CENG 476
Project

Project #18:
Bus Simulation

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1. Project Description

In this project, a transportation problem will be simulated. Firstly, the problem which is the subject of this project is presented. Following that, activities related to this problem is mentioned and then thirdly, design approach is presented. Providing the actual SIMDL model of simulation approach, inputs and outputs are analyzed. Finally two experiments are undertaken in order to control the responsiveness of simulation model and findings are presented.

2. Problem Definition

In this project, the problem given below will be simulated.

[Problem 18]

A party of 100 people has been taken to a football game in four buses, each of capacity 25. When the game is over, each person returns independently to the bus that brought him to the game. The time taken to reach a bus is normally distributed with mean values of 10, 12, 15 and 18 minutes for the four buses. When a bus is full, it leaves, and arrives home after a drive that is normally distributed with a mean of 80 and a standard deviation of 5 minutes. Begin a simulation from the time the game finishes and find the time at which the last bus arrives home.

3. Activities

Complete list of activities in the problem can be listed as following:

1. 100 people come to stadium with 4 buses, 25 people in each
2. Football game is over
3. People start walking from stadium to the buses
4. People take the bus which brought them
5. When a bus is full (25 people in each), it leaves

As mentioned in the problem definition, simulation will start from the Step 3.

4. Design Approach

Design approach in this project is based on four parts, in each the activities of people from different buses are simulated. As a diagram, this approach can be summarized as following:

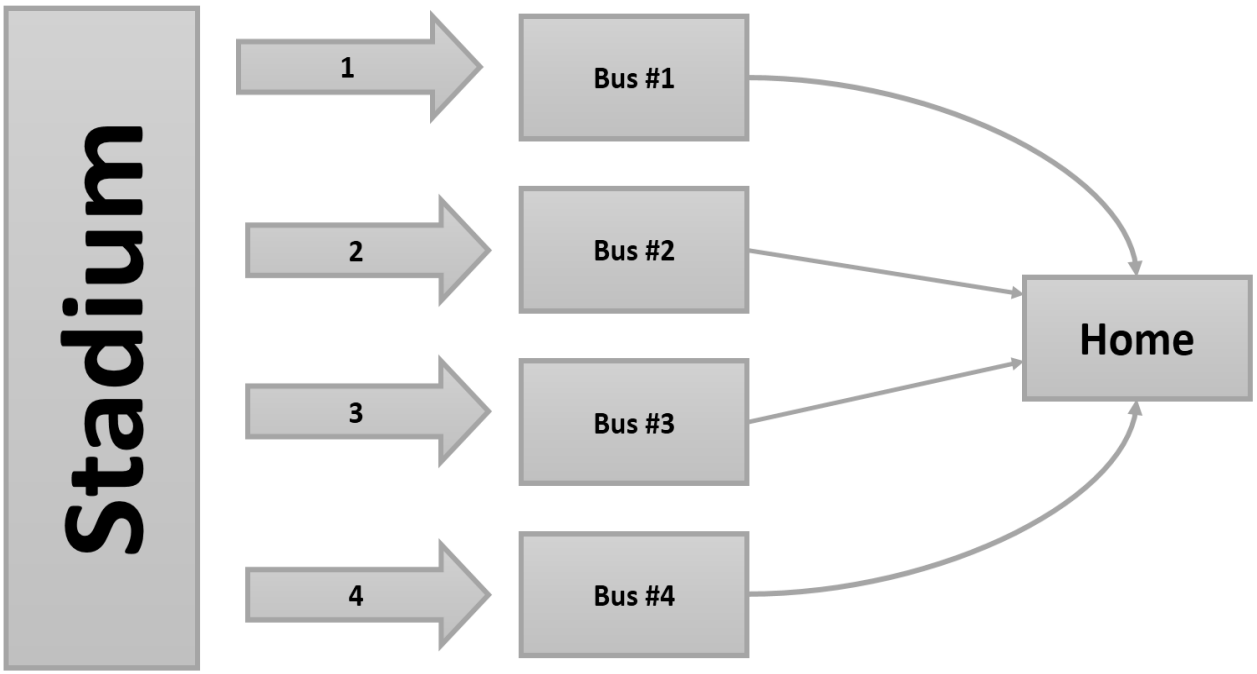

Figure 4.1: Design Approach

As can be seen from the figure above, people will be simulated so that they will walk to their buses and then buses will be simulated so that they will reach home.

4.1. Design Summary

For one bus and the people related to this bus, the following design elements are implemented:

- One generator for people (Batch creation of 25 people)
- One server for walking (Capacity of 25 for concurrent walking)
- One server for bus driving (Capacity of 1)

As mentioned, these three types of elements will be used four times corresponding to each bus.

5. Model Program

In this section, all parts of the model program is explained by dividing into parts.

```
{
Attribute to track if a person
needs to wait for others on the bus
}
     attrib Wait_Others : integer;
```

Figure 5.1: Attributes

```
{
Queue for people walking to bus
}
     queue To_Bus_1 :fifo;
     queue To_Bus_2 :fifo;
     queue To_Bus_3 :fifo;
     queue To_Bus_4 :fifo;

{
Queue for people waiting on the bus
}
     queue Wait_on_Bus_1 :fifo;
     queue Wait_on_Bus_2 :fifo;
     queue Wait_on_Bus_3 :fifo;
     queue Wait_on_Bus_4 :fifo;
```

Figure 5.2: Queues

```
{
Variable for filled time of buses
}
     var Fulled_Time_1 : integer initial(0);
     var Fulled_Time_2 : integer initial(0);
     var Fulled_Time_3 : integer initial(0);
     var Fulled_Time_4 : integer initial(0);

{
Variable for arrival time of buses
}
     var Arrival_Time_1 : integer initial(0);
     var Arrival_Time_2 : integer initial(0);
     var Arrival_Time_3 : integer initial(0);
     var Arrival_Time_4 : integer initial(0);

{
Back counters for people
}
     var Count_1 : integer initial(25);
     var Count_2 : integer initial(25);
     var Count_3 : integer initial(25);
     var Count_4 : integer initial(25);
```

Figure 5.3: Variables

```
{
Driving time statistics for buses
}
     stat Drive_T_1 :standard;
     stat Drive_T_2 :standard;
     stat Drive_T_3 :standard;
     stat Drive_T_4 :standard;

{
Walking time statistics for people
}
     stat Walk_Time_T_1 :standard;
     stat Walk_Time_T_2 :standard;
     stat Walk_Time_T_3 :standard;
     stat Walk_Time_T_4 :standard;
```

Figure 5.4: Statistics

The following generator and servers are implemented for bus #1.

```
{
Generator for people for bus #1
}
generator People_1;
     interarrival 100000;
     destination To_Bus_1;
     generate 25;
     during:
          Wait_Others  := 0;
end People_1;

{
Server for walking action of people for bus #1
}
server Walk_1(25);
     service normal(sinx,0,20,10,3);
     source  To_Bus_1;
     destination Wait_on_Bus_1;
     after:
          Fulled_Time_1 := clock;
end;

{
Server for driving action of bus #1
}
server Driver_1;
     source Wait_on_Bus_1;
     service Wait_Others;
     before:
          Count_1 := Count_1 - 1;
     during:
          collect clock in Walk_Time_T_1;
          if Count_1 = 0 then Wait_Others := normal(1,0,100,80,5);
     after:
          Arrival_Time_1 := clock;
          collect Wait_Others in Drive_T_1;
end;
```

Figure 5.5: Implementation of Bus #1

The following generator and servers are implemented for bus #2.

```
{
Generator for people for bus #2
}
generator People_2;
     interarrival 100000;
     destination To_Bus_2;
     generate 25;
     during:
          Wait_Others  := 0;
end People_2;

{
Server for walking action of people for bus #2
}
server Walk_2(25);
     service  normal(sinx+24,0,30,12,3.5);
     source  To_Bus_2;
     destination Wait_on_Bus_2;
     after:
          Fulled_Time_2 := clock;

end;

{
Server for driving action of bus #1
}
server Driver_2;
     source Wait_on_Bus_2;
     service Wait_Others;
     before:
          Count_2 := Count_2 - 1;
     during:
          collect clock in Walk_Time_T_2;
          if Count_2 = 0 then Wait_Others := normal(2,0,100,80,5);
     after:
          Arrival_Time_2 := clock;
          collect Wait_Others in Drive_T_2;
end;
```

Figure 5.6: Implementation of Bus #2

The following generator and servers are implemented for bus #3.

```
{
Generator for people for bus #3
}
generator People_3;
     interarrival 100000;
     destination To_Bus_3;
     generate 25;
     during:
          Wait_Others  := 0;
end People_3;

{
Server for walking action of people for bus #3
}
server Walk_3(25);
     service  normal(sinx+49,0,40,15,4.5);
     source  To_Bus_3;
     destination Wait_on_Bus_3;
     after:
          Fulled_Time_3 := clock;
end;

{
Server for driving action of bus #3
}
server Driver_3;
     source Wait_on_Bus_3;
     service Wait_Others;
     before:
          Count_3 := Count_3 - 1;
     during:
          collect clock in Walk_Time_T_3;
          if Count_3 = 0 then Wait_Others := normal(3,0,100,80,5);
     after:
          Arrival_Time_3 := clock;
          collect Wait_Others in Drive_T_3;
end;
```

Figure 5.7: Implementation of Bus #3

The following generator and servers are implemented for bus #4.

```
{
Generator for people for bus #4
}
generator People_4;
     interarrival 100000;
     destination To_Bus_4;
     generate 25;
     during:
          Wait_Others  := 0;
end People_4;

{
Server for walking action of people for bus #4
}
server Walk_4(25);
     service normal(sinx+74,0,50,18,5.5);
     source  To_Bus_4;
     destination Wait_on_Bus_4;
     after:
          Fulled_Time_4 := clock;
end;

{
Server for driving action of bus #4
}
server Driver_4;
     source Wait_on_Bus_4;
     service Wait_Others;
     before:
          Count_4 := Count_4 - 1;
     during:
          collect clock in Walk_Time_T_4;
          if Count_4 = 0 then Wait_Others := normal(4,0,100,80,5);
     after:
          Arrival_Time_4 := clock;
          collect Wait_Others in Drive_T_4;
end;
```

Figure 5.8: Implementation of Bus #4

For each bus, firstly, people are generated at a batch of 25 and then sent to “To_Bus_X” queue. Although it is mentioned as queue, since there are 25 servers for walking server, none of them actually waits. In other words, all of the generated people can concurrently walk to bus. When they reach to bus, in other words completed server process of “Walk_X”, they are sent to another queue named “Wait_on_Bus_X”. Another server named as “Driver_X” is used by people from “Wait_on_Bus_X”. However, it is implemented so that any of the people other than the last person directly passes server with 0 time. On the other hand, last person’s service time is arranged as driving time of the bus. This model is simulated for at least 250 time interval, ensuring that all buses arrive at home.

6. Analysis of Design

In this section, implemented design will be analyzed in the sense of inputs and outputs so that we can evaluate behavior of model.

6.1. Input Analysis

In this model, five statistical inputs are used which needs further analysis. Four of these inputs are used for walking times of people and the final one is used for driving time of buses.

Firstly, for walking times of people, mean of the normal distribution is given; however, standard deviations are not provided in problem definition. Therefore, considering the shape and dispersion of normal distribution these standard deviation values are estimated.

For the people related to Bus #1, walking time is chosen as NORMAL(10, 3) considering the dispersion given below:

```
[      1000]                S t a t i s t i c s   D i s p l a y

SAMPLE
                      Sample       Sample   Minimum      Maximum      Mean    Standard
                       Count        Total    Sample       Sample    Sample   Deviation
                        1000      9978.32      0.91        18.90      9.98        3.02

    0.00 -     0.99 [    1] |
    1.00 -     1.99 [    4] |*
    2.00 -     2.99 [    6] |**
    3.00 -     3.99 [   14] |****
    4.00 -     4.99 [   30] |**********
    5.00 -     5.99 [   37] |*************
    6.00 -     6.99 [   66] |***********************
    7.00 -     7.99 [   94] |*********************************
    8.00 -     8.99 [  109] |**************************************
    9.00 -     9.99 [  134] |***********************************************
   10.00 -    10.99 [  142] |**************************************************
   11.00 -    11.99 [  129] |*********************************************
   12.00 -    12.99 [   80] |****************************
   13.00 -    13.99 [   59] |********************
   14.00 -    14.99 [   43] |***************
   15.00 -    15.99 [   27] |*********
   16.00 -    16.99 [   13] |****
   17.00 -    17.99 [    6] |**
   18.00 -    18.99 [    6] |**
                            +---------+---------+---------+---------+---------+
                                     28        56        85       113       142
```

Figure 6.1: Statistics Display for Input #1

For the people related to Bus #2, walking time is chosen as NORMAL(12, 3.5) considering the dispersion given below:

```
[      1000]                S t a t i s t i c s   D i s p l a y

SAMPLE
                      Sample       Sample   Minimum      Maximum      Mean    Standard
                       Count        Total    Sample       Sample    Sample   Deviation
                        1000     11974.71      1.40        22.39     11.97        3.52

    1.00 -     1.99 [    2] |
    2.00 -     2.99 [    5] |**
    3.00 -     3.99 [    8] |***
    4.00 -     4.99 [   10] |****
    5.00 -     5.99 [   23] |*********
    6.00 -     6.99 [   39] |***************
    7.00 -     7.99 [   37] |**************
    8.00 -     8.99 [   66] |*************************
    9.00 -     9.99 [   91] |***********************************
   10.00 -    10.99 [   97] |**************************************
   11.00 -    11.99 [  117] |*********************************************
   12.00 -    12.99 [  124] |************************************************
   13.00 -    13.99 [  116] |*********************************************
   14.00 -    14.99 [   86] |**********************************
   15.00 -    15.99 [   53] |*********************
   16.00 -    16.99 [   41] |****************
   17.00 -    17.99 [   38] |***************
   18.00 -    18.99 [   22] |********
   19.00 -    19.99 [   12] |****
   20.00 -    20.99 [    7] |**
   21.00 -    21.99 [    3] |*
   22.00 -    22.99 [    3] |*
                            +---------+---------+---------+---------+---------+
                                     24        49        74        99       124
```

Figure 6.2: Statistics Display for Input #2

For the people related to Bus #3, walking time is chosen as NORMAL(15, 4.5) considering the dispersion given below:

```
[      1000]                S t a t i s t i c s   D i s p l a y

SAMPLE
                       Sample       Sample   Minimum      Maximum      Mean    Standard
                        Count        Total    Sample       Sample    Sample   Deviation
                         1000     14967.48      1.37        28.35     14.97        4.53

    1.00 -     1.99 [    2] |
    2.00 -     2.99 [    3] |*
    3.00 -     3.99 [    4] |*
    4.00 -     4.99 [    8] |***
    5.00 -     5.99 [    8] |***
    6.00 -     6.99 [   18] |********
    7.00 -     7.99 [   27] |*************
    8.00 -     8.99 [   22] |**********
    9.00 -     9.99 [   38] |******************
   10.00 -    10.99 [   54] |*************************
   11.00 -    11.99 [   68] |*********************************
   12.00 -    12.99 [   63] |******************************
   13.00 -    13.99 [   84] |****************************************
   14.00 -    14.99 [   96] |*********************************************
   15.00 -    15.99 [  102] |************************************************
   16.00 -    16.99 [   88] |*****************************************
   17.00 -    17.99 [   81] |**************************************
   18.00 -    18.99 [   62] |******************************
   19.00 -    19.99 [   41] |********************
   20.00 -    20.99 [   36] |*****************
   21.00 -    21.99 [   30] |**************
   22.00 -    22.99 [   23] |***********
   23.00 -    23.99 [   17] |********
   24.00 -    24.99 [   11] |*****
   25.00 -    25.99 [    5] |**
   26.00 -    26.99 [    3] |*
   27.00 -    27.99 [    4] |*
   28.00 -    28.99 [    2] |
                            +---------+---------+---------+---------+---------+
                                      20        40        61        81       102
```

Figure 6.3: Statistics Display for Input #3

For the people related to Bus #4, walking time is chosen as NORMAL(18, 5.5) considering the dispersion given below:

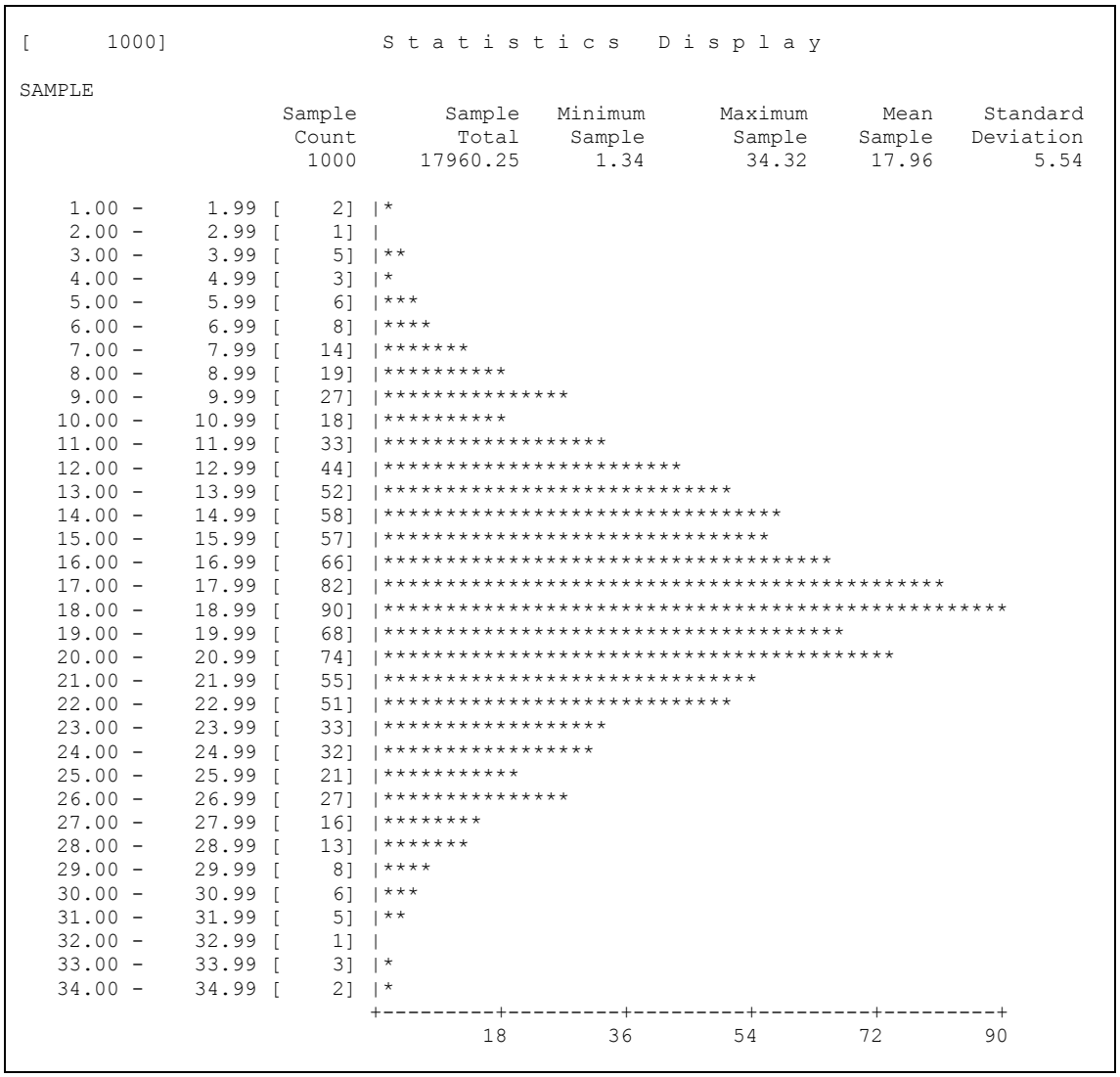

Figure 6.4: Statistics Display for Input #4

Finally, driving time distribution is given as NORMAL(80, 5) and it is checked graphically. As it can be seen from below, although it is a little dense around the mean, since it is given explicitly in the problem definition, no change is made to this input.

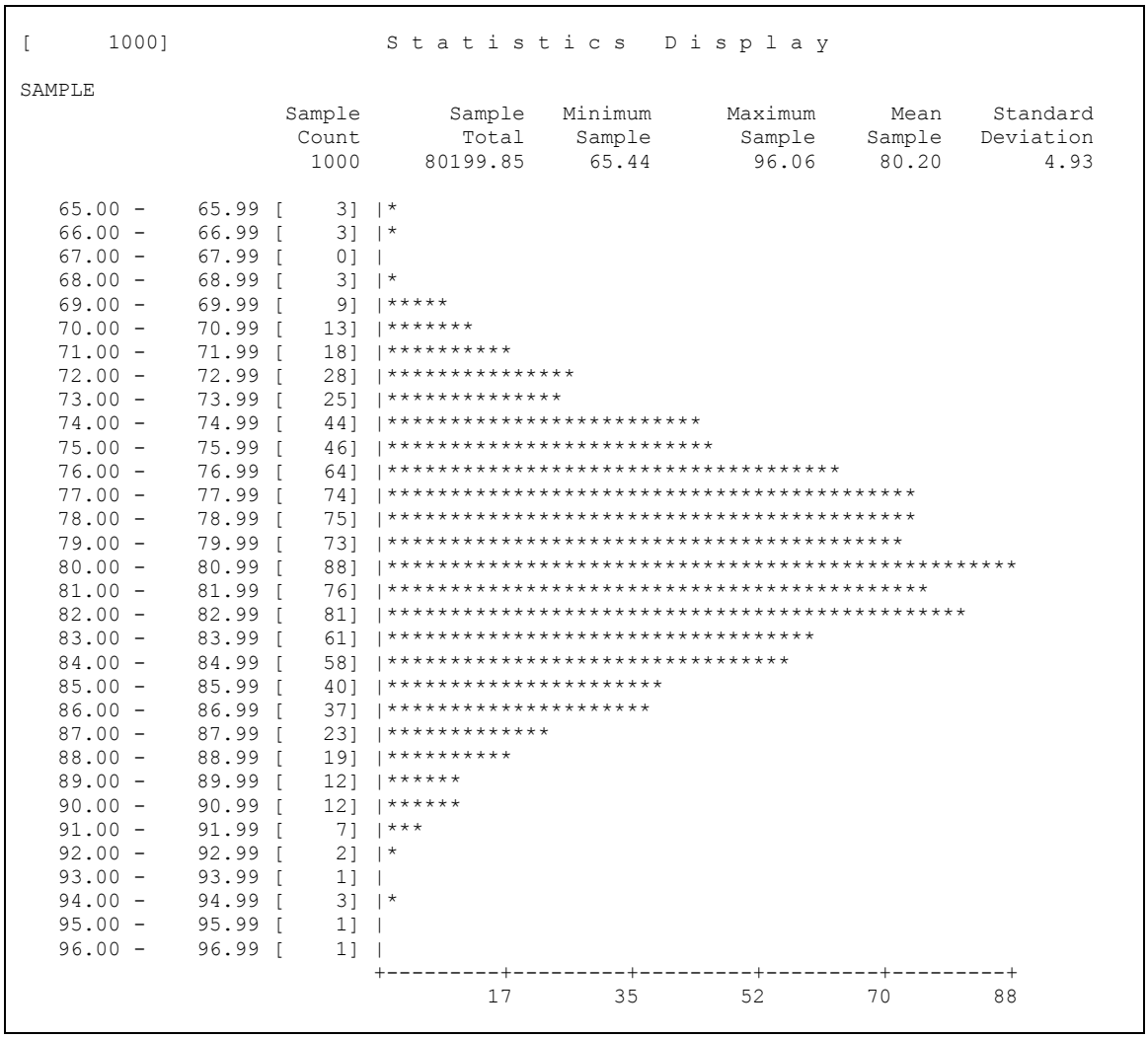

Figure 6.5: Statistics Display for Input #5

To conclude, all statistical inputs used can be summarized as following:

Value #	Input Name	Input Value
Input #1	Walking time for Bus#1 people	NORMAL (10, 3)
Input #2	Walking time for Bus#2 people	NORMAL (12, 3.5)
Input #3	Walking time for Bus#3 people	NORMAL (15, 4.5)
Input #4	Walking time for Bus#4 people	NORMAL (18, 5.5)
Input #5	Driving time	NORMAL (80, 5)

Table 6.1: Inputs used in the model

6.2. Output Analysis

After running the SIMDL model provided in part 5, all gathered outputs are provided in Appendix. In this section, the important ones will be analyzed with their expected values.

Firstly, average walking times of people are recorded. When people grouped according to their buses, the following table is constructed:

Value #	Value Description	Expected	First Run	Difference
Output #1	Average walking time for Bus#1 people	10	10.36	3.6 %
Output #2	Average walking time for Bus#2 people	12	11.68	2.6 %
Output #3	Average walking time for Bus#3 people	15	14.80	1.3 %
Output #4	Average walking time for Bus#4 people	18	19.04	5.7 %

Table 6.2.1: Walking time outputs

In the table above, expected average values are taken from the mean values of inputs provided in Table 6.1. As can be seen above, there is no important difference between "First Run" and "Expected" outputs.

Secondly, departure times of the buses are analyzed. Since the last person's walking time determines this value, probability of the maximum value is considered. In other words, instead of using a calculated expected value, probability of having a higher maximum value will be considered. With this reasoning these probabilities are calculated considering:

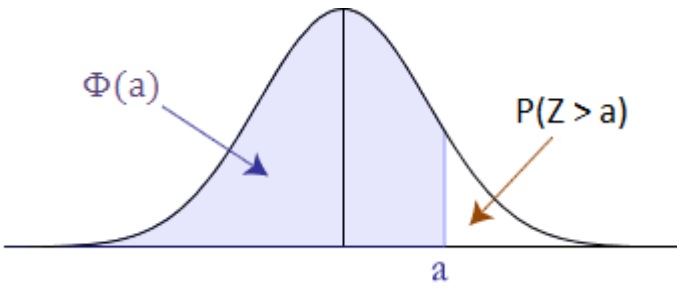

Figure 6.2.1: Normal distribution

Value #	Value Description	First Run	Probability of having a greater value
Output #5	Full time for Bus#1	14	9,12 %
Output #6	Full time for Bus#2	18	4,32 %
Output #7	Full time for Bus#3	24	2,27 %
Output #8	Full time for Bus#4	33	0,31 %

Table 6.2.2: Full time of buses

As can be seen from the table above, full time of the buses gave a little chance to be longer than the output values in the first run. In other words, these maximum values are acceptable for the input values provided in Table 6.1.

Thirdly, average driving time of the buses is analyzed. Considering the normal distribution with the mean of 80, it can be said that driving time is acceptable as can be seen from the table below:

Value #	Value Description	Expected	First Run	Difference
Output #9	Average driving time of buses	80	79	1.25 %

Table 6.2.3: Driving time of buses

Finally, as asked in the problem definition, arrival time of the last bus is analyzed. Considering the walking times, it is expected that the last bus that departures will be the bus #4 because it is related to the slowest walking people in average. Considering the average driving time of 80, the following table can be constructed:

Mean (1)	+ / - Sigma (2)	Probability	Value (3) = (1) + (2)	Average Driving Time (4)	Result (3) + (4)
18	-3 x 5,5	2,1 %	1,5	80	81,5
18	-2 x 5,5	13,6 %	7	80	87
18	-1 x 5,5	34,1 %	12,5	80	92,5
18	0 x 5,5	50 %	18	80	98
18	1 x 5,5	68,2 %	23,5	80	103,5
18	2 x 5,5	95,4 %	29	80	109
18	3 x 5,5	99,7 %	34,5	80	114,5

Table 6.2.4: Normal distribution analysis for maximum value

As can be seen from the table above, arrival time of 114,5 can be expected for the arrival of the last bus in the worst scenario. With this reasoning, as summarized below, result of the run is acceptable.

Value #	Value Description	Expected	First Run	Difference
Output #10	Arrival of the last bus	114,5	121	5,37 %

Table 6.2.5: Arrival of the last bus

7. Experiments and Results

In order to check responsiveness of the model to parameter changes, two experiments are undertaken.

7.1. Experiment #1: Increase in walking times

Firstly, mean of the walking time of people related to bus #3 and #4 increased by 10. These changed inputs can be tabulated as below:

Value #	Input Name	Input Value
Input #3	Walking time for Bus#3 people	NORMAL (25, 4.5)
Input #4	Walking time for Bus#4 people	NORMAL (28, 5.5)

Table 7.1: Changed inputs used in Experiment #1

When the simulation is run, it is thought that departure time of bus #3 and #4 will increase by 10 and arrival of the latest bus will increase too. It is considered in this way because in this experiment walking time of the two slowest groups are increased. Outputs can be tabulated after run:

Value #	Value Description	First Run	Experiment #1	Expected Change
Output #1	Average walking time for Bus#1 people	10.36	10.36	0
Output #2	Average walking time for Bus#2 people	11.68	11.68	0
Output #3	Average walking time for Bus#3 people	14.80	24.80	+10
Output #4	Average walking time for Bus#4 people	19.04	29.04	+10
Output #5	Full time for Bus#1	14	14	0
Output #6	Full time for Bus#2	18	18	0
Output #7	Full time for Bus#3	24	34	+10
Output #8	Full time for Bus#4	33	43	+10
Output #9	Average driving time of buses	79	79	0
Output #10	Arrival of the last bus	121	131	+10

Table 7.2: Changed outputs in Experiment #1

As expected, shift on the mean resulted with a late departure and arrival of the last bus.

7.2. Experiment #2: Decrease in driving times

Secondly, mean of the driving time of the buses is decreased to 60 to check whether arrival of the last bus will change.

Value #	Value Description	First Run
Input #5	Driving time	NORMAL (60, 5)

Table 7.3: Inputs used in the Experiment #2

After making this change, the simulation is run with the expectation of decrease in average driving time of buses and the arrival of the last bus.

Value #	Value Description	First Run	Experiment #2	Expected Change
Output #1	Average walking time for Bus#1 people	10.36	10.36	0
Output #2	Average walking time for Bus#2 people	11.68	11.68	0
Output #3	Average walking time for Bus#3 people	14.80	14.80	0
Output #4	Average walking time for Bus#4 people	19.04	19.04	0
Output #5	Full time for Bus#1	14	14	0
Output #6	Full time for Bus#2	18	18	0
Output #7	Full time for Bus#3	24	24	0
Output #8	Full time for Bus#4	33	33	0
Output #9	Average driving time of buses	79	59	-20
Output #10	Arrival of the last bus	121	101	-20

Table 7.4: Changed outputs in Experiment #2

As expected, driving faster yielded an early arrival of the last bus. Considering two parts of the model, it is showed that the model make reasonable responses to the change in parameters.

8. Conclusion

To sum up, in this project a bus simulation model is constructed for the question given in problem definition. Following the analysis of inputs and outputs, responsiveness of the model is checked by the help of two experiments.

Although results of the experiments found to be exactly as expected, it should be mentioned that due to the little number of random variables (for instance, only four buses), chance of seeing different random numbers decreased.

All output values can be tabulated as below:

Value #	Value Description	First Run	Experiment #1	Experiment #2
Output #1	Average walking time for Bus#1 people	10.36	10.36	10.36
Output #2	Average walking time for Bus#2 people	11.68	11.68	11.68
Output #3	Average walking time for Bus#3 people	14.80	24.80	14.80
Output #4	Average walking time for Bus#4 people	19.04	29.04	19.04
Output #5	Full time for Bus#1	14	14	14
Output #6	Full time for Bus#2	18	18	18
Output #7	Full time for Bus#3	24	34	24
Output #8	Full time for Bus#4	33	43	33
Output #9	Average driving time of buses	79	79	59
Output #10	Arrival of the last bus	121	131	101

Table 8: Summary table

9. Appendix

In this part, important results of the original model are added for further analysis.

[200] V a r i a b l e S t a t u s D i s p l a y

V a r i a b l e	T y p e	V a l u e
ARRIVAL_TIME_1	integer	95
ARRIVAL_TIME_2	integer	88
ARRIVAL_TIME_3	integer	101
ARRIVAL_TIME_4	integer	121
COUNT_1	integer	-1
COUNT_2	integer	-1
COUNT_3	integer	-1
COUNT_4	integer	-1
FULLED_TIME_1	integer	14
FULLED_TIME_2	integer	18
FULLED_TIME_3	integer	24
FULLED_TIME_4	integer	33
GINX	integer	1
SINX	integer	1

[200] S t a t i s t i c s D i s p l a y

DRIVE_T_1

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	81.00	0.00	81.00	3.24	16.20

DRIVE_T_2

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	70.00	0.00	70.00	2.80	14.00

DRIVE_T_3

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	77.00	0.00	77.00	3.08	15.40

DRIVE_T_4

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	88.00	0.00	88.00	3.52	17.60

WALK_TIME_T_1

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	259.00	6.00	14.00	10.36	2.53

WALK_TIME_T_2

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	292.00	6.00	18.00	11.68	3.18

WALK_TIME_T_3

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	370.00	6.00	24.00	14.80	4.52

WALK_TIME_T_4

Sample Count	Sample Total	Minimum Sample	Maximum Sample	Mean Sample	Standard Deviation
25	476.00	5.00	33.00	19.04	6.09