

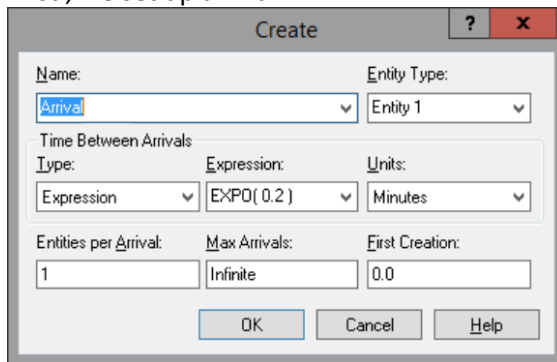
## Question 13.2

In this problem you, can simulate a simplified airport security system at a busy airport. Passengers arrive according to a Poisson distribution with  $\lambda_1 = 5$  per minute (i.e., mean interarrival rate  $\mu_1 = 0.2$  minutes) to the ID/boarding-pass check queue, where there are several servers who each have exponential service time with mean rate  $\mu_2 = 0.75$  minutes. [Hint: model them as one block that has more than one resource.] After that, the passengers are assigned to the shortest of the several personal-check queues, where they go through the personal scanner (time is uniformly distributed between 0.5 minutes and 1 minute).

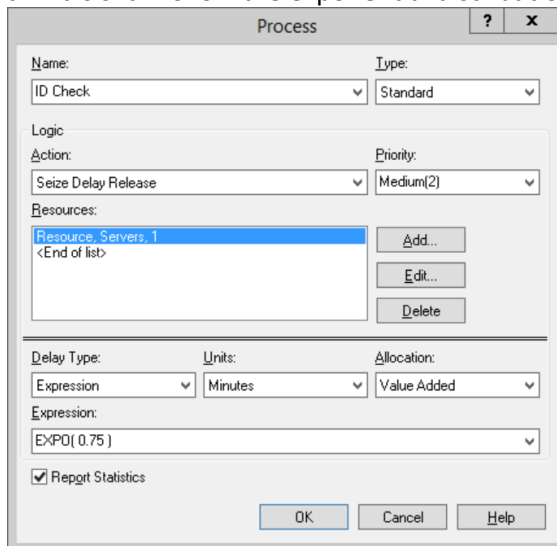
Use the Arena software (PC users) or Python with SimPy (PC or Mac users) to build a simulation of the system, and then vary the number of ID/boarding-pss checkers and personal-check queues to determine how many are needed to keep average wait times below 15 minutes. [If you're using SimPy, or if you have access to a non-student version of Arena, you can use  $\lambda_1 = 50$  to simulate a busier airport.]

We use Arena to construct our model.

First , we set up arrival:



Since passengers arrive according to a Poisson distribution with  $\lambda_1 = 5$  per minute, the time between arrivals shall follow the exponential distribution with mean=0.2



Next is the ID check process. We have several servers who each have exponential service time with mean rate = 0.75 minutes. We can change the number of servers in the capacity of the resource:

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics
1	scanner1	Fixed Capacity	1	0.0	0.0	0.0		0 rows	✓
2	scanner2	Fixed Capacity	1	0.0	0.0	0.0		0 rows	✓
3	scanner3	Fixed Capacity	1	0.0	0.0	0.0		0 rows	✓
4	Servers	Fixed Capacity	3	0.0	0.0	0.0		0 rows	✓

After that, the passengers are assigned to the shortest of the several personal-check queues. In this case, we should add a decide process, to find out which queue is the shortest. We set up 3 scanners first, and the decide and Personal check blocks looks like these:

Decide

Name:

Decide 1

Type:

N-way by Condition

Conditions:

Expression: NQ(Personal Check 1.Queue) <= NQ(Personal Check 2.Queue)

Expression: NQ(Personal Check 2.Queue) <= NQ(Personal Check 1.Queue)

Expression: NQ(Personal Check 3.Queue) <= NQ(Personal Check 2.Queue)

<End of list>

Add...

Edit...

Delete

OK

Cancel

Help

Expression Builder

Expression Type:

Entity

Process

Queue

Resource

Current Number In Queue

Average Number In Queue

Average Wait Time

Average Wait Cost

Value of Queued Entity Attribute

Sum of Queued Entity Attributes

Entity Number Of Queued Entity

Queue Name:

Personal Check 3.Queue

+

-

\*

/

==

<>

<

>

<=

>=

and

or

{ }

C

Current Expression:

NQ(Personal Check 1.Queue) <= NQ(Personal Check 2.Queue) && NQ(Personal Check 3.Queue) <= NQ(Personal Check 1.Queue)

OK

Cancel

Help

Our model looks like this:

```

graph LR
    Arrival[Arrival] --> IDCheck[ID Check]
    IDCheck --> Decide1{Decide 1}
    Decide1 -- Yes --> PersonalCheck1[Personal Check 1]
    Decide1 -- No --> PersonalCheck2[Personal Check 2]
    Decide1 -- Yes --> PersonalCheck3[Personal Check 3]
    PersonalCheck1 --> End1[End1]
    PersonalCheck2 --> End2[End2]
    PersonalCheck3 --> End3[End3]
  
```

**Process**

Name: Personal Check 1 Type: Standard

Logic

Action: Seize Delay Release Priority: Medium(2)

Resources:

Resource, scanner1, 1  
<End of list>

Add...  
Edit...  
Delete

Delay Type: Uniform Units: Minutes Allocation: Value Added

Minimum: .5 Maximum: 1

☒ Report Statistics

OK Cancel Help

At first, passengers arrive according to a Poisson distribution with  $\lambda_1 = 5$  per minute. We try 3 servers at the ID check and 3 scanners at the personal check process, we first set up some variables to detect the average waiting time in each queue. We set up the running hours to 12 hours, and number of replications 5. Then we run the model:

**Run Setup**

Run Speed Run Control Reports Project Parameters

Replication Parameters Array Sizes Arena Visual Designer

Number of Replications: 5

Initialize Between Replications

☒ Statistics ☒ System

Start Date and Time: Thursday, October 24, 2019 9:49:53 AM

Warm-up Period: 0.0 Time Units: Hours

Replication Length: 12 Time Units: Hours

Hours Per Day: 24

Base Time Units: Minutes

Terminating Condition:

OK Cancel Apply Help

## Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	1.4935	0.02	1.4709	1.5048	0.5032	6.9970
NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	80.2567	10.03	72.8442	92.8753	0.00	169.04
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	81.7503	10.04	74.3151	94.3801	0.6107	171.53
Other	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Number In	3613.00	72.00	3528.00	3684.00		
Number Out	2844.60	25.12	2818.00	2867.00		
WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	406.11	52.24	357.51	471.86	0.00	868.00

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	73.4351	13.74	58.7040	89.8397	0.00	163.09
Personal Check 1.Queue	8.0700	6.52	4.1318	16.3066	0.00	33.9812
Personal Check 2.Queue	7.8932	6.60	3.8679	16.2549	0.00	31.9476
Personal Check 3.Queue	7.7927	6.51	3.7859	15.9963	0.00	33.6178

## Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	368.23	72.48	284.95	450.04	0.00	836.00
Personal Check 1.Queue	10.9641	9.05	5.5230	22.5318	0.00	45.0000
Personal Check 2.Queue	10.6401	9.04	5.1939	22.1856	0.00	44.0000
Personal Check 3.Queue	10.3252	9.03	4.9065	21.8599	0.00	44.0000

The waiting time and number of waiting at the ID checking process looks incredibly long, which is 81.75 minutes. So we add the capacity of resources to 4, and the number of scanners to 4:

## Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	1.4938	0.01	1.4850	1.5027	0.5064	7.1201
NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	3.5938	1.12	2.4096	4.7953	0.00	12.7318
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	5.0876	1.13	3.8973	6.2873	0.6107	16.4857

## Other

Number In	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	3618.80	48.70	3569.00	3674.00		
Number Out	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	3597.80	50.80	3552.00	3650.00		
WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	25.5328	5.92	19.2888	31.9402	0.00	72.0000

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check Queue	2.0748	0.94	1.2723	3.0145	0.00	10.6769
Personal Check 1.Queue	1.6902	0.33	1.3144	1.9429	0.00	9.4057
Personal Check 2.Queue	1.5381	0.33	1.1502	1.7898	0.00	9.1385
Personal Check 3.Queue	1.4281	0.32	1.0478	1.6770	0.00	8.6549
Personal Check 4.Queue	1.3774	0.32	0.9880	1.6190	0.00	8.2291

## Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check Queue	10.4445	4.81	6.3068	15.3823	0.00	62.0000
Personal Check 1.Queue	2.2564	0.44	1.7429	2.5997	0.00	12.0000
Personal Check 2.Queue	2.0243	0.43	1.5294	2.3677	0.00	12.0000
Personal Check 3.Queue	1.7807	0.43	1.2878	2.1387	0.00	12.0000
Personal Check 4.Queue	1.5466	0.41	1.0654	1.8679	0.00	11.0000

Now the average waiting time looks much more acceptable( $\leq 15$  minutes), which is 5.09 minutes. At the ID check process, the average waiting time is about 0.3 minutes and at each scanner, the average waiting time is about 2.5 minutes. Meanwhile, we have 4 ID check servers and 4 scanners. If we change ether servers to 3 or scanners to 3, we can see the result below:

3+4:

## Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	1.4972	0.01	1.4926	1.5034	0.5038	8.5688
NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	74.3042	12.74	65.2210	88.2886	0.00	162.95
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	75.8014	12.74	66.7182	89.7831	0.6107	165.49

Number In	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	3639.80	56.41	3597.00	3713.00		
Number Out	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	2880.40	30.89	2838.00	2903.00		
WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	384.52	61.63	342.76	457.33	0.00	830.00

## Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	73.9898	12.70	64.8954	87.9569	0.00	163.01
Personal Check 1.Queue	0.6647	0.03	0.6201	0.6889	0.00	3.3708
Personal Check 2.Queue	0.5398	0.03	0.5053	0.5584	0.00	3.2530
Personal Check 3.Queue	0.4492	0.02	0.4228	0.4605	0.00	3.4623
Personal Check 4.Queue	0.4251	0.04	0.3757	0.4666	0.00	2.4454

## Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	376.35	61.59	334.53	449.07	0.00	822.00
Personal Check 1.Queue	0.8733	0.04	0.8136	0.9081	0.00	4.0000
Personal Check 2.Queue	0.6473	0.03	0.6099	0.6666	0.00	4.0000
Personal Check 3.Queue	0.4202	0.03	0.3829	0.4387	0.00	4.0000
Personal Check 4.Queue	0.2377	0.03	0.1962	0.2670	0.00	4.0000

4+3

## Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	1.4907	0.01	1.4759	1.4987	0.5051	7.5279
NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	74.1510	7.51	66.9613	83.1925	0.00	165.03
Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00
Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	75.6418	7.50	68.4533	84.6684	0.6107	166.13

## Other

Number In	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	3601.20	59.93	3545.00	3654.00		
Number Out	Average	Half Width	Minimum Average	Maximum Average		
Entity 1	2873.40	11.83	2864.00	2884.00		
WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	374.85	37.95	344.12	423.59	0.00	792.00

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	1.7975	0.47	1.4252	2.4108	0.00	10.1956
Personal Check 1.Queue	72.5456	7.15	65.4733	81.1341	0.00	160.12
Personal Check 2.Queue	72.3822	7.06	65.3836	80.5630	0.00	159.07
Personal Check 3.Queue	72.1972	6.89	65.2090	80.1648	0.00	159.55
<b>Other</b>						
Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
ID Check.Queue	9.0119	2.47	7.0433	12.2341	0.00	57.0000
Personal Check 1.Queue	120.05	12.00	109.82	135.22	0.00	253.00
Personal Check 2.Queue	119.72	12.01	109.49	134.92	0.00	252.00
Personal Check 3.Queue	119.38	12.00	109.16	134.55	0.00	252.00

3+4: the total time is 75.80 minutes.

4+3: the total time is 75.64 minutes.

They all look infeasible.

Now we can draw a conclusion that we need at least 4 ID check servers and 4 scanners to make the average waiting time less than 15 minutes.