Traffic Congestion and Possible Methods for Relief

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1 Introduction

The problem of traffic congestion has been a difficult task that many have tried to solve over a long time. Longer travel time caused by congestion frustrates not only the drivers but also the environment due to higher emission from vehicle idling. Many teams in different cities have attempted to resolve congestion through various efforts such as applying higher congestion toll fees, ironically reducing roads or transforming intersections to the form of a roundabout. Through this paper, I, first, have developed a traffic model starting from a simple one-way model to a two-way model, and further traffic road that closely resembles the NYC road structure. Secondly, I analyzed the performance of various means to reduce congestion in the one-way model. By the word "means" in the previous sentence, I refer to the methods that have a basis on Braess's paradox and giving out traffic information to every driver about the traffic density to the paths. Lastly, this paper ends with a conclusion and further potential studies.

2 Explanation for Model

First, we need to construct a traffic system to compare advanced methods. Our one-way traffic model will be a simple model that has the following features: Our model is N by N structure that has 2N inlets and 2N outlets. The direction of traffic flow is to East and South. In other words, the car is not allowed to have a destination that is located in the upper or more West position. For example at figure 1, it is impossible for the car that is generated at the block between nodes 18 and 4 to have a destination of 19 or 20. Further, the numbering of blocks is similar to numbering the intersection. For vertical blocks, exemplary blocks would be that block 1 connects intersection 1 and 2, Block 2 connects 2 and 3, Block 7 connects 8 and 9 and the rest follows the same rule. For horizontal blocks, exemplary blocks would be that block 31 connects 36 and 2, Block 32 connects 37 and 3 and follows the same rule for the rest.

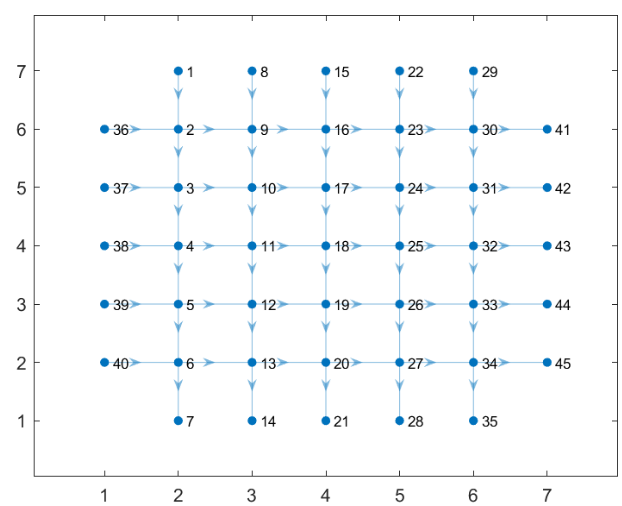

Figure 1: Sample image of N = 5 one-way traffic model

2.1 Parameters

Since in this simple one-way model the length is all the same to 1, the generation of the new car depends entirely on the equation $rand < R * dt$. Rand function refers to the uniformly distributed random number between (0,1). the bigger R * dt is, the higher the probability the car will generate. if R*dt is too low, then the car would be generated less frequently which will result in no congestion. However, the previous surmise is not the desired consequence. Since our model aims to first generate congestion and resolve the problem, I set the rate parameter R to .5 and time step parameter dt to .1 to generate sufficient cars to create necessary congestion.

2.2 Steering Algorithm

For the performance comparison between methods, I borrowed and set Professor Peskin's algorithm[1] which decides the next block for cars as a benchmark for performance comparison. When a car approaches an intersection, it has to choose a block that leaves the intersection. The natural choice is to choose one that brings you the most nearly towards the destination. To determine the block, evaluate the vector from the intersection to the destination, and then the dot product of that vector with the unit vectors of the blocks connected and exiting the intersection. The one that maximizes the dot product will be the choice of the driver. MATLAB code for the algorithm is written below.

$$xd(c) = xi(i1(bd(c))) + pd(c) * ux(bd(c))$$

$$yd(c) = yi(i1(bd(c))) + pd(c) * uy(bd(c))$$

$$xdvec = xd(c) - xi(i)$$

$$ydvec = yd(c) - yi(i)$$

$$dp = ux(bout(i, 1 : nbout(i))) * xdvec + uy(bout(i, 1 : nbout(i))) * ydvec$$

3 Simulation

As we expected from the beginning, the benchmark model will result in traffic congestion as below.

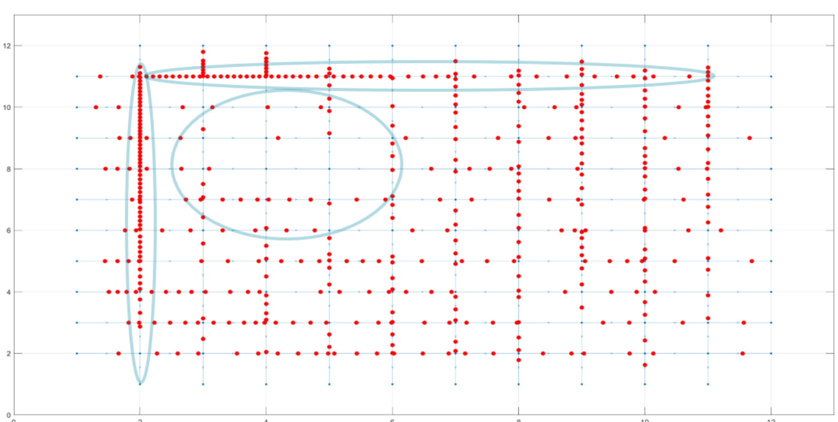

Figure 2: Congested traffic

There is severe congestion at the blocks near the inlets due to the high volume of a car generates. To resolve the current phenomenon, we are going to divide this section into several parts. First, we are going to compare the time taken for each algorithm with a given number of cars to measure how long does it takes(in the simulation phase) to finish the 500 cars. Then, we are going to experiment with Braess's paradox by subtracting each block and analyze which block has the most impact and which block has the least.

3.1 Optimizing Path Algorithm

It would be logical for drivers to drive in the fastest route to their destinations. For most people, the fastest route would be interchangeable with the route with the least number of cars on the road. Therefore, we are going to give each driver information about the traffic ahead. When the driver decides the next block to turn to, we update the number of cars remaining for the blocks ahead of the driver. The method will be calculating the number of cars in the next n blocks and choose the fastest path which in this case will be the route with the least number of cars. Also, another question to address is that if we are going to consider the traffic ahead of us, to which extent are we going to consider? Calculating the traffic of the entire path sounds inefficient in this case, first because of the speed of the codes and second because the traffic situation of roads that are further away would have relatively less impact to the overall travel time.

If you look at the result table in Appendix 6.1, we can see that considering the traffic actually increases the time periods taken. Presumably, it is because of the nature of our model which is 2-in, 2-out. The algorithm does not consider the potential drivers who are scheduled to go into the same block at the same time. Drivers that are at different blocks but are entering into the same intersection will have the same information which will drive them to make the same decision, which can likely cause another congestion that is worse than the previous. For the question of to which extent, we can confirm that adding the traffic information of the all blocks remaining makes the congestion worse. Considering the traffic of just one block ahead has the maximum performance among all.

Now we know that there is room to develop, we are going to implement the advanced method to calculate the traffic situation. we are adding the potential drivers as a consideration too. 'After Adjustment' column of the same table shows the result after implementing the potential drivers into the algorithm. It's average time periods taken is definitely lower than other options, however, it still takes more periods than the original algorithm.

3.2 Removing Blocks

Now we know that adding additional traffic information only causes traffic to be more congested, we are going to test Braess's paradox by removing blocks to see if the removal enhance the traffic or not as Braess's claims. First of all, we are going to remove the blocks that are not inlets and outlets. As provided in Appendix 6.2, the minimum average time taken for removing one block, which is removing block number 26 and on average of 4330.5 time periods taken, is nearly the same as the result from the original setting. Therefore, I am concluding that for this specific one-way traffic model, the removal of a block does not mitigate the traffic congestion.

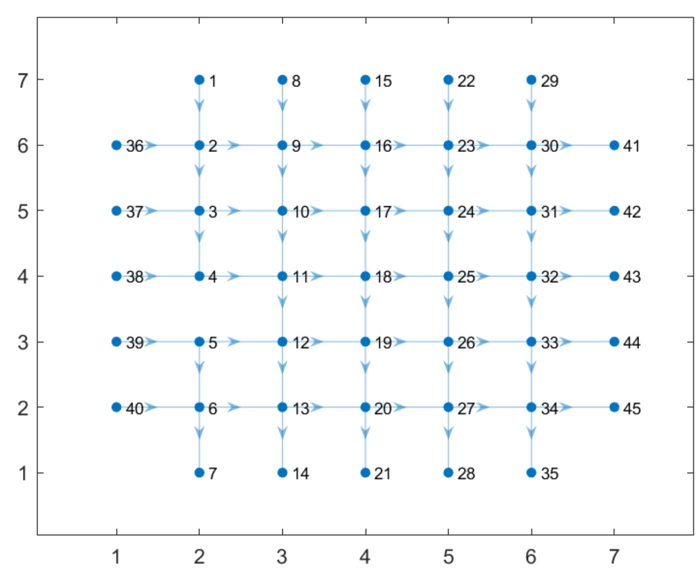

Figure 3: Example Image of Removing Block Number 4

4 Conclusion

Even though commuters are suffering from excessive congestion every day, it might be the case that the current situation is the most optimal situation of all possible methods. Through this paper, I have explored a few methods with a hope to mitigate the current traffic congestion that many cities are suffering. From the simulation and data provided in Appendix, I have concluded that the additional traffic information given to the driver would only cause more congestion and removing a block would not greatly resolve or even worsen the current traffic status. This research contains many things that need further development. For instance, I have not explored the option of adding roads to the current model which might soothe the traffic congestion. Furthermore, the model can be developed more interestingly by adding a collision algorithm that will block the blocks for a few periods after an accident occurs. I have uploaded my version of two-way and NYC traffic model in my **GitHub**.

5 Acknowledgement and Reference

This project would not be possible without Professor Charles Peskin's insightful lectures and notes on the Traffic Simulation. I would like to show my sincere gratitude to Professor Charles Peskin and Guanhua Sun for amazing instruction and guidance throughout the Fall 2019 semester.

[1] Charles S. Peskin. (2017). Notes on Traffic Simulation

6 Appendix

6.1 Time Periods Taken for Steering Algorithm Optimization

Iteration	Original	Next 1 Block	Next 2 Blocks	Next 3 Blocks	All Paths	After Adjustment
1	4345	5698	5507	5949	6037	5367
2	4467	5172	6643	6344	5864	5455
3	4286	5406	5808	5878	6134	5148
4	4132	5150	5666	5412	4957	5318
5	4360	5502	6118	5857	6178	5029
6	4372	5545	5761	5961	5817	5633
7	4710	5101	5748	5757	5723	4999
8	4559	5352	5041	5255	6309	5628
9	4330	5094	5399	5742	5621	5567
10	4431	5131	6157	6000	5573	5585
11	4169	5781	6007	5551	5423	5307
12	4363	5314	6033	5368	4709	5396
13	4563	5273	5626	6033	6096	4990
14	4413	5687	5654	6061	6118	5172
15	4458	4995	5883	6181	6370	4995
16	4257	5453	5925	5367	5963	5269
17	4432	5177	5449	6031	6401	5144
18	4463	5642	5630	5964	6220	5472
19	4442	5721	5955	5994	5822	5763
20	4243	5192	6213	5585	5766	5144
21	4190	5651	6170	5887	6121	5000
22	4308	5821	5665	5745	6213	5623
23	4665	5769	5818	5421	5421	5505
24	4281	4940	6021	6211	5443	5374
25	4552	4824	5839	6075	5309	5304
26	4512	5674	5071	6088	6034	5257
27	4284	5242	5551	5091	6500	5440
28	4538	5278	5342	5711	5697	4933
29	4175	5572	5629	5226	5382	5184
30	4209	4945	5987	5673	5990	4848
31	4247	4951	5542	5244	6011	5213
32	4372	4840	6151	5785	6139	5124
33	4282	5282	5337	5682	6401	5055
34	4269	5471	5557	5923	6188	5648
35	4384	5439	5244	5629	5773	5755
36	4216	5426	5155	6063	5877	5648
37	4490	4738	6311	6481	6496	4999
38	4392	5482	5269	5647	4839	5212
39	4256	5467	5949	5684	6186	5128
40	4313	5811	6108	5956	6044	5186
41	4395	5229	5204	5522	5720	5026
42	4247	5486	6345	5610	6385	5020
43	4512	5221	5515	6407	5647	5368
44	4305	5040	6229	6228	5991	5228
45	4221	5371	5309	5344	6410	5501
46	4433	5359	5970	5716	6180	5188
Average	4364.78	5341.34	5751	5782.86	5903.24	5283.36
Std	132.51	292.42	388.37	319.59	410.43	248.84

6.2 Time period taken for Removal of Blocks

Block Number Removed	1	2	3	4	5	6	7	8	9	10	Average
2	5672	5462	5590	5766	5408	5471	6019	5265	5229	5322	5520.4
3	5340	5480	5392	5587	5616	5462	5998	5563	5416	5283	5513.7
4	5752	5632	5571	5414	5770	5803	5552	5333	5775	5281	5588.3
5	4982	5268	5234	5471	5310	5355	5469	5041	5413	5494	5303.7
8	4682	4544	4537	4536	4730	4389	4458	4777	4527	4289	4546.9
9	4349	4680	4595	4614	4725	4367	4532	4761	4587	4188	4539.8
10	4901	4822	4535	4538	5084	4915	4793	5403	4656	5382	4902.9
11	4990	4557	4550	4915	4246	4717	4434	4861	4671	4831	4677.2
14	5073	4943	5120	4924	4593	4844	4691	4672	5181	5132	4917.3
15	5031	4904	5067	4882	5109	5232	4963	4997	4825	5237	5024.7
16	5576	5345	4830	5520	4537	5036	5251	5202	5148	5470	5191.5
17	5504	5472	5916	5219	4946	4895	5294	5571	6005	5694	5451.6
20	5397	5670	5724	5841	5662	5745	5915	5523	5497	5773	5674.7
21	5109	5926	5479	5276	5315	5614	5724	5466	5672	5655	5523.6
22	5377	6094	5301	5855	5907	6720	6294	6500	6262	5519	5982.9
23	6005	6192	6417	6434	5851	5282	6161	5794	5474	5696	5930.6
26	4511	4346	4227	4328	4245	4328	4298	4194	4392	4436	4330.5
27	4114	4349	4339	4480	4433	4590	4418	4533	4291	4503	4405
28	4424	4579	4945	4955	4831	5185	4666	4580	4662	4957	4778.4
29	4792	5908	5513	5416	5966	5024	5567	5067	5362	5448	5406.3
36	4176	4450	4489	4648	4596	4221	4233	4597	4703	4406	4451.9
37	4801	4632	4428	4781	4371	4238	4769	4527	4607	4720	4587.4
38	4908	4906	4996	5192	5305	5064	4770	4651	5140	4765	4969.7
39	5140	5573	5921	5698	5358	5508	5574	5838	5679	5573	5586.2
40	4216	4394	4502	4045	4212	4452	4465	4489	4260	4416	4345.1
41	4156	4721	4642	4390	4705	5028	5142	4600	4650	4902	4693.6
42	4761	4532	4464	4770	5227	4691	4454	4582	4789	4456	4672.6
43	5307	4516	4935	5200	4934	4977	4629	5182	5026	4630	4933.6
44	5333	5501	5780	5801	5192	5338	5421	5485	4769	5301	5392.1
45	4685	4298	4380	4363	4347	4700	4385	4745	4382	4374	4465.9
46	4780	4789	4958	4702	4906	4811	4434	4378	4631	4485	4687.4
47	5055	4540	5220	4880	4503	4939	4569	4805	4950	4572	4803.3
48	5113	5478	5054	4643	5316	4538	4858	5568	5042	5000	5061
49	6171	5770	5313	5486	6579	5934	5735	5188	5162	5925	5726.3
50	4790	5481	4722	4998	4908	4887	4369	4545	5021	5072	4879.3
51	5339	4795	4583	4438	4797	4504	4822	4459	4654	4868	4725.9
52	4906	4973	4634	4869	4653	4776	4602	4584	4687	4683	4736.7
53	4715	5203	5187	4978	4709	5531	5326	5467	4777	4775	5066.8
54	5677	5957	6277	5917	5947	5982	5653	6029	5556	5837	5883.2
55	5344	5005	5388	5369	5884	5218	5596	4960	4948	5204	5291.6

6.3 Image of NYC traffic model

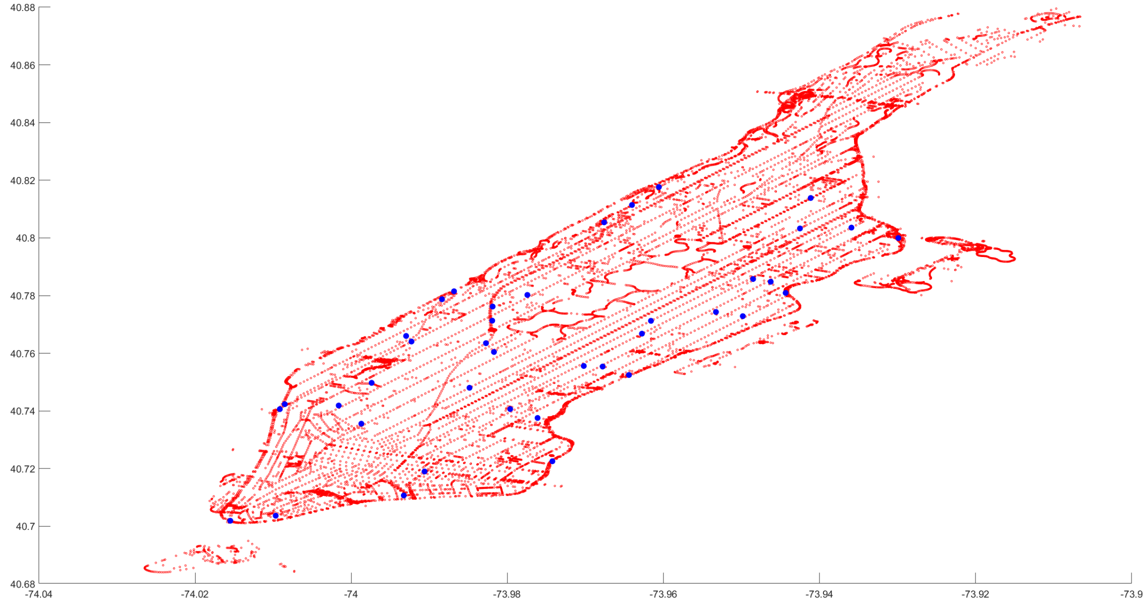

Figure 4: Example Image of Removing Block Number 4