[M] Agent-Based Modeling of Dynamic Congestion in an Urban Road Network

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This paper aims to model agent based traffic in a two dimensional city grid model consisting of connected nodes, which acts as roads and intersections. The cars are represented as agents, choosing their ways based on local parameters such as surrounding traffic, road speed limits, toll prices and roadwork. The system incorporates stochastic elements such as randomly appearing roadworks that slows traffic down. This simple system can be used to understand traffic jams and bottlenecks for car traffics in city grids, providing insight into how complex patterns can emerge from local decision making and uncertainty. This report aims to explore the question, How do random roadworks and variable tolls influence traffic flow and congestion patterns in a city grid?

Project Topic: The fast and the gridlocked

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I. INTRODUCTION

City traffic is a complex and important problem affecting people world wide. Designing cities to match all the needs of the inhabitants while also accounting for traffic flow is not trivial.

The goal is to create a toybox model of a city with many interacting cars to see if it is possible to imitate the congestion created in real life cities like Gothenburg. For referens we can use the real congestion index of Gothenburg that can be found at [1].

Inspiration for this simulation has been taken from

II. OVERVIEW

Agent-based modeling (ABM) In Agent-based modeling (ABM), one uses autonomous agents that individually make decisions based on the present situation and the rules that are set [2]. The ABM is useful in systems where individualism is present, such as in traffic. It comes with the advantages of accurately simulating individuals behavior and creating emergent situations, like gridlocks in traffic. An inconvenience with ABMs is that they can be sensitive to the rules set on each agent and may therefore be hard to calibrate for a certain problem.

Celluar Automata (CA) Cellular Automata models divide space into discrete cells. These cells can be empty or occupied by a vehicle. The vehichle moves according to simple local rules, such as speed limits and distance to nearby cars. CA is commonly used to study traffic flow and congestion [3]. It can also model other systems like forest fires or disease spread[4]. The main advantages are simplicity and computational efficiency, making it easy to simulate large grids. Unfortunately, it doesn't represent individual driver decisions. For this project, CA is less suitable because it doesn't capture traffic patterns from local agent interactions.

Macroscopic Traffic Flow Model Macroscopic traffic flow models simulate traffic like a continuous flow, similar to a fluid. It uses variables such as traffic density, flow, and average speed to determine the flow [5]. These models are useful for studying overall traffic patterns, such as congestion and queue formation. They do not, however, represent individual vehicles or driver decisions, so they cannot capture local behaviors or how traffic jams emerge from interactions between cars. For projects focusing on individual choices and emergent patterns, macroscopic models are less suitable, but they provide a good understanding of overall traffic dynamics.

Dijkskras algorithm Dijkstras algorithm is a path finding algorithm used to find the shortest way between nodes in a weighted graph network [6]. A weighted graph network can, in this case be a road network. The algorithm is useful for simulating a car trying to find the optimal way to work. In this case more cars on the road ahead can be represented as a weighted graph. The strength is the efficiency of the algorithm to fins the best way, which makes it suitable for a traffic simulation with realistic drivers. A weakness is that it is a bit to perfect to represent the average driver. A normal is not omnipotent the way that Dijkstras algorithm is. This can be compensated by adding noice.

The topics above are all relevant and useful methods that could be used for different types of traffic modeling. A brief overview of the methods can be seen in table I. This project will mainly focus on using Agent-based modeling, where cars will act as autonomous agents that make decisions at every intersection. This method fits best to model the behavior of human decision making in traffic. The simplicity and flexibility also allows for many different parameters to effect each agent, such as toll costs and construction work on the roads. Dijkstras algorithm is also used to help the agents navigate the urban environment.

III. METHOD

This project uses agent based modeling to simulate cars in traffic. The cars are traversing a city grid consisting of horizontally and vertical roads of different lengths.

TABLE I. **Overview of simulation methods/models.** Summary of relevant methods for modeling urban traffic.

Method / Model	**Use case**	**Features**	**Suitable?**
Agent-based modeling (ABM)	Modeling individual agents in complex systems, e.g., pedestrians, vehicles, or social interactions	Agents with local decision rules; supports heterogeneity and randomness	Captures how individual driver decisions and local traffic conditions generate congestion patterns in the city grid.
Cellular Automata (CA) Model	Simulating spatially extended systems using discrete time/space, e.g., traffic, forest fires, or disease spread	Discrete time/space; very simple movement rules; efficient	Allows rapid simulation of vehicle movement on a simplified grid, showing traffic density changes over time, though less flexible for modeling individual decision-making.
Macroscopic Traffic Flow Model	Models traffic as a continuous flow, similar to fluid dynamics, to study overall road congestion and capacity.	Uses equations for traffic density, flow, and velocity. It focuses on aggregate behavior rather than individual vehicles.	Less suitable for this project because it cannot capture individual vehicle decisions or emergent traffic patterns like gridlocks in a city grid.
Dijkstra Shortest Path Algorithm	Finding the shortest path for vehicles from origin to destination in a road network	Graph-based search; guarantees shortest path; can incorporate dynamic costs such as congestion	Suitable for routing individual vehicles in the simulation, allowing them to avoid congested or blocked roads.

The cars spawn in at the edge of the grid with a preset destination, meant to represent the average person going to work from their home. The spawnrate of the cars are dictated by the time of day, where the traffic peaks at 08:00 and 17:00 to represent the normal workday. The roads may look like single lane roads, but cars traveling in opposite directions are allowed to pass each other, effectively creating two lane roads. Other obstacles such as traffic lights and roadwork may affect traffic on their way to work.

The car can only move on the road grids. If there is a car in front of them, they will stop creating congestion. To find their way to their destination all car paths are calculated by using Dijkstras algorithm. When a car spawn in, the optimal path, considering the current state of the surrounding traffic is calculated. When encountering an intersection, Dijkstras algorithm is called upon once again, recalculating the optimal path based on the now updated surrounding traffic. This way, all agents make conscious decisions att every intersection.

Inspiration for this project was taken from [7] The agents all move uniformly as if there is a free space in front of it, it will move each timestep. The simulation does not take acceleration or retardation as all the cars moves in uniform speed.

[3] [2] [4] [5] [7] [1]

[1] T. I. B.V., Gothenburg traffic — tomtom traffic index, `https://www.tomtom.com/traffic-index/gothenburg-traffic/`, gives an idea for how a congestioncurve of Gothenburg might look like. A good ground-truth to compare to.

[2] E. Bonabeau, Agent-based modeling: Methods and techniques for simulating human systems, Proceedings of the National Academy of Sciences of the United States of America **99**, 7280-7287 (2002), relevant because it reviews agent-based modelling and shows how emergent phenomena such as traffic jams can be captured.

[3] T. Feng, K. Liu, and C. Liang, An improved cellular automata traffic flow model considering driving styles, Sustainability **15**, 952 (2023), considers driving styles in a CA traffic flow model, showing improved capacity and congestion dissipation.

[4] G. Volpe, A. Callegari, and A. Argun, *Simulation of Complex Systems* (IOP Publishing, 2021) course book, relevant for many different simulation toppics such as autonomus agents. Relevant for discussing other usefull methods.

[5] D. U. of Technology, *Macroscopic Traffic Flow Models* (TU Delft OpenCourseWare, 2021) relevant material, provides an overview of traffic as a continuous flow and the use of density, flow, and speed equations.

[6] A. Javaid, Understanding dijkstras algorithm, SSRN Electronic Journal **1** (2013), explanes Dijkstras algorithm which is used for the traffic simulation.

[7] H. G. Hayatnagarkar and G. M. Krishna, A controlled natural language based knowledge representation approach for agent based simulation results, Researchgate –, – (2017), inspiration for the simulation of a traffic grid.