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Bus Simulation Report

Introduction

The bus simulation program yielded results that the organizers of Bus Route 3 will likely find interesting and useful. The difficulty with choosing a ratio of express buses to regular buses lies in the fact that the inter-arrival rate of passengers differs from stop to stop and by the time of day. While a bus company could minimize the wait time for customers by having a bus at every other stop, this would be costly given the low amount of riders on each bus. Thus, the simulations attempted to identify the ideal ratio between regular and express buses that reduces the average wait time for passengers as much as possible while maintaining a reasonable average bus load relative to each bus' capacity of 50 riders.

Approach

Each simulation had a set number of regular buses and express buses, with the lowest possible amount of regular buses being 0 and the highest number of total buses being 14 (one every other stop). The program ran a simulation for each of the 105 possible bus configurations at 3 different average passenger inter-arrival rates ("loads"). This load was simply a baseline value since different stops, obviously, deviated from this baseline value at random. This process was repeated 3 times (for accuracy), making a total of 945 simulations. Statistics such as the average bus load, average wait time for passengers, average bus ride time, and number of passengers delivered, were tracked.

Minimizing Wait Time

Between the two goals mentioned previously (minimizing wait time and maximizing average bus load), the program put an emphasis on the former. This is because while filling up buses is important, customer satisfaction is, as most companies would agree, the number one priority. Thus, the program printing out statistics about the simulation, of the 945 performed, with the lowest average customer waiting time upon the program's completion. Here are some results gleaned from the program running once:

Statistics for rush hour:

- The simulation with the best average wait time, 238.46747126436782 seconds (3.9744578544061304 minutes), had a maximum wait time of 482.5 seconds (8.041666666666666 minutes) and a maximum line length of 95 people.
- Of the 7 regular buses and 7 express buses, the average bus load was 38 riders across 504 total bus rides.
- Of the total 5952 potential bus riders (throughout all 30 of the stops), this simulation delivered 3670 of them with an average ride time of 18.14223433242507 seconds.

Statistics for off-peak hours:

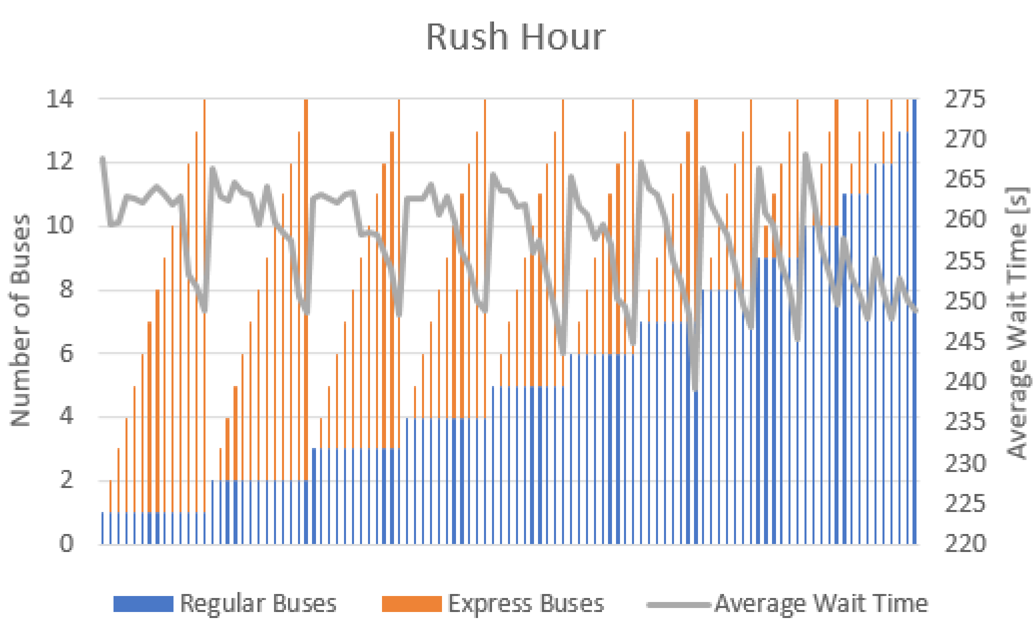
- The simulation with the best average wait time, 57.85407407407408 seconds (0.9642345679012346 minutes), had a maximum wait time of 317.0 seconds

(5.283333333333333 minutes) and a maximum line length of 25 people.

- Of the 1 regular buses and 12 express buses, the average bus load was 12 riders across 509 total bus rides.
- Of the total 1482 potential bus riders (throughout all 30 of the stops), this simulation delivered 1137 of them with an average ride time of 4.952506596306069 seconds.

The program also gave statistics for a “medium” load in-between peak hours and off-peak which are not included here, for brevity’s sake. The program also returned the simulation with the worst average wait time for each of the 3 load values. This, too, is not included in the report because the bus configuration for these simulations were, predictably, always 1 regular bus and 0 express buses (the lowest amount of buses possible) and, therefore, does not represent useful data. The bus configuration for the best average wait time was constant after each program as well. Every time, the best ratio was 7 regular buses and 7 express buses for peak hours but only 1 regular bus for off-peak hours. Thus, this is what one would expect to see when graphing the data across all the simulations.

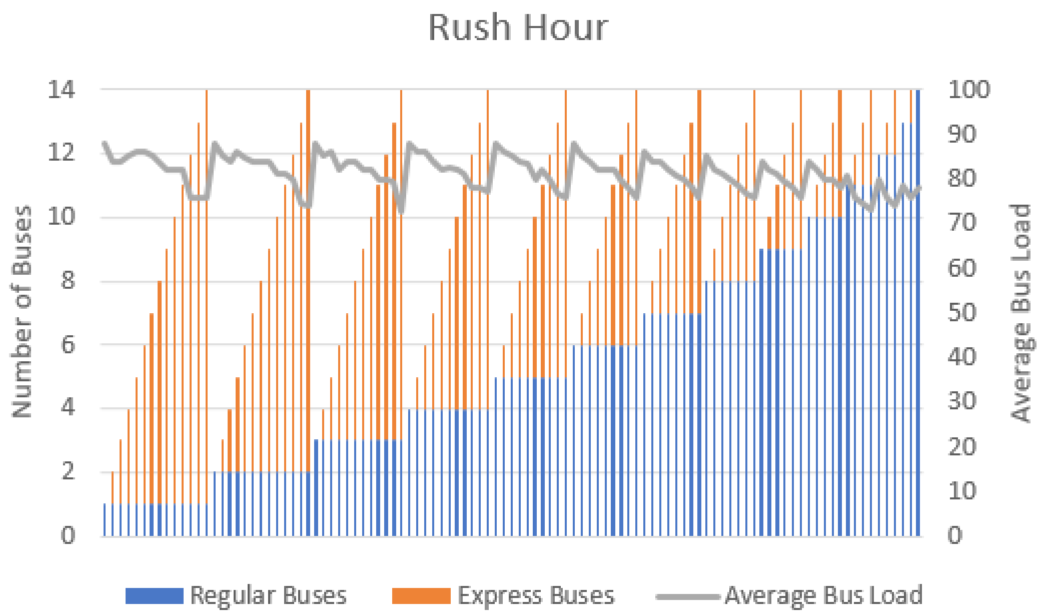
Each time a passenger object was added to a bus, the time they spent waiting for it was added to a queue (which was used because of its ability to grow without needing to be resized). After each simulation, these values were averaged and added to a 3-dimensional array that tracked the number of regular buses for that simulation, the number of express buses, and the average waiting time for bus riders. Since the system was repeated 3 times, each unique regular bus/express bus combination had 3 time values associated with it for a given load. These values, then, were averaged as well. The data for the smallest of the 3 loads (rush hour) can be seen below. Note vertical axis on the right represents the range of the average wait times (which the grey line plots) while the one on the right represents the range of the number of buses for a given bus (with blue lines representing regular and orange one representing express).



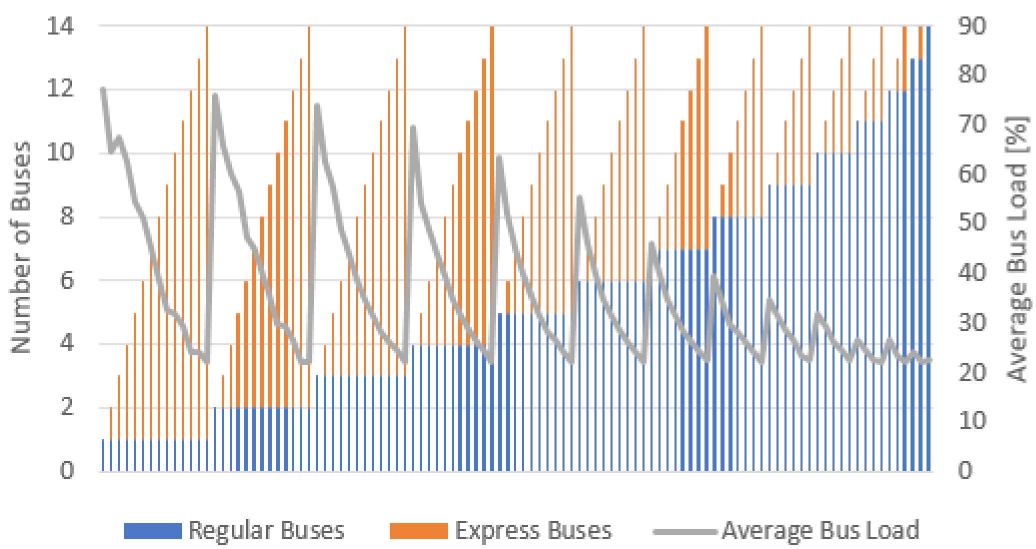
The graph spikes downward, predictably, whenever the amount of buses on the route is at a maximum, regardless of their configuration. Still, these spikes becomes more dramatic around the middle, when the amount of regular buses is slightly higher than the amount of express buses. The graph also displays a clear downward trend, overall, at the end of the graph, when the bus configuration is almost entirely made up of regular buses. Thus, the message is clear: regular buses are more valuable for reducing customer waiting time than express buses during peak hours.

Maximizing Bus Loads

Still, it's important to make sure that the buses are reasonable full. Let's take a look at this exact same graph, but modeling the effect of the bus configuration on the average bus load:



Once again, the graph spikes downward, albeit more slightly, whenever the amount of buses on the route is at a maximum. till, the average bus load remained fairly constant for every configuration. Since the numbers on the right represent percentages of the total capacity (50), the average bus load was around 80% for most configurations during rush hour. Still, this could perhaps be attributed to an overly large supply of passengers during this time. The same graph for off-peak hours looks like:



As one can see, the average bus load is much more variable during off-peak hours due to lower passenger inter-arrival rate. The more express buses that were utilized, the lower the average bus load. Thus, express buses are *also* less valuable than regular ones for maximizing the average load. The solution is not maximizing regular buses, however. As the graph makes clear, too many buses will reduce the average bus load. While the first half of the graph shows peaks that don't decrease too much, the second half begins to trail away. Thus, the buses should be made up of primarily the regular variety but shouldn't extend past about 7 of these regular buses if a company wishes to maximize the average bus load during off-peak hours.

Conclusion

If a company cannot change their bus configuration throughout the day (less buses during off-peak hours, for example), then the results of the simulation indicate that the best bus ratio is roughly 5 regular buses and 2 express buses. Since the passenger inter-arrival rate is at it's quickest and slowest, respectively, during "rush" hours and "slow" hours, they are the only times a company must worry about. While the average bus load deviated sharply depending on the bus configuration during off-peak hours, the average wait time didn't deviate much during peak hours. This means that 5 regular buses (which is relatively low) would succeed in producing a reasonable average bus load without sacrificing too much efficiency. The results also indicate, furthermore, that express buses aren't very useful during either peak or off-peak hours. Thus, the number of express buses should be kept fairly low. These reasons, combined, resulted in this final bus configuration ratio.