A Macroscopic Fundamental Diagram for Airplane Traffic: Empirical Findings

Victor L. Knoop, Mark ter Heide, Joost Ellerbroek
26 July 2023
Traffic Flow Theory and Characteristics Midyear meeting

v.l.knoop@tudelft.nl

Contribution

- Original claim for the macroscopic fundamental diagram by Daganzo (2007): holds for many things, even your desk
- Modelled and tested for road traffic (many...)
- Other modes in city traffic also included (e.g., Loder, 2021cars & bikes)

- Question: does this extend to 3 dimensional modes?
- With possibly a very large amount of airborne vehicles, can we change air traffic management to macroscopic models?

Introduction

- With many airborne vehicles, can air traffic management use to macroscopic models?

TU Delft

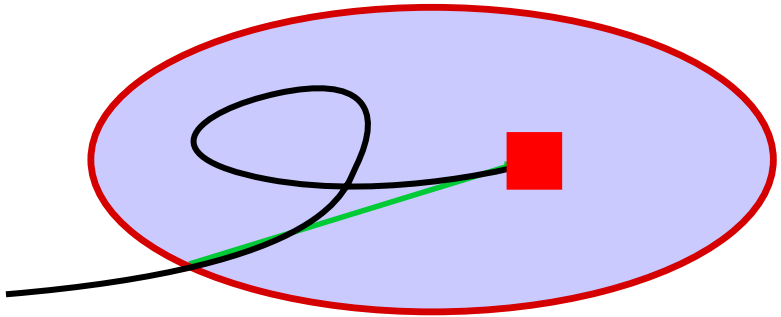
3D MFD models?

- Start of traffic models for drones and control thereof (e.g., Cummings et al, 2021)
- Control based on MFD (Haddad et al, 2022)
- Theoretical derivation of capacities, checked by simulation: (Aarts et al, 2023)
- Empirical validation is still lacking
- Question: is there a relationship between density and production for air traffic?

Intersection design: Doole et al, 2021

Definitions

- 3D extention of Edie's definitions:
  - Density: total travel time / area in space-time
  - Production: effective distance / area in space-time
- In airplane traffic stopping is not an option :)
- Effective distance accounts for detours,
  which are not counted towards effective production



Approach

- Flight data are broadcasted: Automatic Dependent Surveillance-Broadcast (ADS-B).
- The data are recorded by a receiver at the top of the aerospace faculty building of the Delft University of Technology
  - Aggregate over 30 mins
  - density and production
  - Check relationship and interpret

Data

- Amsterdam Schiphol airport (500,000 flights per year)
- Including surroundings
- Exclude high altitude (“through traffic”) keep 5,500 to 19,500 feet
- 42,807 km2
- Select 4 months with various characteristics

TU Delft

Data

- Range over time of day
- Range over years (covid / non covid)

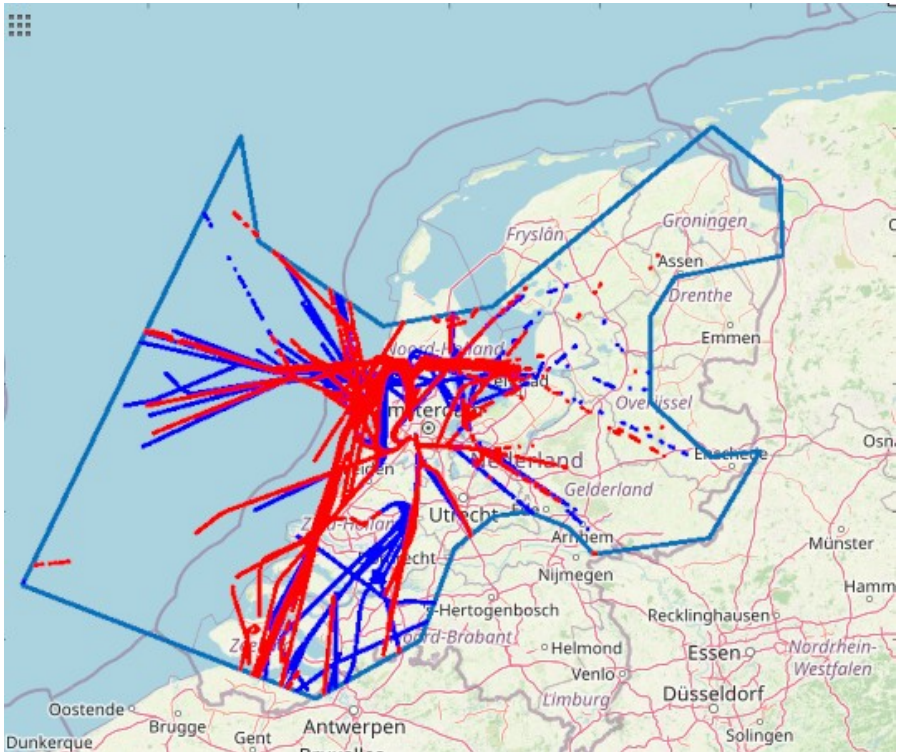
Results

Results

- Densities up to 0.0002 planes/km3
- Minimum separation:
  disk of 5 nautical miles radius and 2x 1000 ft altitude
  = 177 km3
  - Density: 1/177=0,0056 planes/km3
- Flow remains increasing
- Effective speed reduces
- Purple fit
  (Greenshields)

Discussion on densities

- Spatially not much of the airspace is used
- Planes cluster around the airport



TU Delft

Efficiency

- Flow reduction:
  detours or lower speeds?
- Ratio of production and
  [density times speed]
- Did plane go in one direction?
- Less with higher density,
  but the reduction of
  performance (purple line)
  is much stronger:
  speed reduction is more important

Conclusions

- For air traffic, an MFD can be made
- Densities for planes in a larger area do not approach critical density
- Production increases with density, yet flattens
  (effective speed reduces)
- Main cause: reduction of speed; detours less important

References

Daganzo, Carlos F. "Urban gridlock: Macroscopic modeling and mitigation approaches." Transportation Research Part B: Methodological 41.1 (2007): 49-62.

- Loder, A., Bressan, L., Wierbos, M.J., Becker, H. Emmonds, H., Obee, M., Knoop, V.L., Menendez, M., Axhausen, K.W. (2021) How many cars in the city are too many? Towards finding the optimal modal split for a multi-modal urban road network. Frontiers in Future Transportation, section Transportation Systems Modeling
- Doole, M., Ellerbroek, J. Knoop, V.L., Hoekstra, J. (2021) Constrained Urban Airspace Design for Large-Scale Drone-based Delivery Traffic Aerospace
- Cummings, C. and H. Mahmassani, Emergence of 4-D System Fundamental Diagram in Urban Air Mobility Traffic Flow. Transportation Research Record, Vol. 2675, No. 11, 2021, pp. 841–850.
- Haddad, J., B. Mirkin, and K. Assor, Traffic flow modeling and feedback control for future Low-Altitude Air city Transport: An MFD-based approach. Transportation Research Part C: Emerging Technologies, Vol. 133, 2021, p. 103380
- Aarts, M.J.M., Ellerbroek, J. and Knoop, V.L. (2023) Capacity of a constrained urban airspace: Influencing factors, analytical modelling and simulations, Transportation Research Part C: Emerging Technologies, Volume 152. DOI https://doi.org/10.1016/j.trc.2023.104173