# **Lab 7. Simulation as an Evaluation Technique**

## **Task 1. Buffer size analysis**

Simulation outputs (arguments: **RngRun = {0, 26, 69, 88}**):

1. M/M/1 implementation

lambda = 300, mu = 330, tsim = 100, info = 0, **RngRun = 1**

Number of packets handled 29820

Simulation results:

Average waiting time 0.0301727

Average service time 0.00305101

Average response time per customer (waiting time + service time) 0.0332237

**Average number of customers in queue 8.98949**

1. M/M/1 implementation

lambda = 300, mu = 330, tsim = 100, info = 0, **RngRun = 26**

Number of packets handled 30098

Simulation results:

Average waiting time 0.0281996

Average service time 0.00300579

Average response time per customer (waiting time + service time) 0.0312054

**Average number of customers in queue 8.48704**

1. M/M/1 implementation

lambda = 300, mu = 330, tsim = 100, info = 0, **RngRun = 69**

Number of packets handled 30215

Simulation results:

Average waiting time 0.035922

Average service time 0.00305976

Average response time per customer (waiting time + service time) 0.0389817

**Average number of customers in queue 10.8479**

1. M/M/1 implementation

lambda = 300, mu = 330, tsim = 100, info = 0, **RngRun = 88**

Number of packets handled 30302

Simulation results:

Average waiting time 0.0374492

Average service time 0.00306325

Average response time per customer (waiting time + service time) 0.0405124

**Average number of customers in queue 11.3382**

**Result from the mathematical model:**

*lambda = 300;*

*mu = 330;*

*ro = lambda/mu*

*L = ro/(1-ro)*

*L = 10.0000*

*fitdist([8.98949, 8.48704, 10.8479, 11.3382]','normal')*

*Normal distribution*

*mu = 9.91566 [7.70479, 12.1265]*

*sigma = 1.38942 [0.78709, 5.18051]*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **RngRun = 0** | **RngRun = 26** | **RngRun = 69** | **RngRun = 88** | **sigma** | **conf. interval** | **mean** | **mathematical** |
| *8.98949* | *8.48704* | *10.8479* | *11.3382* | *1.3894* | *[7.70479, 12.1265]* | *9.9157* | *10.0000* |

Mathematical model fits confidence intervals. Assuming appropriate time of simulation, we could receive average length of queue equal to 10 as a result from the simulations.

## **Task 2. Packet loss analysis**

Simulation results (**K = {10, 15, 20, 23, 24, 25}**):

1. M/M/1/K implementation

lambda = 8, mi = 10, tmax = 5000, **K = 10**, info = 0, RngRun = 1

Number of packets handled 38768

**Number of packets dropped 945 (2.37957%)**

Simulation Results:

Average waiting time 0.283976

Average service time 0.100592

Average response time per customer (waiting time + service time) 0.384568

Average number of customers in queue 2.20108

1. M/M/1/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 15**, info = 0, RngRun = 1

Number of packets handled 28938

**Number of packets dropped 882 (2.95775%)**

Simulation Results:

Average waiting time 0.0162612

Average service time 0.00304769

Average response time per customer (waiting time + service time) 0.0193089

Average number of customers in queue 4.70501

1. M/M/1/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 20**, info = 0, RngRun = 1

Number of packets handled 29449

**Number of packets dropped 371 (1.24413%)**

Simulation Results:

Average waiting time 0.0206299

Average service time 0.00304812

Average response time per customer (waiting time + service time) 0.0236781

Average number of customers in queue 6.06972

1. M/M/1/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 23**, info = 0, RngRun = 1

Number of packets handled 29495

**Number of packets dropped 325 (1.08987%)**

Simulation Results:

Average waiting time 0.0224598

Average service time 0.00304938

Average response time per customer (waiting time + service time) 0.0255092

Average number of customers in queue 6.61939

1. M/M/1/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 24**, info = 0, RngRun = 1

Number of packets handled 29530

**Number of packets dropped 290 (0.972502%)**

Simulation Results:

Average waiting time 0.0227865

Average service time 0.00304935

Average response time per customer (waiting time + service time) 0.0258359

Average number of customers in queue 6.72454

1. M/M/1/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 25**, info = 0, RngRun = 1

Number of packets handled 29560

**Number of packets dropped 260 (0.871898%)**

Simulation Results:

Average waiting time 0.0229856

Average service time 0.00305052

Average response time per customer (waiting time + service time) 0.0260361

Average number of customers in queue 6.78761

**Result from the mathematical model:**

*lambda = 300;*

*mu = 330;*

*ro = lambda/mu;*

***K = 24;***

*Pblk = ((1-ro)\*ro^K)/(1-ro^(K+1))*

***Pblk = 0.0102 (1.02%)***

*lambda = 300;*

*mu = 330;*

*ro = lambda/mu;*

***K = 25;***

*Pblk = ((1-ro)\*ro^K)/(1-ro^(K+1))*

***Pblk = 0.0092 (0.92%)***

*fitdist([8.98949, 8.48704, 10.8479, 11.3382]','normal')*

*Normal distribution*

*mu = 9.91566 [7.70479, 12.1265]*

*sigma = 1.38942 [0.78709, 5.18051]*

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **K=10** | **K=15** | **K=20** | **K=23** | **K=24** | **K=25** | **sigma** | **conf.int.** | **mean** |
| *2.37957%* | *2.95775%* | *1.24413%* | *1.08987%* | *0.972502%* | *0.871898%* |  |  |  |

|  |  |
| --- | --- |
| **Mathematical K=24** | **Mathematical K=25** |
| *1.02%* | *0.92%* |

Simulations showed, that the buffer should be set to 24 so that the loss is less than 1%. On the other hand, mathematical model showed that to gain such result buffer should be set to 25. It wasn’t easy to calculate this from the mathematical model, easier way to do it is using trial and error method.

## **Task 3. Multi-server analysis**

Simulations result (**m = 2, K = {24, 10, 6}**) :

1. M/M/m/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 24, m = 2**, info = 0, RngRun = 1

Number of packets handled 29820

**Number of packets dropped 0 (0%)**

Simulation results:

Average waiting time 0.000834882

Average service time 0.00305101

Average response time per customer ( waiting time + service time ) 0.0038859

Average number of customer in queue 0.24896

1. M/M/m/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 10, m = 2**, info = 0, RngRun = 1

Number of packets handled 29805

**Number of packets dropped 15 (0.0503018%)**

Simulation results:

Average waiting time 0.000779308

Average service time 0.00305139

Average response time per customer ( waiting time + service time ) 0.0038307

Average number of customer in queue 0.232275

1. M/M/m/K implementation

lambda = 300, mi = 330, tmax = 100, **K = 6, m = 2**, info = 0, RngRun = 1

Number of packets handled 29608

**Number of packets dropped 212 (0.710932%)**

Simulation results:

Average waiting time 0.000694111

Average service time 0.00305049

Average response time per customer ( waiting time + service time ) 0.0037446

Average number of customer in queue 0.205493

**Results from the mathematical model:**

*lambda = 300;*

*mu = 330;*

*ro = lambda/m\*mu;*

*G = lambda/mu;*

***K = 25;***

***m = 2;***

*syms r;*

*a = m^(K-m) \* factorial(m) \* symsum(G^r/factorial(r), r, (0:(m-1)));*

*b = G^m \* (m^(K+1-m)-G^(K+1-m))/(m-G);*

*Pblk = G^K / (a+b)*

***Pblk = 2.0630e-09 (2.063e-07%)***

*lambda = 300;*

*mu = 330;*

*ro = lambda/m\*mu;*

*G = lambda/mu;*

***K = 10;***

***m = 2;***

*syms r;*

*a = m^(K-m) \* factorial(m) \* symsum(G^r/factorial(r), r, (0:(m-1)));*

*b = G^m \* (m^(K+1-m)-G^(K+1-m))/(m-G);*

*Pblk = G^K / (a+b)*

***Pblk = 2.8245e-04 (0.028245%)***

*lambda = 300;*

*mu = 330;*

*ro = lambda/m\*mu;*

*G = lambda/mu;*

***K = 6;***

***m = 2;***

*syms r;*

*a = m^(K-m) \* factorial(m) \* symsum(G^r/factorial(r), r, (0:(m-1)));*

*b = G^m \* (m^(K+1-m)-G^(K+1-m))/(m-G);*

*Pblk = G^K / (a+b)*

***Pblk = 0.0067 (0.67%)***

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| **K=24** | **K=10** | **K=6** | **sigma** | **conf. int.** | **meas** | **K=25** | **K=10** | **K=6** |
| *0%* | *0.0503018%* | *0.710932%* |  |  |  | *2.063e-7%* | *0.028245%* | *0.67%* |

Using two servers, the number of packet loss significantly decreased. With the same size of buffer (K = 24, loss = 0.972502%) simulation show that any packet was lost. The minimal buffer’s size to gain less than 1% loss was 6. The mathematical model shows, that the number of lost packet isn’t equal to 0, but is really small.