Traffic: an Interplay between Models, Simulations, and Control Actions

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Overview

• Gathering traffic data
  – Available infrastructure
  – The nature of the measurements

• Modelling traffic flows
  – Macroscopic models
  – Microscopic models

• Simulating traffic flows
  – Microscopic simulators

• Controlling traffic flows
  – Available control actions
• Single/double loop detectors (embedded in the concrete)

• Gatso-meters

• Cameras

• (counting by ‘hand’)

• …
Gathering traffic data (2/3)

- Automation is becoming a core business:
Gathering traffic data (3/3)

DB

200 cameras
1500 single loop detectors

± 1655 sensors (1 for each lane)
≈ 869,868,000 measurements (3.24 GB)

(this is for one year)
What is being measured?

- **Density** (number of vehicles/kilometre)
  
  \[
  k
  \]

- **Flow** (number of vehicles/hour)
  
  \[
  q
  \]

- **Average speed** (kilometres/hour)
  
  \[
  \bar{v}
  \]

**Fundamental relation:**

\[
q = k \cdot \bar{v}
\]
What do the measurements look like?

- **Flow**

- **Average speed**

- **Incident?**
A full week of measurements

Total flow [vehicles/hour]

Weekdays

Weekend

Monday Tuesday Wednesday Thursday Friday Saturday Sunday
Quality problems!

- Sometimes, a sensor gets ‘stuck’ for several days:

- Or the wrong values are being registered:
Traffic regimes

• Low density allows for safe overtaking:

• Higher densities complicate overtaking manoeuvres:

• Congested traffic results in shock waves:
Measurement correlations

- Example: traffic on the E17

“Fundamental diagram”
Regimes and fundamental diagrams

- In the \((k,q)\) fundamental diagram:
Models of traffic flows

- The mathematical models are based on the consideration of a traffic flow:
  - as a whole
    - macro-/mesoscopic flow models
  - as being composed of individual vehicles
    - microscopic flow models
Macroscopic: fluid or gas?

- Based on partial differential equations.

- *Fluid-dynamic* models consider a traffic flow as a **compressible fluid** (i.e., *continuum* models).

- *Gas-kinetic* models consider a traffic flow as a **many particle system** (= ‘mesoscopic’).

Americans vs. Germans: the former apply ‘*rocket science*’, the latter ‘*particle physics*’.
Microscopic flow models

• Computationally very intensive!

• Many (unnecessary) parameters!
  Sensitivity analysis.

• Much harder to calibrate and validate than macro-/mesoscopic models!
Car following submodel

follower \quad \text{leader(s)}

(n) \quad \text{space gap} \quad (n-1)

response depends on stimuli

\[ a_n(t + \tau) \sim f(t, \Theta) \]

with \( \Theta \supset \{ \text{agression, space headway, time headway, (relative) speeds, } \ldots \} \)
Example: traffic cellular automata

space (grid of cells)

\[ x(t + 1) = x(t) + v(t) \]

Car following submodel = set of local rules

\( t \)

\( v = 0 \)

\( v = 3 \)

\( v = 1 \)

\( t + 1s \)

\( v = 1 \)
Lane changing submodel

\[ p(\text{lane change}) \sim f(\Theta) \]

with \( \Theta \supset \) \{
  \begin{align*}
    &\text{(critical) gap size(s),} \\
    &\text{distance to on/off ramp,} \\
    &\text{(desired) speed,} \\
    &\text{lane changing rules,} \\
    &\ldots
  \end{align*}
\}
Routing

• ‘Each vehicle needs to know where to go.’

• A lane changing submodel needs to do the practical implementation of routing:
  – mandatory lane changes
  – discretionary lane changes

• The actual routing happens on a higher level:
  – OD-matrices
  – splitting rates (also known as turning fractions)
• O = origin, D = destination

OD-matrix
DTA as a core business

(demand)

OD matrices

(time)

(supply)

network topology

Dynamic Traffic Assignment

“equilibrium”

cost

incidents
Microscopic simulators (1/2)

• Developed during research:
  – Mitrasim 2000 (= Microscopic Traffic Simulator)
  – Traffic Cellular Automata
Microscopic simulators (2/2)

- **Commercially:** PARAMICS, AIMSUN, VISSIM, ...
Controlling traffic flows?

• Why control the traffic?
  – postpone/eliminate traffic jams (if possible),
  – early detection and timely reaction to incidents,
  – pursue an environmental friendly policy,
  – ...

• At this moment, Flanders works **locally**.
• In the future, we strive to control on a **network** level.
Prognosis of future traffic flows

Traffic volumes in 1994

Traffic volumes in 2010

Source: “multimodaal model Vlaanderen”
Flanders’ Traffic Centre

- maintaining a database with traffic measurements,
- rudimentary control of traffic in the region of Antwerp,
- provide traffic information for Flanders.

Ideal candidate for future traffic control!
Controlling traffic lights

– At the level of crossings

– At a network level (e.g., de "Leien" in Antwerp)
  ➔ “traffic must leave the city centre as fast as possible”

– At a corridor level (e.g., the A12 Antwerp-Brussels)
  ➔ “The good feeling: always green lights…”
  or “The bad feeling: I keep encountering red lights!”
Dynamical route guiding

• Dynamic routing information panels (DRIPs)
  • Travel times
  • Traffic jams (physical length and time duration !)
  • Alternative routes
Variable Message Signs (VMS)

- Dynamic speed limits (cfr. Dutch motorways)
Incident detection

- Closing of lanes; diverting traffic
- **Rubbernecking** effects on the opposite lane
Automatic incident detection
Other possible control actions

- Change the drivers’ travel times (leave earlier, depart later, don’t make the journey, ...).
- Road pricing and congestion charging.
- Public transport uses special lanes.
- Parking management.
- Lanes have a variable width.
- Detection of fog, snow, heavy rain, ...
- ...

Advanced Traffic Management Systems
Ramp metering

• “Try to control the inflow by drops.”
The idea behind ramp metering

capacity flow at critical density
The idea behind ramp metering

AIM: keep traffic in ‘stable regime’
Benefits of ramp metering

- without control
- with ramp metering

Increased throughput
Ramp metering applied to the E17

Melsele
Zwijndrecht
Linkeroever
Antwerpen
Platoon driving: myth or reality?

- Vehicles are supposed to drive close to each other (in platoons), with a lower average speed.
  - It might be safer...
  - BUT is it better (in terms of flow)?

  More research is needed!

For several years now, the police (i.e., ‘zwaantjes’) apply platoon driving at the E40 during the busy holidays (visits to the Northsea).
Sustainability effects of ATMS

• “Traffic is dynamic in nature”

Demand

Supply

(travellers/traffic flows)

(road infrastructure)

Optimise the traffic using the existing road infrastructure!

Tools for optimisation?

adaptive control strategies

(e.g., model predictive control)

Optimisation criterion?

sustainable cost function

DWTC PODO-II / CP/40
• Characterise the concept of ‘sustainability’, e.g.,

\[
SCF = \text{emissions (air, noise)} + \text{incident risks} + \text{travel times} \quad \text{environment}\]

\[
\text{supply}\]

\[
\text{personal}\]

• **Important:** the SCF involves a *trade-off*!
Illustrative software demonstration