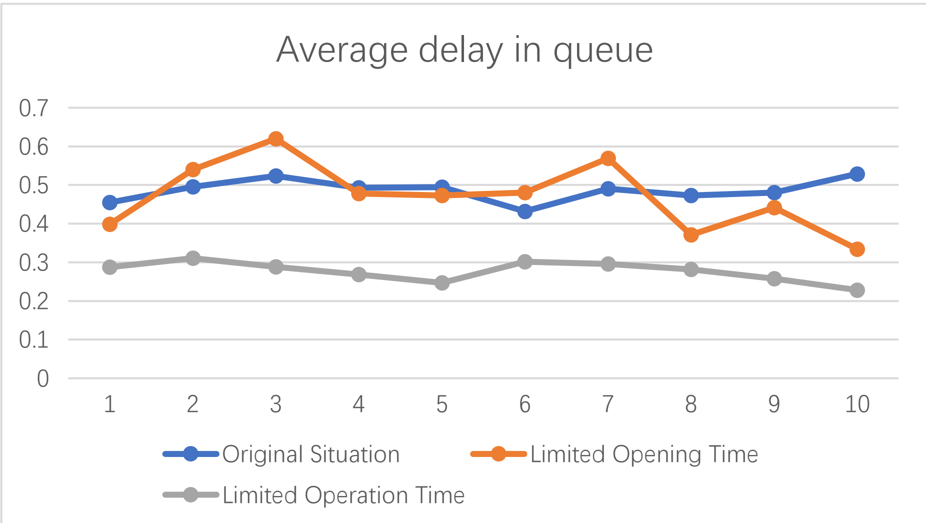
Fig 4.1 Average delay in queue



We can see the average delay in queue result of 1000 customers and 10000 customers when 10 different seeds are used. Since this experiment is non-terminal state simulation, it can be seen that when the number of customers is 10000, the result obtained is closer to the steady state, and the final Average delay in queue is about 0.5 minutes. Therefore, we use the result of customer number of 10000 for analysis.

4.2.2 Average delay in queue

Fig 4.2 Average delay in queue

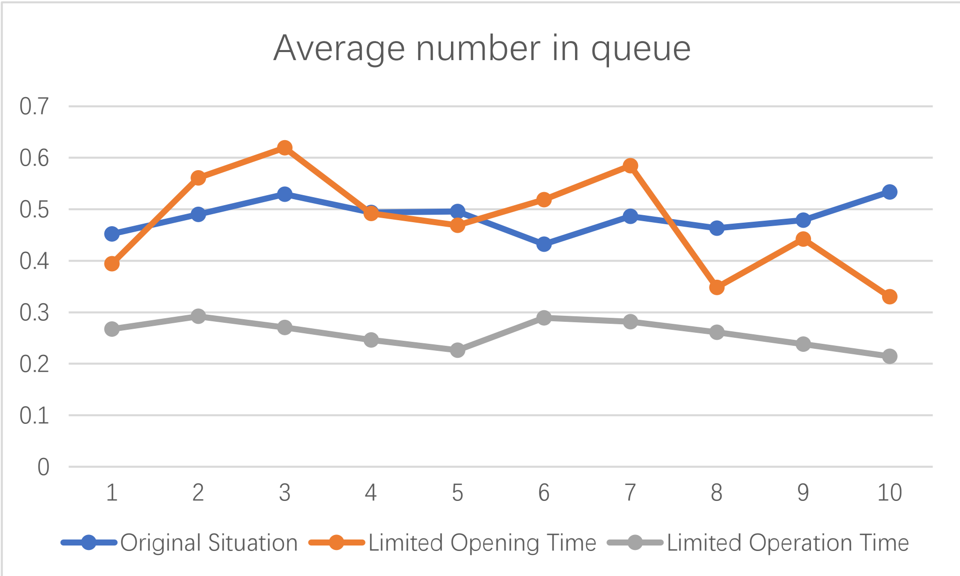


As can be seen from the figure, the simulation results without adding any restrictions are close to the simulation results of restricted open events, that is, the average waiting time of customers in the queue is about 0.5 minutes.

However, after the restriction of operation time and the maximum queuing number of 2 people are increased, the average waiting time of customers in the queue is significantly reduced, and customers can receive service faster.

4.2.3 Average number in queue

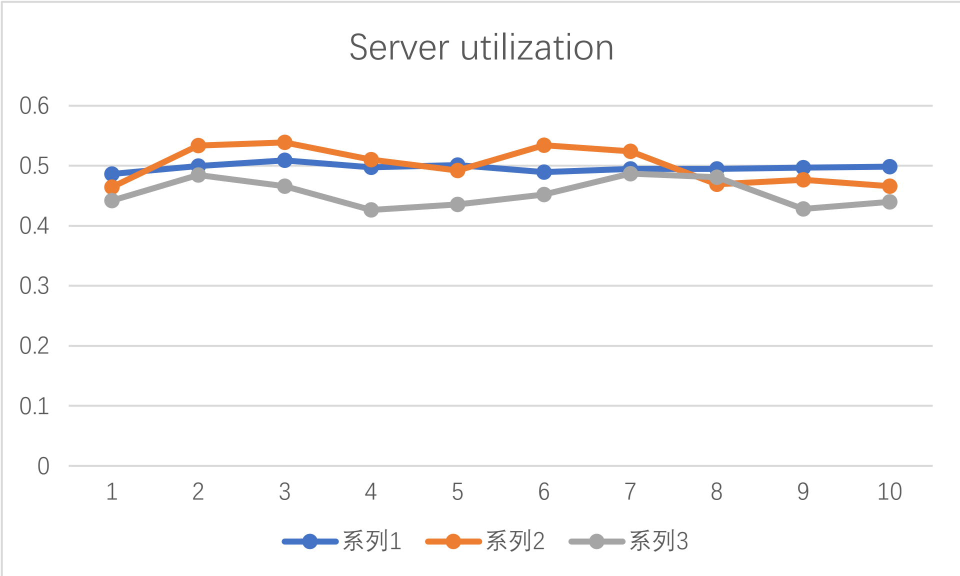
Fig 4.3 Average number in queue



As can be seen from the figure, the average waiting number in the queue is about 0.4-0.6 people without any increase in restrictions and with limited opening time. However, under the simulation condition that the operation time is limited and the maximum queuing number is two people, the average number of people in the queue is only about 0.2-0.3 people.

4.2.4 Server utilization

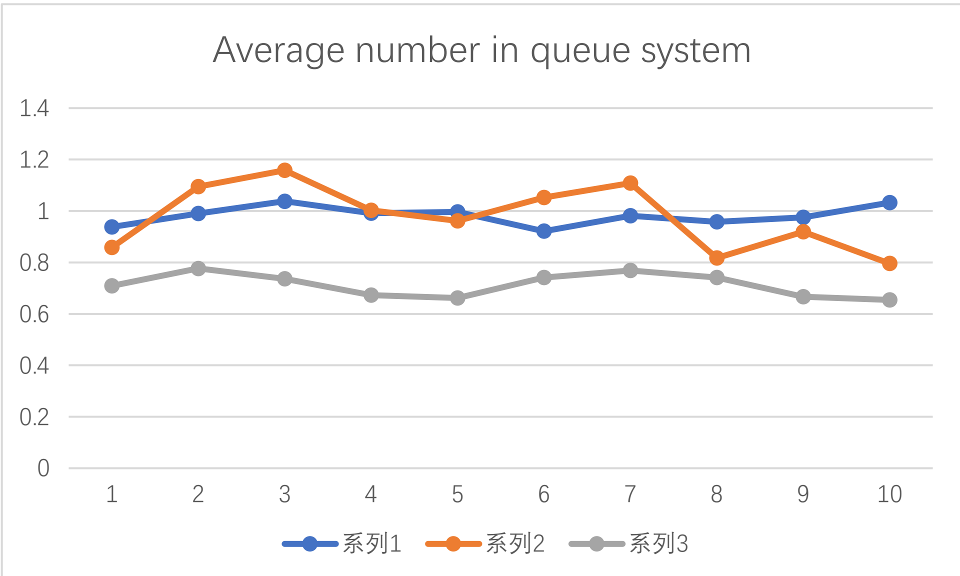
Fig 4.4 Server utilization



The efficiency of the service desk under the three conditions was similar, and there was no significant difference.

4.2.5 Average number in queue system

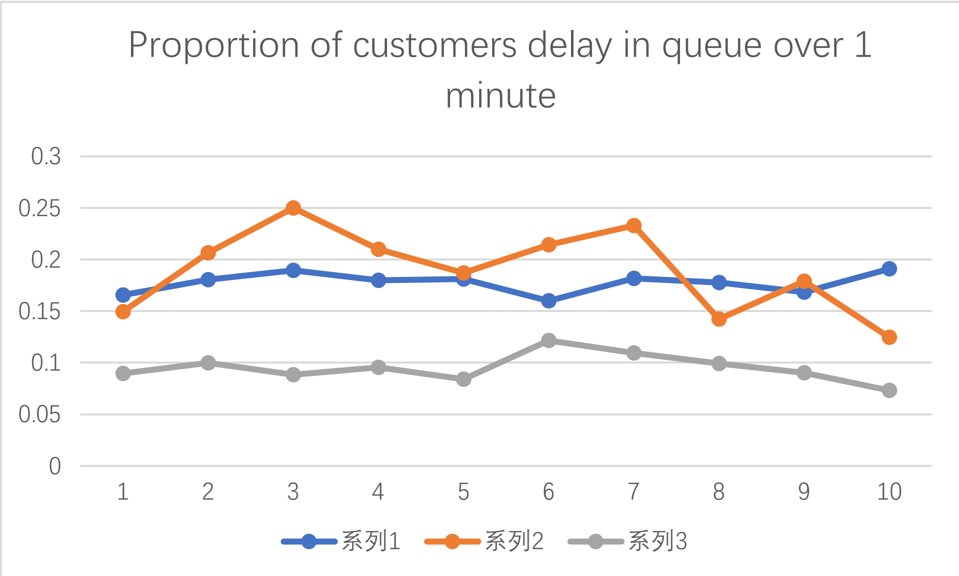
Fig 4.5 Average number in queue system



Similarly, in the case of different seeds, the operation time is limited and the maximum queuing number is two people, the system queuing number is still the lowest.

4.2.6 Proportion of customers delay in queue over 1 minute

Fig 4.6 Proportion of customers delay in queue over 1 minute



Similarly, in the case of different seeds, the operation time is limited and the maximum queuing number is two people, Proportion of customers delay in queue over 1 minute is still the lowest. This means that in this case the waiting time for customers is the shortest and the impact on customer satisfaction is the least.

5. Summary

5.1 Select the optimal situation according to the simulation results

According to the analysis of the above results, it can be seen that for the single service desk queuing system, limiting the number of queuing customers and the operating time can effectively shorten the waiting time of customers without improving service efficiency, thus improving customer satisfaction under the existing circumstances.

However, we should also consider the other influences under the increased restrictions, such as the customers who leave due to the limited number of queuing. This part of customers may bring revenue loss to the business organization, so we need to make decisions in a realistic situation.

5.2 Analyze the costs in actual situations

In fact, in order to obtain the actual business significance through the simulation results, it is not enough to only analyze the optimal system state index. We need to bring it into the actual business environment to analyze its costs and benefits, so as to obtain the results that can maximize the interests of business organizations.