Traffic Congestion Control by Centralised Vehicle Takeover in Smart City with Agent-Based Model

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Introduction

Cities worldwide facing traffic congestion due to increasing populations and expanding urban infrastructures. Smart cities address this issue by leveraging IoT and real-time data to predict congestion, coordinate vehicle flow, and even control cars during severe jams. In this context, we investigates **how effectively a centralised takeover strategy can mitigate traffic congestion in simulated highway based on agent-based model**.

Hypothesis

Centralised vehicle takeover will be significantly more effective than human-based models in mitigating congestion, by dynamically adjusting speed and acceleration in real time.

Numerical Methods

The base model is a human-based model where every agent represent an individual vehicle. These agents drive in a circular single lane and simulates traffic behaviour and congestion. Each agent performs actions based on behavioural rules with its parameter and immediate environment.

The parameters used in the model are based on **[1]**. These include:

- v_{max} : *Maximum speed of an agent.*
- v_{desire} : *Desired speed of an agent.*
- T_p : *Preferred distance in time.*
- a_{normal} : *Normal deceleration rate.*
- a_{max} : *Maximum deceleration rate.*
- b : *Distribution of noise*

This base model is expanded to smart-city model with multiple lanes, and centralised vehicle takeover.

Congestion Index

Density-Based Metric:
Measures the number of vehicles per kilometre

Speed-Based Metric:
Measures the fraction by which average speed falls below free-flow conditions.

Composite Metric:
Combines both density and speed, weighting each to form a more holistic congestion index.

$$C = w_1 \times \left(1 - \frac{v_{avg}}{v_{free}}\right) + w_2 \times \left(\frac{\rho}{\rho_{jam}}\right)$$

Sensitivity Analysis

After experimenting with different parameter values, we found that:

- a_{max}, a_{normal} and v_{desire} barely influence the flow and mean speed.
- the v_{max} increases the mean speed but decreases the flow slightly.
- if T_p increases, both flow and mean speed decrease.
- if the noise factor b increases, both the flow and mean speed also decrease.

Reference

- **[1]** Zhang, F., Li, J., & Zhao, Q. (2005). Single-lane traffic simulation with multi-agent system [ISSN:2153-0017]. *Proceedings. 2005 IEEE Intelligent Transportation Systems, 2005., 56–60.* https://doi.org/10.1109/ITSC.2005.1520219

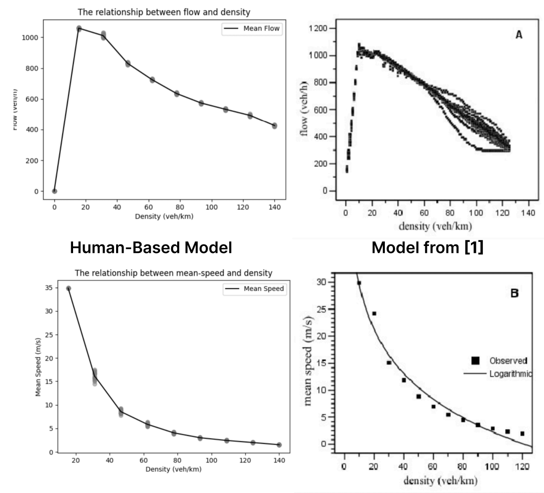
Model Validation

Flow-density graph, shows how the flow changes as density increases:

- Flow: amount of vehicles passing fixed point per hour
- Density: amount of vehicles per kilometre

Mean-speed-density graph, shows how the mean speed of all vehicles changes as density increases:

- Density: amount of vehicles per kilometre

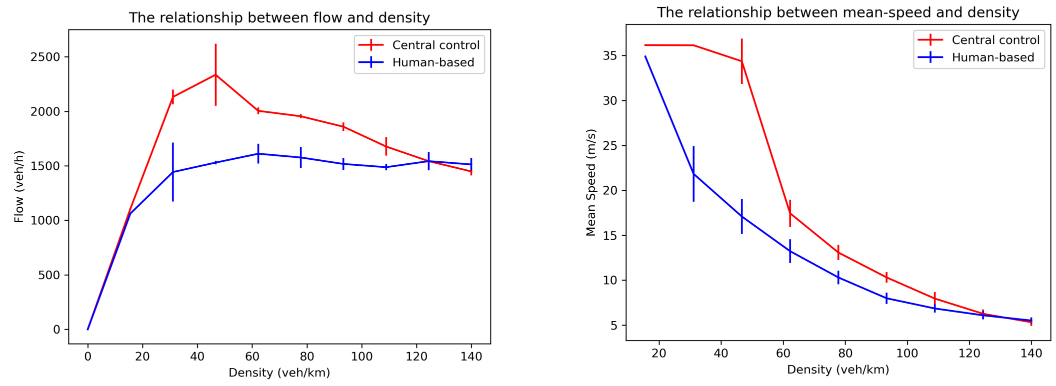


Human-Based Model — Model from [1]

Model Result

The single lane model from [1] has been successfully extended with multiple lanes and a centralised control scheme. The former allows human agents to use the new lane to pass slower cars, allowing the overall congestion to decrease. Furthermore, the centralised model uses average speeds per lane and lower reaction times to allow the vehicles to drive in a more controlled manner.

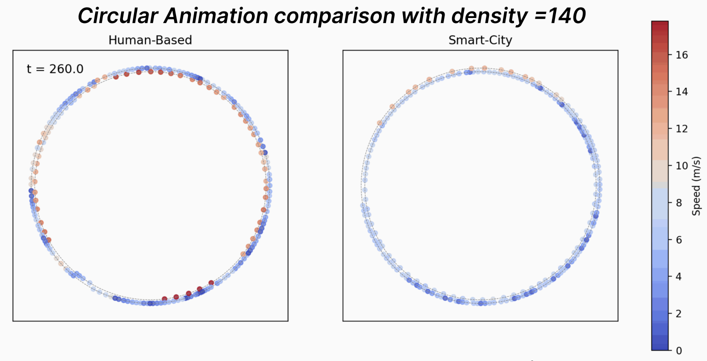
The two-lanes model has been tested with and without centralised control. From the figures it is clear that the flow and mean speeds improve when there's more capacity. Additionally the centralised control manages to use this capacity to an even greater extent. This is visible insofar that the maximum speed is maintained for higher densities, and the flow is at least 33% better in the middle densities.



In the human-based model it is more common to have congestion at any section of the highway at the same time duo to a lot of over-speeding and breaking

While the smart-city model can solve the congestion in relatively small sections of the road, and lead to minimised effect on the entire highway

Circular Animation comparison with density =140



Human-Based ***Smart-City***

Conclusion

The central strategy consistently achieves a higher flow than the agents strategy across low-to-moderate densities, peaking at around 2500 veh/h near 40 veh/km. By 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.