Impact of Vehicle Breakdown in Lane-Free Traffic with Connected and Automated Vehicles

Master‘s Thesis of Abdollah Zoheiri

Mentoring:
Maya Santhira Sekeran M.Sc.
Dr.-Ing. Tanja Niels

Introduction

Lane-Free Traffic

- Vehicles Can move freely across the road width and are not confined to fixed lanes
- Connected and Automated Vehicles (CAVs) adjust positions using local rules
- Leads to higher capacity due to fewer lane changes and allows for a smoother flow [1]

Aim of this work

- Investigate how a vehicle breakdown impacts an LFT system
- Testing if the proposed decentralized avoidance logic (Illegal zone logic) maintains flow and safety
- Compare to traditional lane-based traffic under similar conditions

Methodology

Simulation Environment

- SUMO with a custom C++ lane-free model (TrafficFluid API)
- Potential lines method which assigns lateral position by speed [2][3]

Breakdown Scenario

- Simulated a vehicle breaking down and positioning itself towards the lower boundary

Performance Metrics

- Collected mean speed, travel times, throughput, and collision count

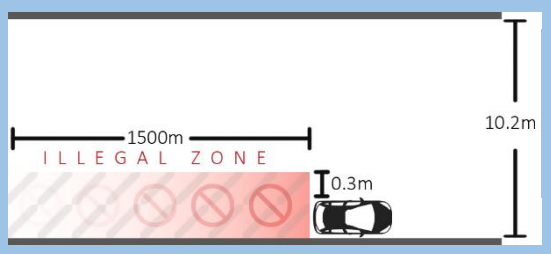
Flow levels tested

- 3600, 6000, 7200, and 14400 vehicles/hour
- Compared to:
    - Ideal LFT (no breakdown)
    - Idealized lane-based scenario

Avoidance Strategy

Illegal Zone Logic

- Defined an illegal zone extending 1500 m behind the broken vehicle



- Vertically, covers the width of the vehicle and 0.3 m safety distance.

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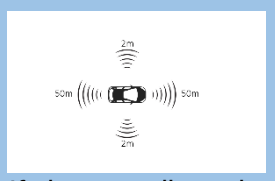
Avoidance Strategy

- Vehicle scans (50m x 2m) to assess local density

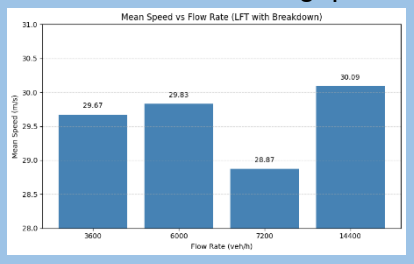


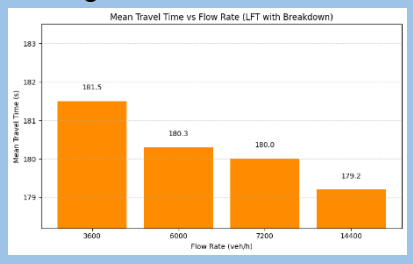
- Then computes a safety factor
- (1 = clear , 0 = blocked)
- If clear, applies a lateral nudging force to move upwards and bypass
- If crowded, vehicles decelerates to wait for space
- Once clear of the zone, gradually accelerates back to desired speed

Results

Safety and Efficiency of tested flows

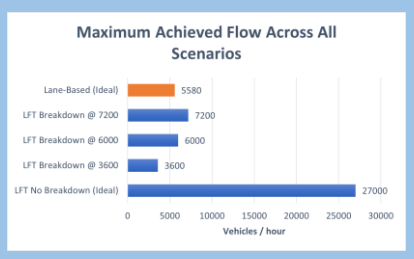
- Flows up to 7200 veh/hour resulted in no collisions and a mean speed of 29 m/s, travel times remained consistent
- Flow of 14400 veh/hour resulted in 22 collisions. The mean speed, travel times, and throughput remained high.

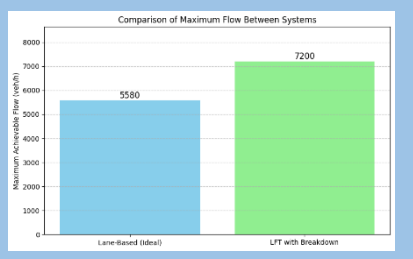




Compared to lane-based

- LFT with a breakdown using the illegal zone logic outperformed an idealized lane-based scenario





Conclusion

- Demonstrated that LFT can robustly handle unexpected disruptions using decentralized and local rules.
- High flexibility and resilience of LFT compared to traditional lane-based systems
- Supports the idea that CAVs can maintain high throughput even under realistic conditions

Future Outlook

- Introducing a centralized coordination layer could further enhance performance, enabling higher traffic densities.

References

[1] M. Rostami-Shahrbabaki, S. Weikl, M. Akbarzadeh and K. Bogenberger, "A Two-Layer Approach for Vehicular Flocking in Lane-Free Environment," in Proceedings of the 11th Triennial Symposium on Transportation Analysis (TRISTAN XI), 2022.

[2] M. Rostami-Shahrbabaki, H. Zhang, M. Sekeran and K. Bogenberger, "Increasing the capacity of a lane-free beltway for connected and automated vehicles using potential lines," Technical University of Munich, Munich, 2022.

[3] M. R.-S. D. T. K. B. H. Zhang, "A Novel Potential Line Strategy for Autonomous Vehicle Control in Lane-Free Traffic," in 2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC), 2023.