# Traffic Simulation

Colette Brown

Minerva Schools at KGI

## Single Lane Simulation

### Flow Over Time

In *Figure 1* the traffic flow for a single lane simulation over time is modeled for three different densities: 0.1, 0.5, and 0.9. Each simulation is run 20 times for the same parameters on a road of length 50 (default) to demonstrate the effect the density has on overall patterns within the system. These visualizations are showing the traffic after the car has moved, before the velocity is updated, which is why there are slight variations between these and those presented by Nagel and Schreckenberg. For the lowest density simulation, cars flow smoothly and every car reaches maximum velocity during the final update step. Traffic jams begin to appear for density 0.5, and are extreme for density 0.9. These show that the more cars on the road, the more traffic jams appear – a phenomenon attributable mostly to random slowing of cars on the road. Without the specified probability of a car slowing down randomly, we would expect to see free flowing traffic in every simulation – cars would simultaneously accelerate.

### Flow and Density

The traffic flow rates for different densities are modeled below in *Figure 2*, showing the average flow rate and the 95% confidence interval for each density. It is clear that there is a maximum flow rate between 0.6 and 0.7 close to a density 0.18. The maximum value shows that there must be a high enough number of cars to show sufficient flow, while not enough cars to slow and hinder the flow of other cars, reducing overall flow rate. The steady decline beyond the peak shows a linear relationship between density and flow, which makes sense intuitively – the more cars on the road, the less they will flow.

## Double Lane Simulation

### Model and Assumptions

The double lane cellular automaton for a double lane model uses the update rules for forward and backward motion in the same way as a single lane model. The differences between the two lie in how the model decides on switching between the lanes – defined in the paper as well. The simulation begins at the "top left", where the first road begins, and checks for the rules described below, and if all conditions are met, the car changes lanes.

Rules:

1. If the gap between the current car and the car ahead in the same lane is less than the velocity of the current car plus one.
2. If the gap between the current car and the car ahead in the other lane is greater than the velocity of the current car plus one.
3. If the gap between the current car and the car behind the current position in the other lane is greater than the maximum velocity.
4. If the same position in the other lane is not filled.
5. And given a number less than a specific probability.

Once every car has an updated lane the update function is used to calculate the new position and velocity of the car.

### Flow Over Time

In *Figure 3* the traffic flow for a double lane simulation over time is modeled for three different densities: 0.1, 0.5, and 0.9. Each simulation is run with identical parameters to a single lane simulation, and has similar emergent patterns. The difference is that the two lane simulation seems to move marginally better for higher densities, although the flow and density comparison figure shows this, numerically, is not the case.

### Flow and Density

The traffic flow rates for different densities are modeled below in *Figure 4*, showing the average flow rate and the 95% confidence interval for each density. Similar to a single lane simulation, the maximum flow rate is around 0.6 close to a density of 0.18.

## Comparisons

The images showing flow over time (*Figures 1* and *3*) do not show a large deviation between the patterns that emerge in one versus two lanes. These results are confirmed by the graphs comparing flow rate and density (*Figures 2* and *4)* for the two simulations, which show a similar maximum value and an inverse relationship beyond the maximum. These results are particularly surprising when comparing to my intuition – more lanes on a freeway should accommodate a higher traffic flow. This intuition relies on the fact that cars can use lane changing methods to optimize their speeds. In a single lane model it is understandable to have large traffic jams, but in multiple lanes, the hope is that cars are able to anticipate when they might be slowed and try to switch lanes in an attempt to avoid these slow downs.

In this model I was unable to complete a 3 lane (or more) simulation, and therefore do not have results showing the difference in traffic flow for varying densities. Seeing how the model did not change significantly between a one lane and a two lane model, I would assume the three lane would not change much either, but I am tempted to believe a three lane model would provide a significant enough difference. This relies on the assumption that all cars have an equal probability of going to a lane on either side (for the lane in the middle), which would allow for more options to optimize the position of the car in different lanes, allowing the overall flow to be optimized for higher densities.

## Hyderabad and Beyond

Traffic in Hyderabad provides the most extreme deviation from this simple model. Where I only model two lanes and single cell cars moving orderly within a confined system, the traffic in Hyderabad required changes in the type and speed of different vehicles, on and off "ramps" randomly shown in widening and shortening the width of roads. The possibilities for expanding this model to incorporate differences in the infrastructure – on/off ramps, sidewalks, added lanes, lane merging – and human behavior – accidents, stopping on the road, slowing down extremely are endless, but I touch on a efw below. In Hyderabad, there are key differences that illuminate how this model could be extended.

1. Vehicle Type: This model supports a cellular automata grid where each cell is representative of a car or an empty space. In Hyderabad, people ride rickshaws (⅔ the side of a car), motorcycles (⅓ the size of a car), trucks (2 the size of a car), and sometimes tractors (4 the size of a car).
2. Velocity: These different vehicles provide one means of extending our model, as they also have varying velocities. The motorcycles have a much higher velocity compared to the tractors slugging around on the side of the road, and this has implications for the slinky style traffic jams we see in the higher density models in *Figure 1*.
3. Lanes: In Hyderabad there simply are no lanes – cars are freely able to travel anywhere on the road (or sidewalk) that has free space. This might be particularly useful for modeling in conjunction with the aforementioned differing vehicle types, as small vehicles are best able to take advantage of this difference. Motos are regularly seen scraping between two larger vehicles, tractors taking over 3 lanes with no regard to other drivers on the road. The modeling implications are endless when the grid size must be adapted to accommodate a free moving motion.

4. Behavior: The only way behavior is represented in this model is through the probability of randomly slowing down. This random slow down, as mentioned above, is what causes the traffic jams to begin, as cars are able to slow and force a ripple in deceleration for each vehicle behind. To incorporate human behavior, particularly in Hyderabad, recklessness is more likely than order – people using their cell phones and causing random deceleration beyond -1, switching "lanes" without regard to the velocity or position of vehicles behind them in the neighboring lane, and the men who stop on the side of the road to go to the bathroom on a dusty highway.
5. Obstacles: Now I don't know much about Cape Town, South Africa, but I think I can fairly assume a traffic model would not have to include obstacles in the shape of cows. Regardless of the type of obstacle – accidents on the side of the road in South Africa or cows wandering the city in Hyderabad – they exist in every city and provide perfect cells and points to force decisions from the drivers. It might be interesting to model a predictive behavior for individuals who see or anticipate obstacles and act accordingly – switching lanes, decelerating, or leaving the road completely.

## Figures

```
Single Lane Traffic Simulation (Density: 0.1)
......1.....5...................3..0............4
....5...2........5...............2.1............
.......3..2...........5............1..2..........
.........2...3.............5.........2..2.........
...........3....4..............5.....1....3......
...............4.....5..............5..2......4..
..5..................5.....5.........1....3......
.......5.................4......5......2......4..
..5.........5................4.......5.....3......
.......5........4................4........5....4..
..5.........5......4................5.......4...
4.....4..........5.....4..................5......
.....5.....5..........5......5.................4..
..5.......5....5.........4.......5...............
.......5.......5...4..........5......4...........
...........5......4....5..........5......5......
...............4.......5....5.........4.......5.
...5..................5......4......5.........5....
5.......5.................5.....4.......5.........
.....5.......5................4......5.......5....
5.........5.......5...............5......5......
('Traffic density:', 0.1)
('Average traffic flow:', 0.45)
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Single Lane Traffic Simulation (Density: 0.5)
.04.5...4...153.....53....121.1..1.0..40.3....32.0
.0.1...3...300...3..0....400.1..2.1.1.0.1...3.0.10
10...2....300.1...1..1...00.1.1.0..1.10..1...1.10.
0.1....2..00.1..2..1...2.0.1.1.1.1..10.1..1..0.0.1
.1..2....200...2..2..2..1.1.1.1.1..20.1.1...2.1.10
1..2...3.00.1....2.1..1..1.1.10...20.1.1..2..1.10.
.1....30.0.1..2...1..2..2.10.0.1..0.1.1.1...20.0.1
1..2..0.1.1.1....3..2..2.10.1.1.1.0..1.1..2.0.1.1.
..2..2.1.10...2...1..1..10.1.10.0..1..1..2.10..1.1
1..1..1.10.1.....3..2..200..10.1.1...2..2.10.1..1.
..2..2.100...2.....2..200.1.0.1.1..2...2.10.1..20.
....2.100.1.....3...1.000..1.1.1..2...3.100..1.00.
.....100.1..2......30.00.1..1.1..2...3.100.1..10.1
.2...00.1..2..2....00.0.1.1.0..1....3.100.1..20.1.
...2.0.1.1...2...3.0.1.1.1.1.1...2...100.1..200..1
.2..1.10...2....3.1.1.1.1.1.1..2...2.00.1..2000...
...2.100......3.0..1.10..1.1..2...3.100..1.000.1..
....100.1......10...10.1..1..2..2.0.00.1..100.1..2
.2..00.1..2....0.1..00...2..2..20.0.0.1..200.1.1..
..1.0.1.1....3..1..20.1....2.1.00..1.1..200.10...2
1..1.1.1..2....2..20.1..2...1.10.1..1..2000.00....
('Traffic density:', 0.5)
('Average traffic flow:', 0.4)
```

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Single Lane Traffic Simulation (Density: 0.9)
.4..0.1..22.4325531.0.1.225113...5.23.005.03.1.505
1..2.1..20.1000000.1.1.100000...3.10.100.10.1.100.
..2.1..20.10000000..10.00000.1...10.100.10.1.100.1
.2.1..20.10000000.1.00.0000.1.1..0.100.10.1.100.1.
2.1..20.100000000..10.1000.1.1.1..100.10.1.100.1..
.1..20.100000000.1.0.1000.1.10...200.10.1.100.1..2
1..20.100000000.1.1.1000.1.10.1..00.10.1.1000...2.
.1.0.100000000.1.1.1000.1.10.1..20.10.10.000.1...1
..1.1000000000..1.1000.10.0.1..20.10.10.100.1..2.0
1..1000000000.1.0.000.100.0...20.10.100.000..1.0..
..2000000000.1.1.100.100.1.1..0.10.100.100.1..1.1.
2.000000000.1.1.1000.00.1.1..20.00.00.1000...2.1..
.1000000000..1.1000.100..1..20.100.0.10000....1.1.
2000000000.1.0.000.100.1...20.100.1.100000....0...
000000000.1.10.000.00.1..2.00.00.1.100000.1....1..
000000000..10.1000.0.1.1..10.10.1.1000000..1....1.
000000000..0.1000.10..1..20.10.1.1000000.1...2..0.
000000000...1000.10.1...20.10.1.10000000...2..1..1
00000000.1..0000.0.1.1..00.0.10.0000000.1....2..20
0000000.1..2000.1.10...20.10.0.1000000.1..2....200
000000.1..2000.1.10.1..0.100..1000000.1..2...3.000
('Traffic density:', 0.9)
('Average traffic flow:', 0.35)
```

Figure 1: Single lane traffic simulations showing the flow of traffic over time for different densities.

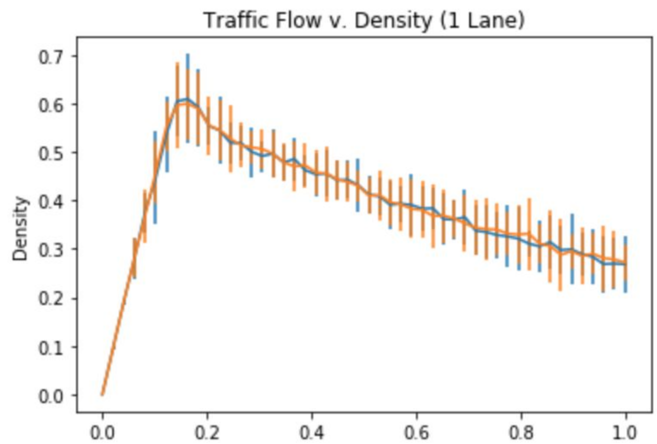


Figure 2: Single lane traffic simulations showing how the traffic flow varies in relation to a number of different densities between 0 and 1.

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Double Lane Traffic Simulation (Density: 0.1)
..........5.....0......1....................33....
.......................4..3........4...4...5......

..............4..1......1...............5...0....4
........................1.....4...........3.....5.

....5..............2......2...............2..1....
...5...............5......2........5.........3....

.........5...........2.......3..............2..2..
........5...............5...3.........4.........4

3.............5.........3........4............2...
....5........5..............4...4..........5.....

....4..............5........4........4...........3
.........5........5.............4....4...........5

...4.....5..............5........5........5.......
....5........4.........5............4.....5.......

........5.....5..............5........5.......4...
.........5........5........4.............5.....5..
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```
Double Lane Traffic Simulation (Density: 0.5)
..0.1....310.3..5......35.4....2.213......43.....3
...43500........11.0..32...1..4...........0.21.4.0

.2.1..2..000..1.....4..0.1....4.100....4..0....4..
1..0000.1.......0.10..0...3.1......5.......10.1.1.

..1..2.1.000....2.....2.1..2...100.1.....2.1.....2
.1.0000...2......100...1..0...2.........5..0.1.1.1

.2..20..100.1.....2...0...2...300.1..2....1.1.....
1.1000.1.....3...00.1....2.1.....3.......1..1.10..

..1.0.1.000...2......3.1.....3000..1...2..0...2...
.1000.1..2......30.1..2...1..2.......4.....20.0.1.

...1.1.1000......3....1..2...000.1...2...20......3
2000.1.1....3...0.1..2...3..2...3.........50.10...

..3.1.1000.1.........4.1....3000...2...2.00.......
000.1.1.1......3.1..2...3..2...3....4.....0.10.1..

...1.1000.1..2.......0...2..0000.....2..10.1......
00.1.1.1..2.....1.1....3..2...3....4.....5.10.1..2
```

```
Double Lane Traffic Simulation (Density: 0.9)
4...5025.11.3..01040112.0...43.1...151....55352.30
..53421.120.403.21.451.233.0....235115.2.3.510....


...3000.100...20000000.1.1..0.1..2.00..2..0000.100
..0000.1000.00.100.00.100.1.1...00000.1.10.000....


1..0000.00.1..0000000.1.1..2.1..2.10.1..1.0000.00.
..000.10000.0.100.10.100.10...2.0000.1.10.100.1...


..2000.100...2000000.10..1..1.1..10.1..2.1000.10.1
..000.00000..100.10.1000.0.1..0.0000..100.00.1.1..


.20000.00.1..0000000.0.1...2.1..200...2.1000.100..
..00.10000.1.000.0.10000..1..2.1000.1.00.10.10...2


.0000.10.1..2000000.1.1..2.0...2000....1000.1000..
.20.10000.1.100.1.10000.1...2.1000.1.10.100.0.1...


.0000.0.1..2000000.1.1..2.1.1..000.1...000.1000.1.
.0.10000.1.100.1.10000.1..2..1000.10.0.100.1.1..2.


20000..1..2000000.1.1..20.0..1.00.1..2.00.1000.1..
2.10000.1.100.1.10000.1..2..2000.100..100.1.1..2..
```

Figure 3: Double lane traffic simulations showing the flow of traffic over time for different densities.

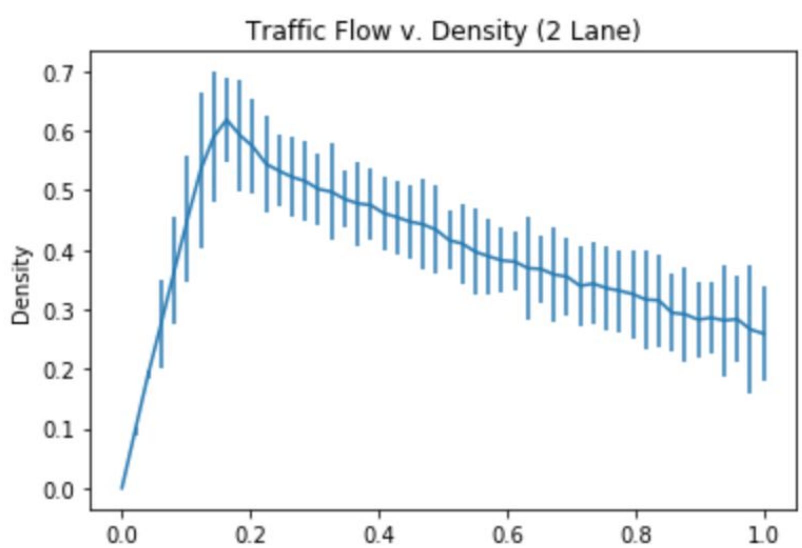


Figure 4: Double lane traffic simulations showing how the traffic flow varies in relation to a number of different densities between 0 and 1.