

University of Delaware
Lerner College of Business & Economics
Operations Management

BUAD 467/667: *Service Management*
Spring 2008

MIDTERM EXAMINATION

This examination is open book and open notes. Pursuant to the Honor Code of the University of Delaware, all cheating will be prosecuted to the maximum extent given by the rules of the University.

The examination will last one hour and 45 minutes; please feel free to ask questions during the examination if there is any confusion. You must show all work in your exam books.

Question 1 (50 points)

Last National Bank is considering a major investment in call center technology that would allow them to handle all calls in one central call center versus in each of their four (4) branches. In order to make this decision, management would like an economic analysis of the relative merits of calls being handled at each branch versus being routed to a single call center. Here are the facts that will be used to make the decision:

- Management has decided to design for the peak hour. They have decided that the service level they wish to achieve is that no customer waits on hold, on average, for more than 5 seconds.
- At the peak hour, each branch receives an average of 30 calls an hour, and the interarrival times for these calls are negative exponentially distributed.
- Each employee, either a branch employee or a call center employee, can handle, on average, 10 calls per hour. The service times are also negative exponentially distributed.
- The fully loaded cost for a branch employee is \$20 per hour; the cost for a call center employee is \$25 per hour.

The attached spreadsheets should be used to calculate the answers to these questions.

In answering these questions, please justify all numbers used and show all work.

- (a) 10 points** What is the optimal number of branch employees to hire for the peak hour if all calls are handled by the branch? What is the optimal cost under this scenario?
- (b) 10 points** What is the optimal number of call center employees to hire for the peak hour if all calls are handled by the call center? What is the optimal cost under this scenario? Should the calls stay in the branches, or be handled in the centralized call center?
- (c) 15 points** After answering (a) and (b), you think you're done. However, the Geek in the back of the room shouts, "What about email?" Mr. Geek has figured out that each branch is also receiving five emails per peak period (with a negative exponential distribution) and each employee can process 5 emails per hour (they're fast talkers, but slow typists); the service times are also negative exponentially distributed. Mr. Suit, the Boss, says, "I want email answered exactly like a letter; no World-Wide Wait here!" Thus, email must also be answered, on average, within five seconds. Redo parts (a) and (b) including the email with the phone calls.

(d) 15 points The finance guru, Mo Money, objects to this analysis: “Why are we designing for the peak period? Say we made this decision for the typical evening hour, not the worst case. In such a typical hour, each branch only receives 20 calls an hour (plus the 5 emails). What's our best decision if we only use the typical hour? Furthermore, given this decision, how bad will things be in the peak period in terms of waiting time and the probability that customers have to wait? Are we really making things terrible during the peak hour if we plan for the typical hour?” Provide an answer to Mr. Money by redoing parts (a) and (b) while planning for the typical hour. Then determine the average waiting time in the queue and the probability of waiting in the peak period *using the staffing levels required for the typical hour* in both the branch and call center.

Question 2 (20 points)

Two department stores are serving customers in three adjacent areas. The size of Store A is 1.5 times of the size of Store B's. The number of households in each area and the average travel time (in minutes) to the grocery stores are shown below. Assume that the average monthly household budget for purchase from the department stores is \$300 per household in all the three areas. Also assume $\lambda = 3$.

Area	1	2	3
Travel time to Store A (minutes)	5	10	12
Travel time to Store B (minutes)	25	16	9
Number of households	500	600	460

(a) 20 points What are the current market shares (in percentage) of Store A and B? Be sure to show all work.

Question 3 (30 points)

Dining Services (a somewhat fictitious group) has been working very hard over the past few years to improve service quality. Premium meals, etc. are all attempts to make the waiting experience *within* the dining facility as good as possible. However, it may be the case that Dining Service has *maxed out* the quality gains from better operations within its facility, and it may be time to consider “bolder” initiatives.

Consider one such initiative – *off-site delivery of pre-packaged breakfasts, lunches and dinners via delivery kiosks in a variety of places (dorms, Trabant Student Center, Lerner, etc.)*. For this initiative:

- (a) 10 points** Clearly define the service package that would be offered to the customer; i.e., what is the package of goods and services offered on the market.

- (b) 10 points** Assuming that Dining Service controls all of the steps of production, draw the complete process map for this service bundle. What are the “bottlenecks” in this process; i.e., what are the points where capacity considerations and/or quality concerns are the largest problem facing the successful implementation of this concept?

- (c) 10 points** Given your analysis on Parts (a)-(b), do you think that this initiative is worth pursuing, taking into account the impact on service quality and cost? Why or why not. Are there other options that exist that would improve upon this idea?

ggs.xls G/G/s Queueing Formula Spreadsheet

Inputs:

lambda 0.416667
 mu 0.138889
 Ca^2 1
 Cb^2 1.222222

Definitions of terms:

lambda = arrival rate
 mu = service rate
 s = number of servers
 Ca^2 = squared coeff. of variation of arrivals
 Cb^2 = squared coeff. of variation of service times
 Nq = average length of the queue
 Ns = average number in the system
 Wq = average wait in the queue
 Ws = average wait in the system
 P(0) = probability of zero customers in the system
 P(delay) = probability that an arriving customer has to wait

lambda/mu
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Outputs:

s	Nq	Ns	Wq	Ws	P(delay)	Utilization
0						
1	infinity	infinity	infinity	infinity	1.000000	1.000000
2	infinity	infinity	infinity	infinity	1.000000	1.000000
3	infinity	infinity	infinity	infinity	1.000000	1.000000
4	1.698113	4.698113	4.075472	11.275472	0.509434	0.750000
5	0.393586	3.393586	0.944606	8.144606	0.236152	0.600000
6	0.110159	3.110159	0.264382	7.464382	0.099143	0.500000
7	0.031371	3.031371	0.075290	7.275290	0.037645	0.428571
8	0.008632	3.008632	0.020718	7.220718	0.012949	0.375000
9	0.002250	3.002250	0.005400	7.205400	0.004050	0.333333
10	0.000551	3.000551	0.001323	7.201323	0.001157	0.300000
11	0.000127	3.000127	0.000304	7.200304	0.000304	0.272727
12	0.000027	3.000027	0.000065	7.200065	0.000074	0.250000
13	0.000006	3.000006	0.000013	7.200013	0.000017	0.230769
14	0.000001	3.000001	0.000003	7.200003	0.000003	0.214286
15	0.000000	3.000000	0.000000	7.200000	0.000001	0.200000
16	0.000000	3.000000	0.000000	7.200000	0.000000	0.187500
17	0.000000	3.000000	0.000000	7.200000	0.000000	0.176471
18	0.000000	3.000000	0.000000	7.200000	0.000000	0.166667
19	0.000000	3.000000	0.000000	7.200000	0.000000	0.157895
20	0.000000	3.000000	0.000000	7.200000	0.000000	0.150000
21	0.000000	3.000000	0.000000	7.200000	0.000000	0.142857
22	0.000000	3.000000	0.000000	7.200000	0.000000	0.136364
23	0.000000	3.000000	0.000000	7.200000	0.000000	0.130435
24	0.000000	3.000000	0.000000	7.200000	0.000000	0.125000
25	0.000000	3.000000	0.000000	7.200000	0.000000	0.120000
26	0.000000	3.000000	0.000000	7.200000	0.000000	0.115385
27	0.000000	3.000000	0.000000	7.200000	0.000000	0.111111
28	0.000000	3.000000	0.000000	7.200000	0.000000	0.107143
29	0.000000	3.000000	0.000000	7.200000	0.000000	0.103448
30	0.000000	3.000000	0.000000	7.200000	0.000000	0.100000
31	0.000000	3.000000	0.000000	7.200000	0.000000	0.096774
32	0.000000	3.000000	0.000000	7.200000	0.000000	0.093750
33	0.000000	3.000000	0.000000	7.200000	0.000000	0.090909
34	0.000000	3.000000	0.000000	7.200000	0.000000	0.088235
35	0.000000	3.000000	0.000000	7.200000	0.000000	0.085714
36	0.000000	3.000000	0.000000	7.200000	0.000000	0.083333
37	0.000000	3.000000	0.000000	7.200000	0.000000	0.081081
38	0.000000	3.000000	0.000000	7.200000	0.000000	0.078947
39	0.000000	3.000000	0.000000	7.200000	0.000000	0.076923
40	0.000000	3.000000	0.000000	7.200000	0.000000	0.075000

Intermediate Calculations:

(l/u)^s/s!	sum (l/u)^s/s!
1.00E+00	1.00E+00
3.00E+00	4.00E+00
4.50E+00	8.50E+00
4.50E+00	1.30E+01
3.38E+00	1.64E+01
2.03E+00	1.84E+01
1.01E+00	1.94E+01
4.34E-01	1.98E+01
1.63E-01	2.00E+01
5.42E-02	2.01E+01
1.63E-02	2.01E+01
4.44E-03	2.01E+01
1.11E-03	2.01E+01
2.56E-04	2.01E+01
5.49E-05	2.01E+01
1.10E-05	2.01E+01
2.06E-06	2.01E+01
3.63E-07	2.01E+01
6.05E-08	2.01E+01
9.55E-09	2.01E+01
1.43E-09	2.01E+01
2.05E-10	2.01E+01
2.79E-11	2.01E+01
3.64E-12	2.01E+01
4.55E-13	2.01E+01
5.46E-14	2.01E+01
6.30E-15	2.01E+01
7.00E-16	2.01E+01
7.50E-17	2.01E+01
7.76E-18	2.01E+01
7.76E-19	2.01E+01
7.51E-20	2.01E+01
7.04E-21	2.01E+01
6.40E-22	2.01E+01
5.65E-23	2.01E+01
4.84E-24	2.01E+01
4.03E-25	2.01E+01
3.27E-26	2.01E+01
2.58E-27	2.01E+01
1.99E-28	2.01E+01
1.49E-29	2.01E+01

ggs.xls G/G/s Queueing Formula Spreadsheet

Inputs:
 lambda 2.333333
 mu 0.145833
 Ca^2 1
 Cb^2 1.1875

Definitions of terms:
 lambda = arrival rate
 mu = service rate
 s = number of servers
 Ca^2 = squared coeff. of variation of arrivals
 Cb^2 = squared coeff. of variation of service times
 Nq = average length of the queue
 Ns = average number in the system
 Wq = average wait in the queue
 Ws = average wait in the system
 P(0) = probability of zero customers in the system
 P(delay) = probability that an arriving customer has to wait

lambda/mu
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Outputs:

s	Nq	Ns	Wq	Ws	P(delay)	Utilization
0						
1	infinity	infinity	infinity	infinity	1.000000	1.000000
2	infinity	infinity	infinity	infinity	1.000000	1.000000
3	infinity	infinity	infinity	infinity	1.000000	1.000000
4	infinity	infinity	infinity	infinity	1.000000	1.000000
5	infinity	infinity	infinity	infinity	1.000000	1.000000
6	infinity	infinity	infinity	infinity	1.000000	1.000000
7	infinity	infinity	infinity	infinity	1.000000	1.000000
8	infinity	infinity	infinity	infinity	1.000000	1.000000
9	infinity	infinity	infinity	infinity	1.000000	1.000000
10	infinity	infinity	infinity	infinity	1.000000	1.000000
11	infinity	infinity	infinity	infinity	1.000000	1.000000
12	infinity	infinity	infinity	infinity	1.000000	1.000000
13	infinity	infinity	infinity	infinity	1.000000	1.000000
14	infinity	infinity	infinity	infinity	1.000000	1.000000
15	infinity	infinity	infinity	infinity	1.000000	1.000000
16	infinity	infinity	infinity	infinity	1.000000	1.000000
17	12.900694	28.900694	5.528869	12.386012	0.737183	0.941176
18	4.647835	20.647835	1.991929	8.849072	0.531181	0.888889
19	2.179152	18.179152	0.933922	7.791065	0.373569	0.842105
20	1.120340	17.120340	0.480146	7.337289	0.256078	0.800000
21	0.598121	16.598121	0.256337	7.113480	0.170892	0.761905
22	0.323486	16.323486	0.138637	6.995780	0.110909	0.727273
23	0.174861	16.174861	0.074940	6.932083	0.069944	0.695652
24	0.093702	16.093702	0.040158	6.897301	0.042835	0.666667
25	0.049515	16.049515	0.021221	6.878363	0.025465	0.640000
26	0.025710	16.025710	0.011019	6.868162	0.014692	0.615385
27	0.013087	16.013087	0.005609	6.862751	0.008226	0.592593
28	0.006519	16.006519	0.002794	6.859937	0.004470	0.571429
29	0.003175	16.003175	0.001361	6.858503	0.002358	0.551724
30	0.001510	16.001510	0.000647	6.857790	0.001208	0.533333
31	0.000702	16.000702	0.000301	6.857444	0.000602	0.516129
32	0.000318	16.000318	0.000136	6.857279	0.000291	0.500000
33	0.000141	16.000141	0.000060	6.857203	0.000137	0.484848
34	0.000061	16.000061	0.000026	6.857169	0.000063	0.470588
35	0.000026	16.000026	0.000011	6.857154	0.000028	0.457143
36	0.000011	16.000011	0.000005	6.857147	0.000012	0.444444
37	0.000004	16.000004	0.000002	6.857145	0.000005	0.432432
38	0.000002	16.000002	0.000001	6.857144	0.000002	0.421053
39	0.000001	16.000001	0.000000	6.857143	0.000001	0.410256
40	0.000000	16.000000	0.000000	6.857143	0.000000	0.400000

Intermediate Calculations:

(l/u)^s/s!	sum (l/u)^s/s!
1.00E+00	1.00E+00
1.60E+01	1.70E+01
1.28E+02	1.45E+02
6.83E+02	8.28E+02
2.73E+03	3.56E+03
8.74E+03	1.23E+04
2.33E+04	3.56E+04
5.33E+04	8.89E+04
1.07E+05	1.95E+05
1.89E+05	3.85E+05
3.03E+05	6.88E+05
4.41E+05	1.13E+06
5.88E+05	1.72E+06
7.23E+05	2.44E+06
8.27E+05	3.27E+06
8.82E+05	4.15E+06
8.82E+05	5.03E+06
8.30E+05	5.86E+06
7.38E+05	6.60E+06
6.21E+05	7.22E+06
4.97E+05	7.71E+06
3.79E+05	8.09E+06
2.75E+05	8.37E+06
1.92E+05	8.56E+06
1.28E+05	8.69E+06
8.17E+04	8.77E+06
5.03E+04	8.82E+06
2.98E+04	8.85E+06
1.70E+04	8.87E+06
9.40E+03	8.88E+06
5.01E+03	8.88E+06
2.59E+03	8.88E+06
1.29E+03	8.88E+06
6.27E+02	8.89E+06
2.95E+02	8.89E+06
1.35E+02	8.89E+06
5.99E+01	8.89E+06
2.59E+01	8.89E+06
1.09E+01	8.89E+06
4.48E+00	8.89E+06
1.79E+00	8.89E+06

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Inputs:

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 Cb^2 1.1875

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lambda/mu
 4

Outputs:

s	Nq	Ns	Wq	Ws	P(delay)	Utilization
0						
1	infinity	infinity	infinity	infinity	1.000000	1.000000
2	infinity	infinity	infinity	infinity	1.000000	1.000000
3	infinity	infinity	infinity	infinity	1.000000	1.000000
4	#####	#####	#####	#####	1.000000	1.000000
5	2.424242	6.424242	4.155844	11.012987	0.554113	0.800000
6	0.622914	4.622914	1.067853	7.924996	0.284761	0.666667
7	0.197036	4.197036	0.337775	7.194918	0.135110	0.571429
8	0.064579	4.064579	0.110707	6.967850	0.059044	0.500000
9	0.020788	4.020788	0.035637	6.892780	0.023758	0.444444
10	0.006427	4.006427	0.011018	6.868161	0.008815	0.400000
11	0.001890	4.001890	0.003240	6.860383	0.003024	0.363636
12	0.000526	4.000526	0.000902	6.858045	0.000962	0.333333
13	0.000139	4.000139	0.000238	6.857380	0.000285	0.307692
14	0.000035	4.000035	0.000059	6.857202	0.000079	0.285714
15	0.000008	4.000008	0.000014	6.857157	0.000021	0.266667
16	0.000002	4.000002	0.000003	6.857146	0.000005	0.250000
17	0.000000	4.000000	0.000001	6.857144	0.000001	0.235294
18	0.000000	4.000000	0.000000	6.857143	0.000000	0.222222
19	0.000000	4.000000	0.000000	6.857143	0.000000	0.210526
20	0.000000	4.000000	0.000000	6.857143	0.000000	0.200000
21	0.000000	4.000000	0.000000	6.857143	0.000000	0.190476
22	0.000000	4.000000	0.000000	6.857143	0.000000	0.181818
23	0.000000	4.000000	0.000000	6.857143	0.000000	0.173913
24	0.000000	4.000000	0.000000	6.857143	0.000000	0.166667
25	0.000000	4.000000	0.000000	6.857143	0.000000	0.160000
26	0.000000	4.000000	0.000000	6.857143	0.000000	0.153846
27	0.000000	4.000000	0.000000	6.857143	0.000000	0.148148
28	0.000000	4.000000	0.000000	6.857143	0.000000	0.142857
29	0.000000	4.000000	0.000000	6.857143	0.000000	0.137931
30	0.000000	4.000000	0.000000	6.857143	0.000000	0.133333
31	0.000000	4.000000	0.000000	6.857143	0.000000	0.129032
32	0.000000	4.000000	0.000000	6.857143	0.000000	0.125000
33	0.000000	4.000000	0.000000	6.857143	0.000000	0.121212
34	0.000000	4.000000	0.000000	6.857143	0.000000	0.117647
35	0.000000	4.000000	0.000000	6.857143	0.000000	0.114286
36	0.000000	4.000000	0.000000	6.857143	0.000000	0.111111
37	0.000000	4.000000	0.000000	6.857143	0.000000	0.108108
38	0.000000	4.000000	0.000000	6.857143	0.000000	0.105263
39	0.000000	4.000000	0.000000	6.857143	0.000000	0.102564
40	0.000000	4.000000	0.000000	6.857143	0.000000	0.100000

Intermediate Calculations:

(l/u)^s/s!	sum (l/u)^s/s!
1.00E+00	1.00E+00
4.00E+00	5.00E+00
8.00E+00	1.30E+01
1.07E+01	2.37E+01
1.07E+01	3.43E+01
8.53E+00	4.29E+01
5.69E+00	4.86E+01
3.25E+00	5.18E+01
1.63E+00	5.34E+01
7.22E-01	5.42E+01
2.89E-01	5.44E+01
1.05E-01	5.45E+01
3.50E-02	5.46E+01
1.08E-02	5.46E+01
3.08E-03	5.46E+01
8.21E-04	5.46E+01
2.05E-04	5.46E+01
4.83E-05	5.46E+01
1.07E-05	5.46E+01
2.26E-06	5.46E+01
4.52E-07	5.46E+01
8.61E-08	5.46E+01
1.57E-08	5.46E+01
2.72E-09	5.46E+01
4.54E-10	5.46E+01
7.26E-11	5.46E+01
1.12E-11	5.46E+01
1.65E-12	5.46E+01
2.36E-13	5.46E+01
3.26E-14	5.46E+01
4.35E-15	5.46E+01
5.61E-16	5.46E+01
7.01E-17	5.46E+01
8.50E-18	5.46E+01
1.00E-18	5.46E+01
1.14E-19	5.46E+01
1.27E-20	5.46E+01
1.37E-21	5.46E+01
1.44E-22	5.46E+01
1.48E-23	5.46E+01
1.48E-24	5.46E+01

ggs.xls G/G/s Queueing Formula Spreadsheet

Inputs:

lambda 2
 mu 0.166667
 Ca^2 1
 Cb^2 1

Definitions of terms:

lambda = arrival rate
 mu = service rate
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 Wq = average wait in the queue
 Ws = average wait in the system
 P(0) = probability of zero customers in the system
 P(delay) = probability that an arriving customer has to wait

lambda/mu
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Outputs:

s	Nq	Ns	Wq	Ws	P(delay)	Utilization
0						
1	infinity	infinity	infinity	infinity	1.000000	1.000000
2	infinity	infinity	infinity	infinity	1.000000	1.000000
3	infinity	infinity	infinity	infinity	1.000000	1.000000
4	infinity	infinity	infinity	infinity	1.000000	1.000000
5	infinity	infinity	infinity	infinity	1.000000	1.000000
6	infinity	infinity	infinity	infinity	1.000000	1.000000
7	infinity	infinity	infinity	infinity	1.000000	1.000000
8	infinity	infinity	infinity	infinity	1.000000	1.000000
9	infinity	infinity	infinity	infinity	1.000000	1.000000
10	infinity	infinity	infinity	infinity	1.000000	1.000000
11	infinity	infinity	infinity	infinity	1.000000	1.000000
12	infinity	infinity	infinity	infinity	1.000000	1.000000
13	8.452652	20.452652	4.226326	10.226326	0.704388	0.923077
14	2.890232	14.890232	1.445116	7.445116	0.481705	0.857143
15	1.276762	13.276762	0.638381	6.638381	0.319190	0.800000
16	0.613722	12.613722	0.306861	6.306861	0.204574	0.750000
17	0.303912	12.303912	0.151956	6.151956	0.126630	0.705882
18	0.151230	12.151230	0.075615	6.075615	0.075615	0.666667
19	0.074609	12.074609	0.037304	6.037304	0.043522	0.631579
20	0.036202	12.036202	0.018101	6.018101	0.024134	0.600000
21	0.017190	12.017190	0.008595	6.008595	0.012892	0.571429
22	0.007962	12.007962	0.003981	6.003981	0.006635	0.545455
23	0.003591	12.003591	0.001795	6.001795	0.003291	0.521739
24	0.001574	12.001574	0.000787	6.000787	0.001574	0.500000
25	0.000671	12.000671	0.000335	6.000335	0.000727	0.480000
26	0.000278	12.000278	0.000139	6.000139	0.000324	0.461538
27	0.000112	12.000112	0.000056	6.000056	0.000140	0.444444
28	0.000044	12.000044	0.000022	6.000022	0.000058	0.428571
29	0.000017	12.000017	0.000008	6.000008	0.000023	0.413793
30	0.000006	12.000006	0.000003	6.000003	0.000009	0.400000
31	0.000002	12.000002	0.000001	6.000001	0.000003	0.387097
32	0.000001	12.000001	0.000000	6.000000	0.000001	0.375000
33	0.000000	12.000000	0.000000	6.000000	0.000000	0.363636
34	0.000000	12.000000	0.000000	6.000000	0.000000	0.352941
35	0.000000	12.000000	0.000000	6.000000	0.000000	0.342857
36	0.000000	12.000000	0.000000	6.000000	0.000000	0.333333
37	0.000000	12.000000	0.000000	6.000000	0.000000	0.324324
38	0.000000	12.000000	0.000000	6.000000	0.000000	0.315789
39	0.000000	12.000000	0.000000	6.000000	0.000000	0.307692
40	0.000000	12.000000	0.000000	6.000000	0.000000	0.300000

Intermediate Calculations:

(l/u)^s/s!	sum (l/u)^s/s!
1.00E+00	1.00E+00
1.20E+01	1.30E+01
7.20E+01	8.50E+01
2.88E+02	3.73E+02
8.64E+02	1.24E+03
2.07E+03	3.31E+03
4.15E+03	7.46E+03
7.11E+03	1.46E+04
1.07E+04	2.52E+04
1.42E+04	3.95E+04
1.71E+04	5.65E+04
1.86E+04	7.51E+04
1.86E+04	9.37E+04
1.72E+04	1.11E+05
1.47E+04	1.26E+05
1.18E+04	1.37E+05
8.84E+03	1.46E+05
6.24E+03	1.53E+05
4.16E+03	1.57E+05
2.63E+03	1.59E+05
1.58E+03	1.61E+05
9.00E+02	1.62E+05
4.91E+02	1.62E+05
2.56E+02	1.63E+05
1.28E+02	1.63E+05
6.15E+01	1.63E+05
2.84E+01	1.63E+05
1.26E+01	1.63E+05
5.41E+00	1.63E+05
2.24E+00	1.63E+05
8.95E-01	1.63E+05
3.46E-01	1.63E+05
1.30E-01	1.63E+05
4.72E-02	1.63E+05
1.67E-02	1.63E+05
5.72E-03	1.63E+05
1.91E-03	1.63E+05
6.18E-04	1.63E+05
1.95E-04	1.63E+05
6.00E-05	1.63E+05
1.80E-05	1.63E+05

ggs.xls G/G/s Queueing Formula Spreadsheet

Inputs:
 lambda 0.5
 mu 0.166667
 Ca^2 1
 Cb^2 1

Definitions of terms:
 lambda = arrival rate
 mu = service rate
 s = number of servers
 Ca^2 = squared coeff. of variation of arrivals
 Cb^2 = squared coeff. of variation of service times
 Nq = average length of the queue
 Ns = average number in the system
 Wq = average wait in the queue
 Ws = average wait in the system
 P(0) = probability of zero customers in the system
 P(delay) = probability that an arriving customer has to wait

lambda/mu
3

Outputs:							Intermediate Calculations:	
s	Nq	Ns	Wq	Ws	P(delay)	Utilization	(l/u)^s/s!	sum (l/u)^s/s!
0							1.00E+00	1.00E+00
1	infinity	infinity	infinity	infinity	1.000000	1.000000	3.00E+00	4.00E+00
2	infinity	infinity	infinity	infinity	1.000000	1.000000	4.50E+00	8.50E+00
3	infinity	infinity	infinity	infinity	1.000000	1.000000	4.50E+00	1.30E+01
4	1.528302	4.528302	3.056604	9.056604	0.509434	0.750000	3.38E+00	1.64E+01
5	0.354227	3.354227	0.708455	6.708455	0.236152	0.600000	2.03E+00	1.84E+01
6	0.099143	3.099143	0.198286	6.198286	0.099143	0.500000	1.01E+00	1.94E+01
7	0.028234	3.028234	0.056468	6.056468	0.037645	0.428571	4.34E-01	1.98E+01
8	0.007769	3.007769	0.015538	6.015538	0.012949	0.375000	1.63E-01	2.00E+01
9	0.002025	3.002025	0.004050	6.004050	0.004050	0.333333	5.42E-02	2.01E+01
10	0.000496	3.000496	0.000992	6.000992	0.001157	0.300000	1.63E-02	2.01E+01
11	0.000114	3.000114	0.000228	6.000228	0.000304	0.272727	4.44E-03	2.01E+01
12	0.000025	3.000025	0.000049	6.000049	0.000074	0.250000	1.11E-03	2.01E+01
13	0.000005	3.000005	0.000010	6.000010	0.000017	0.230769	2.56E-04	2.01E+01
14	0.000001	3.000001	0.000002	6.000002	0.000003	0.214286	5.49E-05	2.01E+01
15	0.000000	3.000000	0.000000	6.000000	0.000001	0.200000	1.10E-05	2.01E+01
16	0.000000	3.000000	0.000000	6.000000	0.000000	0.187500	2.06E-06	2.01E+01
17	0.000000	3.000000	0.000000	6.000000	0.000000	0.176471	3.63E-07	2.01E+01
18	0.000000	3.000000	0.000000	6.000000	0.000000	0.166667	6.05E-08	2.01E+01
19	0.000000	3.000000	0.000000	6.000000	0.000000	0.157895	9.55E-09	2.01E+01
20	0.000000	3.000000	0.000000	6.000000	0.000000	0.150000	1.43E-09	2.01E+01
21	0.000000	3.000000	0.000000	6.000000	0.000000	0.142857	2.05E-10	2.01E+01
22	0.000000	3.000000	0.000000	6.000000	0.000000	0.136364	2.79E-11	2.01E+01
23	0.000000	3.000000	0.000000	6.000000	0.000000	0.130435	3.64E-12	2.01E+01
24	0.000000	3.000000	0.000000	6.000000	0.000000	0.125000	4.55E-13	2.01E+01
25	0.000000	3.000000	0.000000	6.000000	0.000000	0.120000	5.46E-14	2.01E+01
26	0.000000	3.000000	0.000000	6.000000	0.000000	0.115385	6.30E-15	2.01E+01
27	0.000000	3.000000	0.000000	6.000000	0.000000	0.111111	7.00E-16	2.01E+01
28	0.000000	3.000000	0.000000	6.000000	0.000000	0.107143	7.50E-17	2.01E+01
29	0.000000	3.000000	0.000000	6.000000	0.000000	0.103448	7.76E-18	2.01E+01
30	0.000000	3.000000	0.000000	6.000000	0.000000	0.100000	7.76E-19	2.01E+01
31	0.000000	3.000000	0.000000	6.000000	0.000000	0.096774	7.51E-20	2.01E+01
32	0.000000	3.000000	0.000000	6.000000	0.000000	0.093750	7.04E-21	2.01E+01
33	0.000000	3.000000	0.000000	6.000000	0.000000	0.090909	6.40E-22	2.01E+01
34	0.000000	3.000000	0.000000	6.000000	0.000000	0.088235	5.65E-23	2.01E+01
35	0.000000	3.000000	0.000000	6.000000	0.000000	0.085714	4.84E-24	2.01E+01
36	0.000000	3.000000	0.000000	6.000000	0.000000	0.083333	4.03E-25	2.01E+01
37	0.000000	3.000000	0.000000	6.000000	0.000000	0.081081	3.27E-26	2.01E+01
38	0.000000	3.000000	0.000000	6.000000	0.000000	0.078947	2.58E-27	2.01E+01
39	0.000000	3.000000	0.000000	6.000000	0.000000	0.076923	1.99E-28	2.01E+01
40	0.000000	3.000000	0.000000	6.000000	0.000000	0.075000	1.49E-29	2.01E+01

ggs.xls G/G/s Queueing Formula Spreadsheet

Inputs:

lambda 1.666667
 mu 0.138889
 Ca^2 1
 Cb^2 1.222222

Definitions of terms:

lambda = arrival rate
 mu = service rate
 s = number of servers
 Ca^2 = squared coeff. of variation of arrivals
 Cb^2 = squared coeff. of variation of service times
 Nq = average length of the queue
 Ns = average number in the system
 Wq = average wait in the queue
 Ws = average wait in the system
 P(0) = probability of zero customers in the system
 P(delay) = probability that an arriving customer has to wait

lambda/mu
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Outputs:

s	Nq	Ns	Wq	Ws	P(delay)	Utilization
0						
1	infinity	infinity	infinity	infinity	1.000000	1.000000
2	infinity	infinity	infinity	infinity	1.000000	1.000000
3	infinity	infinity	infinity	infinity	1.000000	1.000000
4	infinity	infinity	infinity	infinity	1.000000	1.000000
5	infinity	infinity	infinity	infinity	1.000000	1.000000
6	infinity	infinity	infinity	infinity	1.000000	1.000000
7	infinity	infinity	infinity	infinity	1.000000	1.000000
8	infinity	infinity	infinity	infinity	1.000000	1.000000
9	infinity	infinity	infinity	infinity	1.000000	1.000000
10	infinity	infinity	infinity	infinity	1.000000	1.000000
11	infinity	infinity	infinity	infinity	1.000000	1.000000
12	infinity	infinity	infinity	infinity	1.000000	1.000000
13	9.391835	21.391835	5.635101	12.835101	0.704388	0.923077
14	3.211369	15.211369	1.926821	9.126821	0.481705	0.857143
15	1.418624	13.418624	0.851174	8.051174	0.319190	0.800000
16	0.681913	12.681913	0.409148	7.609148	0.204574	0.750000
17	0.337680	12.337680	0.202608	7.402608	0.126630	0.705882
18	0.168033	12.168033	0.100820	7.300820	0.075615	0.666667
19	0.082899	12.082899	0.049739	7.249739	0.043522	0.631579
20	0.040224	12.040224	0.024134	7.224134	0.024134	0.600000
21	0.019100	12.019100	0.011460	7.211460	0.012892	0.571429
22	0.008847	12.008847	0.005308	7.205308	0.006635	0.545455
23	0.003989	12.003989	0.002394	7.202394	0.003291	0.521739
24	0.001749	12.001749	0.001050	7.201050	0.001574	0.500000
25	0.000745	12.000745	0.000447	7.200447	0.000727	0.480000
26	0.000308	12.000308	0.000185	7.200185	0.000324	0.461538
27	0.000124	12.000124	0.000074	7.200074	0.000140	0.444444
28	0.000048	12.000048	0.000029	7.200029	0.000058	0.428571
29	0.000018	12.000018	0.000011	7.200011	0.000023	0.413793
30	0.000007	12.000007	0.000004	7.200004	0.000009	0.400000
31	0.000002	12.000002	0.000001	7.200001	0.000003	0.387097
32	0.000001	12.000001	0.000001	7.200001	0.000001	0.375000
33	0.000000	12.000000	0.000000	7.200000	0.000000	0.363636
34	0.000000	12.000000	0.000000	7.200000	0.000000	0.352941
35	0.000000	12.000000	0.000000	7.200000	0.000000	0.342857
36	0.000000	12.000000	0.000000	7.200000	0.000000	0.333333
37	0.000000	12.000000	0.000000	7.200000	0.000000	0.324324
38	0.000000	12.000000	0.000000	7.200000	0.000000	0.315789
39	0.000000	12.000000	0.000000	7.200000	0.000000	0.307692
40	0.000000	12.000000	0.000000	7.200000	0.000000	0.300000

Intermediate Calculations:

(l/u)^s/s!	sum (l/u)^s/s!
1.00E+00	1.00E+00
1.20E+01	1.30E+01
7.20E+01	8.50E+01
2.88E+02	3.73E+02
8.64E+02	1.24E+03
2.07E+03	3.31E+03
4.15E+03	7.46E+03
7.11E+03	1.46E+04
1.07E+04	2.52E+04
1.42E+04	3.95E+04
1.71E+04	5.65E+04
1.86E+04	7.51E+04
1.86E+04	9.37E+04
1.72E+04	1.11E+05
1.47E+04	1.26E+05
1.18E+04	1.37E+05
8.84E+03	1.46E+05
6.24E+03	1.53E+05
4.16E+03	1.57E+05
2.63E+03	1.59E+05
1.58E+03	1.61E+05
9.00E+02	1.62E+05
4.91E+02	1.62E+05
2.56E+02	1.63E+05
1.28E+02	1.63E+05
6.15E+01	1.63E+05
2.84E+01	1.63E+05
1.26E+01	1.63E+05
5.41E+00	1.63E+05
2.24E+00	1.63E+05
8.95E-01	1.63E+05
3.46E-01	1.63E+05
1.30E-01	1.63E+05
4.72E-02	1.63E+05
1.67E-02	1.63E+05
5.72E-03	1.63E+05
1.91E-03	1.63E+05
6.18E-04	1.63E+05
1.95E-04	1.63E+05
6.00E-05	1.63E+05
1.80E-05	1.63E+05