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IE306 System Simulation
Homework 1 Report

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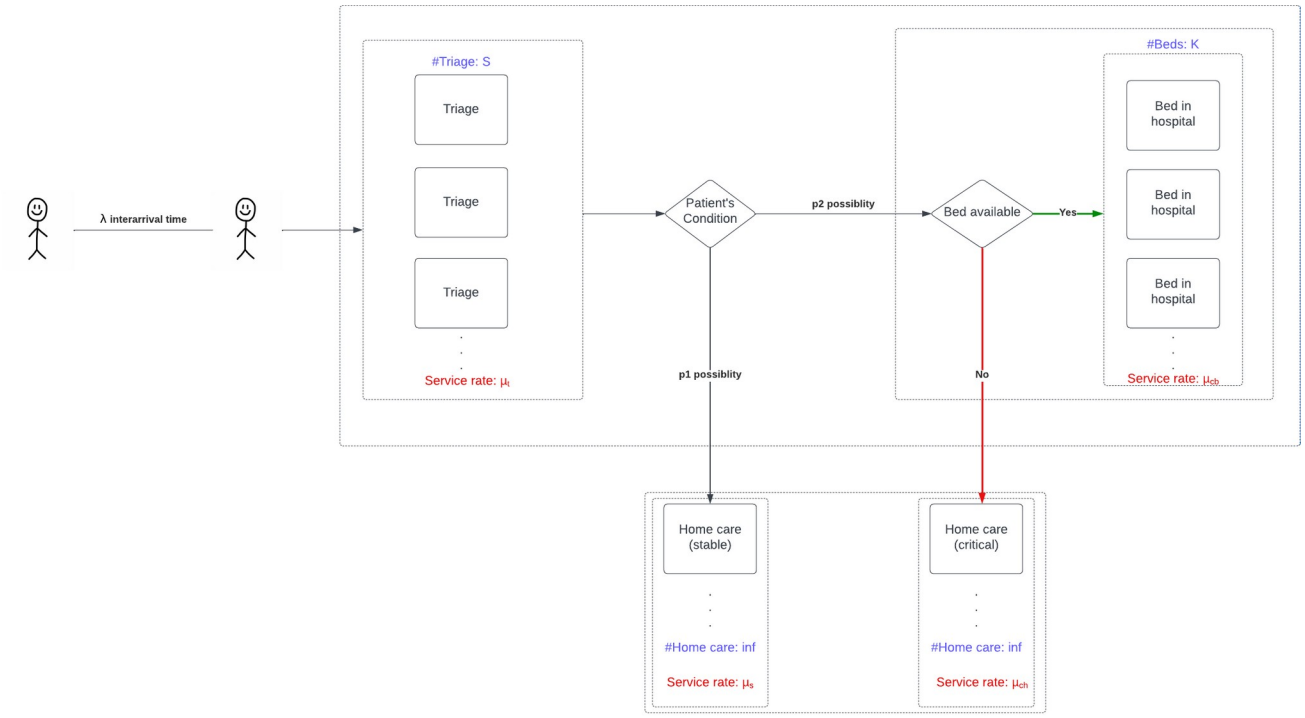
This documentation includes following sections:

1) **Conceptual Model of Hospital Simulation**
2) **Details of the Model**
3) **Flowchart**
4) **Pseudo-code**
5) **Hand Simulation**
6) **Simulation Results for Different Starting Conditions**
7) **Analysis of the Report**

-Conceptual Model of Hospital Simulation



-Details of the model

Entities: Patient (P_i), Nurse (N_i), Bed(B_i)

Attributes: Arrival time of the patient, availabilty of nurse, availabilty of bed.

Types of events: Arrival, triage departure, bed arrival, bed departure, home_care arrival, home_care departure.

Activities: Interarrival time (λ), nurse service time (μ_t), bed service time (μ_{cb}), home service time for stable (μ_s), home service time for critical(μ_{ch}).

Delays: Time spent in triage queue.

System states: # patients waiting in triage, # busy nurses, # busy beds, # patients in home care (stable), # patients in home care (critical).

Random variables:

Interarrival time (λ): Used to generate time between consecutive patient arrivals.

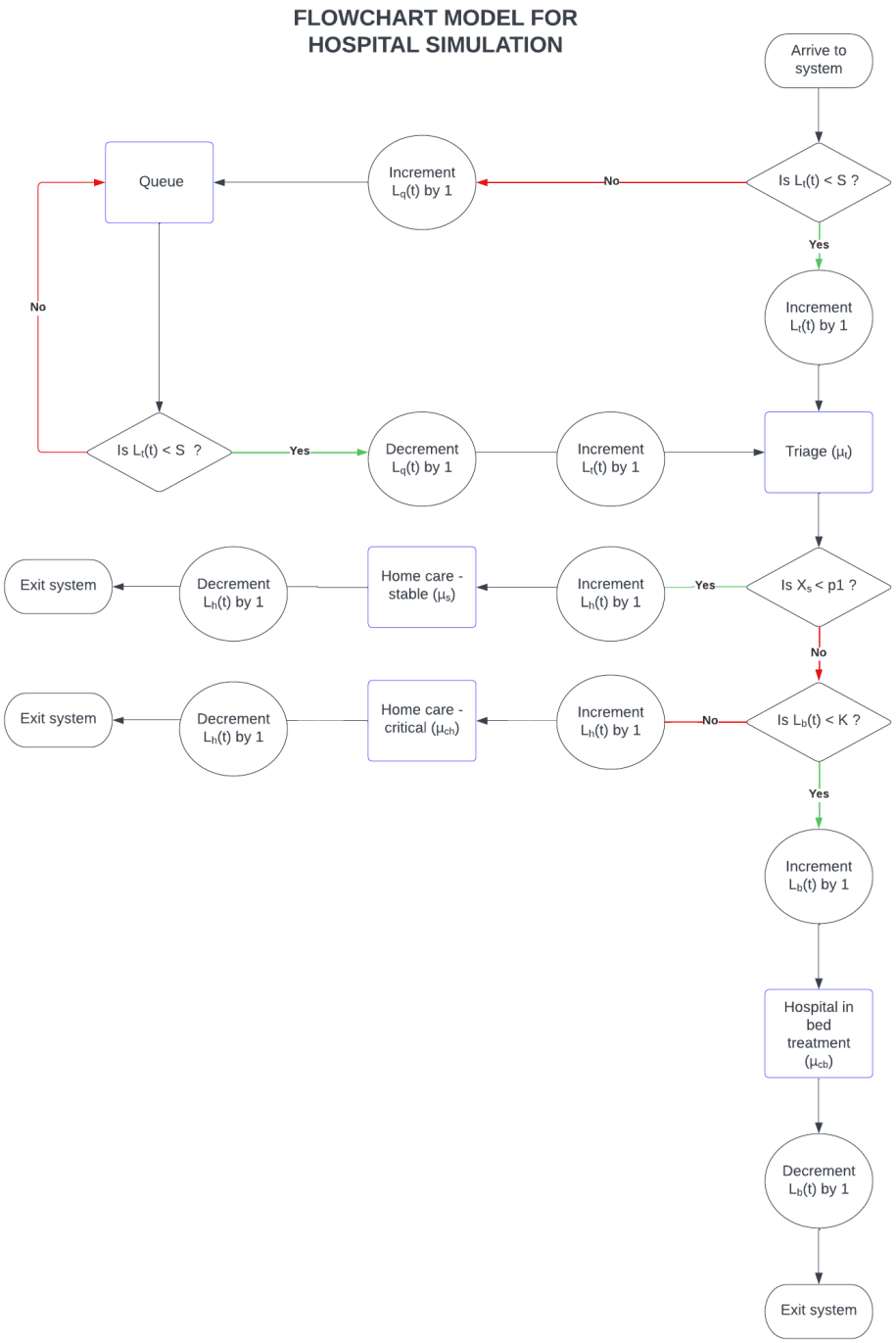
Nurse service time (μ_t): Used to generate service time for triage.

Bed service time (μ_{cb}): Used to generate service time for bedded hospital service.

Home healing time for stable (μ_s): Used to generate home healing time for stable patients.

Home healing time for critical(μ_{ch}): Used to generate home service time for critical patients.

-Flowchart



NOTATIONS:

$L_q(t)$: # people in the queue in time t.

$L_t(t)$: # people in the triage in time t.

$L_b(t)$: # people in the beds (critical condition) in time t.

$L_h(t)$: # people in the home care (both stable and critical condition) in time t.

S: # nurses for triage in the hospital.

K: # beds in the hospital.

X_s: Random number for deciding patient's condition. (If RN < p1, patient is in stable condition; otherwise in critical condition.)

μ_t: Service rate of a nurse in triage.

μ_{cb}: Healing time of a patient in critical condition with hospital care.

μ_{ch}: Healing time of a patient in critical condition with home care.

μ_s: Healing time of a patient in stable condition with home care.

ASSUMPTIONS:

1) p1 < p2 is assumed for decidability.

-Pseudo-code

```
Set Lq(t), Lt(t), Lb(t), Lh(t)  to 0
Set Xs  to 0
Set time to 0
Set S, K, μt, μcb, μch, μs from specified values
Set patient_queue (FIFO) to empty
Fill availabe_nurse_list (FIFO)
Fill availabe_bed_list (FIFO)
Set event_queue (priority queue with respect to ascending time values) to empty

While (stopping_condition):
    event is the front element of the event_queue
    event is popped from the event_queue
    time is the event's time
    event is the event's type
    if the event is Arrival:
        if (Lt(t) < S):
            Increment Lt(t) by 1
            Create Departure_Triage event with service time Generate_Nurse_Service_Time(μt)
            Add event to the event_queue.
        else:
            Increment Lq(t) by 1
            Add patient to the patient_queue
        Create Arrival event with interarrival time Generate_Interarrival(μt)
        Add event to the event_queue
    if (event is Departure_Triage):
        Decrement Lt(t) by 1
        Xs  = Generate_Random_Number
        if (Xs < p1):
            Increment Lh(t) by 1
            Create Treated_at_Home event with healing time Generate_Home_Healing_Time(μs, s)
            Add event to the event_queue.
        else:
            if (Lb(t) < K) :
                Increment Lb(t) by 1
                Create Treated_at_Home event with healing time Generate_Hospital_Healing_Time(μcb)
                Add event to the event_queue.
            else:
                Increment Lh(t) by 1
                Create Treated_at_Hospital event with healing time Generate_Home_Healing_Time(μch, c)
                Add event to the event_queue.
        if (patient_queue is not empty):
            patient is the front element of the patient_queue
            Increment Lt(t) by 1
            Create Departure_Triage event with service time Generate_Nurse_Service_Time(μt)alphaalphaalpha
            Add event to the event_queue.
    if (event is Treated_at_Home):
        Decrement Lh(t) by 1
    if (event is Treated_at_Hospital):
        Decrement Lb(t) by 1
```

-Hand Simulation

	Time	Event Type	Patient ID	FEL	L	Lt	Lb:	Lq	Healed
0	0	Arrival	0	['[A @ 0.20914650	1	1	0	0	0
1	0.209146500485405	Arrival	1	['[A @ 0.48912837	2	2	0	0	0
2	0.489128374369628	Arrival	2	['[A @ 0.83598450	3	3	0	0	0
3	0.835984502066582	Arrival	3	['[A @ 1.05664173	4	4	0	0	0
4	1.0566417392263	Arrival	4	['[A @ 1.90199459	5	4	0	1	0
5	1.90199459029694	Arrival	5	['[DT @ 2.7786391	6	4	0	2	0
6	2.77863912660182	Departure_Triage	2	['[A @ 3.14956246	6	4	1	1	0
7	3.14956246051209	Arrival	6	['[DT @ 3.2148633	7	4	1	2	0
8	3.21486339415868	Departure_Triage	1	['[DT @ 3.8219032	7	4	2	1	0
9	3.82190323162976	Departure_Triage	5	['[A @ 4.42047981	7	4	3	0	0
10	4.42047981252643	Arrival	7	['[A @ 4.42540693	8	4	3	1	0
11	4.42540693508851	Arrival	8	['[T_H @ 4.848247	9	4	3	2	0
12	4.84824712093146	Treated_at_Hospital	5	['[A @ 5.61183899	8	4	2	2	1
13	5.61183899872293	Arrival	9	['[DT @ 6.7772556	9	4	2	3	1
14	6.77725563433077	Departure_Triage	4	['[DT @ 6.8681549	9	4	3	2	1
15	6.86815496232173	Departure_Triage	7	['[DT @ 7.0447078	9	4	4	1	1
16	7.04470782507765	Departure_Triage	8	['[DT @ 7.3785662	9	4	5	0	1
17	7.37856621846291	Departure_Triage	3	['[A @ 7.59777423	9	3	6	0	1
18	7.59777423424492	Arrival	10	['[A @ 7.74162386	10	4	6	0	1
19	7.74162386257073	Arrival	11	['[T_H @ 7.952451	11	4	6	1	1
20	7.95245192460381	Treated_at_Hospital	8	['[T_H @ 8.405577	10	4	5	1	2
21	8.40557787603114	Treated_at_Hospital	3	['[DT @ 8.6896820	9	4	4	1	3
22	8.68968202052297	Departure_Triage	6	['[A @ 8.88261487	9	4	5	0	3
23	8.88261487276844	Arrival	12	['[A @ 9.44285372	10	4	5	1	3
24	9.4428537202445	Arrival	13	['[DT @ 9.6599400	11	4	5	2	3
25	9.65994006986406	Departure_Triage	0	['[A @ 9.70808613	11	4	5	1	3
26	9.70808613037367	Arrival	14	['[A @ 9.80629546	12	4	5	2	3
27	9.80629546730671	Arrival	15	['[DT @ 10.295321	13	4	5	3	3
28	10.2953214273734	Departure_Triage	10	['[A @ 10.4630540	13	4	6	2	3
29	10.463054060666	Arrival	16	['[DT @ 10.627081	14	4	6	3	3
30	10.6270810994515	Departure_Triage	12	['[DT @ 10.641160	14	4	6	2	3
31	10.6411607286014	Departure_Triage	13	['[T_H @ 10.71702	14	4	7	1	3
32	10.7170272732065	Treated_at_Hospital	1	['[A @ 10.8805726	13	4	6	1	4
33	10.8805726829536	Arrival	17	['[T_Hm @ 10.9236	14	4	6	2	4
34	10.9236964401457	Treated_at_Home	12	['[A @ 11.0220912	13	4	6	2	5

Interarrival Times:
[0.20914650048540506, 0.279981873884223, 0.34685612769695395, 0.22065723715972121, 0.8453528510706324, 1.2475678702151543, 1.2709173520143402, 0.004927122562076396, 1.1864320636344217, 1.9859352355219877, 0.14384962832581538, 1.1409910101977068, 0.5602388474760585, 0.2652324101291708, 0.09820933693303982, 0.6567585933592494, 0.4175186222876054, 0.14151858086096616]

Home Healing Times for Stable Patients :
[3.072417801920536, 0.29661534069418105]

Triage Nurse Service Times:
[9.659940069864062, 3.0057168936732728, 2.289510752232194, 6.542581716396329, 3.9986165077289475, 0.6070398374710841, 4.867778788893205, 0.09089932799096077, 0.17655286275592208, 14.815249047802036, 2.6975471931284893, 3.884426268243522, 0.9671410295874304, 0.34583930122799134, 2.902219986814983, 0.9426381832743278]

Hospital Bed Service Times:
[9.25444050814254, 7.502163879047811, 1.026343889301696, 8.8431550215961, 18.01843672704894, 0.907744099526162, 1.0270116575682249, 24.899980255222363, 8.399485214030763, 3.3994177211224046]

-Simulation Results for Different Starting Conditions

-System: “Empty”, Number of Healed Patients: “20”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	0	1	1	0	0	0
1	0.209147	Arrival	1	2	2	0	0	0
2	0.489128	Arrival	2	3	3	0	0	0
3	0.835985	Arrival	3	4	4	0	0	0
4	1.056642	Arrival	4	5	4	0	1	0
5	1.901995	Arrival	5	6	4	0	2	0
6	2.778639	Departure_Triage	2	6	4	1	1	0
7	3.149562	Arrival	6	7	4	1	2	0
8	3.214863	Departure_Triage	1	7	4	2	1	0
9	3.821903	Departure_Triage	5	7	4	3	0	0
10	4.420480	Arrival	7	8	4	3	1	0
11	4.425407	Arrival	8	9	4	3	2	0
12	4.848247	Treated_at_Hospital	5	8	4	2	2	1
13	5.611839	Arrival	9	9	4	2	3	1
14	6.777256	Departure_Triage	4	9	4	3	2	1
15	6.868155	Departure_Triage	7	9	4	4	1	1
16	7.044708	Departure_Triage	8	9	4	5	0	1
17	7.378566	Departure_Triage	3	9	3	6	0	1
18	7.597774	Arrival	10	10	4	6	0	1
19	7.741624	Arrival	11	11	4	6	1	1
20	7.952452	Treated_at_Hospital	8	10	4	5	1	2
21	8.405578	Treated_at_Hospital	3	9	4	4	1	3
22	8.689682	Departure_Triage	6	9	4	5	0	3
23	8.882615	Arrival	12	10	4	5	1	3
24	9.442854	Arrival	13	11	4	5	2	3
25	9.659940	Departure_Triage	0	11	4	5	1	3
26	9.708086	Arrival	14	12	4	5	2	3
27	9.806295	Arrival	15	13	4	5	3	3
28	10.295321	Departure_Triage	10	13	4	6	2	3
29	10.463054	Arrival	16	14	4	6	3	3
30	10.627081	Departure_Triage	12	14	4	6	2	3
31	10.641161	Departure_Triage	13	14	4	7	1	3
32	10.717027	Treated_at_Hospital	1	13	4	6	1	4
33	10.880573	Arrival	17	14	4	6	2	4
34	10.923696	Treated_at_Home	12	13	4	6	2	5
35	11.022091	Arrival	18	14	4	6	3	5
36	11.037037	Arrival	19	15	4	6	4	5
37	11.583799	Departure_Triage	15	15	4	7	3	5
38	12.033080	Treated_at_Hospital	2	14	4	6	3	6
39	12.574108	Departure_Triage	11	14	4	6	2	6
40	12.617399	Arrival	20	15	4	6	3	6
41	12.732358	Treated_at_Home	0	14	4	6	3	7
42	13.529301	Departure_Triage	14	14	4	7	2	7
43	13.856433	Arrival	21	15	4	7	3	7
44	14.040578	Treated_at_Hospital	13	14	4	6	3	8
45	14.547924	Treated_at_Home	11	13	4	6	3	9
46	14.983408	Arrival	22	14	4	6	4	9
47	15.185533	Arrival	23	15	4	6	5	9
48	15.620411	Treated_at_Hospital	4	14	4	5	5	10
49	15.657564	Arrival	24	15	4	5	6	10

```
Long-run probability of arriving patient finds an available nurse
0.0911731284591583
Long-run probability of critical patient finds an available bed
0.6989297052222231
Joint
0.06372360779814738
Average number of people rejected due to bed unavailability
0.28
Average utilization of each nurse
0.890229978433669
Average number of occupied beds
0.38037950462114783
Average number of patients treated at home
0.20588235294117646
Average time a sick person gets better
8.883932320323943
```

-System: “Empty”, Number of Healed Patients: “200”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	0	1	1	0	0	0
1	0.209147	Arrival	1	2	2	0	0	0
2	0.489128	Arrival	2	3	3	0	0	0
3	0.835985	Arrival	3	4	4	0	0	0
4	1.056642	Arrival	4	5	4	0	1	0
5	1.901995	Arrival	5	6	4	0	2	0
6	2.778639	Departure_Triage	2	6	4	1	1	0
7	3.149562	Arrival	6	7	4	1	2	0
8	3.214863	Departure_Triage	1	7	4	2	1	0
9	3.821903	Departure_Triage	5	7	4	3	0	0
10	4.420480	Arrival	7	8	4	3	1	0
11	4.425407	Arrival	8	9	4	3	2	0
12	4.848247	Treated_at_Hospital	5	8	4	2	2	1
13	5.611839	Arrival	9	9	4	2	3	1
14	6.777256	Departure_Triage	4	9	4	3	2	1
15	6.868155	Departure_Triage	7	9	4	4	1	1
16	7.044708	Departure_Triage	8	9	4	5	0	1
17	7.378566	Departure_Triage	3	9	3	6	0	1
18	7.597774	Arrival	10	10	4	6	0	1
19	7.741624	Arrival	11	11	4	6	1	1
20	7.952452	Treated_at_Hospital	8	10	4	5	1	2
21	8.405578	Treated_at_Hospital	3	9	4	4	1	3
22	8.689682	Departure_Triage	6	9	4	5	0	3
23	8.882615	Arrival	12	10	4	5	1	3
24	9.442854	Arrival	13	11	4	5	2	3
25	9.659940	Departure_Triage	0	11	4	5	1	3
26	9.708086	Arrival	14	12	4	5	2	3
27	9.806295	Arrival	15	13	4	5	3	3
28	10.295321	Departure_Triage	10	13	4	6	2	3
29	10.463054	Arrival	16	14	4	6	3	3
30	10.627081	Departure_Triage	12	14	4	6	2	3
31	10.641161	Departure_Triage	13	14	4	7	1	3
32	10.717027	Treated_at_Hospital	1	13	4	6	1	4
33	10.880573	Arrival	17	14	4	6	2	4
34	10.923696	Treated_at_Home	12	13	4	6	2	5
35	11.022091	Arrival	18	14	4	6	3	5
36	11.037037	Arrival	19	15	4	6	4	5
37	11.583799	Departure_Triage	15	15	4	7	3	5
38	12.033080	Treated_at_Hospital	2	14	4	6	3	6
39	12.574108	Departure_Triage	11	14	4	6	2	6
40	12.617399	Arrival	20	15	4	6	3	6
41	12.732358	Treated_at_Home	0	14	4	6	3	7
42	13.529301	Departure_Triage	14	14	4	7	2	7
43	13.856433	Arrival	21	15	4	7	3	7
44	14.040578	Treated_at_Hospital	13	14	4	6	3	8
45	14.547924	Treated_at_Home	11	13	4	6	3	9
46	14.983408	Arrival	22	14	4	6	4	9
47	15.185533	Arrival	23	15	4	6	5	9
48	15.620411	Treated_at_Hospital	4	14	4	5	5	10
49	15.657564	Arrival	24	15	4	5	6	10

```
Long-run probability of arriving patient finds an available nurse
0.36068174708066003
Long-run probability of critical patient finds an available bed
0.7721720754433425
Joint
0.27850837321780403
Average number of people rejected due to bed unavailability
0.25903614457831325
Average utilization of each nurse
0.8033507380290541
Average number of occupied beds
0.6969385829351082
Average number of patients treated at home
0.37327188940092165
Average time a sick person gets better
11.07520075309689
```

-System: “Empty”, Number of Healed Patients: “1000”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	0	1	1	0	0	0
1	0.209147	Arrival	1	2	2	0	0	0
2	0.489128	Arrival	2	3	3	0	0	0
3	0.835985	Arrival	3	4	4	0	0	0
4	1.056642	Arrival	4	5	4	0	1	0
5	1.901995	Arrival	5	6	4	0	2	0
6	2.778639	Departure_Triage	2	6	4	1	1	0
7	3.149562	Arrival	6	7	4	1	2	0
8	3.214863	Departure_Triage	1	7	4	2	1	0
9	3.821903	Departure_Triage	5	7	4	3	0	0
10	4.420480	Arrival	7	8	4	3	1	0
11	4.425407	Arrival	8	9	4	3	2	0
12	4.848247	Treated_at_Hospital	5	8	4	2	2	1
13	5.611839	Arrival	9	9	4	2	3	1
14	6.777256	Departure_Triage	4	9	4	3	2	1
15	6.868155	Departure_Triage	7	9	4	4	1	1
16	7.044708	Departure_Triage	8	9	4	5	0	1
17	7.378566	Departure_Triage	3	9	3	6	0	1
18	7.597774	Arrival	10	10	4	6	0	1
19	7.741624	Arrival	11	11	4	6	1	1
20	7.952452	Treated_at_Hospital	8	10	4	5	1	2
21	8.405578	Treated_at_Hospital	3	9	4	4	1	3
22	8.689682	Departure_Triage	6	9	4	5	0	3
23	8.882615	Arrival	12	10	4	5	1	3
24	9.442854	Arrival	13	11	4	5	2	3
25	9.659940	Departure_Triage	0	11	4	5	1	3
26	9.708086	Arrival	14	12	4	5	2	3
27	9.806295	Arrival	15	13	4	5	3	3
28	10.295321	Departure_Triage	10	13	4	6	2	3
29	10.463054	Arrival	16	14	4	6	3	3
30	10.627081	Departure_Triage	12	14	4	6	2	3
31	10.641161	Departure_Triage	13	14	4	7	1	3
32	10.717027	Treated_at_Hospital	1	13	4	6	1	4
33	10.880573	Arrival	17	14	4	6	2	4
34	10.923696	Treated_at_Home	12	13	4	6	2	5
35	11.022091	Arrival	18	14	4	6	3	5
36	11.037037	Arrival	19	15	4	6	4	5
37	11.583799	Departure_Triage	15	15	4	7	3	5
38	12.033080	Treated_at_Hospital	2	14	4	6	3	6
39	12.574108	Departure_Triage	11	14	4	6	2	6
40	12.617399	Arrival	20	15	4	6	3	6
41	12.732358	Treated_at_Home	0	14	4	6	3	7
42	13.529301	Departure_Triage	14	14	4	7	2	7
43	13.856433	Arrival	21	15	4	7	3	7
44	14.040578	Treated_at_Hospital	13	14	4	6	3	8
45	14.547924	Treated_at_Home	11	13	4	6	3	9
46	14.983408	Arrival	22	14	4	6	4	9
47	15.185533	Arrival	23	15	4	6	5	9
48	15.620411	Treated_at_Hospital	4	14	4	5	5	10
49	15.657564	Arrival	24	15	4	5	6	10

```
Long-run probability of arriving patient finds an available nurse
0.5787447055646788
Long-run probability of critical patient finds an available bed
0.8287317736747841
Joint
0.479624126347507
Average number of people rejected due to bed unavailability
0.17632552404438964
Average utilization of each nurse
0.703812099072887
Average number of occupied beds
0.6978700953888646
Average number of patients treated at home
0.3323353293413174
Average time a sick person gets better
11.00051244527104
```

-System: “All nurses and beds full”, Number of Healed Patients: “20”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	11	12	4	7	1	0
1	0.585610	Departure_Triage	1	12	4	7	0	0
2	0.783949	Departure_Triage	3	12	3	7	0	0
3	1.428077	Arrival	12	13	4	7	0	0
4	1.544601	Treated_at_Hospital	7	12	4	6	0	1
5	1.838615	Departure_Triage	12	12	3	7	0	1
6	1.873105	Treated_at_Hospital	12	11	3	6	0	2
7	2.427993	Treated_at_Hospital	5	10	3	5	0	3
8	2.976415	Treated_at_Home	3	9	3	5	0	4
9	3.005717	Departure_Triage	2	9	2	6	0	4
10	3.166570	Arrival	13	10	3	6	0	4
11	3.586476	Departure_Triage	11	10	2	7	0	4
12	3.813724	Treated_at_Hospital	11	9	2	6	0	5
13	4.429878	Arrival	14	10	3	6	0	5
14	4.492932	Arrival	15	11	4	6	0	5
15	4.856030	Departure_Triage	15	11	3	7	0	5
16	5.723777	Treated_at_Hospital	4	10	3	6	0	6
17	5.883042	Treated_at_Hospital	15	9	3	5	0	7
18	5.917470	Treated_at_Hospital	8	8	3	4	0	8
19	8.727188	Departure_Triage	13	8	2	4	0	8
20	8.732975	Treated_at_Hospital	9	7	2	3	0	9
21	9.254441	Treated_at_Hospital	10	6	2	2	0	10
22	9.659940	Departure_Triage	0	6	1	3	0	10
23	9.784093	Arrival	16	7	2	3	0	10
24	10.666887	Treated_at_Hospital	0	6	2	2	0	11
25	11.310741	Treated_at_Hospital	2	5	2	1	0	12
26	11.637252	Departure_Triage	14	5	1	1	0	12
27	12.978867	Departure_Triage	16	5	0	2	0	12
28	13.205902	Treated_at_Home	1	4	0	2	0	13
29	13.341233	Arrival	17	5	1	2	0	13
30	13.832819	Arrival	18	6	2	2	0	13
31	13.931029	Arrival	19	7	3	2	0	13
32	14.083883	Departure_Triage	17	7	2	3	0	13
33	14.748499	Treated_at_Home	13	6	2	3	0	14
34	14.799960	Departure_Triage	18	6	1	3	0	14
35	14.948482	Treated_at_Hospital	17	5	1	2	0	15
36	15.130955	Arrival	20	6	2	2	0	15
37	15.263839	Departure_Triage	20	6	1	3	0	15
38	15.769953	Departure_Triage	19	6	0	3	0	15
39	16.167462	Arrival	21	7	1	3	0	15
40	16.182408	Arrival	22	8	2	3	0	15
41	16.356454	Treated_at_Hospital	6	7	2	2	0	16
42	16.563714	Departure_Triage	21	7	1	3	0	16
43	16.900539	Treated_at_Hospital	16	6	1	2	0	17
44	17.409452	Treated_at_Home	18	5	1	2	0	18
45	17.874056	Treated_at_Home	19	4	1	2	0	19
46	18.663257	Treated_at_Hospital	20	3	1	1	0	20

```
Long-run probability of arriving patient finds an available nurse
0.9165427303149126
Long-run probability of critical patient finds an available bed
0.8567192256382463
Joint
0.785219778179756
Average number of people rejected due to bed unavailability
0.18181818181818182
Average utilization of each nurse
0.5070167763032367
Average number of occupied beds
0.5261990833286615
Average number of patients treated at home
0.4166666666666667
Average time a sick person gets better
4.111827429755338
```

-System: “All nurses and beds full”, Number of Healed Patients: “200”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	11	12	4	7	1	0
1	0.585610	Departure_Triage	1	12	4	7	0	0
2	0.783949	Departure_Triage	3	12	3	7	0	0
3	1.428077	Arrival	12	13	4	7	0	0
4	1.544601	Treated_at_Hospital	7	12	4	6	0	1
5	1.838615	Departure_Triage	12	12	3	7	0	1
6	1.873105	Treated_at_Hospital	12	11	3	6	0	2
7	2.427993	Treated_at_Hospital	5	10	3	5	0	3
8	2.976415	Treated_at_Home	3	9	3	5	0	4
9	3.005717	Departure_Triage	2	9	2	6	0	4
10	3.166570	Arrival	13	10	3	6	0	4
11	3.586476	Departure_Triage	11	10	2	7	0	4
12	3.813724	Treated_at_Hospital	11	9	2	6	0	5
13	4.429878	Arrival	14	10	3	6	0	5
14	4.492932	Arrival	15	11	4	6	0	5
15	4.856030	Departure_Triage	15	11	3	7	0	5
16	5.723777	Treated_at_Hospital	4	10	3	6	0	6
17	5.883042	Treated_at_Hospital	15	9	3	5	0	7
18	5.917470	Treated_at_Hospital	8	8	3	4	0	8
19	8.727188	Departure_Triage	13	8	2	4	0	8
20	8.732975	Treated_at_Hospital	9	7	2	3	0	9
21	9.254441	Treated_at_Hospital	10	6	2	2	0	10
22	9.659940	Departure_Triage	0	6	1	3	0	10
23	9.784093	Arrival	16	7	2	3	0	10
24	10.666887	Treated_at_Hospital	0	6	2	2	0	11
25	11.310741	Treated_at_Hospital	2	5	2	1	0	12
26	11.637252	Departure_Triage	14	5	1	1	0	12
27	12.978867	Departure_Triage	16	5	0	2	0	12
28	13.205902	Treated_at_Home	1	4	0	2	0	13
29	13.341233	Arrival	17	5	1	2	0	13
30	13.832819	Arrival	18	6	2	2	0	13
31	13.931029	Arrival	19	7	3	2	0	13
32	14.083883	Departure_Triage	17	7	2	3	0	13
33	14.748499	Treated_at_Home	13	6	2	3	0	14
34	14.799960	Departure_Triage	18	6	1	3	0	14
35	14.948482	Treated_at_Hospital	17	5	1	2	0	15
36	15.130955	Arrival	20	6	2	2	0	15
37	15.263839	Departure_Triage	20	6	1	3	0	15
38	15.769953	Departure_Triage	19	6	0	3	0	15
39	16.167462	Arrival	21	7	1	3	0	15
40	16.182408	Arrival	22	8	2	3	0	15
41	16.356454	Treated_at_Hospital	6	7	2	2	0	16
42	16.563714	Departure_Triage	21	7	1	3	0	16
43	16.900539	Treated_at_Hospital	16	6	1	2	0	17
44	17.409452	Treated_at_Home	18	5	1	2	0	18
45	17.874056	Treated_at_Home	19	4	1	2	0	19
46	18.663257	Treated_at_Hospital	20	3	1	1	0	20
47	19.548825	Arrival	23	4	2	1	0	20
48	20.307847	Treated_at_Home	14	3	2	1	0	21
49	20.433095	Departure_Triage	23	3	1	2	0	21

```
Long-run probability of arriving patient finds an available nurse
0.5701157976723213
Long-run probability of critical patient finds an available bed
0.8331917654524394
Joint
0.4750157879749272
Average number of people rejected due to bed unavailability
0.16049382716049382
Average utilization of each nurse
0.7031357550786013
Average number of occupied beds
0.6829330526320435
Average number of patients treated at home
0.3069306930693069
Average time a sick person gets better
10.465134220525105
```

-System: “All nurses and beds full”, Number of Healed Patients: “1000”

```
          Time           Event Type  Patient ID   L  Lt  Lb  Lq  Healed
0     0.000000              Arrival          11  12   4   7   1       0
1     0.585610     Departure_Triage           1  12   4   7   0       0
2     0.783949     Departure_Triage           3  12   3   7   0       0
3     1.428077              Arrival          12  13   4   7   0       0
4     1.544601  Treated_at_Hospital           7  12   4   6   0       1
5     1.838615     Departure_Triage          12  12   3   7   0       1
6     1.873105  Treated_at_Hospital          12  11   3   6   0       2
7     2.427993  Treated_at_Hospital           5  10   3   5   0       3
8     2.976415      Treated_at_Home           3   9   3   5   0       4
9     3.005717     Departure_Triage           2   9   2   6   0       4
10    3.166570              Arrival          13  10   3   6   0       4
11    3.586476     Departure_Triage          11  10   2   7   0       4
12    3.813724  Treated_at_Hospital          11   9   2   6   0       5
13    4.429878              Arrival          14  10   3   6   0       5
14    4.492932              Arrival          15  11   4   6   0       5
15    4.856030     Departure_Triage          15  11   3   7   0       5
16    5.723777  Treated_at_Hospital           4  10   3   6   0       6
17    5.883042  Treated_at_Hospital          15   9   3   5   0       7
18    5.917470  Treated_at_Hospital           8   8   3   4   0       8
19    8.727188     Departure_Triage          13   8   2   4   0       8
20    8.732975  Treated_at_Hospital           9   7   2   3   0       9
21    9.254441  Treated_at_Hospital          10   6   2   2   0      10
22    9.659940     Departure_Triage           0   6   1   3   0      10
23    9.784093              Arrival          16   7   2   3   0      10
24   10.666887  Treated_at_Hospital           0   6   2   2   0      11
25   11.310741  Treated_at_Hospital           2   5   2   1   0      12
26   11.637252     Departure_Triage          14   5   1   1   0      12
27   12.978867     Departure_Triage          16   5   0   2   0      12
28   13.205902      Treated_at_Home           1   4   0   2   0      13
29   13.341233              Arrival          17   5   1   2   0      13
30   13.832819              Arrival          18   6   2   2   0      13
31   13.931029              Arrival          19   7   3   2   0      13
32   14.083883     Departure_Triage          17   7   2   3   0      13
33   14.748499      Treated_at_Home          13   6   2   3   0      14
34   14.799960     Departure_Triage          18   6   1   3   0      14
35   14.948482  Treated_at_Hospital          17   5   1   2   0      15
36   15.130955              Arrival          20   6   2   2   0      15
37   15.263839     Departure_Triage          20   6   1   3   0      15
38   15.769953     Departure_Triage          19   6   0   3   0      15
39   16.167462              Arrival          21   7   1   3   0      15
40   16.182408              Arrival          22   8   2   3   0      15
41   16.356454  Treated_at_Hospital           6   7   2   2   0      16
42   16.563714     Departure_Triage          21   7   1   3   0      16
43   16.900539  Treated_at_Hospital          16   6   1   2   0      17
44   17.409452      Treated_at_Home          18   5   1   2   0      18
45   17.874056      Treated_at_Home          19   4   1   2   0      19
46   18.663257  Treated_at_Hospital          20   3   1   1   0      20
47   19.548825              Arrival          23   4   2   1   0      20
48   20.307847      Treated_at_Home          14   3   2   1   0      21
49   20.433095     Departure_Triage          23   3   1   2   0      21
Long-run probability of arriving patient finds an available nurse
0.6160237140686746
Long-run probability of critical patient finds an available bed
0.8437956663308789
Joint
0.5197981402882002
Average number of people rejected due to bed unavailability
0.14516129032258066
Average utilization of each nurse
0.6852425918945025
Average number of occupied beds
0.697288007348763
Average number of patients treated at home
0.3081570996978852
Average time a sick person gets better
10.920222633550331
```

-System: “Half of the nurses and half of the beds full”, Number of Healed Patients: “20”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	5	6	3	3	0	0
1	0.585610	Departure_Triage	1	6	2	4	0	0
2	0.971197	Departure_Triage	5	6	1	5	0	0
3	1.959873	Treated_at_Hospital	3	5	1	4	0	1
4	2.130211	Treated_at_Hospital	1	4	1	3	0	2
5	2.336636	Arrival	6	5	2	3	0	2
6	3.658699	Arrival	7	6	3	3	0	2
7	4.929617	Arrival	8	7	4	3	0	2
8	5.146417	Arrival	9	8	4	3	1	2
9	5.293037	Arrival	10	9	4	3	2	2
10	5.723777	Treated_at_Hospital	4	8	4	2	2	3
11	5.829826	Departure_Triage	6	8	4	3	1	3
12	5.864316	Treated_at_Hospital	6	7	4	2	1	4
13	6.888667	Treated_at_Hospital	5	6	4	1	1	5
14	7.031530	Arrival	11	7	4	1	2	5
15	7.514292	Treated_at_Hospital	2	6	4	0	2	6
16	7.657316	Departure_Triage	7	6	4	1	1	6
17	7.748215	Departure_Triage	10	6	4	2	0	6
18	7.924768	Departure_Triage	11	6	3	3	0	6
19	7.930482	Departure_Triage	8	6	2	4	0	6
20	8.832512	Treated_at_Hospital	11	5	2	3	0	7
21	9.017465	Arrival	12	6	3	3	0	7
22	9.151836	Departure_Triage	9	6	2	4	0	7
23	9.428269	Departure_Triage	12	6	1	4	0	7
24	9.659940	Departure_Triage	0	6	0	5	0	7
25	9.980874	Arrival	13	7	1	5	0	7
26	10.158784	Treated_at_Hospital	9	6	1	4	0	8
27	10.541113	Arrival	14	7	2	4	0	8
28	11.032700	Arrival	15	8	3	4	0	8
29	11.130910	Arrival	16	9	4	4	0	8
30	11.283764	Departure_Triage	14	9	3	4	0	8
31	11.999841	Departure_Triage	15	9	2	5	0	8
32	12.055727	Treated_at_Home	14	8	2	5	0	9
33	12.330836	Arrival	17	9	3	5	0	9
34	12.463720	Departure_Triage	17	9	2	6	0	9
35	12.969834	Departure_Triage	16	9	1	6	0	9
36	13.367343	Arrival	18	10	2	6	0	9
37	13.382288	Arrival	19	11	3	6	0	9
38	13.763595	Departure_Triage	18	11	2	7	0	9
39	13.865301	Departure_Triage	13	11	1	7	0	9
40	14.922472	Treated_at_Hospital	15	10	1	6	0	10
41	15.073937	Treated_at_Home	16	9	1	6	0	11
42	15.839116	Treated_at_Home	13	8	1	6	0	12
43	15.863137	Treated_at_Hospital	17	7	1	5	0	13
44	16.500471	Treated_at_Hospital	7	6	1	4	0	14
45	16.559463	Treated_at_Home	12	5	1	4	0	15
46	16.748706	Arrival	20	6	2	4	0	15
47	17.807303	Departure_Triage	19	6	1	5	0	15
48	17.987740	Arrival	21	7	2	5	0	15
49	19.114715	Arrival	22	8	3	5	0	15

```
Long-run probability of arriving patient finds an available nurse
0.7431225278215623
Long-run probability of critical patient finds an available bed
0.796576482572724
Joint
0.5919539293326513
Average number of people rejected due to bed unavailability
0.14285714285714285
Average utilization of each nurse
0.527777781149872
Average number of occupied beds
0.3338102695157477
Average number of patients treated at home
0.2222222222222222
Average time a sick person gets better
5.508780807872099
```

-System: “Half of the nurses and half of the beds full”, Number of Healed Patients: “200”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	5	6	3	3	0	0
1	0.585610	Departure_Triage	1	6	2	4	0	0
2	0.971197	Departure_Triage	5	6	1	5	0	0
3	1.959873	Treated_at_Hospital	3	5	1	4	0	1
4	2.130211	Treated_at_Hospital	1	4	1	3	0	2
5	2.336636	Arrival	6	5	2	3	0	2
6	3.658699	Arrival	7	6	3	3	0	2
7	4.929617	Arrival	8	7	4	3	0	2
8	5.146417	Arrival	9	8	4	3	1	2
9	5.293037	Arrival	10	9	4	3	2	2
10	5.723777	Treated_at_Hospital	4	8	4	2	2	3
11	5.829826	Departure_Triage	6	8	4	3	1	3
12	5.864316	Treated_at_Hospital	6	7	4	2	1	4
13	6.888667	Treated_at_Hospital	5	6	4	1	1	5
14	7.031530	Arrival	11	7	4	1	2	5
15	7.514292	Treated_at_Hospital	2	6	4	0	2	6
16	7.657316	Departure_Triage	7	6	4	1	1	6
17	7.748215	Departure_Triage	10	6	4	2	0	6
18	7.924768	Departure_Triage	11	6	3	3	0	6
19	7.930482	Departure_Triage	8	6	2	4	0	6
20	8.832512	Treated_at_Hospital	11	5	2	3	0	7
21	9.017465	Arrival	12	6	3	3	0	7
22	9.151836	Departure_Triage	9	6	2	4	0	7
23	9.428269	Departure_Triage	12	6	1	4	0	7
24	9.659940	Departure_Triage	0	6	0	5	0	7
25	9.980874	Arrival	13	7	1	5	0	7
26	10.158784	Treated_at_Hospital	9	6	1	4	0	8
27	10.541113	Arrival	14	7	2	4	0	8
28	11.032700	Arrival	15	8	3	4	0	8
29	11.130910	Arrival	16	9	4	4	0	8
30	11.283764	Departure_Triage	14	9	3	4	0	8
31	11.999841	Departure_Triage	15	9	2	5	0	8
32	12.055727	Treated_at_Home	14	8	2	5	0	9
33	12.330836	Arrival	17	9	3	5	0	9
34	12.463720	Departure_Triage	17	9	2	6	0	9
35	12.969834	Departure_Triage	16	9	1	6	0	9
36	13.367343	Arrival	18	10	2	6	0	9
37	13.382288	Arrival	19	11	3	6	0	9
38	13.763595	Departure_Triage	18	11	2	7	0	9
39	13.865301	Departure_Triage	13	11	1	7	0	9
40	14.922472	Treated_at_Hospital	15	10	1	6	0	10
41	15.073937	Treated_at_Home	16	9	1	6	0	11
42	15.839116	Treated_at_Home	13	8	1	6	0	12
43	15.863137	Treated_at_Hospital	17	7	1	5	0	13
44	16.500471	Treated_at_Hospital	7	6	1	4	0	14
45	16.559463	Treated_at_Home	12	5	1	4	0	15
46	16.748706	Arrival	20	6	2	4	0	15
47	17.807303	Departure_Triage	19	6	1	5	0	15
48	17.987740	Arrival	21	7	2	5	0	15
49	19.114715	Arrival	22	8	3	5	0	15

```
Long-run probability of arriving patient finds an available nurse
0.5576531740540852
Long-run probability of critical patient finds an available bed
0.9001845830097231
Joint
0.5019907899499253
Average number of people rejected due to bed unavailability
0.075
Average utilization of each nurse
0.7059209311493215
Average number of occupied beds
0.5932284723182741
Average number of patients treated at home
0.2647058823529412
Average time a sick person gets better
9.96730785654288
```

-System: “Half of the nurses and half of the beds full”, Number of Healed Patients: “1000”

	Time	Event Type	Patient ID	L	Lt	Lb	Lq	Healed
0	0.000000	Arrival	5	6	3	3	0	0
1	0.585610	Departure_Triage	1	6	2	4	0	0
2	0.971197	Departure_Triage	5	6	1	5	0	0
3	1.959873	Treated_at_Hospital	3	5	1	4	0	1
4	2.130211	Treated_at_Hospital	1	4	1	3	0	2
5	2.336636	Arrival	6	5	2	3	0	2
6	3.658699	Arrival	7	6	3	3	0	2
7	4.929617	Arrival	8	7	4	3	0	2
8	5.146417	Arrival	9	8	4	3	1	2
9	5.293037	Arrival	10	9	4	3	2	2
10	5.723777	Treated_at_Hospital	4	8	4	2	2	3
11	5.829826	Departure_Triage	6	8	4	3	1	3
12	5.864316	Treated_at_Hospital	6	7	4	2	1	4
13	6.888667	Treated_at_Hospital	5	6	4	1	1	5
14	7.031530	Arrival	11	7	4	1	2	5
15	7.514292	Treated_at_Hospital	2	6	4	0	2	6
16	7.657316	Departure_Triage	7	6	4	1	1	6
17	7.748215	Departure_Triage	10	6	4	2	0	6
18	7.924768	Departure_Triage	11	6	3	3	0	6
19	7.930482	Departure_Triage	8	6	2	4	0	6
20	8.832512	Treated_at_Hospital	11	5	2	3	0	7
21	9.017465	Arrival	12	6	3	3	0	7
22	9.151836	Departure_Triage	9	6	2	4	0	7
23	9.428269	Departure_Triage	12	6	1	4	0	7
24	9.659940	Departure_Triage	0	6	0	5	0	7
25	9.980874	Arrival	13	7	1	5	0	7
26	10.158784	Treated_at_Hospital	9	6	1	4	0	8
27	10.541113	Arrival	14	7	2	4	0	8
28	11.032700	Arrival	15	8	3	4	0	8
29	11.130910	Arrival	16	9	4	4	0	8
30	11.283764	Departure_Triage	14	9	3	4	0	8
31	11.999841	Departure_Triage	15	9	2	5	0	8
32	12.055727	Treated_at_Home	14	8	2	5	0	9
33	12.330836	Arrival	17	9	3	5	0	9
34	12.463720	Departure_Triage	17	9	2	6	0	9
35	12.969834	Departure_Triage	16	9	1	6	0	9
36	13.367343	Arrival	18	10	2	6	0	9
37	13.382288	Arrival	19	11	3	6	0	9
38	13.763595	Departure_Triage	18	11	2	7	0	9
39	13.865301	Departure_Triage	13	11	1	7	0	9
40	14.922472	Treated_at_Hospital	15	10	1	6	0	10
41	15.073937	Treated_at_Home	16	9	1	6	0	11
42	15.839116	Treated_at_Home	13	8	1	6	0	12
43	15.863137	Treated_at_Hospital	17	7	1	5	0	13
44	16.500471	Treated_at_Hospital	7	6	1	4	0	14
45	16.559463	Treated_at_Home	12	5	1	4	0	15
46	16.748706	Arrival	20	6	2	4	0	15
47	17.807303	Departure_Triage	19	6	1	5	0	15
48	17.987740	Arrival	21	7	2	5	0	15
49	19.114715	Arrival	22	8	3	5	0	15

```
Long-run probability of arriving patient finds an available nurse
0.6244179093280644
Long-run probability of critical patient finds an available bed
0.8289366232703594
Joint
0.5176028732679432
Average number of people rejected due to bed unavailability
0.17888198757763976
Average utilization of each nurse
0.6747246158684074
Average number of occupied beds
0.6619968952736573
Average number of patients treated at home
0.338
Average time a sick person gets better
10.923448342543544
```

-Analysis of the Report

The expected number of patients that are treated at home can be calculated via statistic:
p1 + ((1-p1)*(average number of rejected patients))
We can verify this via our outputs. Example output of empty system with 1000 healed patients:

0.3323353293413174 (The expected number of patients that are treated at home found in code)
0.2 + (0.8 * 0.17632552404438964) = 0.34106041923 (Calculated value)

There is an acceptable error. We verify our statistic.

The expected healing the of the patients can be calculated via:
(p1 * (1/mu_s)) + ((1 - p1) * ((average number of rejected patients * (1 / mu_cb) * E[alpha]) + ((1 - average number of rejected patients) * (1 / mu_cb))) + (1 / mu_t)
We can verify this via our outputs. Example output of empty system with 1000 healed patients:

11.00051244527104 (The expected healing time of the patient found in code)
(0.2 * (1/0.16)) + (0.8 * ((0.17632552404438964 * (1 / 0.142857143) * 1.5) + (0.82367447595 * (1 / 0.142857143))) + (1 / 0.357142857) = 7.3437114612 + 2.80000000112 = 10.1437114623

There is about ten percent error. This error is expected because in our formula we did not include the average waiting time of a patient for triage.

These calculations can be iterated with half-full and full systems. But since our limiting condition is 1000 healed patients the calculations will not diverge significantly.