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Project 1 902825462

Hotel/Airport Shuttle Service: Conceptual Model and Initial Software

Final Report

Statement: A bus shuttle service operates to ferry passengers from a hotel in Downtown Atlanta to the Hartsfield-Jackson International airport. The simulation model is to replicate the sequence of discrete-events of customers using the service over 5 hours. The goal of the simulation study is to find the optimal combination of the following two parameters in order to minimize the overall waiting time of passengers using the shuttle service:

- Choice of Bus: Bus A (small but fast) or Bus B (big but slow)
- Bus-wait-time: Duration of wait by the bus at the hotel before departure to the airport

The following report describes in detail the System Under Investigation, relevant simulation parameters and the implemented software. The conceptual model using the ABCMod framework is presented in the Appendix.

Description: A bus service company that operates buses to ferry passengers from hotel lobby to the airport is operating under limited service, with only one bus-operator available. The company has to choose one of two available buses to service all the hotel residents and ensure their satisfaction by minimizing their wait time. The wait time for each passenger is calculated as the total number of minutes the passenger has to wait after he checks in to the queue to board the bus and the time spent on the bus after boarding before it departs the hotel.

pas_total_wait = ∑ (preboard-wait + boarded-wait) [summation for all passengers]

The hotel has observed that passengers are less patient waiting outside the bus as compared to waiting after boarding the bus. Since the company does not want to take any chances of complaints from impatient customers, it decides to assign twice the weightage for every preboard-wait minute, i.e. every minute spent waiting to board the bus is counted as two minutes. The goal, it remains, is to minimize the total passenger wait time.

pas_total_wait = ∑ (2*preboard-wait + boarded-wait) [summation for all passengers]

The total wait time as expressed above is estimated for all passengers for each of the two available buses, Bus A and Bus B. The company wants to make a decision of which bus to use based on the total wait time of its customers over five hours of operation (300 minutes), which is in turn dependent on the bus characteristics (as shown in table 1) and the bus-wait-time at the hotel.

Table 1: Bus characteristics

	Bus A	Bus B
Capacity	20	40
Round trip time (Hotel-Airport)	UNIFORM(10,15)	UNIFORM(20,25)

Details of SUI: Each resident in the hotel must use the bus to go to the airport, in first-come-first-serve order. The interarrival time of the customers for the shuttle service is modelled as a homogeneous stochastic process with an underlying exponential distribution and mean of 1 minutes.

For a given bus, the waiting time of the bus at the hotel while waiting for passengers is either one of 10, 15 or 20 minutes. If the bus is filled to capacity, it can leave irrespective of the wait time.

The sequence of events for any given passenger is as follows and also represented in Figure 1:

- Passenger Arrival Event: Passenger arrives at hotel lobby and checks into queue to board the bus. The queue functions on a first-in-first-out (FIFO) basis. Time spent waiting at lobby is considered preboard-wait time. If the bus is already at the hotel, the preboard-wait time is zero.
- Passenger Boarding Event: When, the bus arrives at hotel, passenger boards the bus as per the queue order. As soon as the passenger boards, the preboard-wait is terminated and boarded-wait time begins.
- Bus Departure Event: The bus departs after a predetermined bus-wait-time interval [varies between 10-20 minutes] and the boarded-wait time ends for the passenger. The bus might also depart if it gets filled before the end of the bus-wait time interval.
- Commute Event: This is a triggered event as soon as the bus departs. Once the bus departs the hotel to the airport, the commute time for the round trip is a uniform probability distribution specific for a given bus, as presented in Table 1.
- Bus Arrival Event: Once the bus arrives at the hotel, any passengers in queue will board the bus. This cycle is executed for 300 minutes, at the end of which passenger arrivals are terminated and only the current scheduled events are executed.

The entities, attributes, activities, and events for this simulation is explicitly defined in the model summary below.

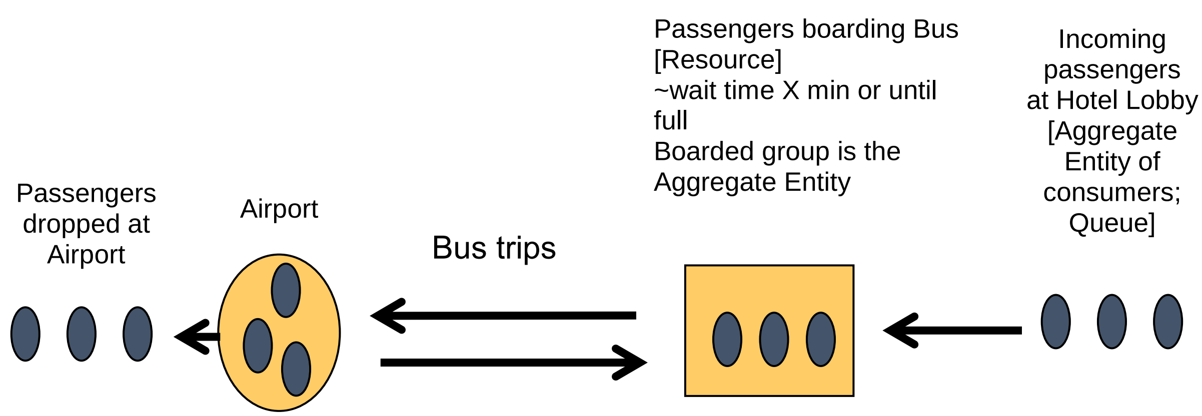


Figure 1: Schematic showing sequence of events

Bus Ferry Model Summary

1. STRUCTURE
   - Entities: Components making up the model
     - Bus [Resource Entity]
     - Individual Passenger [Consumer Entity]
     - Queue of Passengers waiting to board bus [Aggregate Entity]
     - Passengers already boarded onto bus [Aggregate Entity]

- Attributes: Characteristics of model entities
    - Passenger – Preboard-Wait and Boarded-Wait
    - Bus- Arrived at Hotel
    - Bus-Waiting for passengers
    - Bus- Depart Hotel
    - Bus – In transit

2. IO
    - Inputs: The following are the inputs for the model
        - Bus (A or B) which define the capacity and commute time
        - Waiting Time (10, 20 or 30 minute)
        - Passenger Interarrival Distribution
    - Outputs: The following are desired outputs to collect
        - Vacant Seats in Bus over all trips
        - Passenger Wait Times including average preboard-wait time, average boarded_wait time and average wait time
3. BEHAVIOR
    - Activity: Specific unit of behavior
        - Boarding – Bus at hotel and passengers boarding as per A.ToBoard_Que
        - BusTrip – Bus departed hotel
        - BusAtHotel – Bus arrived at hotel
    - Event: Action occurring in the model at an instant of time
        - Passenger Arrival (Insert to A.ToBoard_Que)
        - Passenger Boarding Event (Remove from A.ToBoard_Que , Insert to A.Boarded_Grp)
        - Bus Departure Event (Remove from A.Boarded_Grp)
        - Generate Commute (Triggered)
        - Bus Arrival (After trip completion)

Assumptions and Simplifications:

1. Time between passenger arrivals follows a probability distribution, and are independent and identically distributed.
2. Boarding process occurs instantly, i.e. multiple passengers will board the bus at one instant of time.
3. Only one bus operating for a given experiment
4. Bus always functioning with no breaks
5. Traffic effects are ignored, and the bus commute time follows a probability distribution for time taken to go from hotel to airport and back.
6. Values for distributions like commute time and bus capacities are assumed and will re-calibrated at time of experimental analysis.

Software Implementation

The software was implemented Python 3 programming language, as a package of two files: a main engine file (main.py) that handles the Future Event List (FEL) and the application file (shuttle_service.py) that contains the event handlers and event definitions. The program input parameters are directly modified in the code and results are copied to be separately analyzed. The following section describes the various modules that form the software package.

FEL Implementation: Events are inserted into a FEL, which is implemented using a python list data structure. Each entry in this Eventlist is a tuple of the event name and its timestamp. After processing any given event, the next event is chosen based on the associated timestamp, such that all events are processed in order.

When the final time limit (300 minutes) for the simulation is reached, further passenger arrivals are terminated. After this point, only the remaining scheduled events like boarding and departure are executed. When the Eventlist is empty, the simulation is complete.

Input Parameters:

Bus Characteristics: Bus properties are defined using a class called *bus_prop*, whose attributes include the bus seating capacity (or size) and trip time limits (*Trip_timeA* and *Trip_timeB*). The trip time for a bus is defined using a random number generator as a uniform normal distribution between these trip time limits.

Passenger Interarrival Time: The passenger interarrival periods are defined as a homogeneous stochastic process with an exponential distribution. The mean for the distribution is represented by the variable *Avg_Arr*, with a value of 1 minutes. A time tracking variable, *passclock*, continuously increments as per this distribution to represent the arrival events throughout the simulation period.

Bus Waiting Time: Before the start of each trip, the bus waits for a predetermined fixed time before departing. This is varied between 10,20 and 30 minutes to assess the optimal waiting time.

Simulation Stopping Criteria: Passenger arrivals are scheduled until the system clock reaches the final simulation time, t_f of 300 minutes. After this, the events already scheduled in the Eventlist are executed until there are no more events.

Event Handler Procedures:

Passenger Arrival Event: This event tracks the total number of passengers over simulation time period, and arrival time for each passenger. The timestamp of each arriving passenger is added to a queue (*ToBoard_Que*), from which the passenger boards his/her turn to board arrives. If the arrival time of the next arriving passenger is greater than the maximum wait interval of the bus, a departure event is scheduled prior to the next passenger arrival.

Boarding Event: Boarding of passengers is represented by removing them from the top of the queue and adding to the aggregate entity called *Boarded_Grp*. When the size of the *Boarded_Grp* reaches the seating capacity of the bus, a departure event is scheduled.

Bus Departure Event: Bus departure sets the status of the boarding to zero (AtHotel=0) so that no more boarding events can occur until the bus arrives back at the hotel. This event also triggers the Bus Commute event, which is a uniform random distribution based on trip time limits for a given bus.

Bus Arrival Event: Once the bus arrives at the hotel, the AtHotel condition is set to one, and any passenger in the *ToBoard_Que* are boarded using the Boarding event.

Application Pseudo Code

Define Eventlist=List of Tuples (Event, Timestamp)

While (Simulation Time > 300 minutes hours) and (FEL not null):

Handle Passenger Arrival {
ToBoard_Que.append(passclock)
If AtHotel==1: Handle Boarding Event

Schedule Next passenger event @ passclock=passclock + Random Number Generator
If passclock>Bus Wait Time: Schedule Departure Event @ Bus Wait Time
}

Handle Boarding Event {
While ToBoard_Que not empty:
    Remove first passenger from Que
    Add this passenger to Boarded_Grp
    if len(Boarded_Grp)==Bus Size: Schedule Departure Event
}

Handle Departure Event {
AtHotel==0
Update BusClock = BusClock + Random Number Generator for Trip time
Schedule Bus Arrival Event at BusClock
}

Bus Arrival Event {
AtHotel==1
If ToBoard_Que not empty: Schedule Boarding Event
}

Verification and Validation

Verification of the model was a continuous process throughout the development of the software package. The verification process involved application specific aspects including the following:

- the passenger arrival was modeled as an event independent of the bus arrival, i.e., passengers continuously arrive at lobby even when the bus is not at the hotel. After the bus arrival is scheduled for a future time, the passenger clock pointer takes priority until the time pointer progresses up till the bus clock pointer.
- When the bus is filled even before the maximum wait time is reached, a departure event is scheduled immediately.

- Even when the maximum wait time is reached before the bus is filled, a departure event is scheduled.
- As soon as a departure is scheduled, all relevant variables are updated so that no two departure events are scheduled consecutively.
- Various combinations of values of bus size, passenger interarrival period and bus wait time were executed to study the behavior of the software and locate potential oddities.

The following example demonstrates the process of verification, highlighting the significance of careful evaluation of all possible scenarios to ensure the simulation is correct. The following scenario was encountered with BusA, with capacity 20 seats and trip times represented as a uniform distribution between 5 and 10 minutes. The wait time was set to 10 minutes. Since the wait time was set so low relative to the rate of passenger arrivals, the passenger queue waiting to board the bus continuously increased as the simulation progressed. At the end of the simulation period (300 minutes), the only events allowed to occur was bus arrivals, passenger boarding and bus departures.

Figure 2 depicts the behavior of the Boarded_Grp through the progress of the simulation. The X-axis represents the number of passengers that are boarding and the Y-axis represents the number of people who are on the bus. Clearly, since the bus capacity is 20, the size of the Boarded group cannot be more than 20. Also Figure 3 shows the size of the ToBoard_que as the passengers arrive at the lobby, showing that many people are queueing up waiting for the bus, and then drops dramatically at the end.

A verification study disclosed an additional off-cycle boarding activity that was scheduled causing the anomaly. After rectification, the same parameters show the expected trend seen in Figure 4.

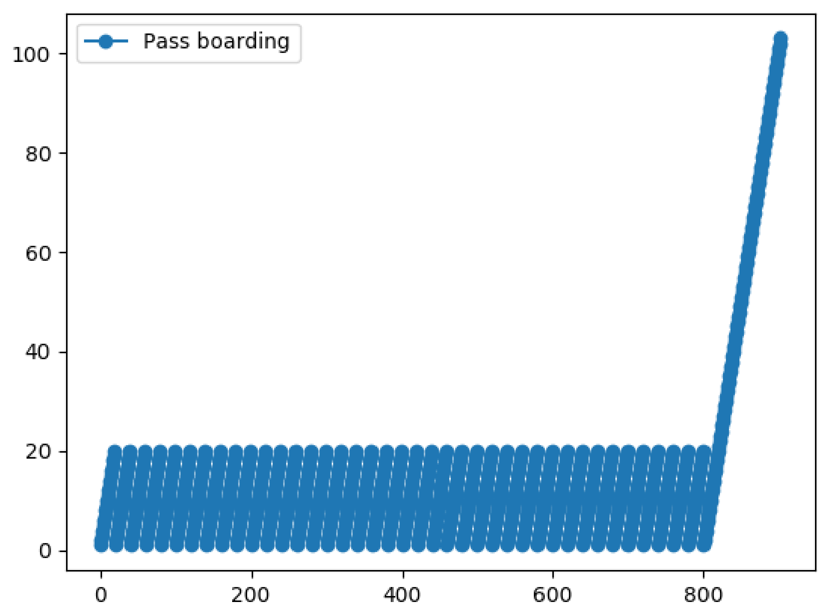


Figure 2: Plot of people on bus versus number of passengers indicating a bug in the simulation

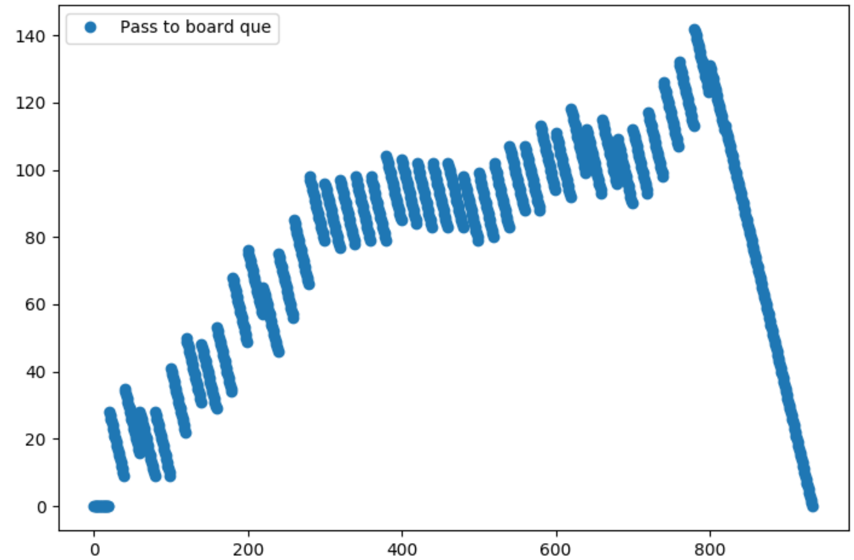


Figure 3: Plot of size of ToBoard_Que showing unrealsitic high passenger arrival rate at 3 passengers per minute

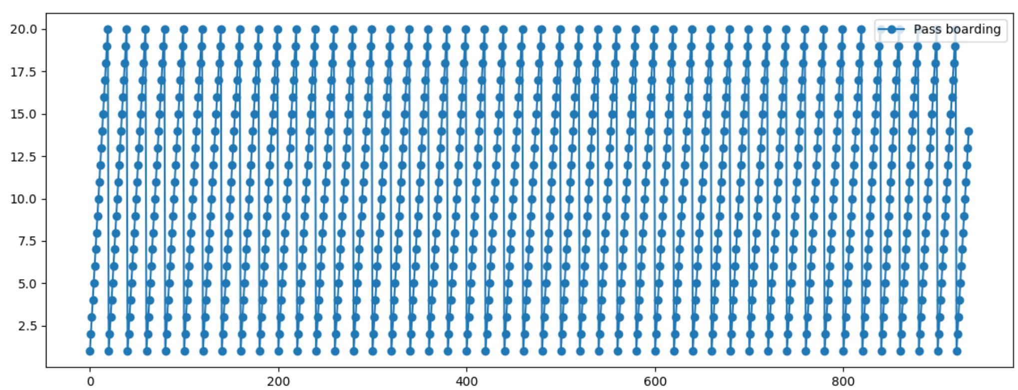
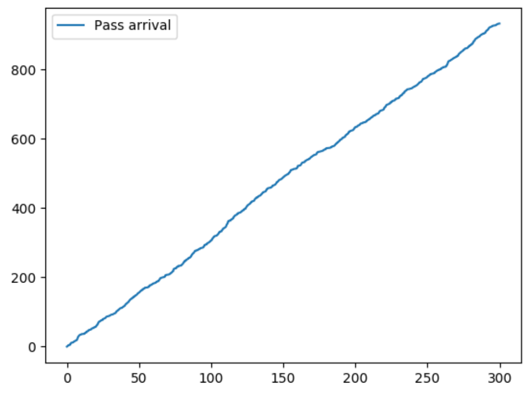


Figure 4: Corrected plot of people on bus versus number of passengers

Validation of the model was also necessary as preliminary runs of the simulation indicated that the ToBoard_Que size had increased to 142 towards the end of the simulation time period, which is unrealistic. Clearly, the parameters used to define the bus and the wait times are not close to real world.

This was caused by a high rate passenger arrivals that was being used, of 3 passenger per minute for all 300 minutes, which resulted in a total number of passengers of 900. This high rate also makes the wait time redundant as the bus does not have to wait every time it arrives at the hotel, because the passenger queue is already long. Therefore, the passenger arrival rate was modified to 0.5 passengers per minute, which reduced the total number of passengers over 300 minutes to under 140. The passenger arrival vs time plots for both rates of arrival are shown in Figure 5.



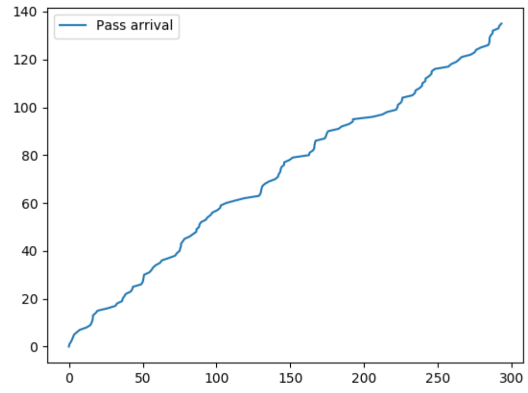


Figure 5: Plots of number of passenger arrivals versus simulation time (minutes) for passenger arrival rate of 3 and 0.5 passengers per minute

However, at 0.5 passengers per minute, the ToBoard_que was almost always zero as seen in Figure 6. To gain a better understanding, the passenger rate was then increased to 1 passenger per minute. This increased the total passengers to 300 as expected (Figure 7) and also the number of people waiting to go up to 12. (Figure 7)

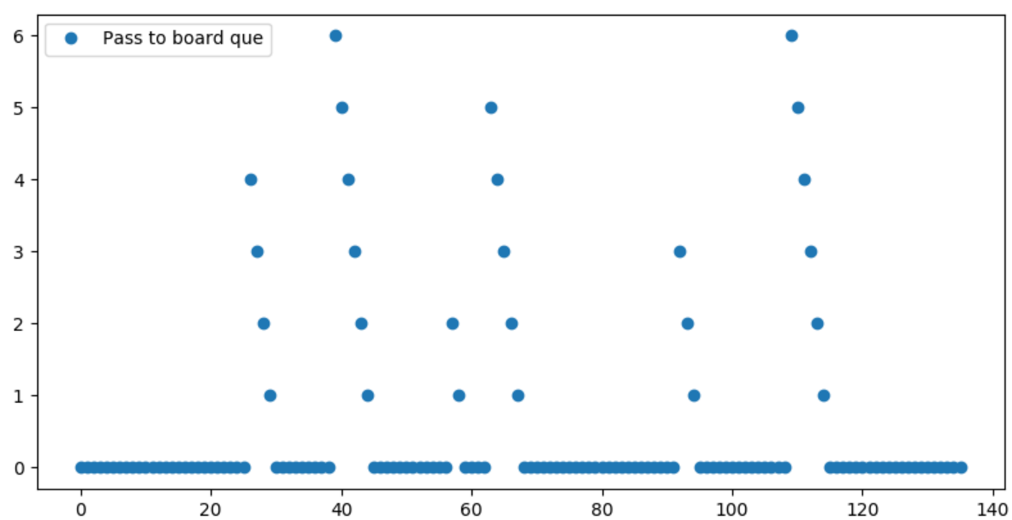


Figure 6**:** Plot of size of ToBoard_Que at 0. Passengers per minute

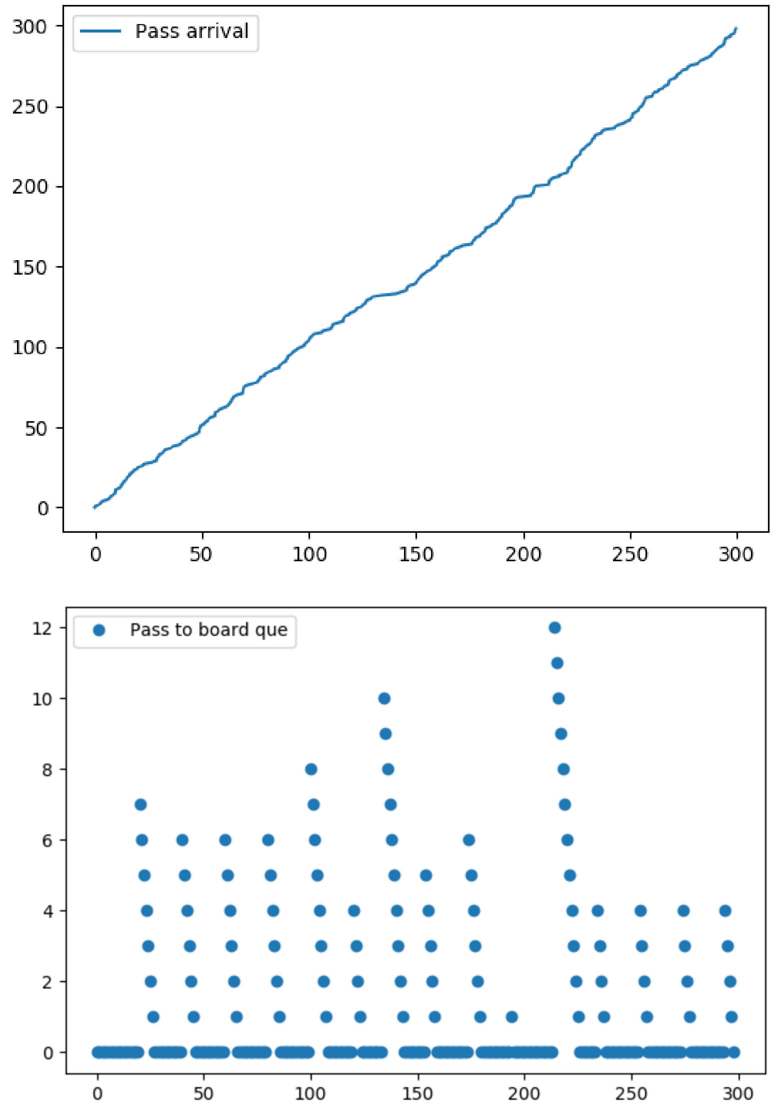


Figure 7: Plots of passenger arrivals and ToBoard_Que at 1 passenger per minute

Other Sample Output Plots

After the arrival rate was tuned and set to 1 passenger/minute, the following plots were also generated, shown here as an example. A sample output page is also presented in Appendix B.

Figures 8 shows the trends of passenger arrivals and passenger boarded on bus versus time for bus A and bus B. The wait times for both runs were 20 minutes, however, Bus B is bigger with 40 seats compared to bus A with 20 seats. Also bus A takes uniform distribution (5,10) for a commute while bus B takes UD(15,20) for a commute. Bus B is keeping more passengers waiting during its longer commute, however, needs fewer trips to ferry all the 300 people. This is clearly seen in Figure 9 as well.

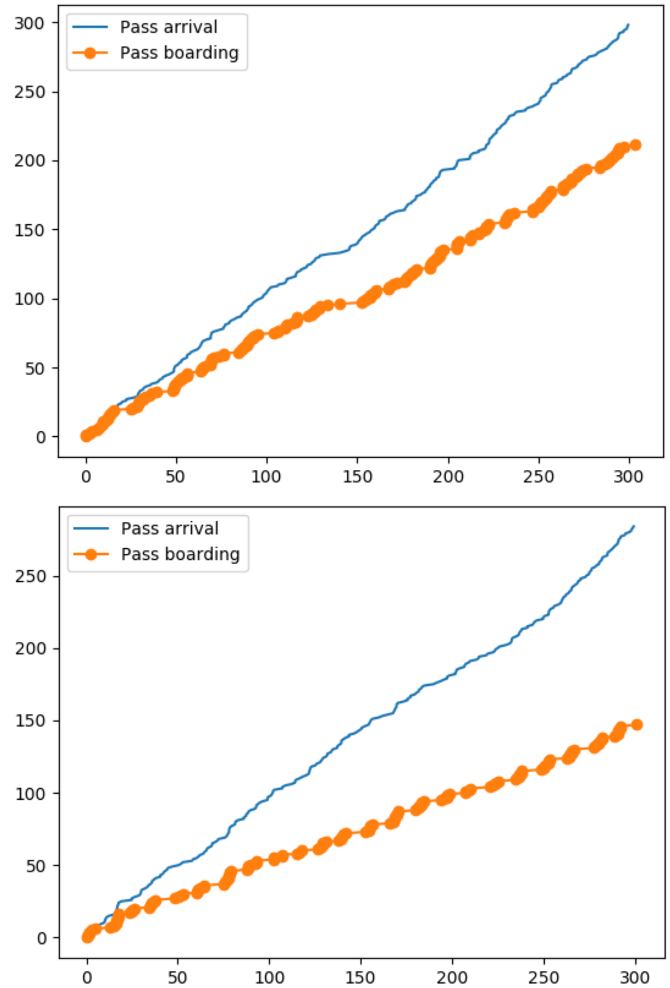


Figure 8: Plot showing the passenger arrival and passenger boarding times for Bus A(left) and Bus B(right)

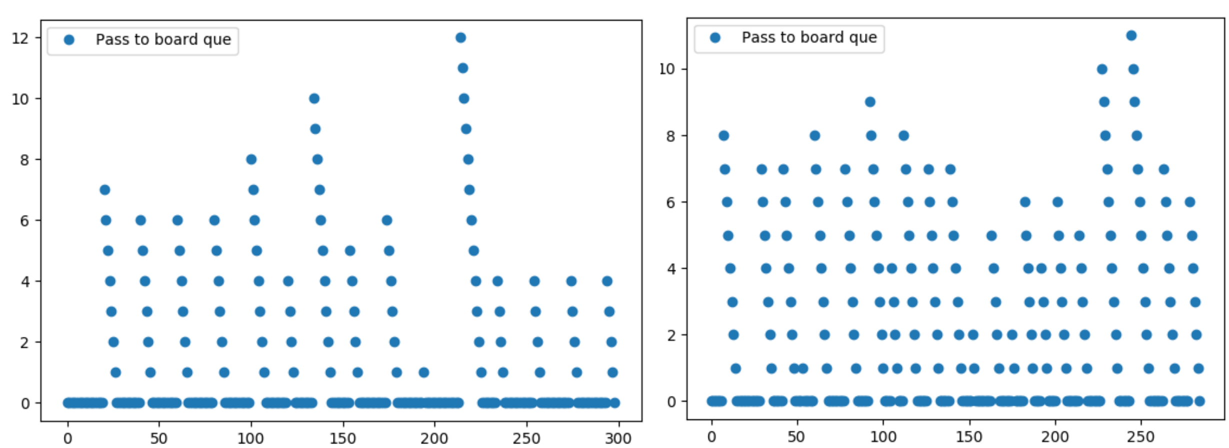


Figure 9: Plots of size of ToBoard_Que versus time for BusA and BusB, showing BusB is keeping more people waiting although bus wait time is the same and Bus B is bigger

These results are property quantified over 20 trials for each scenario and the results are presented in the following section. The experiments run is summarized in the table below. The reported values are averaged over 10 trials.

Table 1: Matrix of experiments

Case ID	Bus ID	Wait Time (min)	No_trials
1	A	10	10
2	A	15	10
3	A	20	10
4	B	10	10
5	B	15	10
6	B	20	10

Results

The above experiments were carried out at 1 passenger per minute and 0.5 passenger per minute rates. This section presents the average passenger wait times (preboard and board) at both arrival rates, followed by a comparison of the total wait time.

Table 2: *Arrival Rate: 1 passenger per minute*

Bus ID	Wait Time	No_trials	Tot Pass	Tot PB Wait	Tot Bwait	Tot Trips
A	10	10	307.8	495.28	630.2	19.4
A	15	10	288.8	454.15	1288.23	16.2
A	20	10	303.3	429.62	2066.83	15.4
B	10	10	301	1709.81	0	11
B	15	10	304.2	1407.63	306.96	9.4
B	20	10	296.6	1224.15	1344.47	8.6

Table 3: *Arrival Rate: 0.5 passenger per minute*

Bus ID	Wait Time	No_trials	Tot Pass	Tot PB Wait	Tot Bwait	Tot Trips
A	10	10	148.2	231.46	0	17.3
A	15	10	154.2	205.72	29.3	13.1
A	20	10	149.4	164.98	148.84	11.3
B	10	10	153.6	840.27	0	11
B	15	10	152.9	662.78	0	9.1
B	20	10	151.8	624.56	0	8

Plots of total trip times and passenger wait times versus bus wait times for both cases are presented in Figures 10,11 and 12.

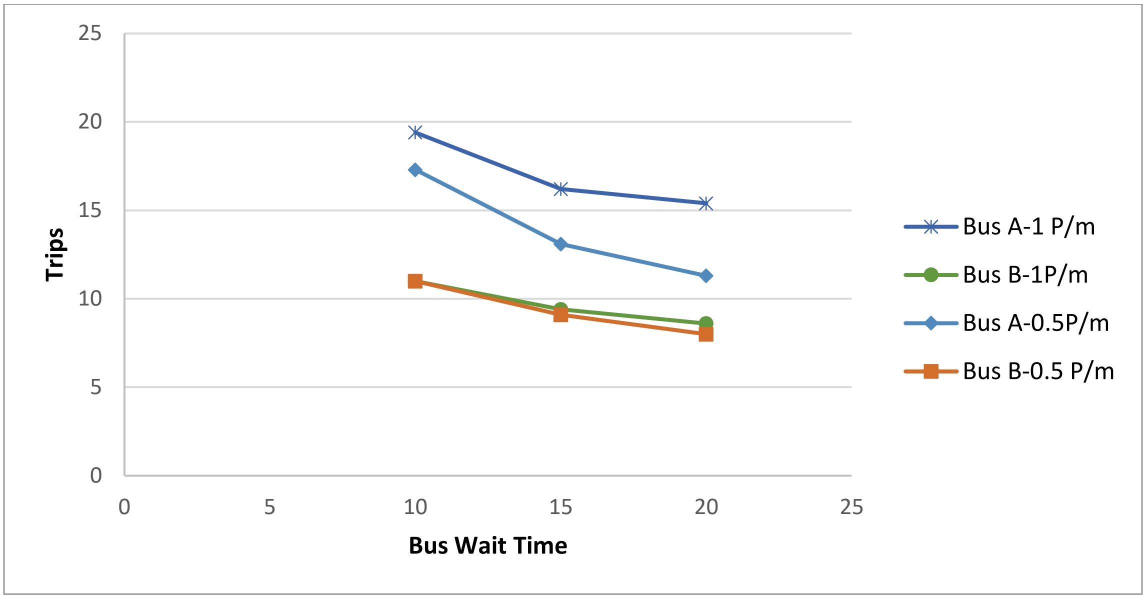


Figure 10: Total trips for bus wait times of 10,15 and 20 minutes and passenger arrival rate of 1 passenger per minute

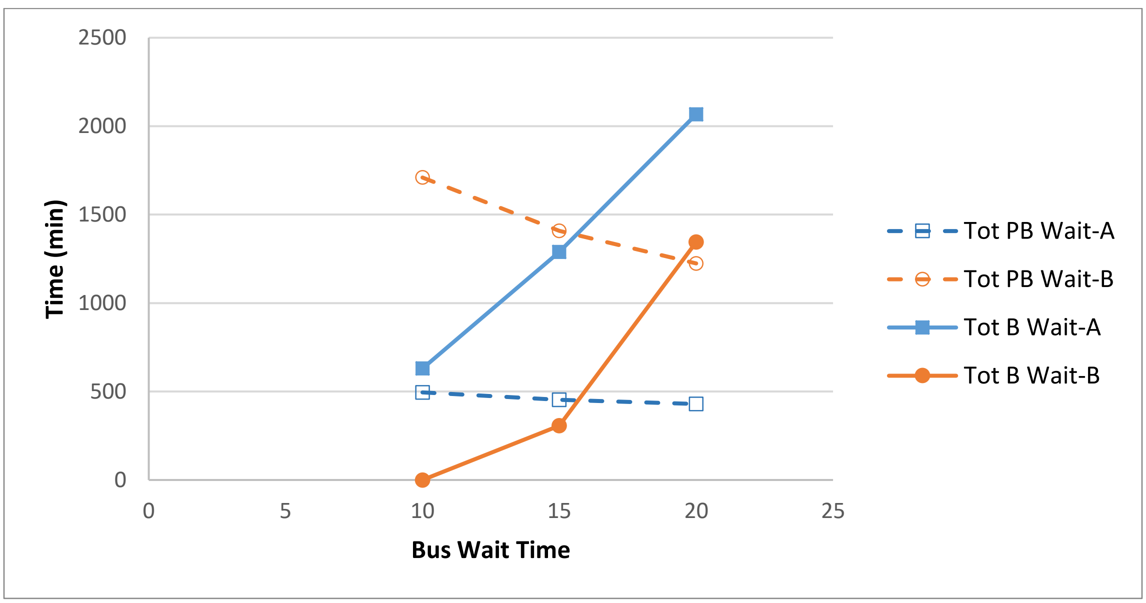


Figure 11: Passenger preboard and boarded wait times for bus wait times of 10,15 and 20 minutes and passenger arrival rate of 1 passenger per minute

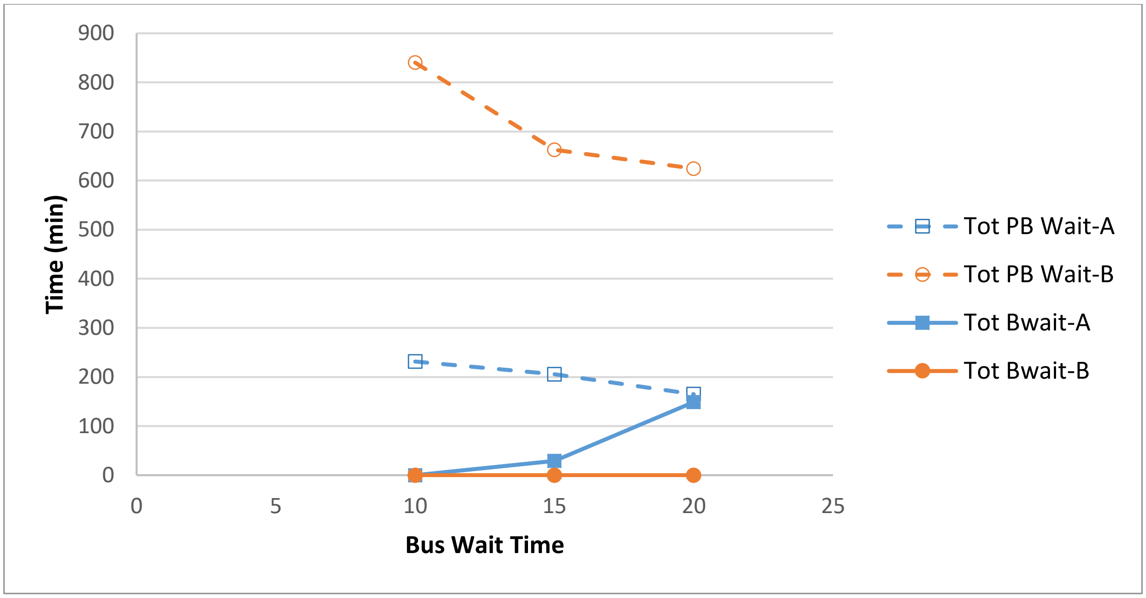


Figure 12: Passenger preboard and boarded wait times for bus wait times of 10,15 and 20 minutes and passenger arrival rate of 0.5 passenger per minute

Observations from Tables 2 and 3 and Figures 10,11 and 12 are as follows:

- From Figure 10, Bus A carries out more trips than Bus B since it has shorter trip times and/or Bus A gets filled faster and therefore does not need to wait for passengers.
- Figures 11 and 12 show that for Bus B, the preboard wait is longer than the boarded wait times. This is attributed to the longer commute time of bus B, which results in the build of the ToBoard_Que at the hotel. This causes the preboard wait time to increase while the boarded wait time is decreased.
- However, Bus A is much faster in commute and this causes a different trend in the two figures. In Figure 11 with higher passenger arrival rate, the bus is getting occupied at a greater rate, which makes the boarded wait time higher than the preboard wait time. Bus departures are goverened by the bus getting filled even before the wait times are reached. At a smaller arrival rate (Figure 12), the prebaord wait is larger than the boarded wait time. Here the bus departures are dominated by the wait times triggering departure.
- Passenger preboard wait times (dotted lines) decrease as the bus wait times are higher. This is understandable as the bus is available for longer duration for the passenger to board. Similarly, as seen in Tables 2 and 3, the total number of trips decrease as the wait time increases.
- Passenger boarded wait times (solid lines) increase as bus wait times increase. For Bus B in Figure 12, all the boarded wait times are 0 as the ToBoard_Que is constantly busy due to the long commute time of Bus B.

As mentioned before the travel company wants to be on the safer side and hence assign a time factor of 2 for the preboard time. Therefore, the total wait time is calculated as twice the preboard time plus the boarded wait time. This is presented in Figures 13 and 15 for the two passenger arrival times. Figure 14 shows the same plot as Figure 13 but with a time factor of 1.

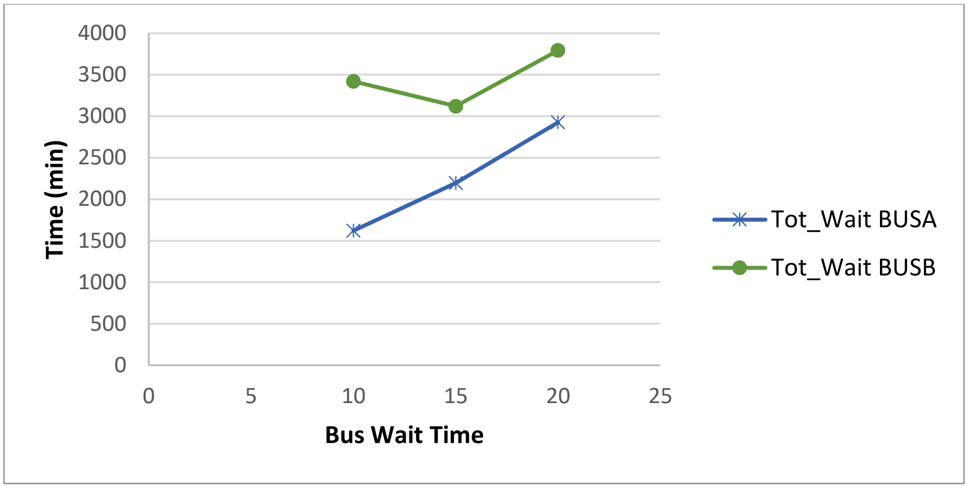


Figure 13: Total wait times for buses A and B at 1 pass/minute and time factor=2

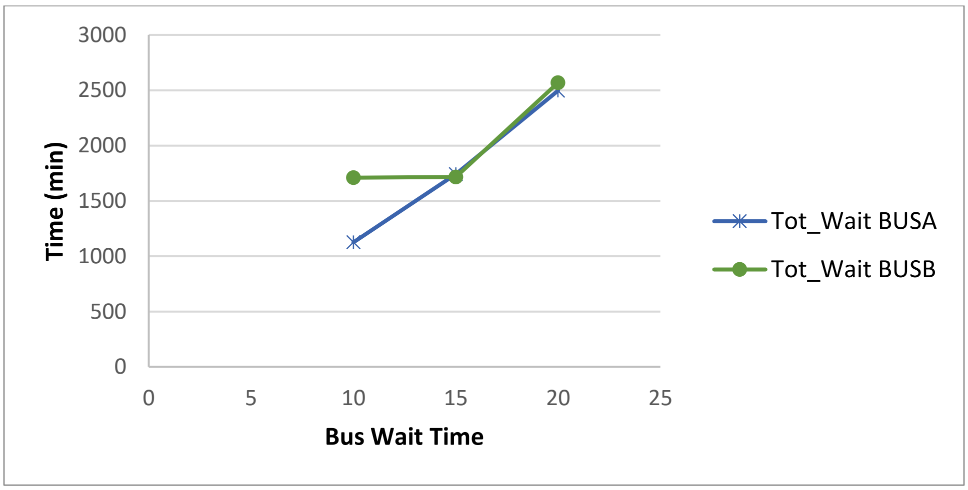


Figure 14: Total wait times for buses A and B at 1 pass/minute and time factor=1

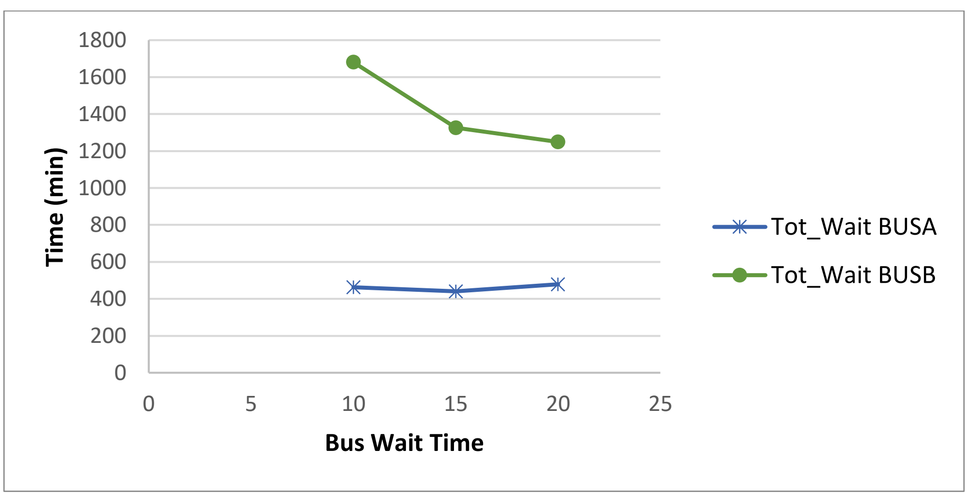


Figure 15: Total wait times for buses A and B at 0.5 pass/minute and time factor=2

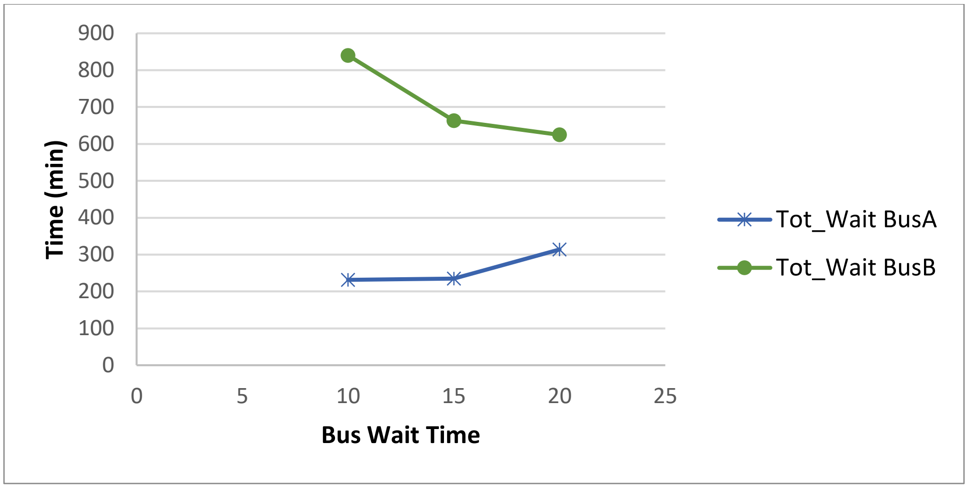


Figure 16: Total wait times for buses A and B at 0.5 pass/minute and time factor=1

Observations from Figures 13-15 are as follows:

- With no time factor and 1 passenger/minute (figure 14), the 15 mins and 20 mins wait times for buses A and B show similar passenger wait times. However, Bus A performs better with the 10 min wait time with a lower passenger wait time. This is possibly because, the short bus commute time for bus A and high passenger arrival rate means passengers are having to wait less at 10 mins-wait, as compared to bus B. However, at 15 and 20 min wait times, the boarded wait times are contributing towards the total wait times increasing, as passengers are waiting for the bus to depart.
- With no time factor and 0.5 passenger/minute (figure 16), the gap is larger which is very interesting. The slower arrival of the passengers is showing a much bigger difference between the performances of the two buses.
- From figures 13,15,16 it is clear that Bus A is much better than bus B at all wait times.
- A 10 minute wait time with Bus A is clearly better for a moderately high arrival rate of 1 passenger per minute. However, at 0.5 passengers/minute, the wait time of 10 or 15 minutes does not show a significant change in passenger wait times with either time factors (Figures 15,16).
- Bus B at a slow passenger arrival rate, the total passenger wait time is lower for larger bus wait times of 20 minutes than 10 minutes. This is opposite to the trend demonstrated by Bus A. This is justified by the bigger size of bus B and longer commute time than of B, which means a longer wait time at the hotel would fit more passengers into the bus.

Closing Comments

The software package correctly implements the project objective, as per the experiments conducted. The experiments conducted involved varying the passenger arrival rate and size and commute times of the two buses available and the wait time of the buses the hotel before departure. Using this information, the simulation program generated detailed outputs including the total number of trips, total waiting time of passengers before boarding the bus and after boarding the bus and the total wait time. The total wait time of the passengers were estimated using the concept of time factor, which selectively penalized the preboard wait time more than the boarded wait time of the passengers, since the preboard wait time generally involves more anxiety and impatience. The values of time factors studied were 1 (conventional) and 2 (preboard wait is penalized twice the amount).

The results were very interesting and especially useful due to the several factors at play, including commute time, wait time before and after boarding, size of the bus as well as arrival rate of passengers. However, in most cases, Bus A performed better with smaller total wait times for the passengers, owing to its smaller size leading to quicker occupation process, and quicker commute time.

The simulation software is also very useful to experiment with different passenger arrival rates to maybe compare the allocation of buses in holiday period with high arrival rates versus low hotel occupancy periods.

References

- CSE6730 Modelling and Simulation: Fundamentals and Implementation, Spring-2018 Lecture Notes, Richard Fujimoto, Georgia Institute of Technology
- L. G. Birta and G. Arbez, Modeling and Simulation: Exploring Dynamic System Behavior, Springer, 2007
- S. Robinson, "Conceptual Modeling for Simulation," *Winter Simulation Conference,* December 2013
- Google Maps in Atlanta area for Trip Time Data

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APPENDIX A: ABCMod Framework Details

Structural Components

Constants		
Name	*Role*	*Value*
t_o	Left boundary of Observation Interval	0 (clock time)
t_f	Right boundary of Observation Interval	300 minutes
passclock	Time of first passenger arrival	0 (clock time)
Avg_Arr	Interarrival Time	10 (minutes)
BusA_Capacity	Max number of passengers in Bus A	20
BusB_Capacity	Max number of passengers in Bus B	40
BusA_Trip_Min	Min time for round trip	10 (minutes)
BusA_Trip_Max	Max time for round trip	15 (minutes)
BusB_Trip_Min	Min time for round trip	20 (minutes)
BusB_Trip_Max	Max time for round trip	25 (minutes)
Parameters		
MaxWait	Max Wait time at hotel before departing	10 or 20 or 30 (minutes)
Bus	Choice of bus	A or B

Consumer Entity: Passenger	
This consumer entity class represents the passengers as they arrive at the hotel lobby to leave for the airport	
Attributes	*Description*
PreboardWait	Timestamp to determine waiting times before boarding
BoardedWait	Timestamp to determine waiting times after boarding
TotalWait	Accumulated waiting time

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Resource Entity: Bus	
This resource entity represents the bus that ferries passengers from hotel to the airport	
Attributes	*Description*
BusID	Choice of bus
Status	Indicates the status of the bus as specified by one of the following values: AtHotel: 1 if available for passengers to board at hotel if , 0 if bus is departing or in transit
BusStartWait	Timestamp to determine when bus wait time at hotel begins
BusWaitTime	Timestamp to determine waiting times of bus at hotel before departure

Aggregate Entity: Boarded_Grp	
This aggregate entity represents the passengers that have boarded the bus at the hotel and are waiting for the bus to depart.	
Attributes	*Description*
List	A list of time attribute of the passengers that have boarded the bus that will be used to calculate boarded wait time
N	Number of passengers on bus (maximum value is bus capacity)

Aggregate Entity: ToBoard_Que	
This aggregate entity represents the passengers that have queued to board the bus at the hotel	
Attributes	*Description*
List	A list of time attributes of the passengers waiting to board the bus that will be used to calculate preboard wait time Discipline: FIFO
N	Number of passengers in list

Input Output Components

Input				
Input Variable	*Description*	*Data Models*		*Action Sequence*
		Domain Sequence	*Range Sequence*	
u(t)	u represents the input entity stream corresponding to the Passenger consumer entity class	First Arrival: t=t_fa Interarrival time: EXP(AvgArr)	All values equal to 1	PassArrivals(C.Passenger)
BusChoice	Bus represents the choice of two buses available : A or B			
MaxWait	Waiting time of bus at hotel			

Trajectory Set	
Name	*Description*
TRJ [A.Boarded_Grp.N]	The time variable A.Boaded_Grp.N is an attribute of aggregate Boarded_Grp and provides number of passengers on bus at any time. The value of N at time of departure to airport can be used to estimate bus occupancy for each trip.

Sample Set	
Name	*Description*
PHI [Passenger.PreboardWait]	This attribute estimates the total time spent waiting in queue to board the bus
PHI [Passenger.BoardedWait]	This attribute estimates the total time spent waiting in the bus upon boarding and before departure
PHI [Passenger.TotalWait]	This attribute estimates the total waiting time for a given passenger

Each instance of the entries in the sample set is the final value of attributes of Passenger for a given instance of consumer entity class.

Derived Scalar Output Variables (DSOVs)			
Name	*Description*	*Output Set Name*	*Operator*
AvgBusOcc	Average number of people in bus	TRJ [A.Boarded_Grp.N]	AVG
Avg_PBWait	Average waiting time before boarding	PHI [Passenger.PreboardWait]	AVG
Avg_Bwait	Average waiting time after boarding	PHI [Passenger.BoardedWait]	AVG
Avg_Overallwait	Average waiting time including preboarding and postboarding wait times	PHI [Passenger.TotalWait]	AVG

Behavior Components

Time Units: Minutes

Observation Interval: t_i=0, t_f=300 minutes

Initialization Requirements: The following initializations represent the bus at the hotel to begin picking up passengers. Iterations are executed for each value of bus wait time and choice of bus.

BusID ← Bus A or Bus B
R.Bus.Status ← AtHotel
R.Bus.BusStartWait <- 0
R.BusWaitTime ← [10,20,30]
A. Boarded_Grp ← 0
A.ToBoard_Que ← 0

Data Modules		
Name	*Description*	*Data Model*
BusSize	Returns value for capacity attribute of chosen bus	Constant for bus
Trav_BusA	Returns round trip travel time for Bus A	UNIFORM(10,15)
Trav_BusB	Returns round trip travel time for Bus B	UNIFORM(20,25)

User Defined Modules	
Name	*Description*
TravelTime	The returned value is the travel time of a bus based on Trav_BusA or Trav_BusB data modules

The following tables represent the activities and action sequences.

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Summary of Activity Constructs	
Action Sequence	
PassArrivals	Input Entity Stream of arriving passengers
Activities	
Boarding	Boarding of passengers at hotel
Departure	Bus departs to airport as soon as it is full or wait time is reached
Triggered Activities	
Commute	Bus is executing a trip to airport and back begins as soon as Departing activity is executed
Arrival	At the end of commute duration, the arrival event is scheduled.

Action Sequence: PassArrival (C.Passenger)	
Precondition	t = u(t)
Event	C.Passenger.PreboardWait <- t
	C.Passenger.BoardedWait <- 0
	C.Passenger.TotalWait <- 0
	SM.InsertQue(A.ToBoard_Que,C.Passenger)

Activity: Boarding	
Precondition	(R.Bus.Status = AtHotel) & (A.ToBoard_Que.N>0) & (A.Boarded_Grp.N<BusSize)
Event	SM.RemoveQue(A.ToBoard_Que,C.Passenger)
	SM.InsertQue(A.Boarded_Grp,C.Passenger)
Duration	While (((t-R.Bus.BusStartWait) < R.Bus.BusWaitTime) & (A.Boarded_Grp.N<BusSize))

Activity: Generate Commute	
Precondition	(R.Bus. = OnTrip)
Event	
Duration	Trav_BusA or Trav_BusB

Triggered Activity: BusArrival	
Precondition	R.Bus.Status = AtHotel
Event	A.Boarded_Grp.N <- 0
	R.Bus.BusWaitTime <- 0
Duration	0

APPENDIX B: Sample Output

Input: Bus A, capacity 20 seats, trip time between 5 and 10 minutes, 1 passenger per minute, wait time of 20 minutes

The following smaple output has been reduced for the first 10 minutes for the sake of brevity of report.

```
PASSENGER ARRIVAL EVENT @  0
Tot pass: 1
Final event list: [('HBE', 0), ('PArr', 0.4468339429829305)]
----------------------------
PASSENGER BOARDING EVENT @  0
Total PBwait: 0.0
Len of boarded group 1
Len of ToBoard_Que 0
Final event list: [('PArr', 0.4468339429829305)]
----------------------------
PASSENGER ARRIVAL EVENT @  0.4468339429829305
Tot pass: 2
Final event list: [('HBE', 0.4468339429829305), ('PArr', 2.4210884020970695)]
----------------------------
PASSENGER BOARDING EVENT @  0.4468339429829305
Total PBwait: 0.0
Len of boarded group 2
Len of ToBoard_Que 0
Final event list: [('PArr', 2.4210884020970695)]
----------------------------
PASSENGER ARRIVAL EVENT @  2.4210884020970695
Tot pass: 3
Final event list: [('HBE', 2.4210884020970695), ('PArr', 2.893156662438438)]
----------------------------
PASSENGER BOARDING EVENT @  2.4210884020970695
Total PBwait: 0.0
Len of boarded group 3
Len of ToBoard_Que 0
Final event list: [('PArr', 2.893156662438438)]
----------------------------
PASSENGER ARRIVAL EVENT @  2.893156662438438
Tot pass: 4
Final event list: [('HBE', 2.893156662438438), ('PArr', 3.7607850158864)]
----------------------------
PASSENGER BOARDING EVENT @  2.893156662438438
Total PBwait: 0.0
Len of boarded group 4
Len of ToBoard_Que 0
```

Final event list: [('PArr', 3.7607850158864)]

PASSENGER ARRIVAL EVENT @ 3.7607850158864
Tot pass: 5
Final event list: [('HBE', 3.7607850158864), ('PArr', 6.222377712599966)]

PASSENGER BOARDING EVENT @ 3.7607850158864
Total PBwait: 0.0
Len of boarded group 5
Len of ToBoard_Que 0
Final event list: [('PArr', 6.222377712599966)]

PASSENGER ARRIVAL EVENT @ 6.222377712599966
Tot pass: 6
Final event list: [('HBE', 6.222377712599966), ('PArr', 7.219907055664782)]

PASSENGER BOARDING EVENT @ 6.222377712599966
Total PBwait: 0.0
Len of boarded group 6
Len of ToBoard_Que 0
Final event list: [('PArr', 7.219907055664782)]

PASSENGER ARRIVAL EVENT @ 7.219907055664782
Tot pass: 7
Final event list: [('HBE', 7.219907055664782), ('PArr', 7.694101219763174)]

PASSENGER BOARDING EVENT @ 7.219907055664782
Total PBwait: 0.0
Len of boarded group 7
Len of ToBoard_Que 0
Final event list: [('PArr', 7.694101219763174)]

PASSENGER ARRIVAL EVENT @ 7.694101219763174
Tot pass: 8
Final event list: [('HBE', 7.694101219763174), ('PArr', 8.762447467655166)]

PASSENGER BOARDING EVENT @ 7.694101219763174
Total PBwait: 0.0
Len of boarded group 8
Len of ToBoard_Que 0
Final event list: [('PArr', 8.762447467655166)]

PASSENGER ARRIVAL EVENT @ 8.762447467655166
Tot pass: 9

Final event list: [('HBE', 8.762447467655166), ('PArr', 9.433571848240767)]

PASSENGER BOARDING EVENT @ 8.762447467655166
Total PBwait: 0.0
Len of boarded group 9
Len of ToBoard_Que 0
Final event list: [('PArr', 9.433571848240767)]

PASSENGER ARRIVAL EVENT @ 9.433571848240767
Tot pass: 10
Final event list: [('HBE', 9.433571848240767), ('PArr', 9.581706012940247)]

PASSENGER BOARDING EVENT @ 9.433571848240767
Total PBwait: 0.0
Len of boarded group 10
Len of ToBoard_Que 0
Final event list: [('PArr', 9.581706012940247)]

PASSENGER ARRIVAL EVENT @ 9.581706012940247
Tot pass: 11
Final event list: [('HBE', 9.581706012940247), ('PArr', 9.689257849404935)]

PASSENGER BOARDING EVENT @ 9.581706012940247
Total PBwait: 0.0
Len of boarded group 11
Len of ToBoard_Que 0
Final event list: [('PArr', 9.689257849404935)]

PASSENGER ARRIVAL EVENT @ 9.689257849404935
Tot pass: 12
Final event list: [('HBE', 9.689257849404935), ('PArr', 11.563871838091496)]

PASSENGER BOARDING EVENT @ 9.689257849404935
Total PBwait: 0.0
Len of boarded group 12
Len of ToBoard_Que 0
Final event list: [('PArr', 11.563871838091496)]

PASSENGER ARRIVAL EVENT @ 11.563871838091496
Tot pass: 13
Final event list: [('HBE', 11.563871838091496), ('PArr', 12.230791709068424)]

PASSENGER BOARDING EVENT @ 11.563871838091496
Total PBwait: 0.0

Len of boarded group 13
Len of ToBoard_Que 0
Final event list: [('PArr', 12.230791709068424)]

PASSENGER ARRIVAL EVENT @ 12.230791709068424
Tot pass: 14
Final event list: [('HBE', 12.230791709068424), ('PArr', 12.398665154143895)]

PASSENGER BOARDING EVENT @ 12.230791709068424
Total PBwait: 0.0
Len of boarded group 14
Len of ToBoard_Que 0
Final event list: [('PArr', 12.398665154143895)]

PASSENGER ARRIVAL EVENT @ 12.398665154143895
Tot pass: 15
Final event list: [('HBE', 12.398665154143895), ('PArr', 13.095829646381464)]

PASSENGER BOARDING EVENT @ 12.398665154143895
Total PBwait: 0.0
Len of boarded group 15
Len of ToBoard_Que 0
Final event list: [('PArr', 13.095829646381464)]

PASSENGER ARRIVAL EVENT @ 13.095829646381464
Tot pass: 16
Final event list: [('HBE', 13.095829646381464), ('PArr', 13.489173380246964)]

PASSENGER BOARDING EVENT @ 13.095829646381464
Total PBwait: 0.0
Len of boarded group 16
Len of ToBoard_Que 0
Final event list: [('PArr', 13.489173380246964)]

PASSENGER ARRIVAL EVENT @ 13.489173380246964
Tot pass: 17
Final event list: [('HBE', 13.489173380246964), ('PArr', 14.486439669294494)]

PASSENGER BOARDING EVENT @ 13.489173380246964
Total PBwait: 0.0
Len of boarded group 17
Len of ToBoard_Que 0
Final event list: [('PArr', 14.486439669294494)]

PASSENGER ARRIVAL EVENT @ 14.486439669294494
Tot pass: 18
Final event list: [('HBE', 14.486439669294494), ('PArr', 14.97368749024897)]

PASSENGER BOARDING EVENT @ 14.486439669294494
Total PBwait: 0.0
Len of boarded group 18
Len of ToBoard_Que 0
Final event list: [('PArr', 14.97368749024897)]

PASSENGER ARRIVAL EVENT @ 14.97368749024897
Tot pass: 19
Final event list: [('HBE', 14.97368749024897), ('PArr', 15.457070530917283)]

PASSENGER BOARDING EVENT @ 14.97368749024897
Total PBwait: 0.0
Len of boarded group 19
Len of ToBoard_Que 0
Final event list: [('PArr', 15.457070530917283)]

PASSENGER ARRIVAL EVENT @ 15.457070530917283
Tot pass: 20
Final event list: [('HBE', 15.457070530917283), ('PArr', 16.366303347477665)]

PASSENGER BOARDING EVENT @ 15.457070530917283
Total PBwait: 0.0
Len of boarded group 20
Len of ToBoard_Que 0
Final event list: [('PArr', 16.366303347477665), ('HDE', 15.457070530917283)]

BUS DEPARTURE EVENT @ 15.457070530917283
Final event list: [('PArr', 16.366303347477665), ('BArr', 25.096254960931333)]

PASSENGER ARRIVAL EVENT @ 16.366303347477665
Tot pass: 21
Final event list: [('BArr', 25.096254960931333), ('PArr', 16.42451662275281)]

PASSENGER ARRIVAL EVENT @ 16.42451662275281
Tot pass: 22
Final event list: [('BArr', 25.096254960931333), ('PArr', 17.689922313456773)]

PASSENGER ARRIVAL EVENT @ 17.689922313456773
Tot pass: 23
Final event list: [('BArr', 25.096254960931333), ('PArr', 18.12521642067819)]

PASSENGER ARRIVAL EVENT @ 18.12521642067819
Tot pass: 24
Final event list: [('BArr', 25.096254960931333), ('PArr', 19.78509266241881)]

PASSENGER ARRIVAL EVENT @ 19.78509266241881
Tot pass: 25
Final event list: [('BArr', 25.096254960931333), ('PArr', 20.313645067450576)]

PASSENGER ARRIVAL EVENT @ 20.313645067450576
Tot pass: 26
Final event list: [('BArr', 25.096254960931333), ('PArr', 22.56198823265413)]

PASSENGER ARRIVAL EVENT @ 22.56198823265413
Tot pass: 27
Final event list: [('BArr', 25.096254960931333), ('PArr', 22.732780069643965)]

PASSENGER ARRIVAL EVENT @ 22.732780069643965
Tot pass: 28
Final event list: [('BArr', 25.096254960931333), ('PArr', 26.38954431073386)]

BUS ARRIVAL EVENT @ 25.096254960931333
Final event list: [('PArr', 26.38954431073386), ('HBE', 25.096254960931333)]

PASSENGER BOARDING EVENT @ 25.096254960931333
Total PBwait: 8.729951613453668
Len of boarded group 1
Len of ToBoard_Que 7
Total PBwait: 17.40168995163219
Len of boarded group 2
Len of ToBoard_Que 6
Total PBwait: 24.80802259910675
Len of boarded group 3
Len of ToBoard_Que 5
Total PBwait: 31.779061139359893
Len of boarded group 4
Len of ToBoard_Que 4
Total PBwait: 37.09022343787242
Len of boarded group 5
Len of ToBoard_Que 3
Total PBwait: 41.87283333135318
Len of boarded group 6
Len of ToBoard_Que 2
Total PBwait: 44.40710005963038

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Len of boarded group 7
Len of ToBoard_Que 1
Total PBwait: 46.77057495091775
Len of boarded group 8
Len of ToBoard_Que 0
Final event list: [('PArr', 26.38954431073386)]
