CSCI 1933 Project 4 Report

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Introduction

This project tries to solve a problem encountered by an increasingly more popular bus route. Since the number of people who choose to take this bus increased remarkably recently, the old bus system can no longer satisfy the demand of the whole passengers. Under such circumstances, a solid and reasonable report describing the status quo as well as the influence derived from corresponding modifications of relevant variables is of outmost importance for the bus company. Therefore, this project tries to apply java program to simulate the operation of the whole bus system in order to find out results derived from different changes to the system variables such as bus number, bus size and passenger load. With the data gathered from the simulation processes, the company can decide which bus size or how many buses to implement facing different loads represented by different passenger arrive intervals so that both the company's interests represented by passenger miles per gallon as well as passengers' utility represented by average travel time can arrive at their optimizations.

The java program which focuses to solve this problem apply one class to simulation every part of the problem. According to the problem described above, the problem can be clearly divided into two general parts. The first part is the objects in this problem such as buses, passengers and stations along the bus route. The second part is for the events in this problem. Since the this bus system is dynamic, everything is changing as the moving forward. Therefore, there are lots of events during the process such as buses arrive at stations or passengers start waiting at stations. The third part is a schedule on which the events happening or are going to happen will be properly recorded. The last part is to gather necessary information. In the java program, three classes called Passenger, Stop and Bus are used to represent the three components of the first part of the problem. Besides, two classes named PassengerEvent and BusEvent are established to simulate the events when buses arrive at certain stations or passengers start waiting at certain stations. Then a class called BusSim whose instances contain variable of priority queue type to represent the schedule. In order words, this schedule also play the role of the engine to push the whole system move forward. Finally, a class denoted by name Stat has been set up to gather and modify necessary information so that useful results can be displayed after the termination of the program.

After the code has been run for different inputs, several conclusions have been generated which are listed as follows:

1. When the bus size is fixed, as the number of bus increase, the average travel time as well as the passenger miles per gallon both decrease. However, the average travel time decrease dramatically at the beginning but much smaller when the number of bus is really large. The change of passenger miles per gallon has similar pattern except that the decrease doesn't suddenly slow sown.
2. When the passengers arrive interval increases, in other words when the load of the system decreases, the system still operate in the similar manner as described in point 1.
3. When extend the total simulation time, the system still operate in a similar manner, except that when the bus size is chosen, if the number of bus is really small for instance if there is only 1 bus, then when the simulation time increases, both the average travel time as well as the passengers miles per gallon will have a

remarkable increase as the time extends. However when the number of bus is really large than such increase tends to fade away.

4. Given two types of capacity of buses 40 and 60, when average travel time is similar, smaller bus tends to have higher passenger miles per gallon.

Presentations of Findings

The following several tables contain the data findings derived from different combination of system variables. Among the tables, table 1 and table 2 display the change of simulation results as bus number increases given default passenger arrive interval and bus size fixed at 120 seconds per passenger and 40 separately. Table 3 and table 4 describe the simulation results as the bus number increases when bus size and default passenger arrive interval are fix at 60 and 120 seconds per passenger separately. Table 5 and table 6 are two tables with bus size fixed at 40 and default passenger arrive interval be set to 140 seconds per passenger and 160 seconds per passenger separately, then the simulation results are derived as bus numbers increases. Table 7 and 8 are two table with bus size and default passenger arrive interval fixed at 40 and 120 seconds per passenger but table 7 provides the information when simulation time is 10000 seconds and table 8 reveals the data found when simulation time is 30000 seconds. Similarly, table 9 and table 10 are basically the same as table 8 and table 9 except the bus size in these two tables is fixed at 60.

Table1
Default passenger arriving interval = 120
Bus size = 40

Bus numbers	1	2	3	4	5	6	7	8	9
Total simulation time (seconds)	20001	20022	20005	20004	20016	20015	20002	20034	20010
Total passengers in the system	1845	1854	1858	1859	1846	1851	1826	1827	1847
Total passengers arrived destinations	781	1485	1693	1707	1724	1753	1738	1731	1752
Average travel time (seconds)	4779.0	2468.1	1469.7	1304.0	1211.4	1025.6	1001.8	1025.6	977.7
Maximum travel time (seconds)	16143	13779	4741	3361	3210	2492	2487	2448	2454
Average waiting length	30.0	11.1	3.8	3.0	2.6	1.7	1.5	1.5	1.4
Maximum waiting length	144	93	27	20	19	13	11	14	14
Maximum waiting time (seconds)	15022	12909	4538	2026	1960	934	831	957	961
Average people on bus	33.2	29.2	22.4	16.5	12.6	10.6	9.0	8.1	7.1
PMPG	199.5	175.3	134.6	98.8	75.4	63.7	54.0	48.9	42.3

Table 2
Default passenger arriving interval = 120
Bus size = 40

Bus numbers	10	11	12	13	14	15	16	17	18
Total simulation time (seconds)	20004	20004	20004	20003	20004	20004	20016	20010	20010
Total passengers in the system	1835	1848	1875	1841	1836	1830	1834	1844	1839
Total passengers arrived destinations	1744	1752	1786	1762	1768	1750	1752	1761	1765
Average travel time (seconds)	959.6	951.4	890.5	862.9	857.1	841.4	823.8	819.7	798.1
Maximum travel time (seconds)	2690	2418	2192	2194	2111	2064	2130	2088	1941
Average waiting length	1.3	1.3	1.0	0.9	0.8	0.7	0.7	0.6	0.6
Maximum waiting length	11	12	10	7	7	8	7	6	6
Maximum waiting time (seconds)	968	904	484	473	492	467	450	444	205
Average people on bus	6.3	5.8	5.4	5.3	4.6	4.2	3.9	3.8	3.6
PMPG	38.1	35.0	32.5	31.6	27.2	25.4	23.5	22.7	21.7

Table 3
Default passenger arriving interval = 120
Bus size = 60

Bus numbers	1	2	3	4	5	6	7	8	9
Total simulation time (seconds)	20010	20004	20014	20016	20004	20004	20004	20004	20004
Total passengers in the system	1834	1815	1822	1866	1797	1822	1853	1846	1797
Total passengers arrived destinations	1022	1612	1698	1725	1672	1713	1761	1756	1721
Average travel time (seconds)	4404.8	1947.7	1412.4	1275.7	1110.9	1005.6	978.9	958.0	898.7
Maximum travel time (seconds)	16839	5937	3676	3324	2924	2381	2375	2475	2153
Average waiting length	22.9	5.7	3.3	2.8	2.0	1.5	1.4	1.4	1.0
Maximum waiting length	121	27	21	16	15	11	11	14	7
Maximum waiting time (seconds)	15341	5005	2065	1824	1443	695	918	992	447
Average people on bus	44.7	34.3	22.4	16.4	12.5	10.4	9.14	7.9	6.8
PMPG	178.9	137.3	89.4	65.5	50.0	41.7	36.6	31.7	27.2

Table 4
Default passenger arriving interval = 120
Bus size = 60

Bus numbers	10	11	12	13	14	15	16	17	18
Total simulation time (seconds)	20004	20022	20016	20004	20010	20004	20028	20004	20016
Total passengers in the system	1836	1852	1821	1834	1852	1850	1817	1860	1826
Total passengers arrived destinations	1757	1776	1751	1753	1771	1770	1738	1780	1750
Average travel time (seconds)	890.7	874.5	872.2	847.9	837.1	827.5	825.1	812.4	792.4
Maximum travel time (seconds)	2123	2137	2142	2050	2130	2217	2054	1995	1928
Average waiting length	1.0	0.95	0.9	0.8	0.8	0.7	0.7	0.6	0.5
Maximum waiting length	10	9	8	7	9	8	7	6	7
Maximum waiting time (seconds)	466	403	422	428	474	492	442	462	205
Average people on bus	6.3	5.8	5.3	4.8	4.5	4.2	3.9	3.8	3.5
PMPG	25.3	23.0	21.0	19.0	18.0	16.8	15.6	15.0	13.8

Table 5
Default passenger arriving interval = 140
Bus size = 40

Bus numbers	1	2	3	4	5	6	7	8	9
Total simulation time (seconds)	20006	20003	20013	20002	20008	20019	20018	20006	20006
Total passengers in the system	1570	1531	1539	1599	1583	1584	1546	1537	1561
Total passengers arrived destinations	814	1295	1382	1462	1486	1505	1471	1447	1487
Average travel time (seconds)	4496.7	2251.9	1653	1403.3	1147.2	1005.2	985.1	943.5	886.6
Maximum travel time (seconds)	14879	11429	5203	3327	3296	2256	2365	2369	2136
Average waiting length	21.0	7.2	4.3	3.0	2.0	1.3	1.2	1.1	0.9
Maximum waiting length	108	59	32	20	16	9	10	7	8
Maximum waiting time (seconds)	13924	10789	5763	1818	1785	687	831	750	415
Average people on bus	32.7	26.8	18.0	14.0	10.8	9.1	7.6	6.6	5.8
PMPG	196	160.7	108.2	84.0	64.8	51.6	45.6	39.5	35.0

Table 6
Default passenger arriving interval = 160
Bus size = 40

Bus numbers	1	2	3	4	5	6	7	8	9
Total simulation time (seconds)	20010	20008	20016	20005	20003	20007	20008	20008	20008
Total passengers in the system	1341	1371	1353	1341	1325	1352	1307	1356	1328
Total passengers arrived destinations	782	1189	1203	1245	1245	1295	1247	1293	1267
Average travel time (seconds)	4180.8	1990.3	1524.1	1344.3	1105.0	1026.5	968.0	915.4	890.9
Maximum travel time (seconds)	14534	7690	5243	3240	2632	2347	2374	2349	2136
Average waiting length	16.2	5.0	3.5	2.3	1.5	1.2	1.0	0.9	0.8
Maximum waiting length	94	36	24	15	10	8	8	9	5
Maximum waiting time (seconds)	13726	7053	4532	1831	1154	634	676	715	399
Average people on bus	31.1	24.5	15.3	11.7	9.0	8.0	6.5	5.7	5.0
PMPG	186.4	147.2	91.9	70.1	54.1	48.0	38.7	34.0	30.2

Table 7
Default passenger arriving interval = 120
Bus size = 40
Simulation time = 10000

Bus numbers	1	3	6	9	12	15	18
Total simulation time (seconds)	10002	10014	10008	10008	10002	10008	10008
Total passengers in the system	926	943	935	945	923	948	930
Total passengers arrived destinations	870	793	833	866	842	873	860
Average travel time (seconds)	2954.0	1450.1	1008.5	871.5	861.0	837.4	795
Maximum travel time (seconds)	8569	3870	2358	2154	2146	2099	1941
Average waiting length	15.0	3.6	1.6	1.1	1.0	0.7	0.5
Maximum waiting length	60	18	10	10	11	7	5
Maximum waiting time (seconds)	7890	2038	643	431	417	436	200
Average people on bus	31.4	21.4	10.5	6.7	5.1	4.3	3.5
PMPG	188.4	128.5	63.1	40.5	30.5	25.9	20.8

Table 8
Default passenger arriving interval = 120
Bus size = 40
Simulation time = 30000

Bus numbers	1	3	6	9	12	15	18
Total simulation time (seconds)	30012	30006	30005	30003	30012	30012	30006
Total passengers in the system	2706	2752	2765	2751	2792	2747	2742
Total passengers arrived destinations	1210	2579	2657	2661	2700	2659	2667
Average travel time (seconds)	6092.2	1475.9	1042.8	907.4	904.1	847.9	810.0
Maximum travel time (seconds)	26245	3832	2573	2171	2264	2180	1947
Average waiting length	41.8	3.7	1.7	1.1	1.2	0.8	0.6
Maximum waiting length	228	22	13	8	10	8	5
Maximum waiting time (seconds)	25840	3363	603	486	588	526	209
Average people on bus	33.0	22.5	10.8	7.2	5.3	4.2	3.6
PMPG	203.2	135.0	64.9	42.8	31.6	25.4	21.4

Table 9
Default passenger arrive interval = 120
Bus size = 60
Simulation time = 10000

Bus numbers	1	3	6	9	12	15	18
Total simulation time (seconds)	10008	10002	10008	10008	10002	10001	10020
Total passengers in the system	909	940	925	920	915	924	921
Total passengers arrived destinations	440	804	822	844	834	849	849
Average travel time (seconds)	2959.0	1398.1	1001.1	861.9	870.4	829.7	789.3
Maximum travel time (seconds)	8051	3207	2385	2117	2188	2111	1950
Average waiting length	12.5	3.3	1.5	1.1	0.9	0.7	0.6
Maximum waiting length	54	20	9	9	6	8	8
Maximum waiting time (seconds)	7585	1588	633	424	425	429	204
Average people on bus	40.7	22.3	10.3	6.7	5.1	4.1	3.4
PMPG	162.9	89.1	41.2	26.7	20.4	16.6	13.6

Table 10
Default passenger arriving interval = 120
Bus size = 60
Simulation time = 30000

Bus numbers	1	3	6	9	12	15	18
Total simulation time (seconds)	30006	30012	30006	30012	30003	30010	30018
Total passengers in the system	2734	2779	2766	2781	2723	2827	2781
Total passengers arrived destinations	1578	2607	2669	2658	2677	2730	2712
Average travel time (seconds)	5375.0	1467.3	1027.2	900.6	892.2	848.0	800.7
Maximum travel time (seconds)	24411	3835	2445	2173	2217	2192	1947
Average waiting length	32.0	3.6	1.6	1.1	1.0	0.8	0.6
Maximum waiting length	177	30	12	8	9	8	6
Maximum waiting time (seconds)	23139	2414	880	452	579	569	205
Average people on bus	47.3	22.9	10.9	7.1	5.2	4.4	3.6
PMPG	189.2	91.9	43.7	28.6	20.8	17.5	14.2

Actually, table 1 and 2 show the whole picture of the simulations results when bus size is 40 and default passenger arriving interval is 120 seconds per passenger. Meanwhile table 3 and table 4 display the whole picture of the simulation results when bus size is 60 and default passenger arriving interval is 120. In these four tables, we can see that when bus size is fixed, as the number of buses in the system increases, both average travel time and passenger miles per gallon decrease. One very remarkable feature of the decrease is that the speed of decrease slows down as the bus number increases. At the beginning stage when there are only several bus, every one increase of bus number will cause significant decrease in both these two data, however, when the bus number is already very large, an little increment of bus number won't change the data a lot. But compare the decrease scale between average travel time and passenger miles per gallon, it's easy to detect that the decrease of average travel time slows down faster than the value passenger miles per gallon does. In other words, after a certain number of increase of the bus number, average travel time is nearly constant with little tendency to decrease while passenger miles per gallon still seem to decrease in little scale.

Comparison the data in table 1 and table 3 as well as tale 2 and table 4 can provides information about how bus size influences the results of average travel time and passenger miles per gallon given passenger arriving interval and bus number fixed. According to the data presented in these four tables, it's easy to find that larger bus tend to have smaller average travel time and lower passenger miles per gallon. But since the goal is to maximize passenger miles per gallon meanwhile minimize average travel time, we can compare situations with different bus sizes but similar average travel time. For instance, if compare table 1 with total 5 buses and table 3 with total 5 buses it's easy to find the although the average travel time is similar, the passenger miles per gallon for smaller bus case is much more higher then the larger bus case. On the contrary, compare table 1 total 4 buses and table 3 total 3 buses, it's easy to detect that both case have similar passenger miles per gallon at around 90 however the average travel time in smaller bus case is relatively lower than the larger bus case. Several different combinations such as table 1 total 6 buses and table 3 total 4 buses or table 1 total 7 buses and table 3 total 5 buses also support this rule.

Table 5 and table 6 are used to verify the results of situations when the load of the system changes, how relative simulation results will change correspondingly. Load in this project is represented by the default arriving interval of passengers. As shown in table 5 and table 6, the change of averages travel time as well as passenger miles per gallon still act in the similar manner that they both decrease rapidly at the beginning stage and then slows down but average travel time slows down faster than passenger miles per gallon. Since the simulation results after total 9 buses are really flat, which means the changes are really small, it's unnecessary to put the whole table here. The first 9 cases starting from 1 bus to 9 buses are sufficient enough to support the findings in the first four tables. Therefore, the cases for 10 buses to 18 buses for both tables are ignored.

Finally, table 7 to table 10 is a verification trying to demonstrate the stability of the simulation system. Among these four tables, table 7 and table 8 are used to present the changes of test results derived from changes in simulation times when bus size is 40 while table 9 and table 10 are use to show the changes of test results derived from changes in simulation times when bus size is 60. The reason to choose these total bus amount is that in this cases, the distribution of buses can be set equally manually. Since the simulation time extends, there exists the possibility that the some buses may catch up the one in front of them. If these happened, it will influence the test results. Therefore, choose to equally distribute bus will largely avoid this awkward situation. Since this is a discrete simulation program, not a continuous simulation, one can't assign a number somewhere between two integers to represent bus locations, therefore, by choosing numbers that can divide 18 is one solution. As shown in these four tables, the findings generated from table 1 to 4 still applies here. Besides, compare table 7 with table 8 or table 9 with table 10, when the only independent variable is simulation time, then when bus number is small there is a huge difference of average trade time and the passenger miles per gallon between short simulation time and long simulation time. But when the total bus number increases, these difference tend to be smoothed over.

Proof of Correct Result

First to proof that the simulation system is at equilibrium, the best way is to extend the simulation time. as shown in table 7 to table 10, when load and bus size are fixed, as simulation time increases, the test results for average travel time have little difference when the numbers of bus are really large. But when the number of bus is small for instance if there is only 1 bus in the system, then as simulation time increases, both the average travel time as well as the passenger miles per gallon increase remarkably. The reason why this happen is that when there is only small amount of bus, the carrying capacity of the system is much less then the load of the system. In other words, the load be implemented to this system requires much stronger carrying capacity than what it really has. Therefore, more and more people get into the system waiting at the bus stations until they get in to the front of the queue and get ride when there is some vacancy in the bus. Therefore, as described in the table, the main contribution to such a large difference in the average travel time for the system with different simulation time is the maximum waiting. It is equal to say that people still have similar ride time in these two cases, however, in longer simulation time case, the passengers spend more time waiting before they get into the bus. Therefore, it is easy to predict in this case, if the simulation time keep increasing, then the average travel will keep increasing since more and more people cumulate at bus stations with only one bus going around. And average people on bus will tend to be the bus size therefore, the passenger miles per gallon will tend to maximum. But when it comes to the case when there are lot of buses in the system, then there do have subtle increases in the average travel time as well as the passenger miles per gallon, but such increase can be reasonable since the average arriving interval for passengers is 120 seconds at each station, but the least running time for a bus between two stations is 195 seconds. Let's consider the case when there are 18 buses which is the maximum amount of bus this system can possess. Even in this case which you are sure that after at least 195 seconds, there will be bus appear at a certain station, there will be more than 1 passenger arrive at this station joining the queue either going eastbound or westbound. Therefore, as time moves forward, there is a tendency also super slight for the queue at each station to cumulate. As long as this tendency exists, then assume the simulation time becomes very large, then people will start to form queues at each stop. And the waiting time is the main source for the increase of average travel time. Also, there is a better way to testify the statement above, that is to set the running time for bus to be 120 seconds between. In this case, if there are 18 buses running in the system, then whatever the simulation time is, the average travel time will be around 500 seconds and passenger miles per gallon will be around 9. Therefore, it’s solid to believe that the java simulation system can correctly represent the real situation.

It is also very important to measure the reasonableness of the output we gathered. Let’s start from total passengers involved in the system. Since the appearance of a passenger at a certain stop is determined by the PassengerEvent class and how long the next passenger will appear is based on the interval. Therefore, it’s necessary to take a deep look at the chooseInterval method in the PassengerEvent class. In this method, the program will first generate a random integer between 1 and 100. According to the captain probability different integer values will generate different operations on the interval which will be set as the time it takes for the next passenger event to happen in this station. Since our default passenger arriving interval is 120 seconds and since the expectation of interval is 120 seconds, then the passengers involved in the system in 20000 seconds should be around 20000/120 which is 167 for each stations. Since there are 10 stations along the bus route and considering that there are three downtown stations where passengers arrive 30 seconds faster than the normal stations therefore the reasonable passengers involved in this system during

20000 seconds period should be 7 * (20000/120) + 3 * (20000/90) = 1833. Then take a look at the total passengers, it’s somehow around this number. The total passengers arrive at destination is increasing as the number of bus in the system increases which make sense since more buses represent the stronger ability to carry passengers. Also compare the case when bus size is the only independent variable then if everything stays at the same, larger bus case will always have more passengers arrive at their destinations than small bus cases, which still make sense since larger size of the bus means stronger ability to carrying passengers. For the average travel time, it decreases as the number of buses be put into the system increases. But during the first several increase of the bus amount, it decreases dramatically, If we combine the result of average people on bus, then the change of average travel time is reasonable since if there is only few buses then the bus will be very crowded and if you add even one more bus into the system, then the average people on bus will largely decrease which in turn will let more people waiting at station get into bus and this will lead to a decrease in the waiting time as you can see for the change of average waiting length. Since the travel time is the summation of ride time and wait time then the decrease in waiting time will lead to decrease in travel time. And the change of average waiting length should be corresponding to the change of average travel time since waiting tine is the only determination of travel time (ride time between stations are basically the same). Here in this project, the three variables which are maximum waiting time, maximum waiting length and maximum travel time are not actually very good index to represent the real situation. The reason is that this project apply a discrete simulation approach to simulate the real cases, then the distribution of buses really matter. Think about the case when there are two buses in the system, both of them are heading the same direction and they are at adjacent stations. then the one waiting at the one station before the second bus will wait nearly whole round to get on the bus. But if two buses are equally distribute, then this passenger only need to wait for half round, which is much better than the previous one. Therefore, the three maximum index are not very good criterion. But when looking at general tendency, then these three indexes still represent the real case. they all decrease as more and more buses be put in to the system and they also decrease as the bus size becomes larger. Finally, as for the passenger miles per gallon, It is bound with the value of average people on bus. For different bus size, simply times the average people on bus with its corresponding miles per gallon will generate the result. Then as you see in the tables, all values of PMPG are several times of the value of average people on bus. And as the amount of buses be put into the system increases, the bus will become less crowded which means the PMPG will also decreases. The data in the tables verify the real case.

Summary of Findings and General Recommendations

After analyzing the data listed in tables shown above, we can draw following conclusions:

1. Increasing the amount of buses in the system can decrease the time people spend to travel, however, the effect also decreases as the amount of bus increases.
2. Expand the bus size can cut down the time people spend to travel, however, for large bus case, the energy efficiency for each bus will be lower than the one in small bus case.

3. For two cases both provide passengers with similar average travel time, the one applies large bus will have lower energy efficiency for each bus, however the advantage is that it can use less buses.
4. If the load of the system changes, the results will have similar manner.

Finally, let's summary the general trend of some important variable in the system.

1. If the load of the system increases then keep bus number and bus size fixed, average travel time as well as passenger miles per gallon for each bus will both increase.
2. If everything stays at the same level except the number of bus increases, then both the average travel time and passenger miles per gallon will decrease.
3. If everything stays at the same level except the bus size increases, then both the average travel time and passenger miles per gallon will decrease.