AGENT BASED TRAFFIC SIMULATIONS

Major Qualifying Project

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ABSTRACT

This paper concerns the exploration and implementation of agent based simulations of highway traffic conditions that are based on human psychology and personality. The pursuit of such a simulation is intended to provide insight into the meaning and implications of individual behavior and decision making on traffic conditions, and to explore how we might mathematically model such behavior.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Traffic engineering problems are extremely important issues for engineering safe and efficient highways in this country. There are a number of mathematical models that can be employed in simulations to provide insight into the mechanics of traffic behavior that cannot be empirically measured or predicted. The model implemented in this paper is an agent based simulation that simulates the position, velocity and behavior of each individual agent in the system. This type of model allows a user to carefully consider and design a set of realistic driving behavior for individual drivers.

CHAPTER 2

BACKGROUND

2.1 Typical Highway Properties

Empirical data on the subject suggests that for a highway that is experiencing free flow conditions, the speeds of cars on that highway tend to form a normal distribution[1]. In some cases bimodal distributions can be observed[2], but such conditions are thought to only occur when there is a large variance in speeds on a sufficiently densely packed highway, such as a number of tractors or three-wheelers.

The 85th percentile speed is a widely used figure in designing traffic systems. It denotes the speed at which 85% of cars travel below, which is one standard deviation above the mean for a typically normally distributed highway. The Manual on Uniform Traffic Control Devices, which is a Federal Highway Administration approved national standard for highway design, recommends setting the speed limit within 5 miles per hour of this 85th percentile. [3] Despite this recommendation, a study by the National Highway Traffic Safety Administration[4] showed that in 2009 a majority of drivers drove above the speed limit in each measured road class (limited access, major arterial and minor arterial).

2.2 Link Transmission Models

Link Transmission Method (LTM) is a Dynamic Network Loading (DNL) method for solving is a min-cost multicommodity flow problem. It is designed for macroscopic traffic simulation. It's general form is as follows. [5]

For network of i links, each link has a start x_i^0, end x_i^L, length L_i and are connected to nodes.

$N(x,t)$ - cumulative number of vehicles having passed position x at time t. The number of cars in link i at time t is $N(x_i^L,t) - N(x_i^0,t)$.

First in first out (FIFO) principles are observed. The simulation is run in time intervals Δt. The Courdrant-Friedrich-Lewy condition[6] states that this interval must be lower than the smallest link travel time, otherwise the solution may not be accurate.

The sending flow $S_i(t)$ is the maximum number of cars that could leave a given link during time interval $[t, t+\Delta t]$ if it were feeding into an infinite reservoir of cars. Likewise, the receiving flow $R_i(t)$ is the maximum number of cars that could enter a given link during time interval $[t, t+\Delta t]$ if it were fed from a infinite reservoir of cars.

The transition flow $G_{i,j}(t)$ is the number of cars that were transferred from link i to link j at time increment $[t, \Delta t]$.

The set of paths (commodities) of the graph is P.

The set of incoming links for node n: I_n and outgoing links: J_n.

Each time interval involves the following steps.

At each Δt, and for each node n:

1. $\forall i \in I_n, \forall j \in J_n$, find S_i, S_j, G_i, j
2. Determine $N(x_i^L, t+\Delta t) = N(x_i^L, t) + \sum_{j \in J_n} G_{i,j}(t)$
   and $N(x_j^0, t+\Delta t) = N(x_j^0, t) + \sum_{i \in I_n} G_{i,j}(t)$

At a given node n, the transmission flow as a general form for any intersection:
$G_{i,j} = p_{ij} min(min(\frac{R_j S_i}{\sum_{q \in I_n} p_{qj} S_q}), S_i)$
Where p_{ij} is the proportion of cars from link i going to link j.

The LTM model above can be augmented with intersection models that simulate car travel time delays for node updates. As it is above, vehicles are assumed to travel though intersections without delay. For increasingly dense areas, a model which does not incorporate such delays will fail to represent time spent driving.

The basic LTM model uses Kinematic Wave Theory (KWT) to calculate sending and receiving flows. The density and flow of a link can be determined by the cumulative numbers having entered and left it. A simplified fundamental diagram is used to bound these values by the maximum flow of a link. $S_i(t)$ and $R_i(t)$ require the boundary conditions of the link at the given time interval. Sending flow requires upstream boundary conditions and vice versa.

Because the LTM models use kinematic wave theory to simulate the flow of traffic, they are not useful in modeling individual driver behavior. To model such behaviors, an agent based simulation which models individual driver choices would be needed. Such a simulation is detailed for the scope it simulates, but much more computationally intensive than a KWT based simulation. The Link Transmission Models were developed as an evolution of the Cell Transmission models,[7] which were n times more computationally complex, for n being the average number of cells per link.[5]

In exploring the Link Transmission model, it becomes clear what an agent based simulation can offer which the LTM cannot. Because the LTM does not simulate individual drivers, it is not responsive to changes in the types of drivers on the road. If the critical density at which a highway starts to enter traffic jams changes based on certain behavior, an agent based model could therefore inform us which types of behavior drivers should emulate.

2.3 Driver Psychology

One of the main advantages of an agent based traffic simulation is the control it affords us over the behavior of individual vehicles. In order to make the most of this control it is necessary to understand various elements of driver psychology.

Information regarding a driver's ability to estimate their speed under various conditions has been recorded by M. A. Recarte and L. M. Nunes[8]. Divers have a tendency to underestimate their speed, especially when going slower. This estimation can be modeled by the given exponential function:

$ES = 0.2 * RS^{1.31}$

And linear function:

$ES = 1.09 * RS - 22.73$

The average estimation differed from the average actual speed by -14.8 kph, or -9.20 mph. Sex and driving experience had negligible effects on people's ability to estimate their speed. It's also quite interesting that drivers would estimate higher speeds after accelerating.

This study further provides models describing findings for how drivers produce an adjusted speed (AS) when attempting to reach a target speed (TS) in both linear and exponential form:

$AS = 3.92 * TS^{0.711}$

$AS = 0.77TS + 26.68$

Drivers tended to overadjust on average (5.4 kph), but start to underadjust as the target speed is larger. Drivers tended to decelerate less than they accelerate to adjust the same absolute difference in speed.

These results have interesting implications regarding the free-flowing vehicle acceleration, but are not implemented in our simulation as they would otherwise conflict with or replace our current acceleration model.

There are also a variety of studies which seek to characterize and measure the actions drivers perform when changing lanes[9]. Drivers are estimated to use 2.5 head movements on average during a lane change, corresponding to 3.7 seconds without and 6.1 seconds with traffic to visually survey their surroundings and prepare for a lane change. Although this is not implemented in our current simulation it would be a good subject to explore for the project in the future.

CHAPTER 3

METHODOLOGY

3.1 Methodology

Our simulation simulates a 5000 meter highway for 10 minutes, with .25 second time steps. Although we can design our own highway scenarios, our testing concerned this 5000 meter stretch with three lanes and an on ramp.

Our vehicles are spawned according to a poisson distribution, with the spawn rate controlled by a lambda value[10]. These vehicles are given a desired speed according to a normal distribution[1].

Much of our implementation of individual driving behavior is based on the paper "Modeling Drivers' Acceleration and Lane Changing Behavior by Kazi Iftekhar Ahmed[11]. This method distinguishes between two acceleration models, car following and free flowing.

For each time step of our simulation, we call an acceleration function on each vehicle which updates which acceleration regime they are in. This function, much as it is outlined in the above paper, sorts vehicles into a car following regime if the time headway between them and the car in front of them is less than their preferred headway. Time headway refers to the time it would take for two cars to collide given their relative velocity remain constant, which is as opposed to distance headway which refers to the distance between them. Studies have validated the perspective that drivers typically respond according to time headway, as opposed to distance headway[12]

According to this model, a driver at time t must react to their headway at time $t - \tau_n$, where τ_n is the reaction speed of driver n. Our simulation iterates through time steps which correspond to a quarter of a second, which is roughly a person's average reaction speed. Therefore, when as we set the regime of the next iteration according to the current iteration, we are accounting for this average reaction speed.

For the free flowing model, we update the vehicles acceleration according to the equation:

$$a = 0.5 * (v_d - v_c)$$

where:

$$a = acceleration, v_d = desiredvelocity, v_c = currentvelocity$$

Velocity is then updated:

$$v_j = a * t + v_c$$

where:

v_j = the velocity of the vehicle at the next iteration

By substituting the first formula for a into the second, we can take the general form for v_i: the velocity of the car at iteration i to be:

$$v_i = \frac{1}{2} v_d + \frac{1}{2} v_{i-1}$$

From this, a series can be constructed for vehicle velocity v_n at some iteration n. It is assumed for this following equation that at all iterations, the car was in a free flowing state, such that the above formula applies.

$$v_n = \sum_{i=1}^{n} \frac{1}{2^i} v_d + \frac{1}{2^n} v_1$$

To consider the limit of this value:

$$\lim_{n\to\infty} v_n = \lim_{n\to\infty} \sum_{i=1}^{n} \frac{1}{2^i} v_d + \lim_{n\to\infty} \frac{1}{2^n} v_1 = \frac{\frac{1}{2}}{1-\frac{1}{2}} v_d + 0 v_1 = v_d$$

This demonstrates that the speed of a driver in free flowing conditions converges towards their desired speed. In Kazi Iftekhar Ahmed's model[11], v_j has an additional random term added to it, to reflect the imprecise nature of a driver's actions. We have opted to ignore this value for our simulation, but if the mean of this term is zero it's overall effect will approach zero according to the central limit theorem.

For the car following regime, this regime can be further separated into the car following acceleration and car following deceleration regimes. If the relative velocity between it and the car it's following is greater than zero, then the distance between the two is increasing and the car enters the acceleration regime. If this relative velocity is less than or equal to zero, it enters the deceleration regime. These two regimes are separate to allow for different sets of parameters to control separately how the car accelerates or decelerates, but the equations are otherwise the same.

Our implementation of a lane changing model is also based off work of Kazi Iftekhar Ahmed. There are two types of lane changing operations for a car under this model, the mandatory and discretionary lane change. Mandatory lane changes are those done under urgent circumstances, such as running out of lane on a highway entrance ramp. Discretionary lane changes are those which are made simply to improve the driving conditions of the driver, such as changing lanes to pass a slower driver.

In our model, mandatory lane changes will be triggered if a car is in a merging on ramp and has enough space to merge into it's left lane. A discretionary lane change will be triggered if there is a large discrepancy between a car's desired and current velocity or if it is excessively close to a neighbor car. Additionally, this lane change will only occur if there is sufficient space in an adjacent lane.

CHAPTER 4

RESULTS

4.1 Results

The simulation for the following graphs has been set to run 30 times and spawn cars with a lambda value of .01, increasing by .0018 with every simulation. This is intended to observe a collection of highway simulations under different conditions in order to observe how varied spawning rates impact various aspects of the simulation.

Figure 4.1 shows various values of each of the 30 simulations over each time step. We can

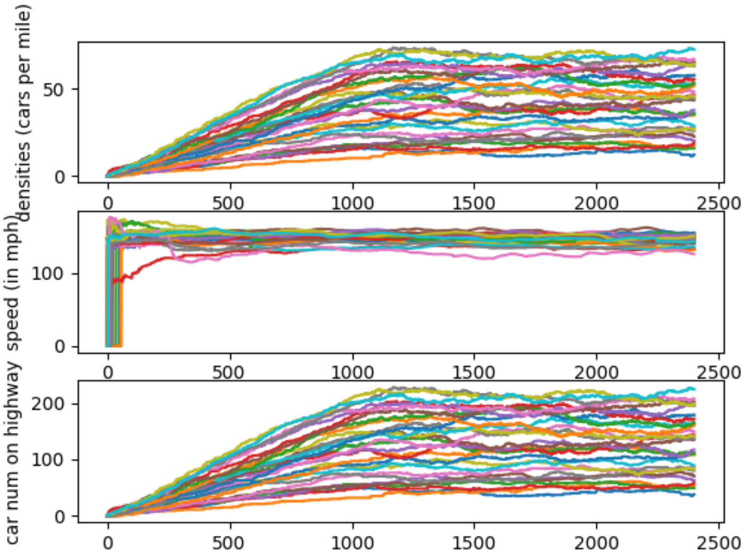

Figure 4.1

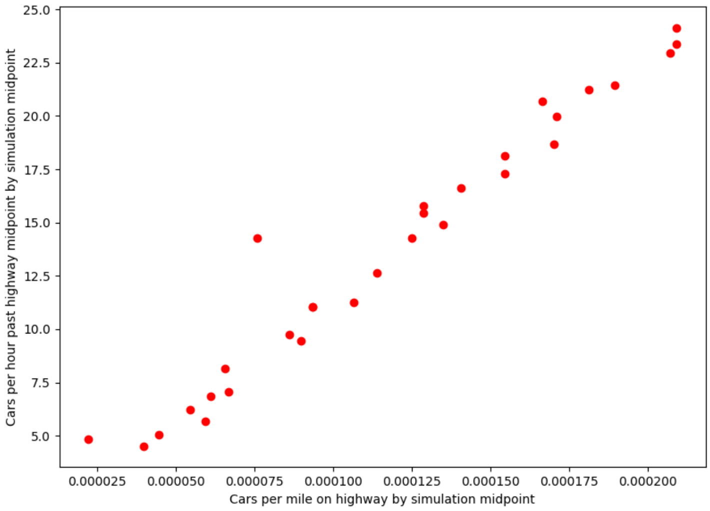

Figure 4.2: *Various values per simulation iteration*

see these values for density and car number increase until cars begin to leave the far end of the simulation, at which point the highway reaches it's full capacity.

In figure 4.2 can see the flow of the highway positively correlating with the density. The fundamental diagram of highway flow predicts a critical density for a highway, at which point greater density is associated with reduced flow, and cars tend to enter a state of congestion. Our simulation appears to be only simulating a number of cars for which they can travel in mostly free flowing conditions, so this critical density could not observed. Thus it is not possible at this time to verify whether the agent based model we currently employ could reproduce the conditions simulated by kinematic wave equations. It does demonstrate free flow conditions with a correlation between flow and density.

The simulation itself is not computationally efficient enough to explore much higher lambda values in a reasonable amount of time. Increasingly high spawn rates correspond to worse highway performance, but the highway densities that we are able to simulate do not correspond to real world densities that would typically correspond to a breakdown in free flow conditions. The density at which such a breakdown would occur is referred to as the jam density and for most highways it is typically occurring at around 180-250 vehicles per mile per lane[13]. Our simulations in comparison would only reach approximately 60 cars per pile per lane.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The agent based simulation that we implemented for this project used a variety of systems to reproduce realistic driver behavior. Our vehicles would pass each-other, trail behind each-other, navigate on ramps, and consistently avoid crashing scenarios. They were initialized according to a poisson distribution and assigned a normally distributed desired speed which matches empirical measures of highway conditions. The simulation has produced a realistic reproduction of free flowing traffic conditions but could not operate under realistic jam densities.

5.2 recommendations

A notable feature that may be worth adding to driver behavior for future work on this simulation include a more sophisticated model for surveying surroundings when lane changing based on research on the subject[9]. Additionally, refinements to the computational complexity of the simulation such that traffic jams could be better simulated would be extremely useful. If critical densities could be measured based on parameters of driver behavior, we could more easily compare the efficiencies of different types of behavior and use them to assign edge capacities of Link Transmission Models.

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