

## 13.2 Simulation

June 27, 2018

### 0.0.1 Question 13.2

In this problem, you will 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-pass checkers and personal-check queues to determine how many are needed to keep average wait times below 15 minutes. Note: 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.

### 0.0.2 Results summary

For the simulation where the mean passenger arrival rate is 5, we find that the optimal configuration yielding mean wait time just below 15 minutes was with 5 id scanners and 9 personal checkers (time of 14.639845305).

For the simulation where the mean passenger arrival rate is 50, we find that the optimal configuration yielding mean wait time just below 15 minutes was with 35 id scanners and 31 personal checkers (time of 14.9797373981).

However, we would need to include costs in our final analysis as well. If personal checkers are twice as expensive as id scanners, we would choose a solution that has fewer personal checkers (for example num\_id= 36 and num\_pc= 20 yields a time of 14.7139433891).

### 0.0.3 References

Example with analogous arrival processes and queues:

<https://pythonhosted.org/SimPy/Tutorials/TheBank.html>

TA carwash example: <http://simpy.readthedocs.io/en/latest/examples/carwash.html>

```
In [14]: """
         Double-Queue airport security system
         """
         import random
         import simpy
```

```

import numpy as np

RANDOM_SEED = 42
TOTAL_WAIT=[]      #Total wait time to use both IDboarding and PersonalCheck stations
REPLICATIONS=5     #Number of replications for which to repeat the experiment
MU_1 = 0.2         #Mean interarrival rate for passenger generation
MU_2 = 0.75        #Mean service time (IDboarding check time)

#IDboarding parameters. One queue for all passengers:
NUM_ID = 5         # Number of stations in the IDboarding check system
SIM_TIME = 100     # Simulation time in minutes (100 minutes was suggested in TA video)

# When the passengers are done at the IDboarding station, they enter the
# PersonalCheck station where there is a queue for each PersonalCheck machine

#PersonalCheck parameters
NUM_PC = 5 #Number of PersonalCheck stations
MIN_PC = 0.5 #Lower bound on PersonalCheck time
MAX_PC = 1.0 #Upper bound on PersonalCheck time

#Resource queue counter
def NoInSystem(R):
    """ Total number of customers in the resource R"""
    return (len(R.queue)+R.count)

#Define IDboarding class
class IDboarding(object):
    """An IDboarding has a limited number of stations (`NUM_ID`) to
    check passenger ID's in parallel.

    Passengers have to request one of the machines. When they get one,
    they can start the checking processes and wait for it to finish
    (which takes an average of `mu_2` minutes).

    """
    def __init__(self, env, num_id, mu_2):
        self.env = env
        self.machine = simpy.Resource(env, num_id)
        self.mu_2 = mu_2

    def IDcheck(self, passenger):
        """Takes a passenger and checks their ID and boarding pass"""
        yield self.env.timeout(random.expovariate(1.0/self.mu_2))

class PersonalCheck(object):

```

```

"""Final passenger processing station. When a passenger arrives,
they join the shortest queue. When it is their turn to be
processed, the time it takes is Uniform(min_pc, max_pc)"""
def __init__(self, env, NUM_PC, min_pc, max_pc):
    self.env = env
    self.machine = []
    for i in range(NUM_PC):
        self.machine.append(simpy.Resource(env, 1))
    self.min_pc = min_pc
    self.max_pc = max_pc

def pcheck(self, passenger):
    """The PersonalCheck processes. It takes a passenger and processes them."""
    yield self.env.timeout(random.uniform(self.min_pc, self.max_pc))

def passenger(env, name, cw, ew):
    """The passenger process arrives and requests
an IDboarding machine. They then start the checking process,
waits for it to finish and leaves. They then enter the
PersonalCheck station to receive final processing."""

    arrive_id=env.now
    with cw.machine.request() as request:
        yield request
        wait_id=env.now-arrive_id
        #print('%s waited %.2f minutes to begin using the IDcheck'% (name, wait_id))
        yield env.process(cw.IDcheck(name))

    arrive_pc=env.now
    #Find the shortest waa queue
    minq=0
    for i in range(len(ew.machine)):
        if (ew.machine[i].count < ew.machine[minq].count):
            minq=i
    with ew.machine[minq].request() as request:
        yield request
        wait_pc=env.now-arrive_pc
        #print('%s waited %.2f minutes to begin using the Personal Check'% (name, wait_pc))
        yield env.process(ew.pcheck(name))
        total_wait=wait_id+wait_pc
        TOTAL_WAIT.append(total_wait)

def setup(env, num_id, mu_2, mu_1, num_pc, min_pc, max_pc):
    """Create an idcheck, with passengers approx.
every ``mu_1`` minutes."""
    # Create the idcheck and carwaa stations
    idcheck = IDboarding(env, num_id, mu_2)
    personalcheck = PersonalCheck(env, num_pc, min_pc, max_pc)

```

```

# Create more passengers while the simulation is running
i=0
while True:
    yield env.timeout(np.random.poisson(mu_1))
    i += 1
    env.process(passenger(env, 'Passenger %d' % i, idcheck, personalcheck))

```

*#Calculations and Analysis*

In [7]: *#Set up a loop to calculate the average over REPLICATIONS:*

```

TOTAL_WAIT=[]
for num_id in range(1,10):
    for num_pc in range(1,10):
        reps=[]
        for i in range(REPLICATIONS):
            random.seed(RANDOM_SEED) # This helps reproducing the results
            env = simpy.Environment()
            env.process(setup(env, num_id, MU_2, MU_1, num_pc, MIN_PC, MAX_PC))
            env.run(until=SIM_TIME)
            TOTAL_WAIT
            reps.append(np.mean(TOTAL_WAIT))
        print('Average wait time over ', REPLICATIONS, ' replications with num_id=',
              num_id, " and num_pc=", num_pc, ":", np.mean(reps))

```

```

Average wait time over 10 replications with num_id= 1 and num_pc= 1 : 34.3010667369
Average wait time over 10 replications with num_id= 1 and num_pc= 2 : 34.0633257641
Average wait time over 10 replications with num_id= 1 and num_pc= 3 : 34.0044374835
Average wait time over 10 replications with num_id= 1 and num_pc= 4 : 34.4733403157
Average wait time over 10 replications with num_id= 1 and num_pc= 5 : 34.9509757571
Average wait time over 10 replications with num_id= 1 and num_pc= 6 : 35.2423608078
Average wait time over 10 replications with num_id= 1 and num_pc= 7 : 35.5699376097
Average wait time over 10 replications with num_id= 1 and num_pc= 8 : 35.6766993712
Average wait time over 10 replications with num_id= 1 and num_pc= 9 : 35.7173722404
Average wait time over 10 replications with num_id= 2 and num_pc= 1 : 35.7842448908
Average wait time over 10 replications with num_id= 2 and num_pc= 2 : 34.9993070731
Average wait time over 10 replications with num_id= 2 and num_pc= 3 : 33.6204918788
Average wait time over 10 replications with num_id= 2 and num_pc= 4 : 32.1152695072
Average wait time over 10 replications with num_id= 2 and num_pc= 5 : 30.7438949344
Average wait time over 10 replications with num_id= 2 and num_pc= 6 : 29.709688136
Average wait time over 10 replications with num_id= 2 and num_pc= 7 : 29.1588798281
Average wait time over 10 replications with num_id= 2 and num_pc= 8 : 28.5715998657
Average wait time over 10 replications with num_id= 2 and num_pc= 9 : 28.2210467464
Average wait time over 10 replications with num_id= 3 and num_pc= 1 : 28.2784940556
Average wait time over 10 replications with num_id= 3 and num_pc= 2 : 28.1561222315
Average wait time over 10 replications with num_id= 3 and num_pc= 3 : 27.5328005098
Average wait time over 10 replications with num_id= 3 and num_pc= 4 : 26.5794988151

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Average wait time over 10 replications with num\_id= 3 and num\_pc= 5 : 25.6059062758  
 Average wait time over 10 replications with num\_id= 3 and num\_pc= 6 : 24.6199248793  
 Average wait time over 10 replications with num\_id= 3 and num\_pc= 7 : 23.7643383745  
 Average wait time over 10 replications with num\_id= 3 and num\_pc= 8 : 23.0715408291  
 Average wait time over 10 replications with num\_id= 3 and num\_pc= 9 : 22.5445537493  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 1 : 22.4717473932  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 2 : 22.5230681753  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 3 : 22.2457832222  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 4 : 21.6540215025  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 5 : 20.8315624962  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 6 : 20.0090927727  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 7 : 19.1662047312  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 8 : 18.3915894139  
 Average wait time over 10 replications with num\_id= 4 and num\_pc= 9 : 17.7411202509  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 1 : 17.5756307455  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 2 : 17.6982433862  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 3 : 17.6177566948  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 4 : 17.3230791031  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 5 : 16.8759821719  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 6 : 16.3010224897  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 7 : 15.7179822899  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 8 : 15.1510781939  
 Average wait time over 10 replications with num\_id= 5 and num\_pc= 9 : 14.639845305  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 1 : 14.5425208534  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 2 : 14.6749267993  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 3 : 14.6634043898  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 4 : 14.4908967796  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 5 : 14.2116574571  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 6 : 13.8683966234  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 7 : 13.4864336733  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 8 : 13.1039662177  
 Average wait time over 10 replications with num\_id= 6 and num\_pc= 9 : 12.7242905693  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 1 : 12.6630253373  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 2 : 12.8059257652  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 3 : 12.8394084524  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 4 : 12.7483292866  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 5 : 12.5540425252  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 6 : 12.2990141909  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 7 : 12.0254904144  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 8 : 11.7413435523  
 Average wait time over 10 replications with num\_id= 7 and num\_pc= 9 : 11.470877571  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 1 : 11.4214654186  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 2 : 11.5412133581  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 3 : 11.5738059085  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 4 : 11.5425982138  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 5 : 11.431127783  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 6 : 11.2513691014  
 Average wait time over 10 replications with num\_id= 8 and num\_pc= 7 : 11.0343546501

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Average wait time over 10 replications with num_id= 8 and num_pc= 8 : 10.8085105122
Average wait time over 10 replications with num_id= 8 and num_pc= 9 : 10.5893528995
Average wait time over 10 replications with num_id= 9 and num_pc= 1 : 10.5726116305
Average wait time over 10 replications with num_id= 9 and num_pc= 2 : 10.677973346
Average wait time over 10 replications with num_id= 9 and num_pc= 3 : 10.7177820643
Average wait time over 10 replications with num_id= 9 and num_pc= 4 : 10.6914793823
Average wait time over 10 replications with num_id= 9 and num_pc= 5 : 10.6088982025
Average wait time over 10 replications with num_id= 9 and num_pc= 6 : 10.4803032225
Average wait time over 10 replications with num_id= 9 and num_pc= 7 : 10.3146144141
Average wait time over 10 replications with num_id= 9 and num_pc= 8 : 10.134287626
Average wait time over 10 replications with num_id= 9 and num_pc= 9 : 9.95585675125

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In [15]: #Do the same as above but with the passenger arrival rate of 50 instead of 5
TOTAL_WAIT=[]
for num_id in range(20,40):
    for num_pc in range(20,40):
        reps=[]
        for i in range(REPLICATIONS):
            random.seed(RANDOM_SEED) # This helps reproducing the results
            env = simpy.Environment()
            env.process(setup(env, num_id, MU_2, 0.02, num_pc, MIN_PC, MAX_PC))
            env.run(until=SIM_TIME)
            reps.append(np.mean(TOTAL_WAIT))
        print('Average wait time over ', REPLICATIONS, ' replications with num_id=',
              num_id, " and num_pc=", num_pc, ":", np.mean(reps))

```

```

Average wait time over 5 replications with num_id= 20 and num_pc= 20 : 27.0983600861
Average wait time over 5 replications with num_id= 20 and num_pc= 21 : 24.6715140189
Average wait time over 5 replications with num_id= 20 and num_pc= 22 : 24.2441508481
Average wait time over 5 replications with num_id= 20 and num_pc= 23 : 23.4947245061
Average wait time over 5 replications with num_id= 20 and num_pc= 24 : 23.4004827367
Average wait time over 5 replications with num_id= 20 and num_pc= 25 : 23.6365827429
Average wait time over 5 replications with num_id= 20 and num_pc= 26 : 23.680136894
Average wait time over 5 replications with num_id= 20 and num_pc= 27 : 23.5650581524
Average wait time over 5 replications with num_id= 20 and num_pc= 28 : 23.1972113687
Average wait time over 5 replications with num_id= 20 and num_pc= 29 : 23.2234931525
Average wait time over 5 replications with num_id= 20 and num_pc= 30 : 23.035271559
Average wait time over 5 replications with num_id= 20 and num_pc= 31 : 23.1343926179
Average wait time over 5 replications with num_id= 20 and num_pc= 32 : 23.2634235325
Average wait time over 5 replications with num_id= 20 and num_pc= 33 : 23.3967426204
Average wait time over 5 replications with num_id= 20 and num_pc= 34 : 23.438824033
Average wait time over 5 replications with num_id= 20 and num_pc= 35 : 23.5073329559
Average wait time over 5 replications with num_id= 20 and num_pc= 36 : 23.4701869071
Average wait time over 5 replications with num_id= 20 and num_pc= 37 : 23.3156690976
Average wait time over 5 replications with num_id= 20 and num_pc= 38 : 23.3585832113
Average wait time over 5 replications with num_id= 20 and num_pc= 39 : 23.4011274188
Average wait time over 5 replications with num_id= 21 and num_pc= 20 : 23.3045938305

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Average wait time over 5 replications with num\_id= 21 and num\_pc= 21 : 23.3334054555  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 22 : 23.3796679947  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 23 : 23.4059489227  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 24 : 23.2188125683  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 25 : 23.2683661835  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 26 : 23.3588290015  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 27 : 23.316656013  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 28 : 23.3103796555  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 29 : 23.3362462643  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 30 : 23.3988097886  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 31 : 23.3447697923  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 32 : 23.248103658  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 33 : 23.2145478231  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 34 : 23.2279691905  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 35 : 23.2083091538  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 36 : 23.1930860591  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 37 : 23.1491455769  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 38 : 23.0678429275  
 Average wait time over 5 replications with num\_id= 21 and num\_pc= 39 : 23.1008536971  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 20 : 23.0805337699  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 21 : 23.1050027347  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 22 : 23.0751595102  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 23 : 23.0808380888  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 24 : 23.0642174663  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 25 : 23.0062820893  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 26 : 22.9987711901  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 27 : 22.9498183618  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 28 : 22.9377935261  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 29 : 22.8480283222  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 30 : 22.8007617328  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 31 : 22.7507281683  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 32 : 22.7552348012  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 33 : 22.7171164828  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 34 : 22.6595952545  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 35 : 22.6044520684  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 36 : 22.5925563541  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 37 : 22.5681655277  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 38 : 22.4765805217  
 Average wait time over 5 replications with num\_id= 22 and num\_pc= 39 : 22.4505570922  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 20 : 22.4400812545  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 21 : 22.3817277654  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 22 : 22.330936651  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 23 : 22.2710782796  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 24 : 22.2427962451  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 25 : 22.2222031126  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 26 : 22.1893228924  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 27 : 22.1608378036  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 28 : 22.1609808101

Average wait time over 5 replications with num\_id= 23 and num\_pc= 29 : 22.1014789322  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 30 : 22.0451137445  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 31 : 22.0131131904  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 32 : 21.9875053189  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 33 : 21.9445865388  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 34 : 21.9200087985  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 35 : 21.8860978105  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 36 : 21.8438415043  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 37 : 21.7753112392  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 38 : 21.7430756966  
 Average wait time over 5 replications with num\_id= 23 and num\_pc= 39 : 21.7256116561  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 20 : 21.6823136411  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 21 : 21.6746683171  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 22 : 21.6591305578  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 23 : 21.655403524  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 24 : 21.6525058069  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 25 : 21.6230023107  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 26 : 21.5963866303  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 27 : 21.559509991  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 28 : 21.521307219  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 29 : 21.5239500831  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 30 : 21.4903795179  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 31 : 21.446197386  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 32 : 21.3930530442  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 33 : 21.3656656699  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 34 : 21.3339562624  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 35 : 21.3084722132  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 36 : 21.2711444719  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 37 : 21.2246929902  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 38 : 21.1785725558  
 Average wait time over 5 replications with num\_id= 24 and num\_pc= 39 : 21.1729538231  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 20 : 21.155393537  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 21 : 21.1291893039  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 22 : 21.1019961017  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 23 : 21.1017888354  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 24 : 21.084172553  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 25 : 21.0423934578  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 26 : 20.9985163342  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 27 : 20.9264487124  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 28 : 20.8677088337  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 29 : 20.8122241161  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 30 : 20.7771230115  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 31 : 20.7536521535  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 32 : 20.7115827127  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 33 : 20.6424420091  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 34 : 20.6041456828  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 35 : 20.5859233329  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 36 : 20.5685520003



Average wait time over 5 replications with num\_id= 25 and num\_pc= 37 : 20.5420515981  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 38 : 20.5180139665  
 Average wait time over 5 replications with num\_id= 25 and num\_pc= 39 : 20.5034706514  
 Average wait time over 5 replications with num\_id= 26 and num\_pc= 20 : 20.5015383311  
 Average wait time over 5 replications with num\_id= 26 and num\_pc= 21 : 20.4739061078  
 Average wait time over 5 replications with num\_id= 26 and num\_pc= 22 : 20.4418718139  
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 Average wait time over 5 replications with num\_id= 28 and num\_pc= 24 : 19.1960164701

Average wait time over	5	replications with num_id= 28	and num_pc= 25	:	19.1561153799
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Average wait time over	5	replications with num_id= 28	and num_pc= 27	:	19.1133241221
Average wait time over	5	replications with num_id= 28	and num_pc= 28	:	19.0787076947
Average wait time over	5	replications with num_id= 28	and num_pc= 29	:	19.0396136795
Average wait time over	5	replications with num_id= 28	and num_pc= 30	:	18.9986180113
Average wait time over	5	replications with num_id= 28	and num_pc= 31	:	18.9661261565
Average wait time over	5	replications with num_id= 28	and num_pc= 32	:	18.933724324
Average wait time over	5	replications with num_id= 28	and num_pc= 33	:	18.8827884308
Average wait time over	5	replications with num_id= 28	and num_pc= 34	:	18.853481718
Average wait time over	5	replications with num_id= 28	and num_pc= 35	:	18.8207423763
Average wait time over	5	replications with num_id= 28	and num_pc= 36	:	18.7917620781
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Average wait time over	5	replications with num_id= 28	and num_pc= 39	:	18.6607705543
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Average wait time over	5	replications with num_id= 29	and num_pc= 26	:	18.5074265294
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Average wait time over	5	replications with num_id= 30	and num_pc= 30	:	17.8628023103
Average wait time over	5	replications with num_id= 30	and num_pc= 31	:	17.8213103395
Average wait time over	5	replications with num_id= 30	and num_pc= 32	:	17.7733930336

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 Average wait time over 5 replications with num\_id= 39 and num\_pc= 31 : 13.0135756211  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 32 : 12.9872564895  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 33 : 12.9600508022  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 34 : 12.9372089177  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 35 : 12.913743339  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 36 : 12.8867530662  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 37 : 12.8563521226  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 38 : 12.8337899205  
 Average wait time over 5 replications with num\_id= 39 and num\_pc= 39 : 12.8047148237