Using Agent-Based Modeling to Reduce Traffic Emissions

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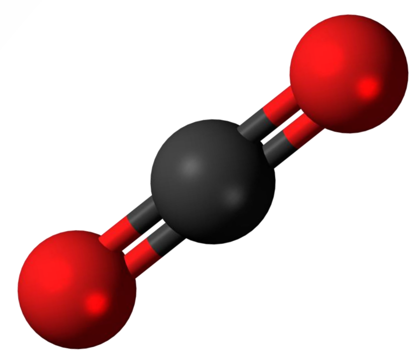
Introduction

Climate change is currently one of the most pressing issues facing humanity. A key goal in the effort to fight climate change is a reduction in the emissions of greenhouse gasses. The EPA estimates that transportation accounts for 29% of greenhouse gas emissions in the United States (EPA, 2023). Therefore, it is very important to understand how to reduce traffic CO_2 emissions. My big question in creating this model is:



What factors lead to increased or decreased CO_2 emissions from cars?

Many studies have already investigated this and found that emissions vary by the speed that cars drive. Emissions are lowest when cars drive between 50 and 80 kph, and increase if cars drive faster or slower (Alessandrini et. al, 2012).

My goal in this project was to create a model in the program NetLogo that could simulate traffic congestion to determine which conditions reduce CO_2 emissions. Specifically, I examined the interaction between four different factors:

Speed limit: Cars tend to produce the fewest CO_2 emissions when they drive between 50 and 80 kilometers per hour. Therefore, the speed limit of the road will have a major impact on overall emissions.

Traffic density: In general, if there are more cars on the road, cars tend to drive more slowly. This can either lead to an increase or decrease in CO_2 emissions depending on the speed limit.

Number of lanes: If there are fewer lanes, cars will be more tightly packed, which can lead them to drive at lower speeds.

Car accidents: Crashes can be a major disruption to traffic flow by blocking lanes and forcing other cars to merge to a different lane. This has the effect of increasing traffic congestion under certain conditions.

Existing Models

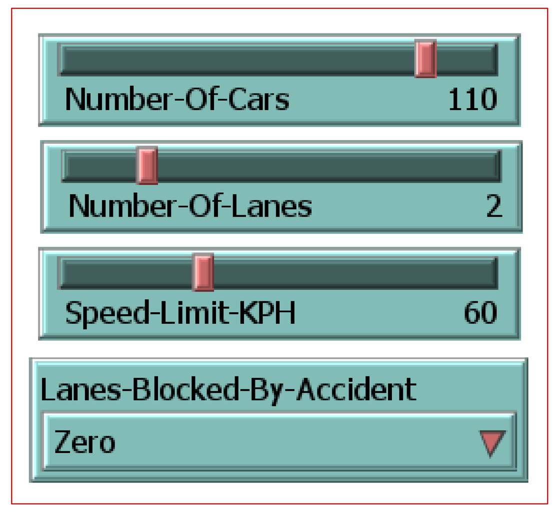
Many studies have already examined the factors that influence CO_2 emissions. These studies have several key takeaways.

Traffic congestion leads to increased emissions: A study examined the relationship between traffic congestion and greenhouse gas emissions in the city of Mumbai, India. The study found a nearly 1-to-1 relationship between increased travel times and increased CO_2 emissions (Bharadwaj et. al, 2017).

Greater traffic density leads to greater congestion: Another study found that an increase in the number of cars on the road led to an increase in travel times, indicating greater traffic congestion (Bani Younes and Boukerche, 2015).

More lanes leads to decreased congestion: One study found evidence that increasing the overall number of roads and lanes has the effect of decreasing congestion (Ewing et. al, 2018). Another study had similar findings despite using a completely different approach (Tsekeris & Geroliminis, 2013).

My Model



The NetLogo model contains four different variables that can be modified by the user. These different variables are as follows:

Number-Of-Cars: Determines the number cars on the road at a given time.

Number-Of-Lanes: Changes the number lanes on the road.

Speed-Limit-KPH: Sets the "speed limit" for the road, dictating the maximum speed cars can drive.

Lanes-Blocked-By-Accident: Determines whether any lanes are blocked in a way that simulates a car accident.

When the model is set up, a certain number of cars and a certain number of lanes are created based on user input. When the "Go" button is hit, the cars begin to move forward. CO_2 emissions are calculated at every tick for every car based on its speed. The data used for calculating emissions based on speed can be found in Figure 3 of "Driving style influence on car CO_2 Emissions," by Allesandrini et. al.

Methods

There were two different experiments performed for this analysis.

Experiment 1: The variable "Number-Of-Lanes" was varied from 1 to 6 by an increment of 1; the variable "Number-Of-Cars" was varied from 60 to 120 by an increment of 10; and the variable "Speed-Limit-KPH" was varied from 30 to 120 by an increment of 10.

Experiment 2: All variables were varied as they were in the first experiment, except that "Lanes-Blocked-By-Accident" was now set equal to "One." Additionally, the variable "Number-Of-Lanes" was varied from 2 to 6 by an increment of 1. Two repetitions were performed for each combination of variables in both experiments.

Results

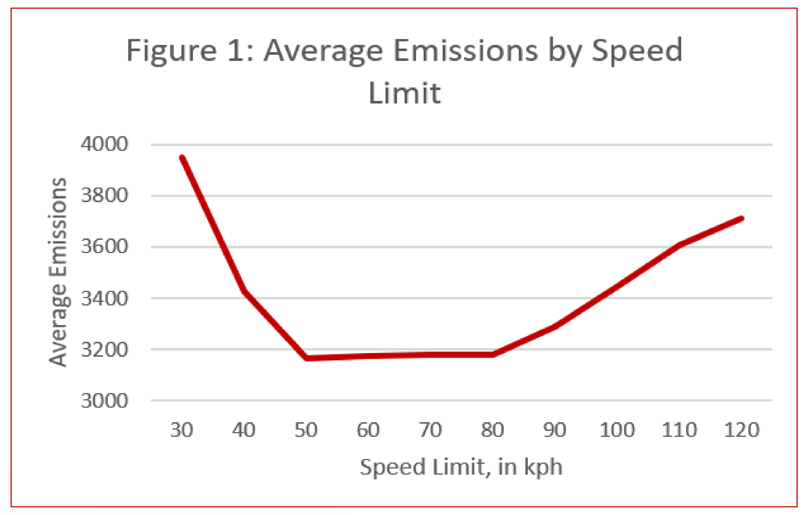


Figure 1: Speed limit is by far the greatest contributor to overall emissions, with 50 to 80 kph producing the least emissions.

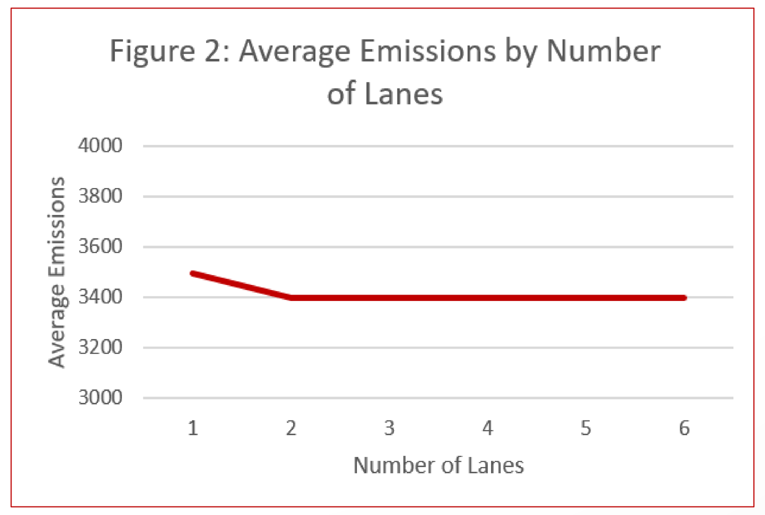


Figure 2: Having more than one lane of traffic seems to be beneficial, although there is a point of diminishing returns.

Results - Continued

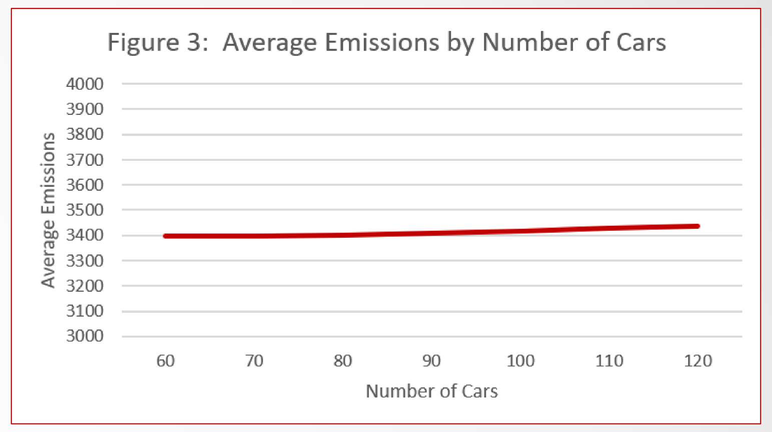


Figure 3: It is slightly more efficient for there to be fewer cars on the road at a time.

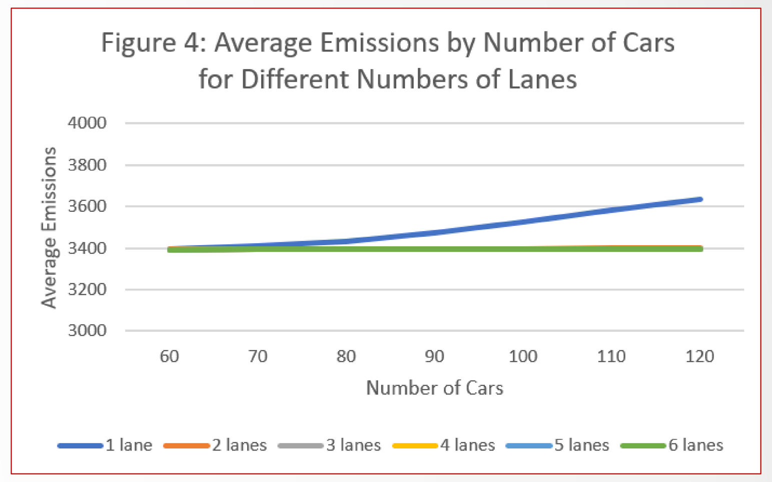
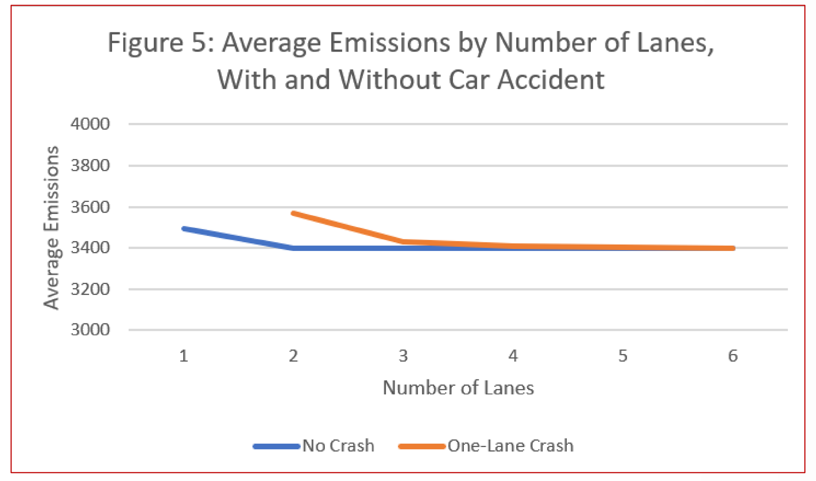
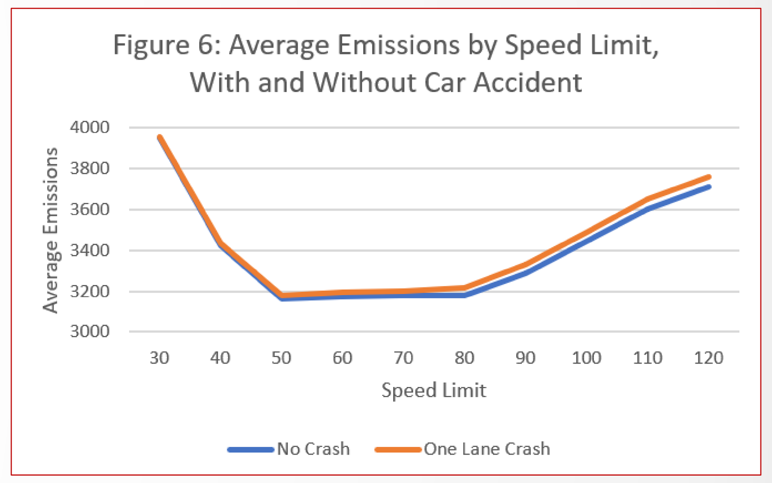


Figure 4: When there is only one lane, emissions increase significantly as the number of cars on the road increases.

Figure 5: A car crash blocking one lane of traffic led to a significant increase in emissions when there were only two lanes on the road.

Figure 6: A car crash increases emissions by a greater amount when the speed limit is higher.





Discussion

The analysis identified two main factors that influence car CO_2 emissions.

Speed limit: The main factor that influences CO_2 emissions among cars is the speed limit. In order to minimize emissions, the speed limit should be set to somewhere between 50 and 80 kph. However, even slight decreases in high speed limits can lead to decreases in emissions. Reducing the speed limit from 120 kph to 110 kph would result in a 2.9% decrease in emissions.

Number of lanes: The number of lanes on the road also has an impact on traffic emissions. Based on my model, increasing the number of lanes from one to two decreases CO_2 emissions by 2.8% on average. When traffic density was high, adding a second lane reduced CO_2 emissions by 6.5%. Additionally, when a car accident blocked one lane of the road, having three lanes reduced emissions by 4.1% compared to only having two.

This a fairly uncomplicated model that makes some simplifying assumptions. However, this model provides an accurate representation of a simple road traveled by passenger vehicles, and stands as an effective tool to better understand traffic patterns and their effects on CO_2 emissions.

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