A2_DES_next_event_sim Final

March 15, 2019

1 Next-Event Simulation Assignment

1.0.1 Year 2018-2019 - Semester II

1.0.2 CCE3501 / CCE3502

1.1 #### Developed by - Adrian Muscat, 2019

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In this assignment you will be implementing next-event simulations for systems involving queues and service nodes in resource allocation systems.

Tasks and Questions (repeated below at the appropriate position)

1. You are given a ready-coded single server queuing system simulation. Go through the code and note the event service routines, timing routine, iat and st generators, etc.
2. Develop a function to plot the queue length versus time
3. Develop functions to calculate the average queue length, average interarrival rate and server utilisation.
4. Compare the answers in 3 to the M/M/1 analytical model
5. modify the event routines (re-write new ones) to model a resource allocation system without queuing, i.e if a customer calls and the server is busy, the customer is blocked.
6. Plot the blocking rate versus number of servers (N=1, 2, 3 .... 20)
7. Add a buffer of finite size to the resource allocation system, such that when a customer calls and the server is busy, the customer is queued.
8. Plot the blocking rate versus buffer size.

In [16]:
```
import random, math
import numpy as np
import matplotlib.pyplot as plt
# import scipy.stats as stats
```

In [17]:
```
# this line plots graphs in line
%matplotlib inline
```

1.2 1. Below is a ready-coded single server queuing system simulation. Go through the code and note the event service routines, timing routine, iat and st generators, etc.

In [18]:
```
fileOutA=True   # Flag, if true output to file
stateList=[]    # List containing [q(t), s(t), time]
```

```
servTimeList=[]
eventList=[]     # Event calendar list
notice=[]        # notice = [ notice number, time, type ]
                 # type = 0, arrival
                 # type = 1, begin service
                 # type = 2, end service
now = 0.0        # Simulation time
Q = 0            # Queue Length, Q=0 when empty
S=0              # Server State 0=idle, 1=busy
EN=0             # Event Notice Number
avgintarrtimeList = [] #list for accumulating interarrival time
```

In [19]:
```
def ScheduleEventNotice(notice):
    global eventList
    if len(eventList)==0:
        eventList.append(notice)
    elif len(eventList)==1:
        if eventList[0][1] <= notice[1]:
            eventList.append(notice)
        else:
            eventList.insert(0,notice)
    elif eventList[len(eventList)-1][1] < notice[1]:
        eventList.append(notice)
    else:
        i=0
        while (eventList[i][1]<=notice[1] and i<(len(eventList)-1)):
            i += 1
        eventList.insert(i,notice)
```

In [20]:
```
def DisplayEventList(header):
    print (header)
    i=0
    while i<len(eventList):
        print (eventList[i])
        i += 1

def writeToFile():
    #print 'Q = ',Q, '   S = ',S, '   now = ', now
    stateEntry = [Q, S, now]
    stateList.append(stateEntry)

def DisplayStateList(header):
    print (header)
    i=0
    while i<len(stateList):
        print (stateList[i])
        i += 1
```

In [21]:
```
def InterArrivalTime():
```

```
        #return -10*math.log(random.random())
        return np.random.exponential()*8.001


    def ServiceTime():
        #return -8*math.log(random.random())
        return np.random.exponential()*8
```

In [22]:
```
def EventRoutineArrival():
    global EN, Q, S
    EN=EN+1
    intarrivaltime = InterArrivalTime()
    avgintarrtimeList.append(intarrivaltime)
    eventTime = now+intarrivaltime
    #notice=[EN+1, now+InterArrivalTime(), 0]
    notice=[EN, eventTime, 0]
    ScheduleEventNotice(notice)
    Q = Q + 1
    if S==0:
        EN+=1
        notice=[EN, now, 1]
        ScheduleEventNotice(notice)
    if fileOutA: writeToFile()
```

In [23]:
```
def EventRoutineBeginService():
    global EN, Q, S
    Q = Q - 1
    S = 1
    EN+=1
    sT = ServiceTime()
    servTimeList.append(sT)
    eventTime = now+sT
    notice=[EN, eventTime, 2]
    ScheduleEventNotice(notice)
    if fileOutA: writeToFile()
```

In [24]:
```
def EventRoutineEndService():
    global EN, Q, S
    S=0
    if Q>0:
        EN=EN+1
        eventTime = now
        notice = [EN, eventTime, 1]
        ScheduleEventNotice(notice)
    if fileOutA: writeToFile()
```

In [25]:
```
# Schedule arrival event at time NOW;
notice=[EN, now, 0]
ScheduleEventNotice(notice)
```

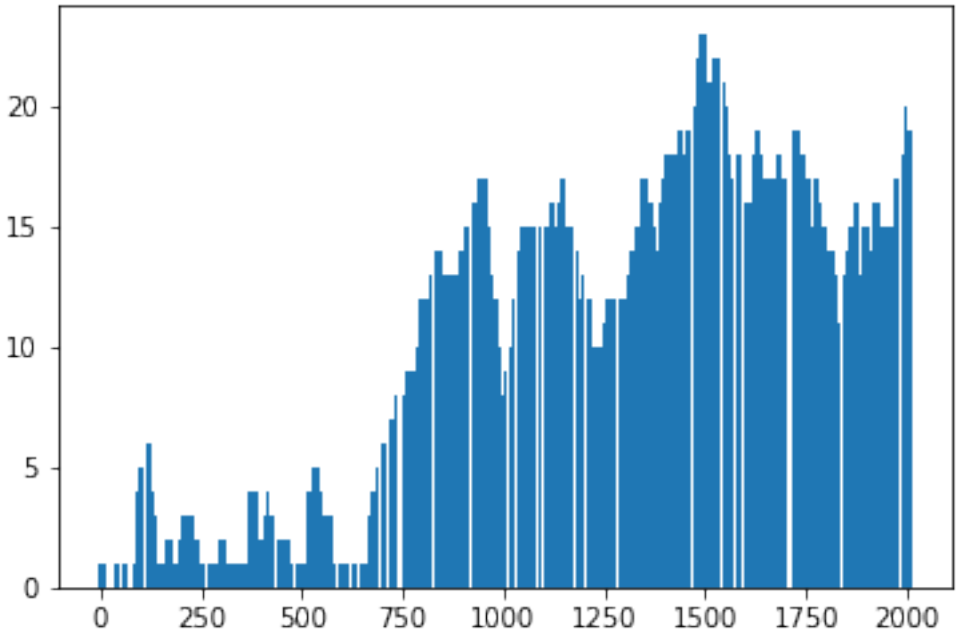
```
print ('Start of Simulation run')

while (eventList!=[] and now<2000): #200000
    now = eventList[0][1]
    #print now,'   ',eventList[0]
    #print 'Q = ',Q, '   S = ',S
    #DisplayEventList('Hello')
    if eventList[0][2]==0:
        EventRoutineArrival()
    elif eventList[0][2]==1:
        EventRoutineBeginService()
    elif eventList[0][2]==2:
        EventRoutineEndService()
    else:
        print ('Unknown event type')
    #Remove first notice
    eventList.pop(0)

print ('End of Simulation run')
```

```
Start of Simulation run
End of Simulation run
```

2 GRADED QUESTIONS BELOW: 7 questions, Total = 70, weight =15%

2.1 2. Develop a function to plot the queue length versus time [5 marks]

In [26]:
```
x = np.array(stateList)
plt.bar(x[:,2],x[:,0], width=10,align='center')
plt.show()
```



In [ ]:

2.2 3. Develop functions to calculate the average queue length, average interarrival rate, server utilisation and mean waiting time. [10 marks]

```
In [39]: def avgQlength():
             x = np.array(stateList)
             extracted = x[:,0]
             b = sum(extracted)
             avgQueueLength = b/len(extracted)
             return avgQueueLength

         def avgservice():
             sum = 0
             for i in range(1000):
                 x = ServiceTime()
                 sum += x

             avgservicerate = sum/1000
             return avgservicerate

         def avgIrate():
             sum = 0
             for i in range(1000):
                 x = InterArrivalTime()
                 sum += x
```

```
            avgArrivalRate = sum/1000
            return avgArrivalRate

        def serverUtil(a,b):
            # = lambda/mu   = row = 1/mean rate of arrival / 1/mean service rate
            x = (1/a) / (1/b)
            print(x)

        def meanWaitingT():
            x = np.array(stateList)
            extracted = x[:,2]
            b = sum(extracted)
            answer = b/len(extracted)
            print(answer)


        avgservice = avgservice()
```

In [40]:
```
#Question 1
print(avgQLen)
```

```
9.789877300613497
```

In [41]:
```
#Question 2
print(avgArrivalRate)
```

```
8.005255367886113
```

In [42]:
```
#Question 3
serverUtil(avgArrivalRate,avgservice)
```

```
0.9926755393901777
```

In [43]:
```
#Question4
meanWaitingT()
```

```
1004.2780049277006
```

2.3 4. Compare the answers in 3 to the M/M/1 analytical model [5 marks]

In [44]:
```
#M/M/1:
#L = p^2/1-p
#L = mean no of customers
# = server utilization = (1/mean rate of arrivals)/(1/mean service rate)
```

```
# lambda = 1/interarrival time
# mu = 1/servicetime


def avgQlength():
    x = np.array(stateList)
    extracted = x[:,0]
    b = sum(extracted)
    avgQueueLength = b/len(extracted)
    return avgQueueLength

def avgIrate():
    sum = 0
    for i in range(1000):
        x = InterArrivalTime()
        sum += x

    avgArrivalRate = sum/1000
    return avgArrivalRate

def avgservice():
    sum = 0
    for i in range(1000):
        x = ServiceTime()
        sum += x

    avgservicerate = sum/1000
    return avgservicerate

def serverUtil(a,b):
    # = lambda/mu   = row = 1/mean rate of arrival / 1/mean service rate
    x = (1/a) / (1/b)
    return x


def meanWaitingT():
    x = np.array(stateList)
    extracted = x[:,2]
    b = sum(extracted)
    answer = b/len(extracted)
    return (answer)


#M/M/1 model to compare with average queue length
def MM1meancustomers(b):
    x = (b**2)/(1-b)
    return x
```

```
        #M/M/1 model to compare with average waiting time, wait in queue = mean no of custome
        def MM1meanwaiting(a,b):
            c = 1/b
            x = a/c
            return x

        avgservice = avgservice()
        avgArrivalRate = avgIrate()
        A = serverUtil(avgArrivalRate,avgservice)
        avgQLen = avgQlength()
        meanwaitrate = meanWaitingT()

        B = MM1meancustomers(A)
        C = MM1meanwaiting(B,avgArrivalRate)
```

```
In [47]: print(B)
```

```
20.4117639572627
```

```
In [48]: print(C)
```

```
166.37656658931732
```

2.4 5. Modify the appropriate functions (re-write new ones) to model a resource allocation system (with N servers) without queuing, i.e if a customer calls and all servers are busy, the customer is blocked. Set mean iat = 5, mean service rate =170 and N=8. Run the simulation and compute the blocking rate. [10 marks]

```
In [19]: blockedCustomers = 0

         endedCustomers = 0
```

```
In [20]: fileOutA=True    # Flag, if true output to file
         stateList=[]     # List containing [q(t), s(t), time]
         servTimeList=[]
         eventList=[]     # Event calendar list
         notice=[]        # notice = [ notice number, time, type ]
                          # type = 0, arrival
                          # type = 1, begin service
                          # type = 2, end service
         now = 0.0        # Simulation time
         #Q = 0            # Queue Length, Q=0 when empty
         S=0              # No of Servers occupied
         EN=0             # Event Notice Number
         avgintarrtimeList = [] #list for accumulating interarrival time
         n=0              #no of servers
```

```
In [21]: def ScheduleEventNotice(notice):
             global eventList
             if len(eventList)==0:
                 eventList.append(notice)
             elif len(eventList)==1:
                 if eventList[0][1] <= notice[1]:
                     eventList.append(notice)
                 else:
                     eventList.insert(0,notice)
             elif eventList[len(eventList)-1][1] < notice[1]:
                 eventList.append(notice)
             else:
                 i=0
                 while (eventList[i][1]<=notice[1] and i<(len(eventList)-1)):
                     i += 1
                 eventList.insert(i,notice)

In [22]: def DisplayEventList(header):
             print (header)
             i=0
             while i<len(eventList):
                 print (eventList[i])
                 i += 1

         def writeToFile():
             #print 'Q = ',Q, '   S = ',S, '   now = ', now
             stateEntry = [Q, S, now]
             stateList.append(stateEntry)

         def DisplayStateList(header):
             print (header)
             i=0
             while i<len(stateList):
                 print (stateList[i])
                 i += 1

In [23]: def InterArrivalTime():
             #return -10*math.log(random.random())
             return np.random.exponential()*5


         def ServiceTime():
             #return -8*math.log(random.random())
             return np.random.exponential()*170

In [24]: def EventRoutineArrival(n):
             global EN, Q, S, blockedCustomers
             EN=EN+1
```

```
        intarrivaltime = InterArrivalTime()
        avgintarrtimeList.append(intarrivaltime)
        eventTime = now+intarrivaltime
        #notice=[EN+1, now+InterArrivalTime(), 0]
        notice=[EN, eventTime, 0]
        ScheduleEventNotice(notice)
        Q = Q + 1
        if (S >= n):
            blockedCustomers+=1
        else:
            notice=[EN, now, 1]
            ScheduleEventNotice(notice)
        if fileOutA: writeToFile()
```

In [25]:
```
def EventRoutineBeginService():
    global EN, Q, S
    S += 1
    EN+=1
    sT = ServiceTime()
    servTimeList.append(sT)
    eventTime = now+sT
    notice=[EN, eventTime, 2]
    ScheduleEventNotice(notice)
    if fileOutA: writeToFile()
```

In [26]:
```
def EventRoutineEndService():
    global EN, Q, S, endedCustomers
    endedCustomers += 1
    S-=1
    if fileOutA: writeToFile()
```

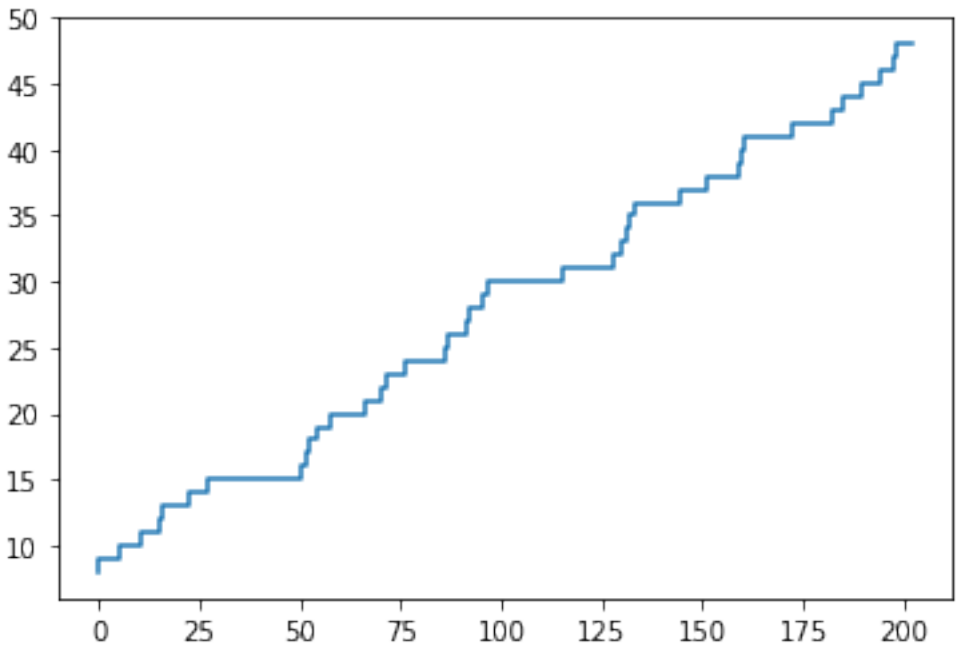
In [27]:
```
# Schedule arrival event at time NOW;
n = 8
notice=[EN, now, 0]
ScheduleEventNotice(notice)

print ('Start of Simulation run')

while (eventList!=[] and now<200): #200000
    now = eventList[0][1]
    #print now,'   ',eventList[0]
    #print 'Q = ',Q, '   S = ',S
    #DisplayEventList('Hello')
    if eventList[0][2]==0:
        EventRoutineArrival(n)
    elif eventList[0][2]==1:
        EventRoutineBeginService()
```

```
            elif eventList[0][2]==2:
                EventRoutineEndService()
            else:
                print ('Unknown event type')
            #Remove first notice
            eventList.pop(0)

        print ('End of Simulation run')
        print ('Blocking rate is {b}/{e}'.format(b=blockedCustomers,e = endedCustomers+blocke
```

```
Start of Simulation run
End of Simulation run
Blocking rate is 27/33
```

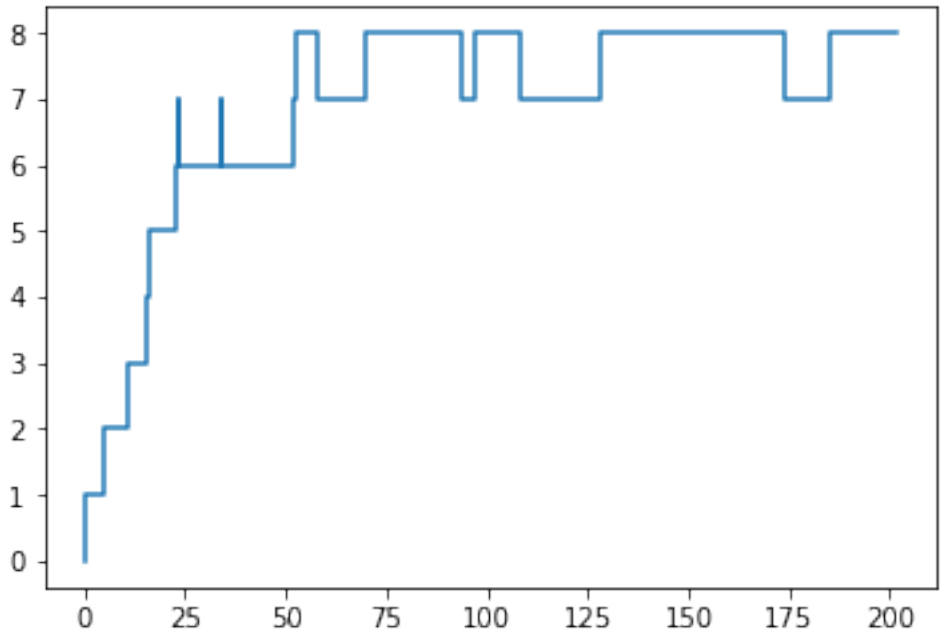
```
In [28]: b = np.asarray(stateList)
         x1=b[:,2]
         y1=b[:,0]
         y12=b[:,1]
         #n=8
         print(np.shape(x1),np.shape(y1),np.shape(y12))
         #PlotQueueLengthVSTime(x1,y1)
         AvgQueueLen(x1,y1)
         AvgIntArrivalTime(x1,y1)
```

```
(61,) (61,) (61,)
```



```
Average queue length is equal to : 27.9015406285575
Average interarrival time: 5.007706514138418
```

```
In [29]: ServerUtil(x1,y12,8)
```




```
1395.3963946411761
201.84930481368062
Server util is equal to : 0.8641325244649797
```

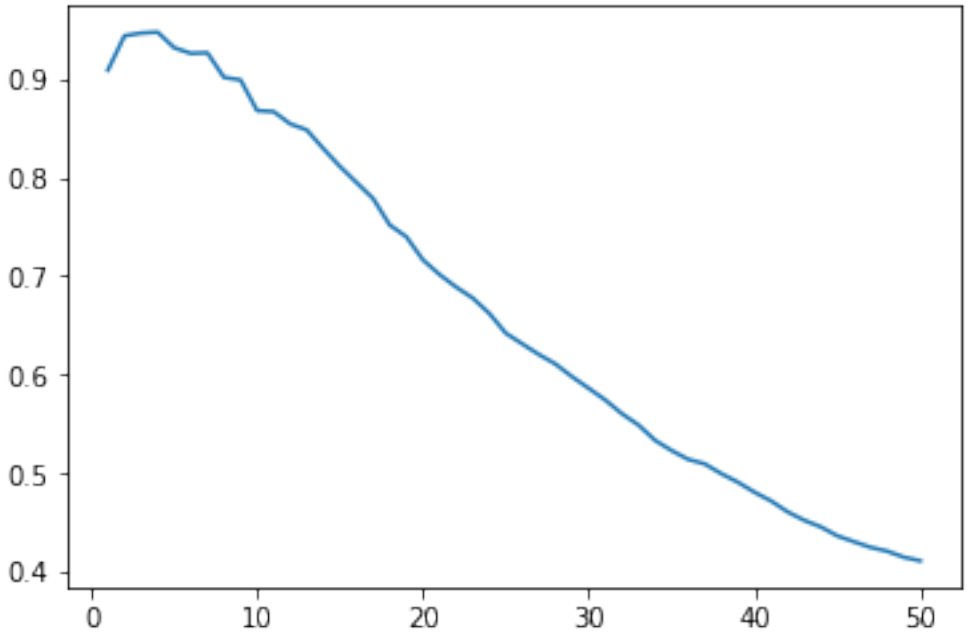
```
In [ ]:
```

2.5 6. Plot the blocking rate versus number of servers (N=1, 2, 3 .... 50) [10 marks]

```
In [30]: i = 0
         blockingRate = []
         servers = []
         while (i<50):
             fileOutA=True    # Flag, if true output to file
             stateList=[]     # List containing [q(t), s(t), time]
             servTimeList=[]
             eventList=[]     # Event calendar list
             notice=[]        # notice = [ notice number, time, type ]
                              # type = 0, arrival
                              # type = 1, begin service
```

```
                    # type = 2, end service
        now = 0.0       # Simulation time
        #Q = 0           # Queue Length, Q=0 when empty
        S=0             # No of Servers occupied
        EN=0            # Event Notice Number
        avgintarrtimeList = [] #list for accumulating interarrival time
        n=i
        notice=[EN, now, 0]
        ScheduleEventNotice(notice)

        #print ('Start of Simulation run')

        while (eventList!=[] and now<200): #200000
            now = eventList[0][1]
            #print now,'   ',eventList[0]
            #print 'Q = ',Q, '   S = ',S
            #DisplayEventList('Hello')
            if eventList[0][2]==0:
                EventRoutineArrival(n)
            elif eventList[0][2]==1:
                EventRoutineBeginService()
            elif eventList[0][2]==2:
                EventRoutineEndService()
            else:
                print ('Unknown event type')
            #Remove first notice
            eventList.pop(0)

        #print ('End of Simulation run')
        #print ('Blocking rate is {b}/{e}'.format(b=blockedCustomers,e = endedCustomers+b
        blockingRate.append(blockedCustomers/(endedCustomers+blockedCustomers))
        servers.append(i+1)
        i+=1
    #print (blockingRate)
    #print (servers)
    plt.plot(servers,blockingRate)
```

Out[30]: [<matplotlib.lines.Line2D at 0x27ae14b82e8>]



2.6 7. Add a buffer of finite size to the resource allocation system, such that when a customer calls and the server is busy, the customer is queued. [5 marks]

```
In [46]: fileOutA=True    # Flag, if true output to file
         stateList=[]     # List containing [q(t), s(t), time]
         servTimeList=[]
         eventList=[]     # Event calendar list
         notice=[]        # notice = [ notice number, time, type ]
                          # type = 0, arrival
                          # type = 1, begin service
                          # type = 2, end service
         now = 0.0        # Simulation time
         Q = 0            # Queue Length, Q=0 when empty
         S=0              # Server State 0=idle, 1=busy
         EN=0             # Event Notice Number
         avgintarrtimeList = [] #list for accumulating interarrival time
         buffersize = 20
         n=0              #no of servers
         enteredCustomers = 0

In [47]: def ScheduleEventNotice(notice):
             global eventList
             if len(eventList)==0:
                 eventList.append(notice)
             elif len(eventList)==1:
                 if eventList[0][1] <= notice[1]:
```

```
                    eventList.append(notice)
                else:
                    eventList.insert(0,notice)
            elif eventList[len(eventList)-1][1] < notice[1]:
                eventList.append(notice)
            else:
                i=0
                while (eventList[i][1]<=notice[1] and i<(len(eventList)-1)):
                    i += 1
                eventList.insert(i,notice)
```

In [48]:
```
def DisplayEventList(header):
    print (header)
    i=0
    while i<len(eventList):
        print (eventList[i])
        i += 1

def writeToFile():
    #print 'Q = ',Q, '   S = ',S, '   now = ', now
    stateEntry = [Q, S, now]
    stateList.append(stateEntry)

def DisplayStateList(header):
    print (header)
    i=0
    while i<len(stateList):
        print (stateList[i])
        i += 1
```

In [49]:
```
def InterArrivalTime():
    #return -10*math.log(random.random())
    return np.random.exponential()*14


def ServiceTime():
    #return -8*math.log(random.random())
    return np.random.exponential()*7
```

In [50]:
```
def EventRoutineArrival(n,b):
    global EN, Q, S, blockedCustomers, enteredCustomers#buffersize
    EN=EN+1
    enteredCustomers+=1
    intarrivaltime = InterArrivalTime()
    avgintarrtimeList.append(intarrivaltime)
    eventTime = now+intarrivaltime
    #notice=[EN+1, now+InterArrivalTime(), 0]
    notice=[EN, eventTime, 0]
```

```
            ScheduleEventNotice(notice)
            Q = Q + 1

            if S<n and Q<=b: # if idle

                if(b > 0):
                    Q += 1
                EN += 1
                notice=[EN, now, 1]
                ScheduleEventNotice(notice)
            elif Q<b:
                Q += 1
            else:
                blockedCustomers += 1

            if fileOutA: writeToFile()
```

In [51]:
```
def EventRoutineBeginService():
    global EN, Q, S
    Q = Q - 1
    S += 1
    EN+=1
    sT = ServiceTime()
    servTimeList.append(sT)
    eventTime = now+sT
    notice=[EN, eventTime, 2]
    ScheduleEventNotice(notice)
    if fileOutA: writeToFile()
```

In [52]:
```
def EventRoutineEndService():
    global EN, Q, S, endedCustomers
    endedCustomers += 1
    S-=1
    if Q>0:
        EN=EN+1
        eventTime = now
        notice = [EN, eventTime, 1]
    if fileOutA: writeToFile()
```

In [53]:
```
# Schedule arrival event at time NOW;
buffersize = 8

# def WithBufferSize(b):
#     global stateList, servTimeList, eventList, notice, now, Q, S, EN, avgintarrtime
# #     fileOutA=True   # Flag, if true output to file
#     stateList=[]    # List containing [q(t), s(t), time]
```

```
#     servTimeList=[]
#     eventList=[]    # Event calendar list
#     notice=[]       # notice = [ notice number, time, type ]
#                     # type = 0, arrival
#                     # type = 1, begin service
#                     # type = 2, end service
#     now = 0.0       # Simulation time
#     Q = 0           # Queue Length, Q=0 when empty
#     S=0             # Server State 0=idle, 1=busy
#     EN=0            # Event Notice Number
#     avgintarrtimeList = [] #list for accumulating interarrival time
#     buffersize = 0
#     n=0             #no of servers
#     enteredCustomers = 0
#     n = 8

notice=[EN, now, 0]
ScheduleEventNotice(notice)

print ('Start of Simulation run')

while (eventList!=[] and now<2000): #200000
    now = eventList[0][1]
    #print now,'   ',eventList[0]
    #print 'Q = ',Q, '   S = ',S
    #DisplayEventList('Hello')
    if eventList[0][2]==0:
        EventRoutineArrival(n,buffersize)
    elif eventList[0][2]==1:
        EventRoutineBeginService()
    elif eventList[0][2]==2:
        EventRoutineEndService()
    else:
        print ('Unknown event type')
    #Remove first notice
    eventList.pop(0)

print ('End of Simulation run')
```

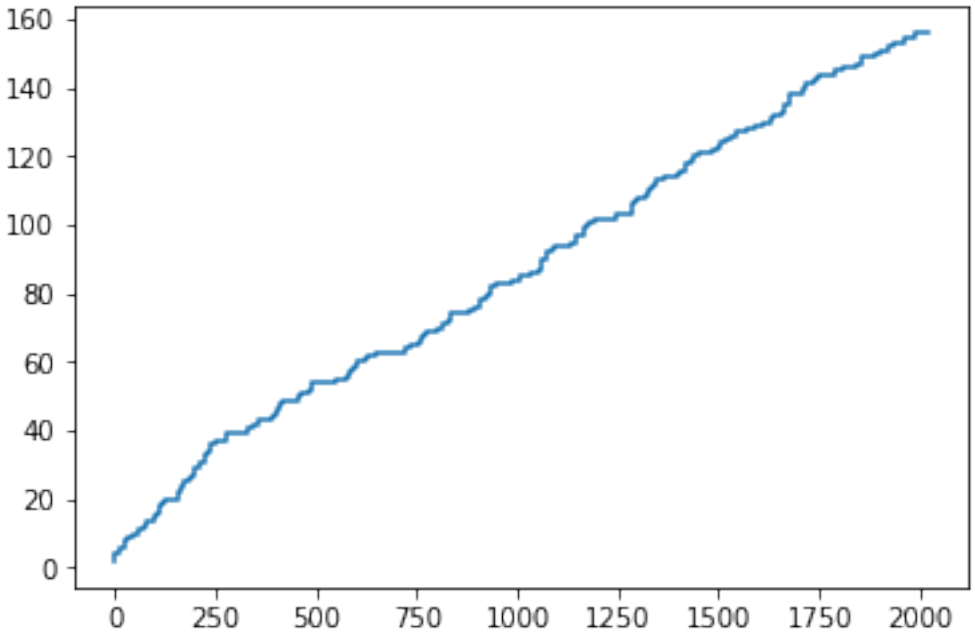
```
Start of Simulation run
End of Simulation run
```

```
In [54]: # WithBufferSize(buffersize)
```

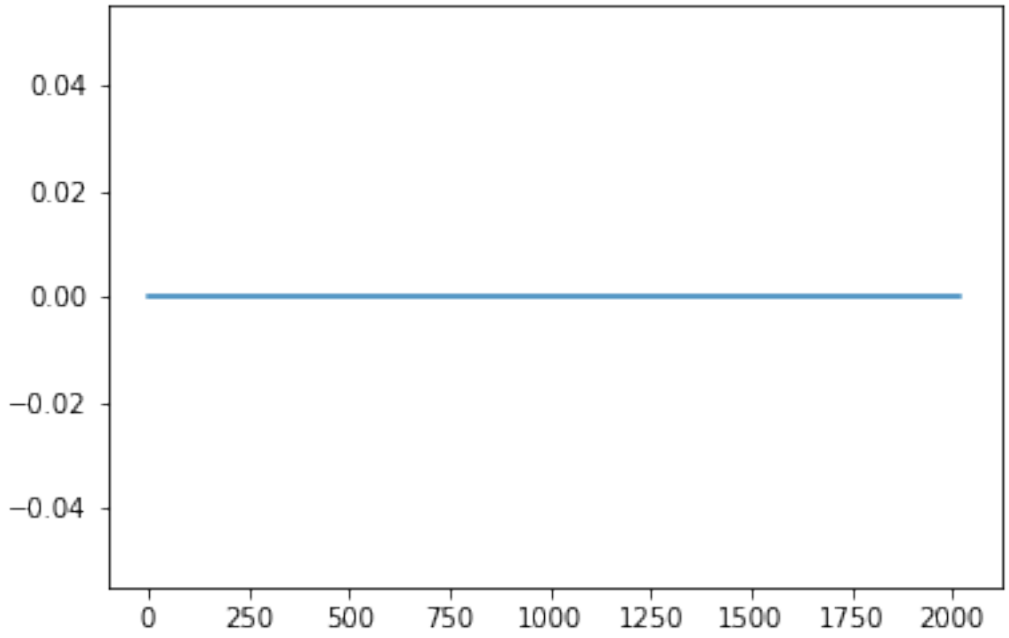
```
In [55]: c = np.asarray(stateList)
         x1=c[:,2]
         y1=c[:,0]
```

```
y12=c[:,1]
#n=8
print(np.shape(x1),np.shape(y1),np.shape(y12))
#PlotQueueLengthVSTime(x1,y1)
AvgQueueLen(x1,y1)
AvgIntArrivalTime(x1,y1)
ServerUtil(x1,y12,n)
#print ((blockedCustomers,(enteredCustomers)))
```

```
(152,) (152,) (152,)
```




```
Average queue length is equal to : 86.62430650303934
Average interarrival time: 13.300819866764009
```




```
0.0
2020.1782176634374
Server util is equal to : nan


C:\Users\matth\Anaconda3\lib\site-packages\ipykernel_launcher.py:40: RuntimeWarning: invalid va
```

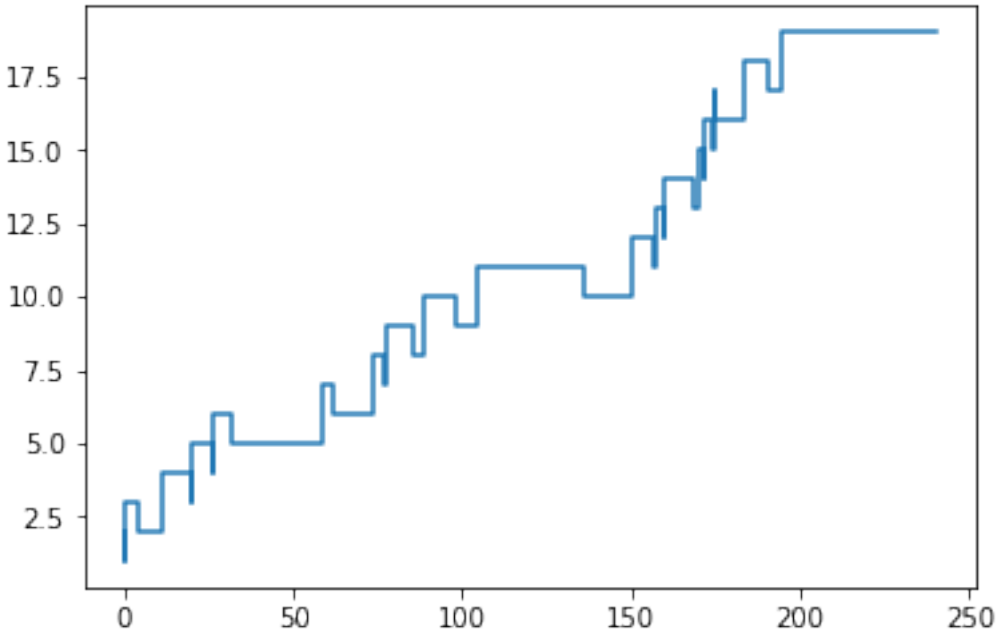
2.7 8. Plot the blocking rate versus buffer size. [5 marks]

```
In [41]: i = 1
         n=8
         buffersize = 0
         #blockedCustomers = 0

         blockingRate = []
         buffersizePerRun = []

         while (i<50):
             fileOutA=True   # Flag, if true output to file
             stateList=[]    # List containing [q(t), s(t), time]
             servTimeList=[]
             eventList=[]    # Event calendar list
             notice=[]       # notice = [ notice number, time, type ]
                             # type = 0, arrival
                             # type = 1, begin service
```

```
                    # type = 2, end service
            now = 0.0       # Simulation time
            Q = 0           # Queue Length, Q=0 when empty
            S=0             # No of Servers occupied
            EN=0            # Event Notice Number
            avgintarrtimeList = [] #list for accumulating interarrival time
            blockedCustomers = 0
            enteredCustomers = 0
            notice=[EN, now, 0]
            ScheduleEventNotice(notice)
            #print ('Start of Simulation run')

            while (eventList!=[] and now<200): #200000
                now = eventList[0][1]
                #print now,'   ',eventList[0]
                #print 'Q = ',Q, '   S = ',S
                #DisplayEventList('Hello')
                if eventList[0][2]==0:
                    EventRoutineArrival(n,buffersize)
                elif eventList[0][2]==1:
                    EventRoutineBeginService()
                elif eventList[0][2]==2:
                    EventRoutineEndService()
                else:
                    print ('Unknown event type')
                #Remove first notice
                eventList.pop(0)

            #print ('End of Simulation run')
            print ('Blocking rate is {b}/{e}'.format(b=blockedCustomers,e = enteredCustomers))
            blockingRate.append((blockedCustomers/(enteredCustomers)))
            buffersizePerRun.append(i+1)
            i+=1
            buffersize+=1
        d = np.asarray(stateList)
        x1=d[:,2]
        y1=d[:,0]
        y12=d[:,1]
        AvgIntArrivalTime(x1,y1)
        AvgQueueLen(x1,y1)
        #ServerUtil(x1,y12,50)
        # print (blockingRate)
        # print (servers)
        plt.plot(buffersizePerRun,blockingRate)
```

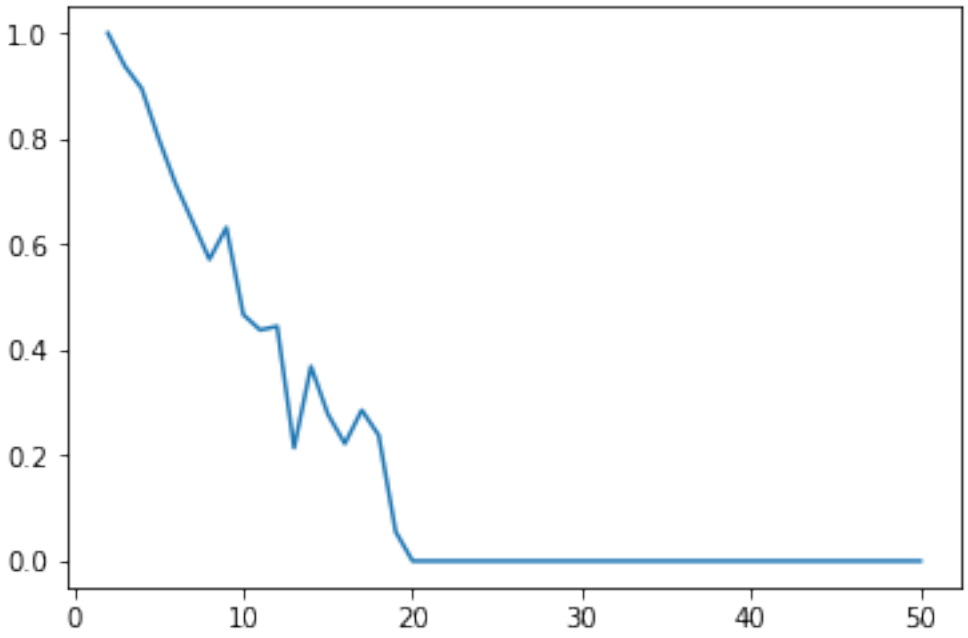
```
Blocking rate is 20/20
Blocking rate is 15/16
Blocking rate is 17/19
```

```
Blocking rate is 12/15
Blocking rate is 10/14
Blocking rate is 9/14
Blocking rate is 8/14
Blocking rate is 12/19
Blocking rate is 7/15
Blocking rate is 7/16
Blocking rate is 8/18
Blocking rate is 3/14
Blocking rate is 7/19
Blocking rate is 5/18
Blocking rate is 4/18
Blocking rate is 6/21
Blocking rate is 5/21
Blocking rate is 1/18
Blocking rate is 0/18
Blocking rate is 0/15
Blocking rate is 0/14
Blocking rate is 0/16
Blocking rate is 0/15
Blocking rate is 0/11
Blocking rate is 0/15
Blocking rate is 0/11
Blocking rate is 0/14
Blocking rate is 0/14
Blocking rate is 0/17
Blocking rate is 0/21
Blocking rate is 0/14
Blocking rate is 0/26
Blocking rate is 0/8
Blocking rate is 0/13
Blocking rate is 0/15
Blocking rate is 0/18
Blocking rate is 0/18
Blocking rate is 0/15
Blocking rate is 0/22
Blocking rate is 0/16
Blocking rate is 0/11
Blocking rate is 0/14
Blocking rate is 0/19
Blocking rate is 0/15
Blocking rate is 0/10
Blocking rate is 0/15
Blocking rate is 0/14
Blocking rate is 0/10
Blocking rate is 0/18
Average interarrival time: 15.565527510891176
```




```
Average queue length is equal to : 11.06174509413068
```

```
Out[41]: [<matplotlib.lines.Line2D at 0x27ae17d87b8>]
```



In [ ]:

In [ ]:

In [ ]: