University of Amsterdam

Final report

Traffic congestion control System by centralized vehicle takeover for smart city with agent-based model

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Students:
Hamid Ahmadi
14473380

Adam Dong
13654675

Sebastian Gielens
14657287

Sietse van de Griend
12652776

Group:
Team 6

Lecturer:
Dr. Závodszky

Course:
Project Computational Science

URL of GitHub repository: `https://github.com/Laika404/ComputationalProject`

Abstract

This project tried to investigate how effectively a centralised takeover strategy can mitigate traffic congestion in simulated highway based on agent-based model. This was done through the reproduction of an already existent agent-based model based on a paper by Zhang, Li, and Zhao 2005. The model was expanded upon by adding agent behaviour for multiple lanes and logic that simulates a central controller. It was hypothesized that centralized vehicle takeover will be significantly more effective than human-based models in mitigating congestion. This was confirmed as the central vehicle takeover managed to increase the average speed of the vehicles and maintain a higher flow under congested conditions.

1 Numerical method

For our research we have used an existing agent-based model from Zhang, Li, and Zhao 2005, with the intention of extending it to test centralised control. This model uses a handful of parameters to simulate human drivers, including desired speed and distance from the car in front of them. An agent based approach was chosen over cellular automata and macroscopic flow simulations because this allows for more fine-grained control over individual driver behaviour.

2 Single-lane model validation

To validate the single-lane model, we opted to reproduce the two figures as depicted in the section "Macroscopic Characteristics" of Zhang, Li, and Zhao 2005. In figure 1 a side-by-side comparison of our flow-density model (on the left) and the model of Zhang, Li, and Zhao 2005 (on the right) can be found. It's visible that the two figures resemble each other closely, the only difference is the variability over multiple runs.

In figure 2 a side-by-side comparison of our mean-speed-density model (on the left) and the model of Zhang, Li, and Zhao 2005 (on the right) can be found. In general the two figures resemble those from the paper, as can be seen from the overall shape and certain values.

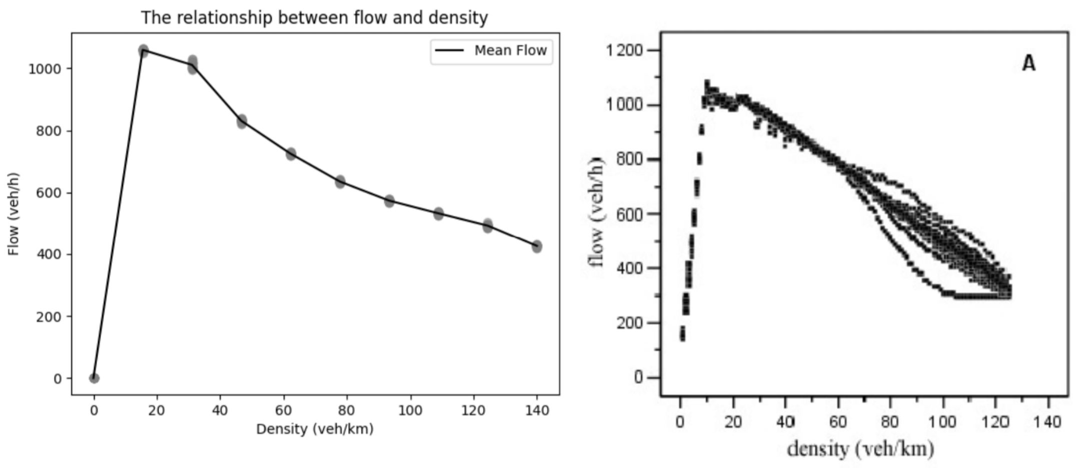

Figure 1: Comparison of the flow-density graph. On the left is our produced graph, and on the right the one of Zhang, Li, and Zhao 2005. The flow-density graph shows how the flow (amount of vehicles passing a fixed reference point per hour) changes as the density (amount of vehicles per kilometre) increases.

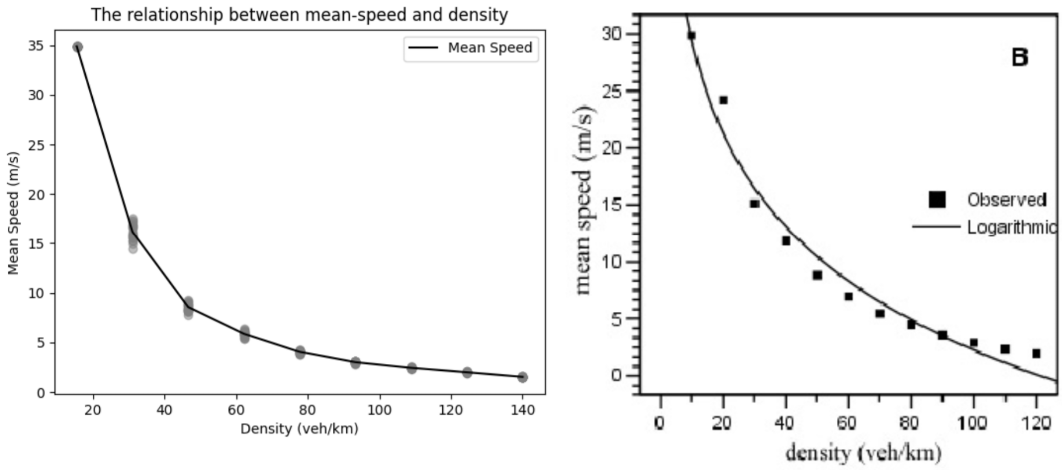

Figure 2: Comparison of the mean-speed-density graph. On the left is our produced graph, and on the right the one of Zhang, Li, and Zhao 2005. The mean-speed-density graph shows how the mean speed of all vehicles changes as the density (amount of vehicles per kilometre) increases.

3 Multi-lane

The single-lane model has been extended to include another lane that agents can use to pass other cars instead of braking. To this end we've extended the agent behaviour such that can switch to the passing lane if the leader is much slower. For this a difference of 5 m/s is used as a threshold, as this showed that cars had to brake less drastically. Agents also merge back into the "slow" lane when there is a large gap available. These behaviours are intended to broadly mimic how drivers use highways in the Netherlands.

4 Central control

In the central control model, every agent has access to more general data about the system which the agents use for decision making. This data contains the average speed in the current lane, the amount of cars on the lane, and the preferred amount of cars on the lane. The agents try to match the mean speed and a percentage of the cars try each simulation cycle to increase this average by speeding up. The cars also try to switch lanes when the amount of cars on the lane is too high. The expansion of behaviour associated with central control is only activated when it is safe for the cars.

5 Results and discussion

With the multi-lane and central control extensions we tested the model to assert whether switching to a centralised model improves traffic. The results are plotted in figures 3 and 4. These show that our hypothesis is indeed true within our model; the flow and mean speed increase across the various vehicle densities. On the higher end of the vehicle density range, this difference shrinks. We are not entirely sure why this is, but we hypothesise that the road reaches its maximum capacity at this point.

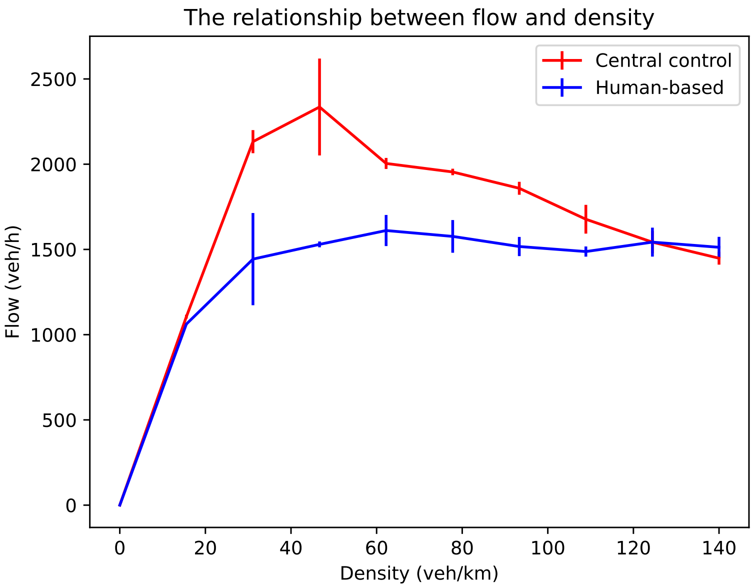

Figure 3: Comparison of flows between centralized and human-based models.

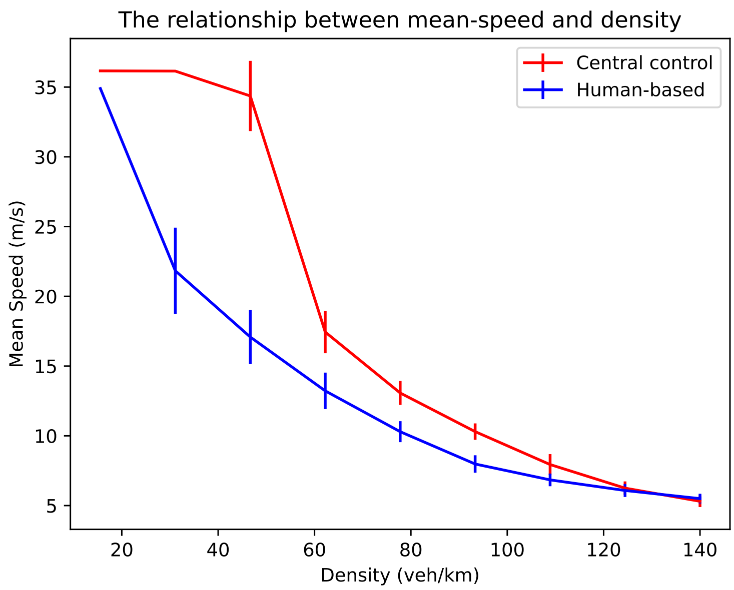

Figure 4: Comparison of mean speeds between centralized and human-based models.

However, this does not necessarily mean that we can expect similar results in the real world. Given a lack of publicly accessible field data to tune our agent based models against, it is difficult to say to what degree our models are realistic. Proper validation and parameter fine-tuning is left to future works. Additionally, our model may be extended with more variation between agents, as we do not consider that cars may have different top speeds, acceleration and deceleration rates, lengths, etc. This leads into the final major limitation, being that we've barely explored the possibilities of centralised control. It may be advantageous to give agents access to more or different global statistics, thereby improving traffic conditions even more.

6 Conclusion

The central strategy consistently achieves a higher flow than the agents strategy in low to moderate densities, peaking at around 2500 veh/h near 40 veh/km. In contrast, the agents line has a lower maximum flow around 1500–1600 veh/h and remains below the central strategy at most densities. Only at very high densities above 120 veh/km do the two strategies converge to similar flow levels.

Human-driven traffic systems are prone to widespread congestion caused by over-speeding and abrupt braking. In contrast, a smart-city model can localise and ease congestion in smaller sections, thereby minimising its overall impact on the entire highway.

7 Team contributions

For the most part we have worked on everything together; tasks like peer review, coding and writing the report were done by all team members. Within the code Hamid worked reproducing and validating the single lane model from Zhang, Li, and Zhao 2005. Sebastian and Sietse worked on the multi-lane extension and central control respectively. Finally Adam worked on the animated visualisation and poster design and layout. Everyone contributed sections and figures related to their parts of the codebase to the poster and report.

7.1 Git fame

Author	hrs	mths	loc	coms	fils	distribution
HamidA7777	3	2	652	23	19	30.6/35.9/47.5
Adam-Mac	2	2	563	6	4	26.4/ 9.4/10.0
Sebastian Gielens	3	2	538	17	10	25.3/26.6/25.0
Sietse	3	1	377	18	7	17.7/28.1/17.5

Figure 5: Output from `git fame`.

References

Zhang, Fa, Jinling Li, and Qiaoxia Zhao (2005). "Single-lane traffic simulation with multi-agent system". In: *Proceedings. 2005 IEEE Intelligent Transportation Systems, 2005.* IEEE, pp. 56–60.

A Sensitivity analysis

As part of our research we also conducted sensitivity analysis of the parameters of the agents: v_{max}, v_{desire}, T_p, a_{normal}, a_{max}, b. After experimenting with different parameter values, we obtained the following:

b (noise)

- **Increase (0.2 → 0.4):** Maximum flow decreases as density increases, and mean speed is lower.
- **Decrease (0.2 → 0.1):** No significant change; the pattern for both flow and mean speed remains similar.

$\mathbf{T_p}$ (time headway)

- **Increase (1.2 → 1.6):** Maximum flow decreases with increasing density, and mean speed drops significantly (from 35 m/s to 26 m/s).

- **Decrease (1.2 → 0.8):** Maximum flow increases with density. Mean speed remains the same, but drivers tend to drive faster. This makes sense, as they prefer to drive closer to the leader, increasing flow.

$\mathbf{a_{normal}}$ (normal acceleration)

- **Increase (3.05 → 4.05):** Hardly any change; the pattern remains the same for both flow and mean speed.
- **Decrease (3.05 → 2.05):** Similarly, no significant change; the pattern remains mostly the same.

$\mathbf{a_{max}}$ (maximum acceleration)

- **Increase (6.04 → 7.04):** Maximum flow decreases slightly (around 5%), but mean speed remains unchanged.
- **Decrease (6.04 → 5.04):** The graph remains almost the same for both flow and mean speed.

$\mathbf{v_{max}}$ (maximum speed)

- **Increase (35 → 40):** The overall pattern remains the same, but the maximum mean speed increases to 40 m/s.
- **Decrease (35 → 30):** Flow decreases slightly (about 3%), and the maximum mean speed drops to 30 m/s.

$\mathbf{v_{desired}}$ (desired speed)

- **Increase (30 → 35):** Flow decreases slightly (around 2–3%), but the mean-speed graph remains unchanged.
- **Decrease (30 → 25):** Flow also decreases by about 2–3%, while the mean-speed graph stays the same.

B Proposal and peer reviews

B.1 Our proposal feedback for group 7

Submitted by team: Sebastian Gielens; Sietse van de Griend; Hamid Ahmadi; Adam Dong
To review the project titled: Modeling Mold using DLA
From team: Ishana Bohorey; Sara Stoof; Oskar Linke; Windar Mazzori

After reading the project proposal thoroughly, using the guidelines on what to review from the initial lecture slide titled "Peer review - Use the template from Canvas!", we make the following constructive remarks (min 50, max 200 words):
The scientific question could be improved further by constructing between 1 to 3 hypotheses for the scientific question, which could be supported by one or more sources. Validating the model with the results of another model is good, but if it is possible you could maybe also validate by using real world data, although this is not obligatory.

B.2 Our proposal feedback for group 8

Submitted by team: Sebastian Gielens; Sietse van de Griend; Hamid Ahmadi; Adam Dong
To review the project titled: Jupiter: protector against Centaurs?
From team: David Kraakman; Joel Shefer; Thijs Spoor

After reading the project proposal thoroughly, using the guidelines on what to review from the initial lecture slide titled "Peer review - Use the template from Canvas!", we make the following constructive remarks (min 50, max 200 words):

In general the paper looks good, clearly formulated but we have some recomendations;

- It is not exactly clear what the model exactly will include and what type of simulations will be made. Will it include all planets or only Jupiter?
- Has there also been discussion about the time step sizes and the effect on accuracy of these sizes on the simulation. Smaller time step sizes increase accuracy but slow simulation speed etc. It could be handy to add a comment about this in the numerical method.
- The hypothesis is just one sentence long, it could be extended upon by including a justification for the hypothesis. You could include sources.

B.3 The feedback we received from group 5

The text introduces the problem of urban traffic congestion and its impacts, highlighting smart city technologies as potential solutions. It clearly explains the phenomenon of phantom traffic jams, supported by a reference, and connects it to the research focus. The scientific question is well-defined, proposing the use of a centralized vehicle takeover strategy to mitigate congestion in a simulated highway model. The hypothesis is clear and detailed, predicting reduced travel times, smoother traffic flow, and fewer stop-and-go waves. A potential improvement for validation could include testing the model against observed patterns of phantom traffic jams or experimental data from multi-lane traffic scenarios. For agent-based modelling in Python, the Mesa library can be used for visualisation purposes. Overall, the project proposal is clear and organized.

B.4 The feedback we received from group 4

Some improvements could be:
- How is the congestion threshold determined?
- How exactly does the system transition between normal and centralised vehicle control? This clarification would help understand the system functionality
- Plan and specify the model validation approach/criteria for the simulation results. Also, perhaps existing models have even more interesting evaluation criteria (on top of flow or speed against density)
- With respect to the way that the work has been divided, make sure that a singular person doesn't end up doing > 30-40% of the code. Some interesting additions to consider:
- road configurations beyond a single-lane circle, e.g. urban grids / a three-lane square.
- Some sensitivity analysis on few of the parameters to probe their influence. You could create a ranking of the parameters, by criticality. This can also help check model robustness
- To strengthen the data analysis component, you could use machine learning to predict congestion based on historical data. Additionally, it could be interesting to analyse whether the proposed system might have prevented (a) specific real-world incident(s) - if there is historical accident data available