Generalised Network Fundamental Diagram Modelling and control

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Contribution

• Network fundamental diagram studied and empirically checked
• Make influence of inhomogeneity explicit
• Empirical checks
• Modelling & control
Data increase with scale

- Data requirement increases with scale
- Time horizon increases with scale
- Solution space increases with scale

Simple relationships are needed
Stochasticity in local data

- Macroscopic fundamental diagram
- “Average” fundamental diagram for an area

Fig: (Geroliminis and Daganzo)
Concept –
Generalised Network Fundamental Diagram
Network with periodic boundary
Build up of congestion
Resulting NFDs?

- Still scattered
  - hysteresis?
- 2nd explanatory variable: \( \text{stdev of density} \)
- Generalised Network Fundamental Diagram
Fitting a functional form

\[ P(A) = A^*(c_1 + c_2A + c_3A^2) - c_4\sigma \]

Homogeneous traffic situation

Inhomogeneous traffic situation
Fitting a functional form

\[ P(A) = A^* (c_1 + c_2 A + c_3 A^2) - c_4 \sigma \]
Fitting a functional form

Different traffic conditions

Accumulation (veh/km/lane)

Production (veh/h)

Inhomogeneity (veh/km/lane)
Improvement: Generalised NFD

Generalised Macroscopic Fundamental Diagram

Accumulation =>

Std of density =>

[Graph showing the Generalised Macroscopic Fundamental Diagram with axes labeled as Accumulation and Std of density, and a color scale on the right side ranging from 100 to 1100.]
Causes of decrease with inhomogeneity

1) Averaging of states
2) **Network dynamics**

![Graph showing performance versus accumulation](image)
Causes of decrease with inhomogeneity

Create GNFD without dynamics
Impact of network dynamics

![Graph 1: Impact of A (veh/km)](image1)

![Graph 2: Impact of A (veh/km/lane)](image2)
Empirics
Empirical study – site

- A10 motorway
- 21 km
- Mostly 3 lanes
- 80-100 km/h speed limit
Road impression
Predicting production: methodology

1. Split data set (calibration/validation)
2. Create NFD
3. For validation set: predict production based on accumulation using NFD
Fit and predictive power

- Severe underestimation of production near capacity
Empirical evidence

Accumulation => Inhomogeneity

GMFD top view fit

Inhomogeneity (veh/km/lane)

Accumulation (veh/km/lane)
Fit and predictive power (2)

- Fit much better
- Bias much smaller
# Quality of fit

<table>
<thead>
<tr>
<th>R2</th>
<th>MFD</th>
<th>GMFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>All data</td>
<td>0.85</td>
<td>0.86</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>R2</th>
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<tbody>
<tr>
<td>A&gt;18 veh/km</td>
<td>0.0016</td>
<td>0.39</td>
</tr>
</tbody>
</table>

**Graphs:**
- **Prediction AFD fit**
  - Estimated production (veh/h) vs Measured production (veh/h)
- **Prediction GAFD fit**
  - Estimated production (veh/h) vs Measured production (veh/h)
Two representations

\[ \text{Inhomogeneity} = \text{Accumulation} \Rightarrow \text{Speed} \]

- Production
- Speed

Accumulation =>
Tracing dynamics
Control
Build up of congestion
Methodology

- Test different routing strategies
- In a macroscopic simulation program
- Routing in a grid network
  1. Shortest path (distance)
  2. Shortest path (time)
  3. Area-based
     a) Average speed
     b) Network Fundamental Diagram
     c) Generalised Network Fundamental Diagram

Reference
Create subnetworks
Good network performance

- Less than with “full routing”
- Factor 100 less data / computations needed
Good network performance (2)

- Relative to no routing
- NFD relatively poor
- GNFD on par with full info (and sometimes better!)

![Graph showing relative performance over time](chart.png)
Performance similar to mean speed – but why?

• Similar arrivals due to perfect speed prediction

Best Network Fundamental Diagram

Generalised Network Fundamental Diagram

Using fit
Outside the fitted area: NFD prediction

R² = 0.42
R² = 0.98
Modelling and practice
Use in traffic optimization

- Coordinate ramp meters
- Hold traffic further upstream
- What levels of metering to be used in which network parts
Network control

- Individual ramp metering limited
- Coordination does not allow enough storage space
- Maximum queue lengths for each intersection determined
Network control

- Maximum queue lengths for each intersection determined
- Network-wide criterion which lengths allowed
Conclusions

- Traffic control using the Generalised NFD is possible
- Speed prediction is excellent
- Future work:
  - Predict future speeds
  - Interaction network properties and network dynamics
  - Use in model predictive control
  - Routing, perimeter control
Conclusions

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• Future work:
  • Predict future speeds (model predictive control)