Problem Statement

The system under consideration is an airline ticket counter operating during a regular 16-hour day. The counter serves two types of customers — frequent flyers and regular customers — during two shifts. The first shift is from 8 am to 4 pm and the second shift is from 4 pm to midnight, when the counter closes. During the day shift, one agent serves the frequent flyers and four agents serve regular customers, as the latter make up 80% of the customer base. However, if the queue for the regular agents only has two customers while the frequent flyer agent is busy, the frequent flyer chooses to join the regular customer queue. Also, both types of customers are served by the four "regular" agents during the night shift, since customers arrive less frequently in the evenings. On average, it takes 7 minutes to serve each frequent flyer and 10 minutes to serve each regular customer. Upon completion of the service customers exit the system one at a time. The ticket counter starts empty and idle. The agents are available at all times during both shifts.

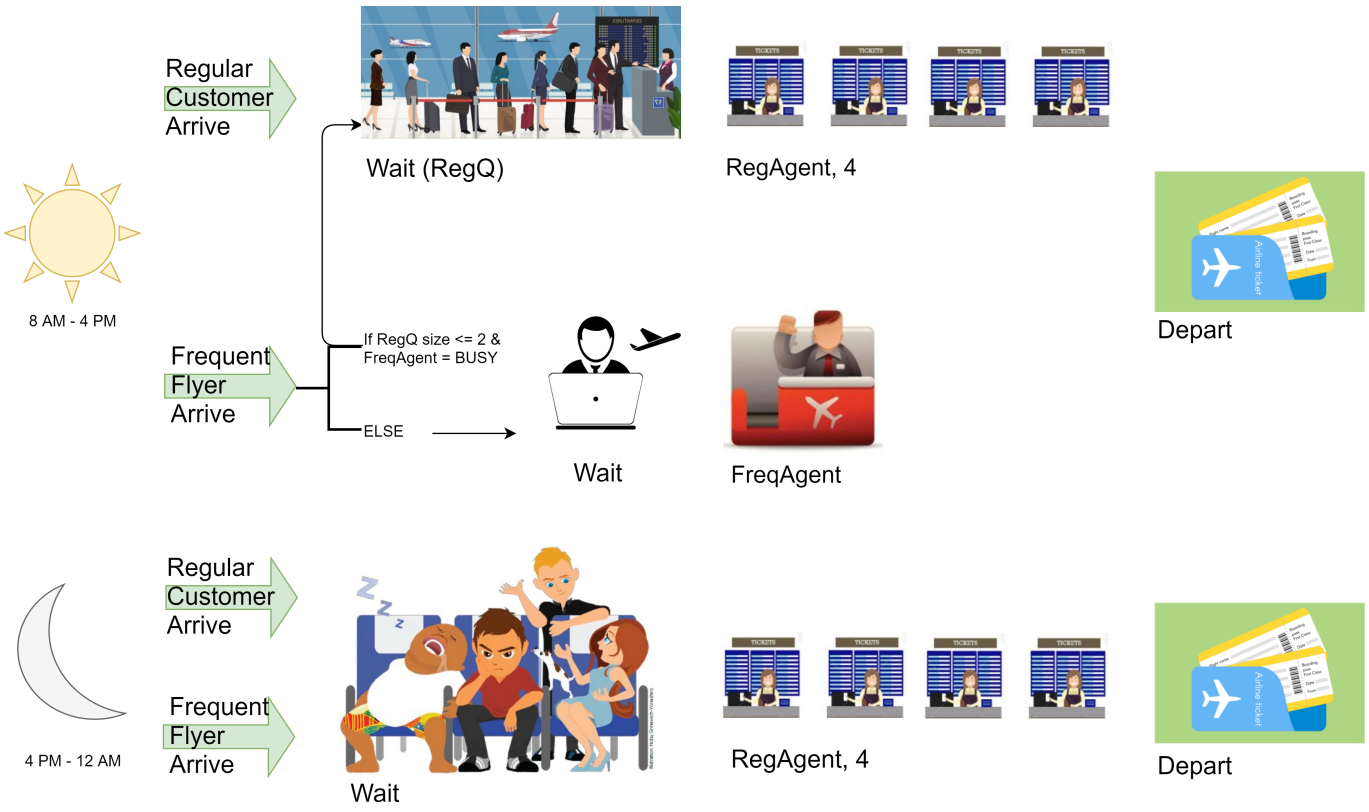

Figure 1: System Diagram for the airline ticket counter

The objective is to gain insights about the queue sizes at the ticket counters and how well the agents are utilized. An additional point of interest is to identify how often the frequent flyers chose to use the regular customer queue during the day shift.

Model Description

This simulation model analyzes airline ticket counter's performance. The two types of customers entering the system are the entities that move through the system and change its state by activating agent-service related processes. The block diagram in Figure 2 presents the movement of those entities through the system.

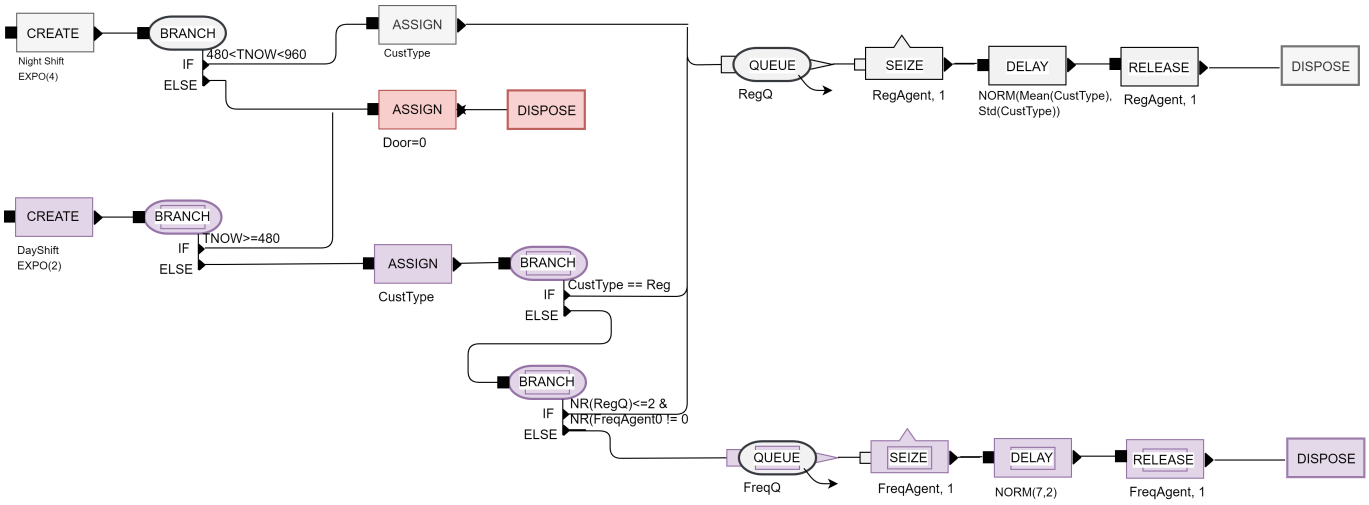

Figure 2: Block Diagram for the airline ticket counter

Entities can enter the model at one of the two CREATE blocks. The CREATE blocks with exponential interarrival times correspond to the customers arriving during the day and night, respectively. On average, day-shift-customers arrive every 2 minutes while night-shift-customers arrive every 4 minutes. Once the entities are created, the flow is directed either into an ASSIGN block, where customer type is assigned, or into another ASSIGN block, which we use to send off the customers based on the current time ("closed door procedure"). For instance, if an entity is created at the day-shift CREATE block after 4 pm, we would send off the entity and no future events would be scheduled for the day shift operations. Similarly, if an entity arrives outside the 4pm-12am window, the entities are not admitted to the night shift. This "closed door procedure" helps differentiate between the shifts and with stooping the entity creation after midnight when the counter closes.

If the entity stays in the system, an attribute `CustType` helps distinguish between the frequent flyers and regular customers denoted as a type 1 and type 2, respectively. Also, we use variable arrays called `Mean` and `Std` to assign means and standard deviations for the normal distribution used on the DELAY block, which represents the customer service times by regular agents.

The following summary describes the flow direction for the day shift customers:

1. Create arriving jobs at the `DayShift` CREATE block,
2. Branch with the following conditions:
   if TNOW >= 480 minutes (4 pm), go to `Closed Door`
   else, go to step 3,
3. Assign 20% of customers as `CustType` = 1 and the rest as `CustType` = 2,

4. Branch with the following conditions:
   if *CustType* = 2, go to step 6 (RegQ)
   else, go to step 5,
5. Branch with the following conditions:
   if number of customers in the regular queue is less than two and the frequent flyer agent is busy, go to step 6 (RegQ)
   else, go to step 11 (FreqQ),
6. Wait for the regular agent to be idle,
7. Seize the regular agent,
8. Delay by the service time based on the customer type,
9. Release the regular agent for the next waiting entity, if any,
10. Dispose the entity;
11. Wait for the frequent flyer agent to be idle,
12. Seize the frequent flyer agent,
13. Delay by the service time,
14. Release the frequent flyer agent for the next waiting entity, if any,
15. Dispose the entity.

The following summary describes the flow direction for the night shift customers:

1. Create arriving jobs at the `NightShift` CREATE block,
2. Branch with the following conditions:
   if 480 <TNOW < 960 minutes, go to step 3
   else, go to `Closed Door`,
3. Assign 20% of customers as `CustType` = 1 and the rest as `CustType` = 2,
4. Wait for the regular agent to be idle,
5. Seize the regular agent,
6. Delay by the service time based on the customer type,
7. Release the regular agent for the next waiting entity, if any,
8. Dispose the entity.

Multiple COUNT blocks are placed within the system to count the number of customers moving through the system by `CustType` and shift type. When the entities through the RELEASE blocks, they pass through the TALLY block where depending on the type of the entity the tallies compute time each entity spent in the system since arriving. The statistics are also collected on the queue sizes and the agent utilities.

Results

The charts and tables of the model's output are given below. Table 1 presents the data on the average total number of customers served by customer type and the associated standard deviations. This table illustrates that around 21% of the customers were frequent flyers which meets our expectation that approximately 2 out of 10 customers have frequent flyer memberships.

	AvgObs	StdDev
Total Frequent Flyers	75	3.215
Total Regular Customers	282	2.082
Total Customers Served	357	5.292

Table 1: Total customers served by type (across all replications)

Figure 3 is an extension of the Table 1 as it breaks down the number of customers served by customer type, the shift type, and the queue type. Approximately, 17% of the frequent flyers that arrived during the day shift chose to wait in the regular queue.

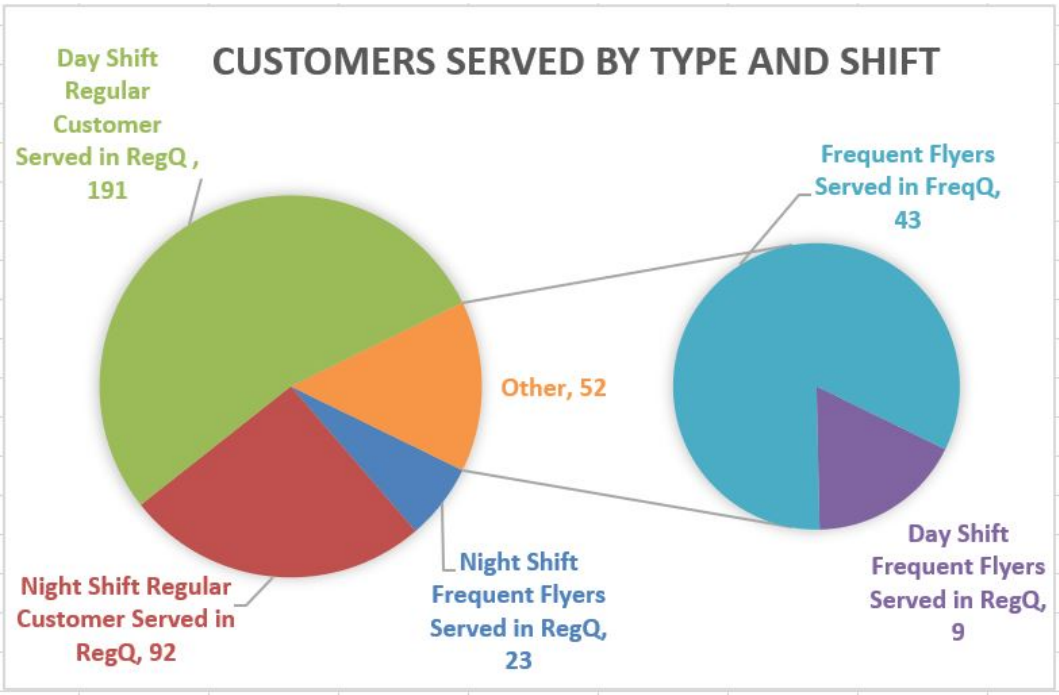

Figure 3: Pie chart of the number of customers served by customer type and shift type

Table 2 summarizes statistics on the time spent in the system by customer type depending on the queue, regular and frequent flyer queues, and agent utilities.

	MinObs	MaxObs	AvgObs	NumObs	StdDev
Frequent Flyers Time in Sys. RegQ	3.80	22.34	9.39	32.00	4.67
Regular Customer Time in Sys. RegQ	1.03	42.22	17.21	282.33	8.33
Frequent Flyers Time in Sys. FreqQ	3.19	32.64	12	42.67	7.00
Regular Queue	0.00	12.00	2.21	42.67	3.00
Frequent Flyer Queue	0.00	4.00	0.23	42.67	1.00
RegAgent Util.	0.00	4.00	3.05	42.67	1.00
FreqAgent Util.	0.00	1.00	0.30	42.67	0.00

Table 2: Statistics on the time in the system, queue sizes, and agent utility

Figure 4 illustrates the traversal times of the entities. The results are grouped by the customer type and for the frequent flyers by the queue of choice. The $x-$axis represents the minimum, average, and maximum times spent in the system while y-axis is measured in minutes.

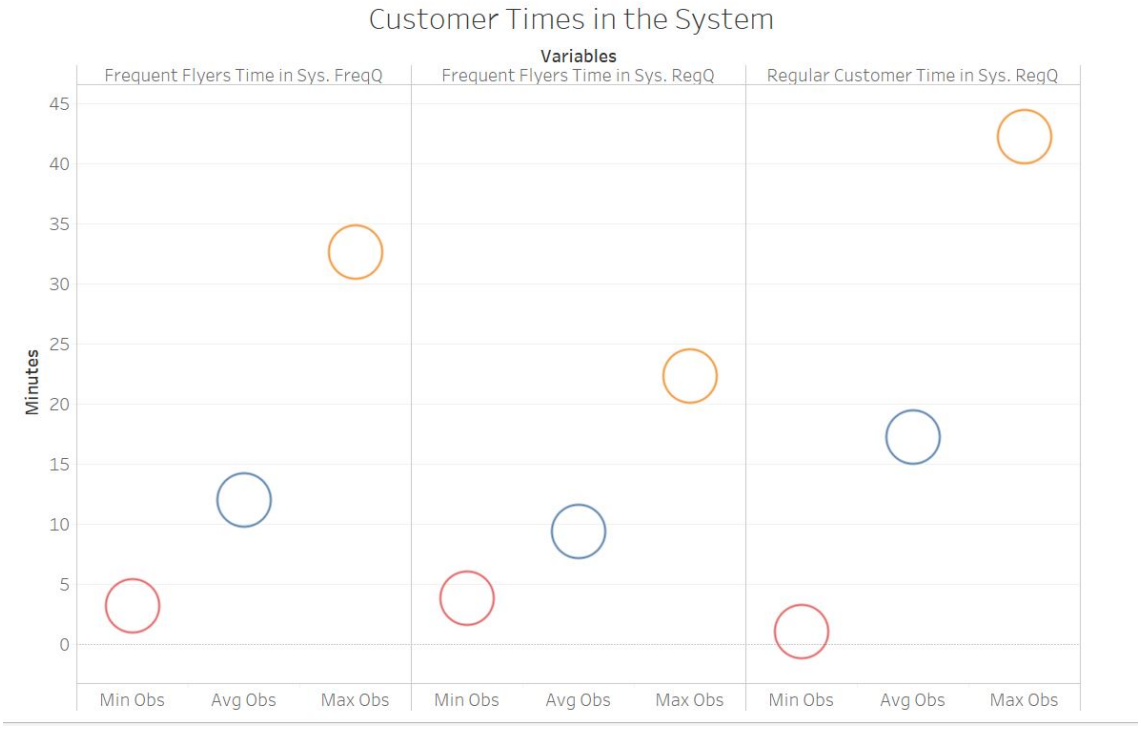

Figure 4: The minimum, average, and maximum times spent in the system

Next, Figure 5 shows the queue-size related statistics for the regular and frequent flyer queues. The results are presented for the average and maximum queue observations plotted against the associated standard deviations for each queue. From the plot, the size-statistics for the frequent flyer queue is smaller than for the regular one. These differences could be attributed either to the fact that approximately 80% of the customers are regular for whom the service time average is 2 more minutes than for the frequent flyers (or both). Also, frequent flyers can choose to use the regular queue. Yet, the total number of frequent flyers that chose to switch to the regular queue is equal to 9, which is around 21% of the total frequent flyers. Then this choice factor might not be significant.

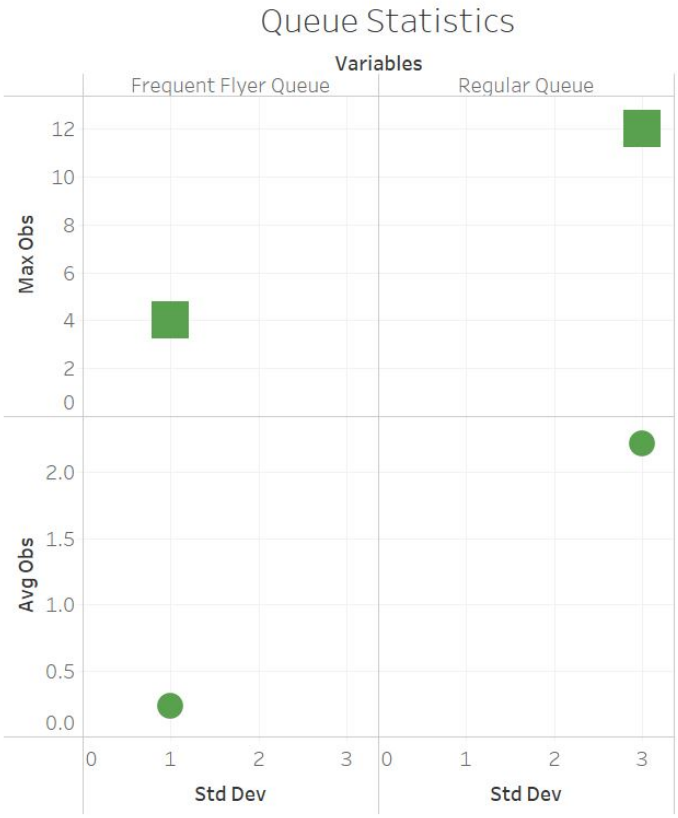

Figure 5: The average and maximum queue sizes plotted against the standard deviation.

Figure 6 describes the agent utilization for regular agents and the frequent flyer agent. The average and maximum utilization data is demonstrated along with the utilization standard deviations.

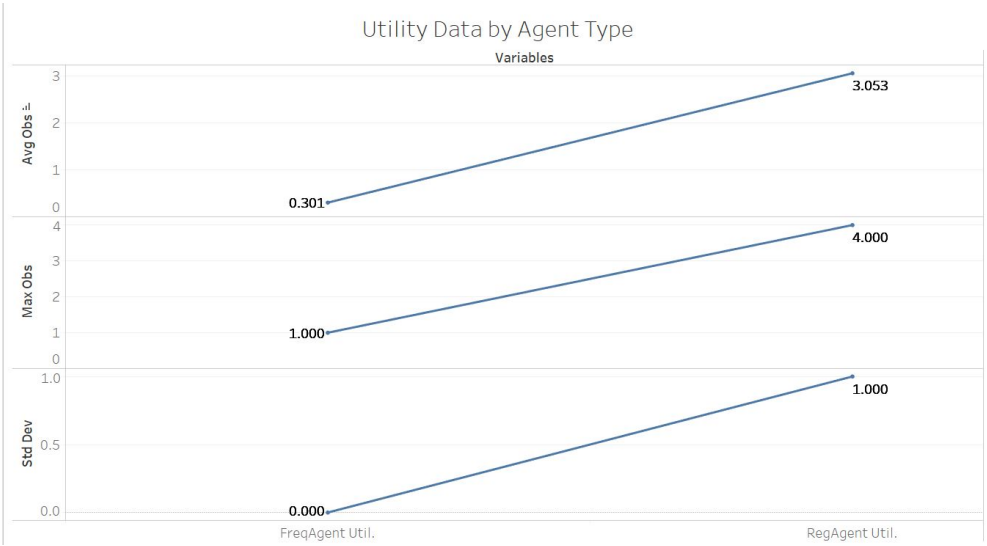

Figure 6: Plots for the agents utilization

The analysis of the data shown in the table and charts is carried in the next section of this report.

Analysis

The focus of the analysis will be centered around the agent utilizations for the regular and frequent flyer agents, as well as the traversal times for the customers. First, let's look at whether the system was behaving as expected. Table 1 showed how many customers went through the system by customer type. Table 4 summarizing expected customer numbers, which also breaks down the number of customers expected by shift type.

	Frequent Flyers	Regular Customers	Total
Day	48	192	240
Night	24	96	120
Total	72	288	360

Table 3: Customer number estimates

The values in the table are estimated using the following formula:

$$\text{Customers by customer type } = \frac{480}{\text{mean arrival time}} \cdot \%\text{CustType.}$$

The values in the Table 4 are extremely close to the average observed values based on three simulation runs, which indicates that the system is behaving as expected. Referring back to the Figure 3 percentage of the frequent flyers who chose to wait in the regular queue is $9/48 = 0.1875$. We will use this value in the utility calculations.

Next, let's compare the agent utilities by agent type and shift type. Table 2 shows that average regular agent utility is 3.05, which is $3.05/4 = 0.7625$ per agent. It seems like the regular agents are quite busy. Yet, the regular agents' utility will differ based on the shift they are working. The calculations carried to estimate the appropriate utility values is as follows:

$$\begin{aligned}
\lambda_{\text{day}} = \frac{1}{2} \text{ cust/min};\ \ \lambda_{\text{night}} &= \frac{1}{4} \text{ cust/min} \\
\mu_r = \frac{1}{10};\ \ \mu_f &= \frac{1}{7} \\
\%\text{ Frequent Flyers in RegQ } &= 0.1875 \\
\rho_{Dr} &= \frac{\lambda_{day}}{\mu_r} \cdot 0.8 + \frac{\lambda_{day}}{\mu_f} \cdot (0.2 * 0.1875) = 4 + .013125 = 4.13125 \\
\rho_{Dr}/\text{agent } &= 4.13125/4 = 1.033 \\
\rho_{Df} &= \frac{\lambda_{day}}{\mu_f} \cdot (0.2 * .8125) = 0.569 \\
\rho_{total_D}/\text{agent } &= \frac{\rho_{Dr} + \rho_{Df}}{5} = \frac{4.13125 + 0.569}{5} = 0.94 \\
\rho_{Nr} &= \frac{\lambda_{night}}{\mu_r} \cdot 0.8 + \frac{\lambda_{night}}{\mu_f} \cdot 0.2 = 2 + 0.35 = 2.35 \\
\rho_{Nr}/\text{agent } &= 2.35/4 = 0.588
\end{aligned} \tag{1}$$

Based on these calculations, regular agents are extremely busy during the first shift and are overworking, while the frequent flyer agent utility and regular agent utility per agent night utility indicate that there are no bottlenecks here.

	D	N
ρ_R	1.033	0.588
ρ_F	0.569	—
ρ_T	0.94	0.588

Table 4: Customer number estimates

Finally, let's form 95% confidence interval for the traversal times with $\alpha = 0.05$. We get the following confident intervals:
Regular customer time: $17.21 \pm t_{0.025} \cdot \frac{8.33}{\sqrt{288}} = 17.21 \pm 0.97 = [16.24, 18.18]$.
Frequent flyer in the regular queue: $[5.79, 12.99]$.
Frequent flyer in the frequent flyer queue: $[9.73, 14.27]$.

Conclusions

The analysis of the agent utility indicates that the regular agents are extremely busy during the day. Then, the recommendation is to add 2 regular agents during the day. This would bring the utility ρ_{Dr} to 0.67. If budget is of concern, number of the regular agents working during the night shift can be reduced to 3 and one more day shift agent can be hired. This would affect $\rho_{Nr} = 0.78$ and $\rho_{Dr} = 0.78$. Adding more regular agents during the day shift will also improve the traversal time for the regular customers.

A SIMAN Files and Output Reports:

SIMAN model source file for the airline ticket counter problem

```
BEGIN;
                CREATE:         EXPO(2): MARK(TimeIn);                  ! Day shift arrivals
                BRANCH, 1:
                        IF, TNOW<=480, Shift1:                          ! before 4 pm, Day Shift
                        ELSE, Close;                                    ! Send off?
                CREATE:         EXPO(4): MARK(TimeIn);                  ! Night shift arrivals
                BRANCH, 1:
                        IF, TNOW>480.AND.TNOW<960, Shift2:              ! after 4 pm to midnight, Night Shift
                        ELSE, Close;                                    ! Send off?
Close           ASSIGN:         Door =0: NEXT(Leave);                   ! Set max. Batches to 0
Shift2          ASSIGN:         CustType = DISC(0.2, 1,                 ! Frequent Flyer = 1
                                            1, 2);                      ! Regular customer = 2
                COUNT:          CustType: NEXT(Q2);                     ! Count night shift cust type, Send to RegQ
Shift1          ASSIGN:         CustType = DISC(0.2, 1,                 ! Frequent Flyer = 1
                                            1, 2);                      ! Regular customer = 2
                BRANCH, 1:
                        IF, CustType == 2, CountReg:                    ! Reg.Customer to ReqQ
                        ELSE, B1;                                       ! Frequent Flyer to next BRANCH
CountReg        COUNT:          5: NEXT(Q2);                            ! Count reg cust during the day
B1              BRANCH, 1:                                              ! RegQ<=2 & FreqAgent is busy, send to COUNT
                        IF, NQ(RegQ)<=2.AND.NR(FreqAgent)<>0, CountFreq:
                        ELSE, Q1;                                       ! otherwise FregQ
CountFreq       COUNT:          4;                                      ! Count FreqFlyer jobsDone in RegQ
Q2              QUEUE,          RegQ;                                   ! wait for RegAgent
                SEIZE:          RegAgent, 1;                            ! get RegAgent
                DELAY:          NORM(Mean(CustType), Std(CustType));    ! delay by Customer Type
                RELEASE:        RegAgent, 1;                            ! Release the RegAgent
                TALLY:          CustType, INT(TimeIn);                  ! Tally time in system by cust.type
Leave           DISPOSE;                                                ! leave the system
Q1              QUEUE,          FreqQ;                                  ! Wait for FreqAgent
                SEIZE:          FreqAgent, 1;                           ! get FreqAgent
                DELAY:          NORM(7,2);                              ! delay
                RELEASE:        FreqAgent, 1;                           ! release FreqAgent
                COUNT:          3;                                      ! count jobs done by FreqAgent
                TALLY:          3, INT(TimeIn): NEXT(Leave);            ! Freq Flyer time in system through FreqQ
END;
```

SIMAN experiment source file for the airline ticket counter problem

```
BEGIN;
PROJECT,        HW 7, Leyli G;
ATTRIBUTES:     TimeIn:
                CustType;
VARIABLES:      Door, 10000:
                Mean(2),  7, 10:                    ! FreqFlyer = 7, Reg=10
                Std(2),   2,  4;                    ! FreqFlyer= 2, Reg = 4
QUEUES:         RegQ:
                FreqQ;
RESOURCES:      RegAgent, 4:
                FreqAgent, 1;
COUNTERS:       Night Shift Frequent Flyers JobsDone in RegQ:
                Night Shift Regular Customer JobsDonein RegQ:
                Frequent Flyers JobsDone in FreqQ:
                Day Shift Frequent Flyers JobsDone in RegQ:
                Day Shift Regular Customer JobsDone in RegQ;
TALLIES:        Frequent Flyers Time in Sys. RegQ:
                Regular Customer Time in Sys. RegQ:
                Frequent Flyers Time in Sys. FreqQ;
DSTATS:         NQ(RegQ), Regular Queue:
                NQ(FreqQ), Frequent Flyer Queue:
                NR(RegAgent), RegAgent Util., "RegAgentHistory.dat":
                NR(FreqAgent), FreqAgent Util., "FreqAgentHistory.dat";
REPLICATE,      3, 0, 980;
END;
```

SIMAN output report for the airline ticket counter problem:

```
                                ARENA Simulation Results
                                     <user unknown>

                               Summary for Replication 1 of 3

Project: HW 7                                                  Run execution date :10/22/2019
Analyst: Leyli G                                               Model revision date:10/22/2019

Replication ended at time      : 980.0 Hours
Base Time Units: Hours

                                        TALLY VARIABLES

Identifier                               Average   Half Width  Minimum    Maximum   Observations
-------------------------------------------------------------------------------------------------

Frequent Flyers Time in Sys.RegQ          9.0003     (Insuf)    5.0264     20.557         23
Regular Customer Time in Sys.RegQ         19.738     (Insuf)    .00000     49.234        280
Frequent Flyers Time in Sys.FreqQ         13.819     (Insuf)    1.6036     34.837         48

                                    DISCRETE-CHANGE VARIABLES

Identifier                               Average   Half Width  Minimum    Maximum   Final Value
-------------------------------------------------------------------------------------------------

Regular Queue                             2.8904     (Corr)     .00000     14.000     .00000
Frequent Flyer Queue                      .33919     (Insuf)    .00000     5.0000     .00000
RegAgent Util.                            2.9602     (Insuf)    .00000     4.0000     .00000
FreqAgent Util.                           .33770     (Insuf)    .00000     1.0000     .00000

                                         COUNTERS

Identifier                                 Count   Limit
-------------------------------------------------------------

Night Shift Frequent Flyers JobsDone in Re       17  Infinite
Night Shift Regular Customer JobsDonein Re       91  Infinite
Frequent Flyers JobsDone in FreqQ                48  Infinite
Day Shift Frequent Flyers JobsDone in RegQ        6  Infinite
Day Shift Regular Customer JobsDone in Reg      189  Infinite


                                ARENA Simulation Results
                                     <user unknown>

                               Summary for Replication 2 of 3

Project: HW 7                                                  Run execution date :10/22/2019
Analyst: Leyli G                                               Model revision date:10/22/2019

Replication ended at time      : 980.0 Hours
Base Time Units: Hours

                                        TALLY VARIABLES

Identifier                               Average   Half Width  Minimum    Maximum   Observations
-------------------------------------------------------------------------------------------------

Frequent Flyers Time in Sys.RegQ          8.4701     (Insuf)    3.3846     15.021         33
Regular Customer Time in Sys.RegQ         14.949     (Insuf)    1.3703     35.875        283
Frequent Flyers Time in Sys.FreqQ         11.967     (Insuf)    4.3828     28.163         43

                                    DISCRETE-CHANGE VARIABLES

Identifier                               Average   Half Width  Minimum    Maximum   Final Value
-------------------------------------------------------------------------------------------------
```

Regular Queue	1.5034	(Corr)	.00000	10.000	.00000
Frequent Flyer Queue	.20744	(Insuf)	.00000	3.0000	.00000
RegAgent Util.	3.0988	(Insuf)	.00000	4.0000	.00000
FreqAgent Util.	.31767	(Insuf)	.00000	1.0000	.00000

COUNTERS

Identifier	Count	Limit
Night Shift Frequent Flyers JobsDone in Re	23	Infinite
Night Shift Regular Customer JobsDonein Re	98	Infinite
Frequent Flyers JobsDone in FreqQ	43	Infinite
Day Shift Frequent Flyers JobsDone in RegQ	10	Infinite
Day Shift Regular Customer JobsDone in Reg	185	Infinite

ARENA Simulation Results
<user unknown>

Summary for Replication 3 of 3

Project: HW 7 Run execution date :10/22/2019
Analyst: Leyli G Model revision date:10/22/2019

Replication ended at time : 980.0 Hours
Base Time Units: Hours

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Frequent Flyers Time in Sys.RegQ	10.710	(Insuf)	3.0006	31.435	40
Regular Customer Time in Sys.RegQ	16.950	(Insuf)	1.7342	41.536	284
Frequent Flyers Time in Sys.FreqQ	10.220	(Insuf)	3.5917	34.915	37

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Final Value
Regular Queue	2.2500	(Corr)	.00000	12.000	.00000
Frequent Flyer Queue	.13740	(Insuf)	.00000	4.0000	.00000
RegAgent Util.	3.0993	(Insuf)	.00000	4.0000	.00000
FreqAgent Util.	.24849	(Insuf)	.00000	1.0000	.00000

COUNTERS

Identifier	Count	Limit
Night Shift Frequent Flyers JobsDone in Re	29	Infinite
Night Shift Regular Customer JobsDonein Re	86	Infinite
Frequent Flyers JobsDone in FreqQ	37	Infinite
Day Shift Frequent Flyers JobsDone in RegQ	11	Infinite
Day Shift Regular Customer JobsDone in Reg	198	Infinite

Simulation run time: 0.00 minutes.
Simulation run complete.