Transport modeling: jams, crowds, molecular pedestrians, etc

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From individuals to macrosopic collective effects

Fluids

Vehicles

Pedestrians

Molecular motors

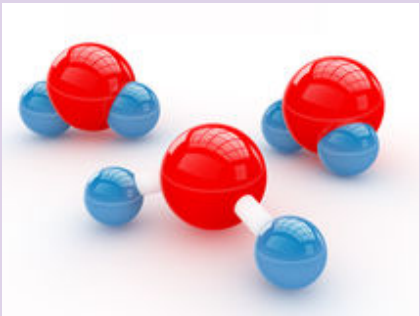
[Ijsbrand Kramer, Univ. Bordeaux]

Macroscopic Models: Conservation Laws

Henri Navier
(1785 Dijon–1836 Paris)
- mechanical engineer
- mathematician
- physicist
- economist

George Gabriel Stokes
(1819 Ireland – 1903)
- mathematician
- physicist

Molecules



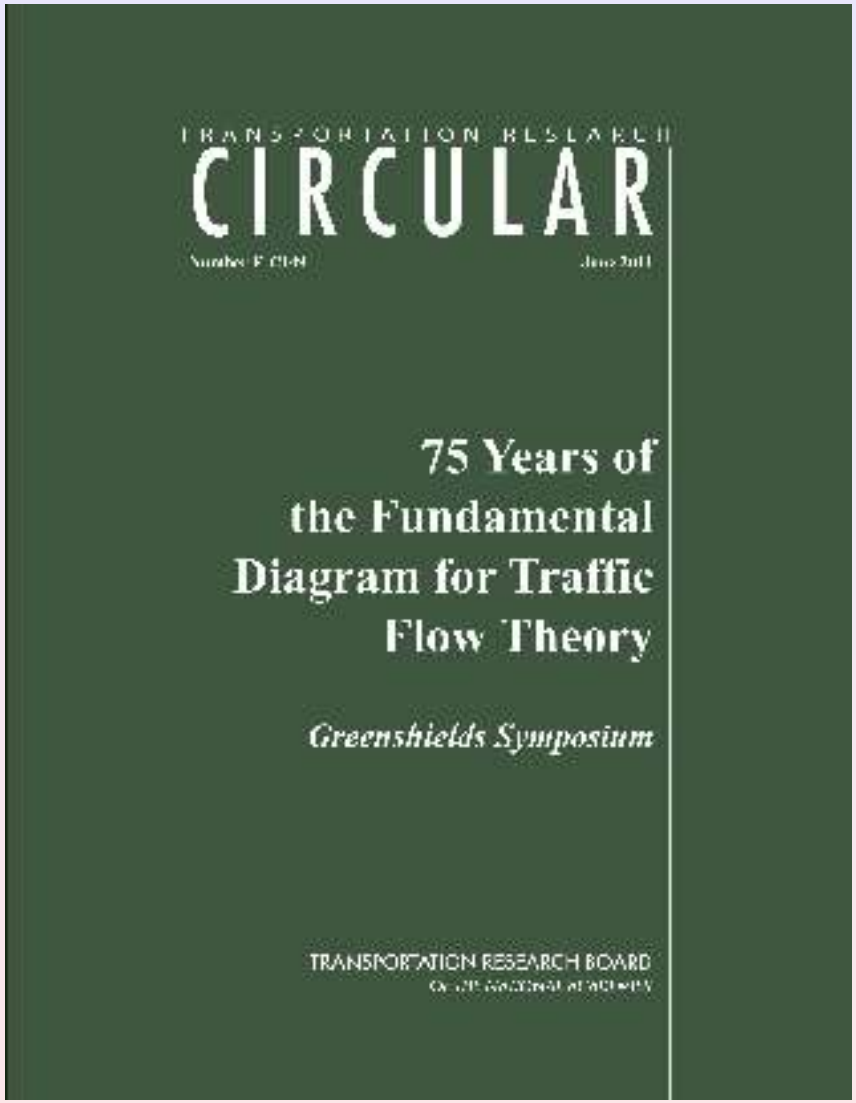
- Mass conservation
- Momentum conservation

Fluid

Navier-Stokes Equations (1823-1845)

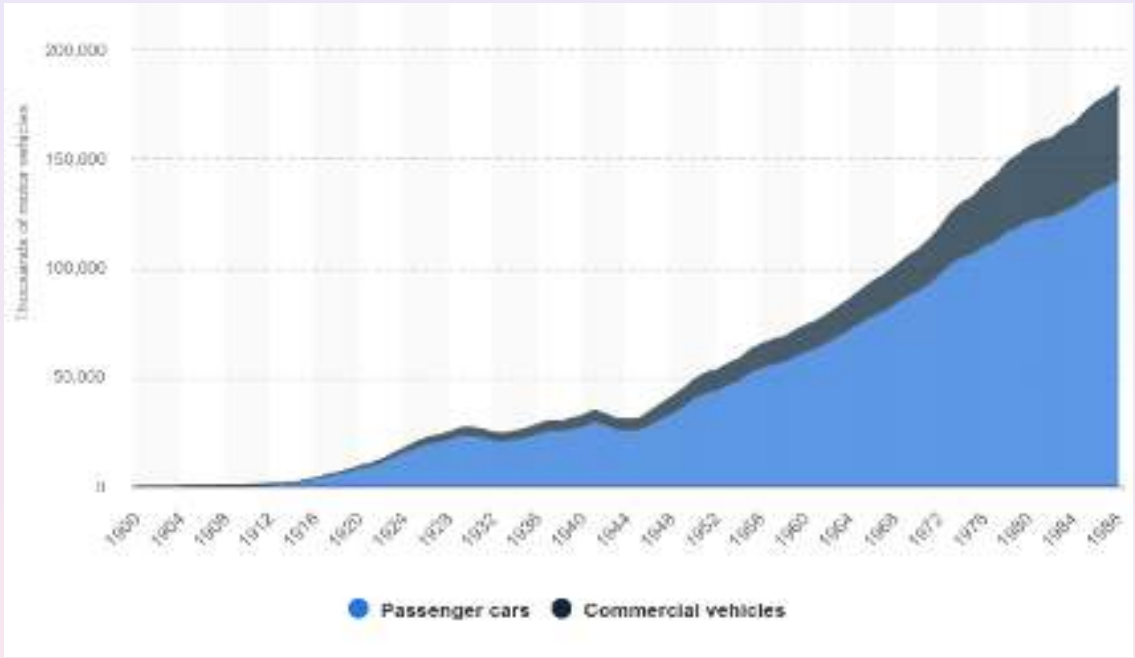
- 2 equations
  - Mass conservation
  - Momentum conservation
- 2 unknowns (density ρ, velocity u)

First Measurements for road traffic



Start of road traffic

1908



Statista 1993

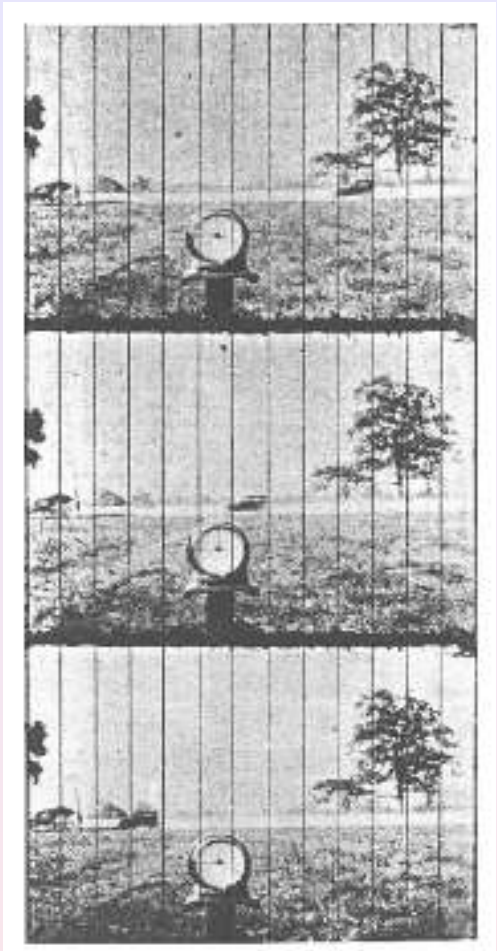
First Measurements for road traffic

[Charansonney et al, TFTC (2018)]

Johnson 1929

[Kühne, TRB (2011)]

Greenshield 1933



[Kühne, TRB (2011)]

Greenshield 1933

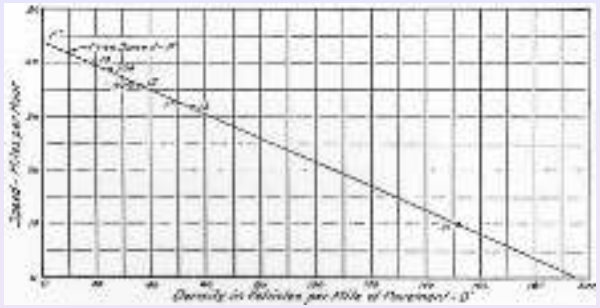
First Measurements for road traffic

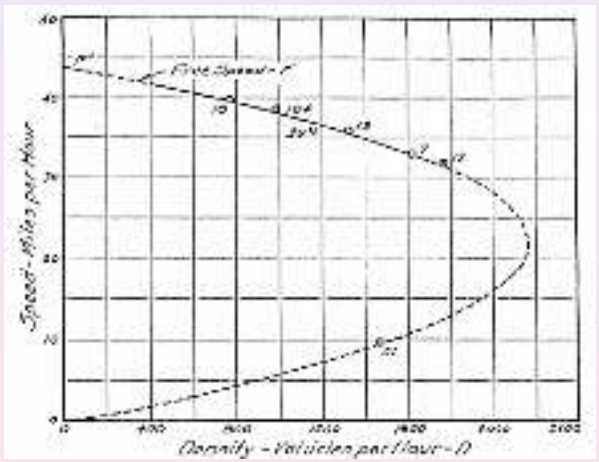
[Charansonney et al, TFTC (2018)]

Johnson 1929

[Kühne, TRB (2011)]

Greenshield 1933

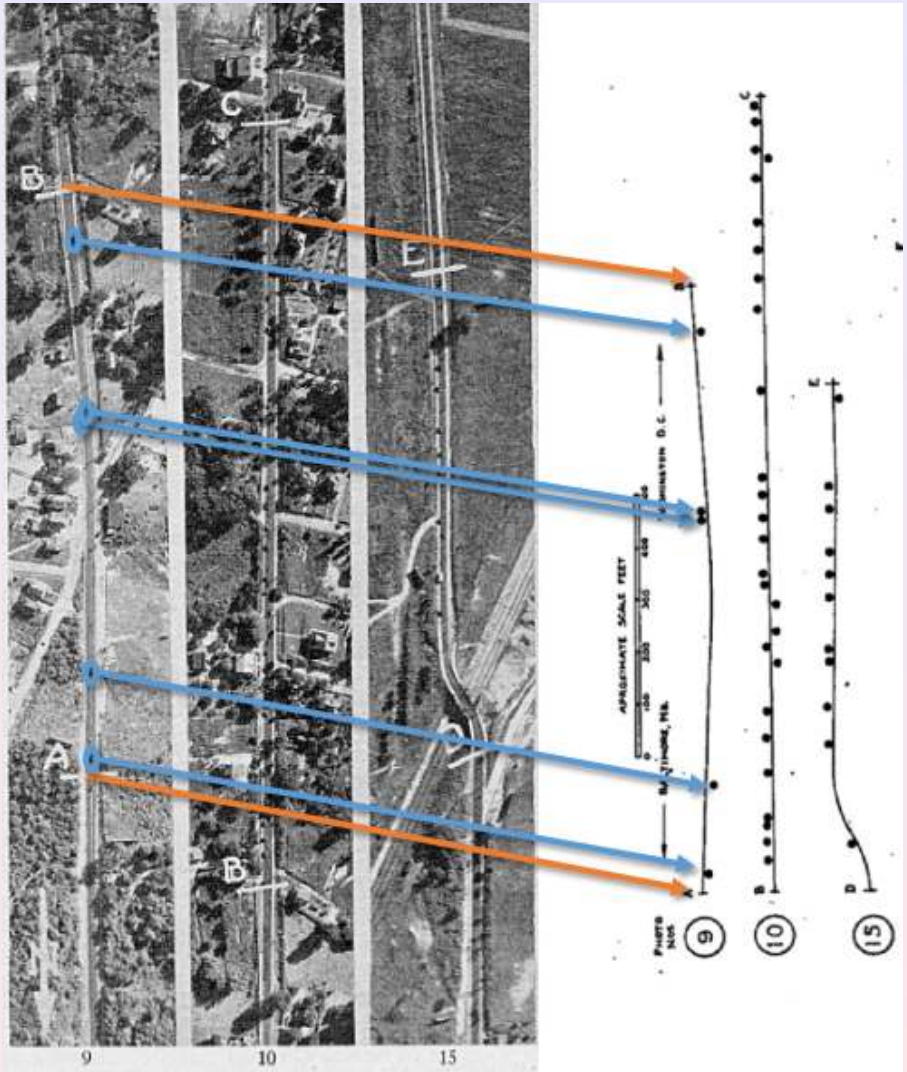




[Kühne, TRB (2011)]

Greenshield 1933

First Measurements for road traffic



[Charansonney et al, TFTC (2018)]

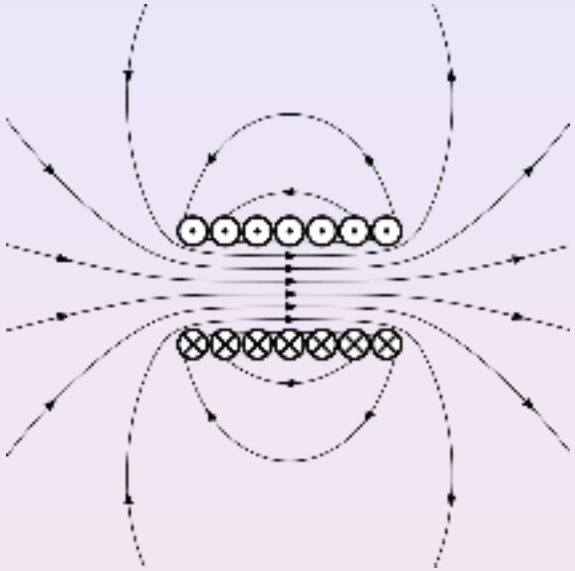
Johnson 1929
Aerial view

Vehicular Flux Measurements

Inductance loops

Vehicular Flux Measurements

Solenoid



[Wikimedia, by Geek3]

Solenoid with iron core

➥ Electromagnet.

Vehicular velocity Measurements

Double loops

From [Treiber, M2 Course]

Vehicular velocity Measurements

Double loops

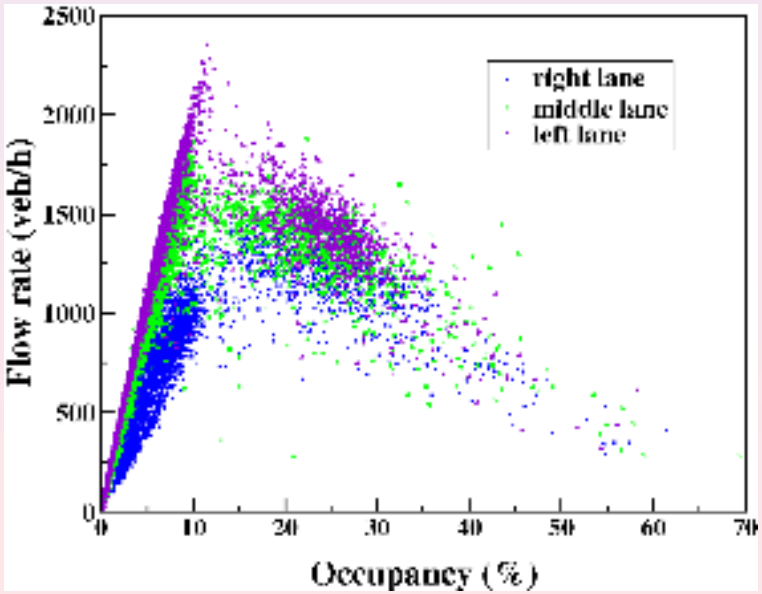
From [Coifman (2018), Traffic Flow Theory and Characteristics Committee Mid-Year Meeting]

Macroscopic Models for road traffic

Model LWR (1955-1956)

$$\partial_t \rho + \partial_x(\rho u) = 0 \quad \text{(Mass conservation)}$$

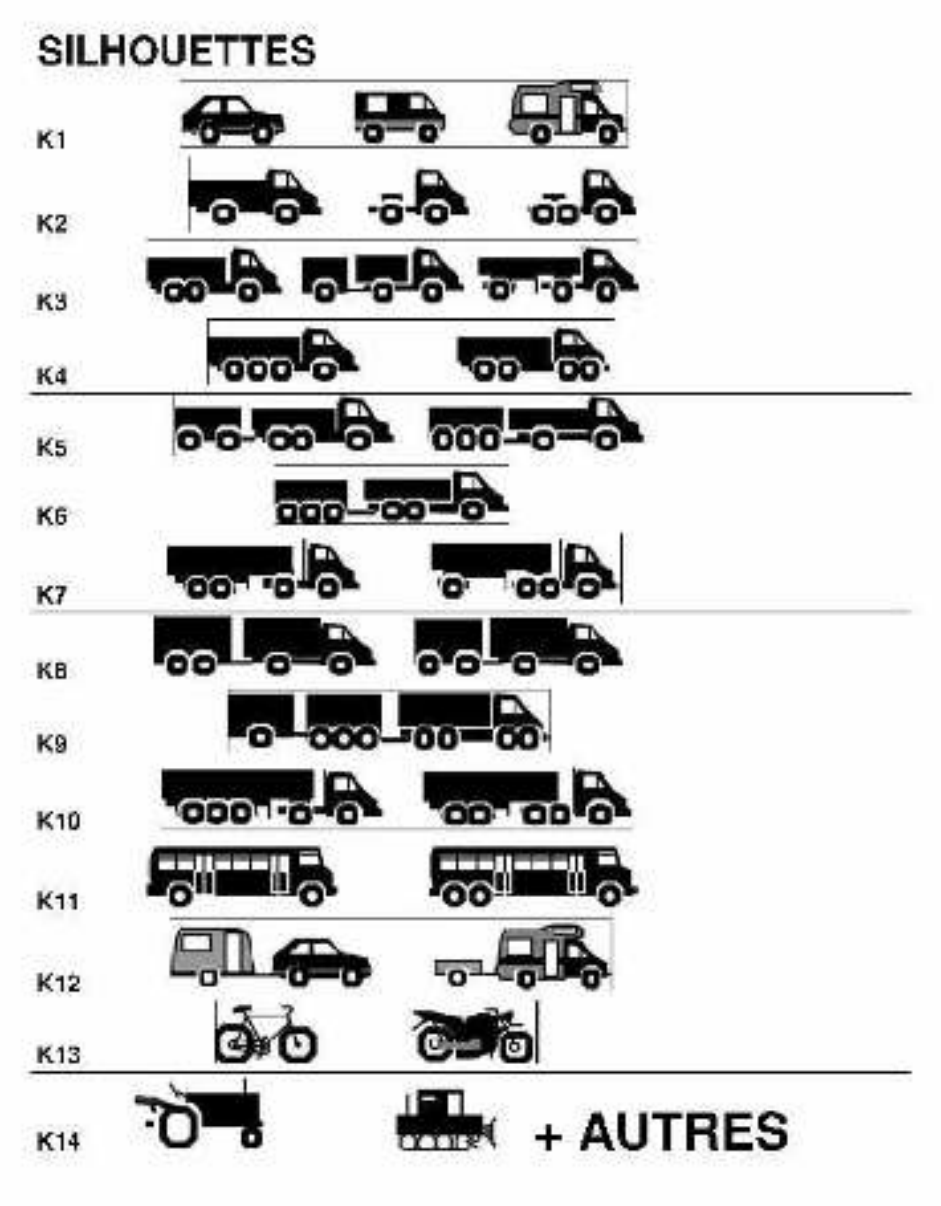
$$u = V(\rho) = \frac{F(\rho)}{\rho} \quad \text{(Fundamental Diagram)}$$



Single vehicle data

- Passage time
- velocity
- length
- SETRA category

SETRA categories

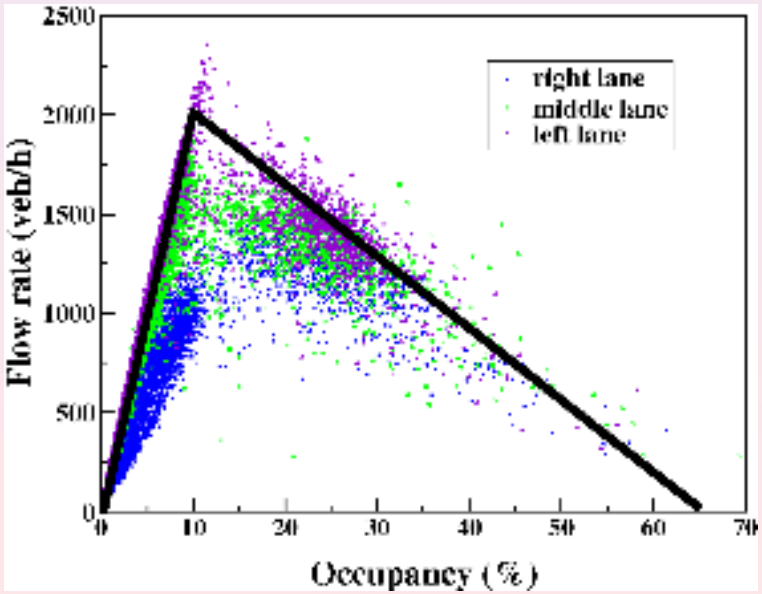


Macroscopic Models for road traffic

Model LWR (1955-1956)

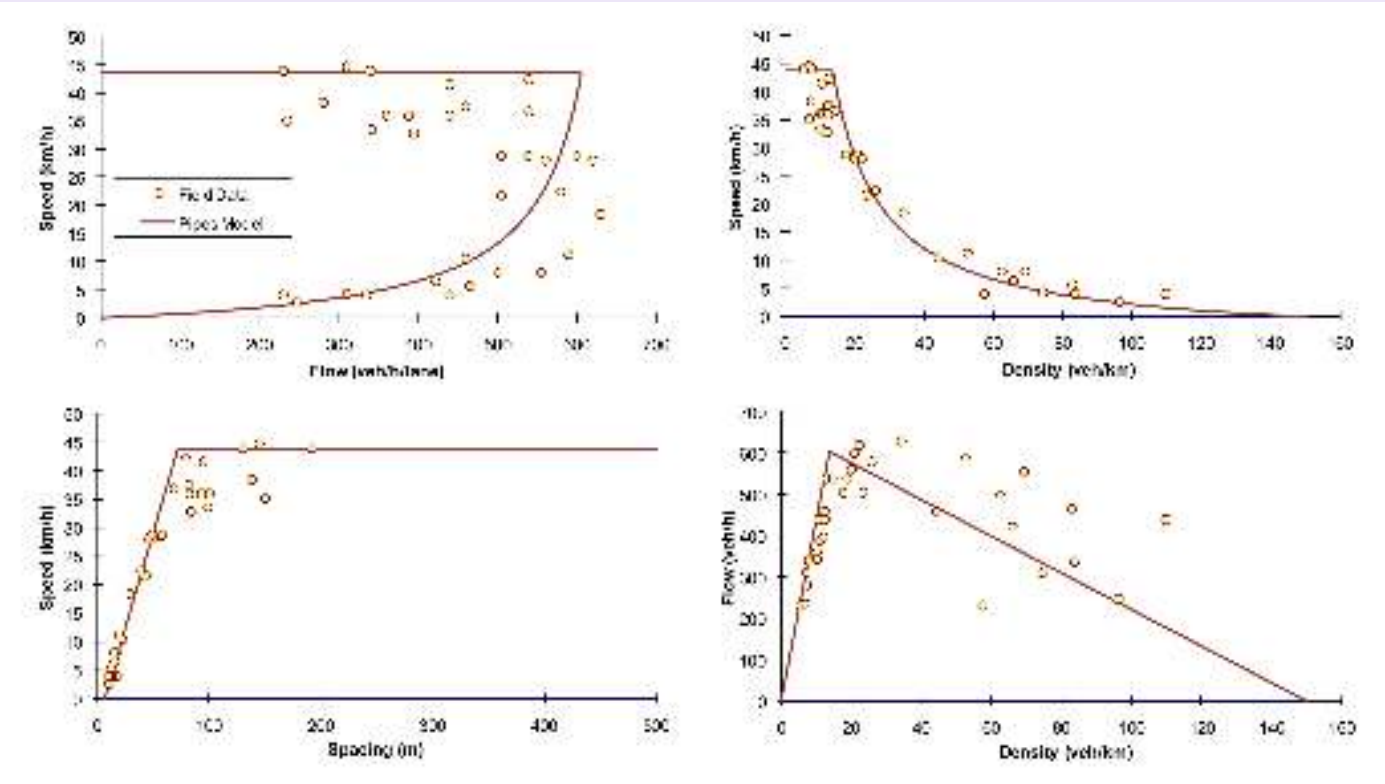
$$\partial_t \rho + \partial_x \left(F(\rho) \right) = 0 \quad \text{(Mass conservation)}$$

$$F(\rho) \quad or \quad V(\rho) \equiv \frac{F(\rho)}{\rho} \quad \text{(Fundamental diagram)}$$



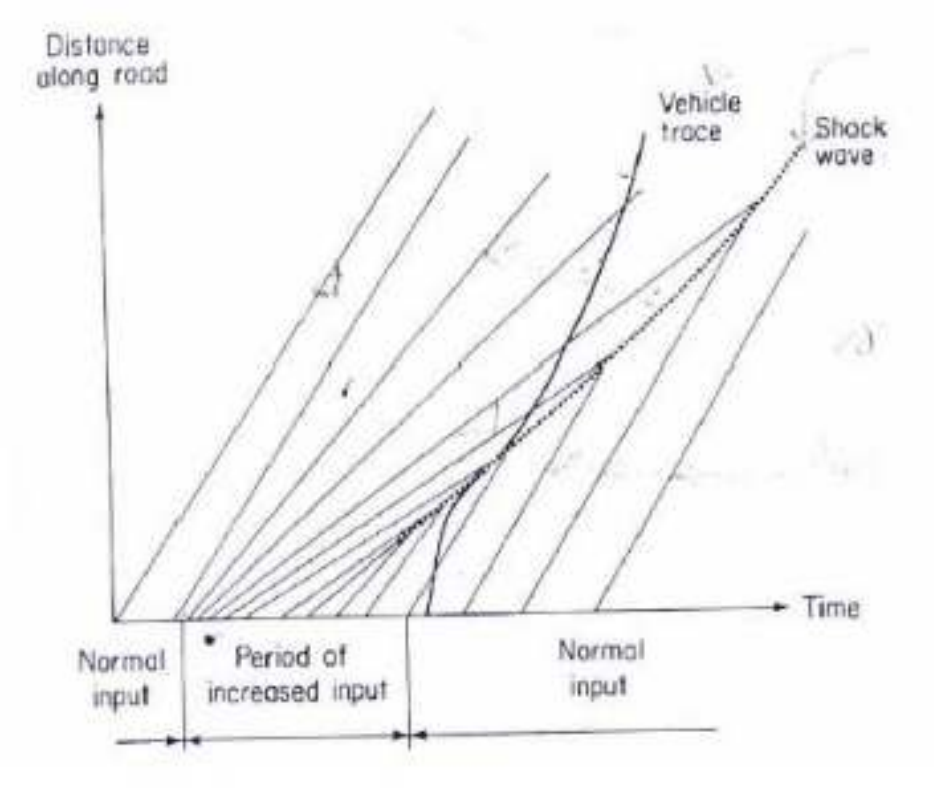
Fundamental diagrams

Various equivalent representations of the fundamental diagram



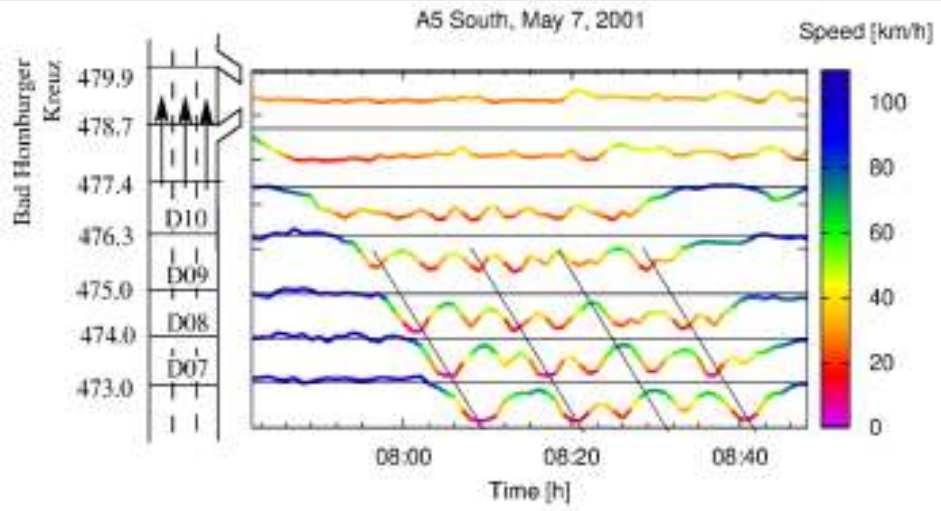
From [Rakha & Gao (2011), 75 Years of FD]

Characteristics and shocks



From [Dingra et al (2011)]

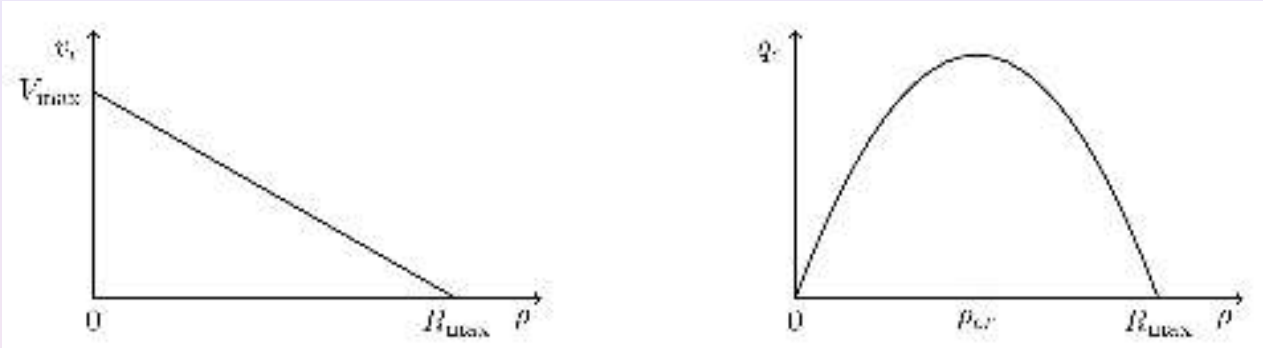
Measuring the wave speed w

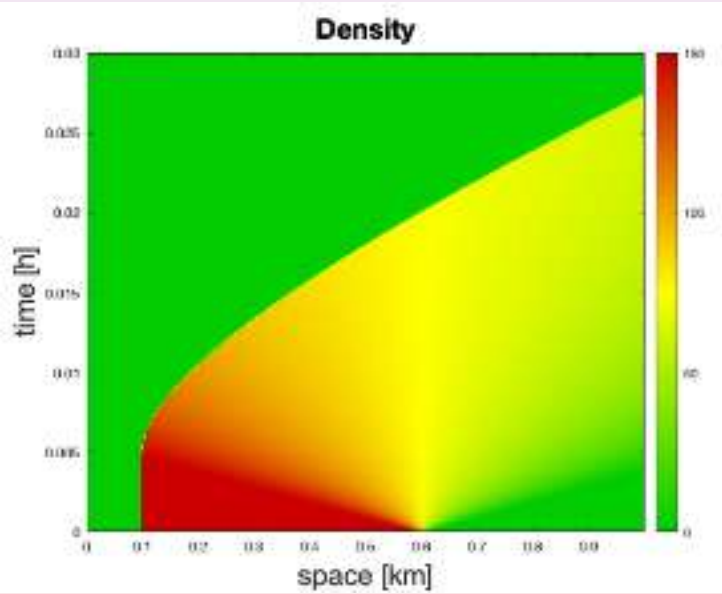


From [Treiber, M2 course]

Example of simulation of the LWR model

Model LWR with fundamental diagram $V(\rho) = V_{max}\left(1 - \frac{\rho}{\rho_{max}}\right)$ (Greenshield's fundamental diagram)





From [Goatin (2023), review paper]

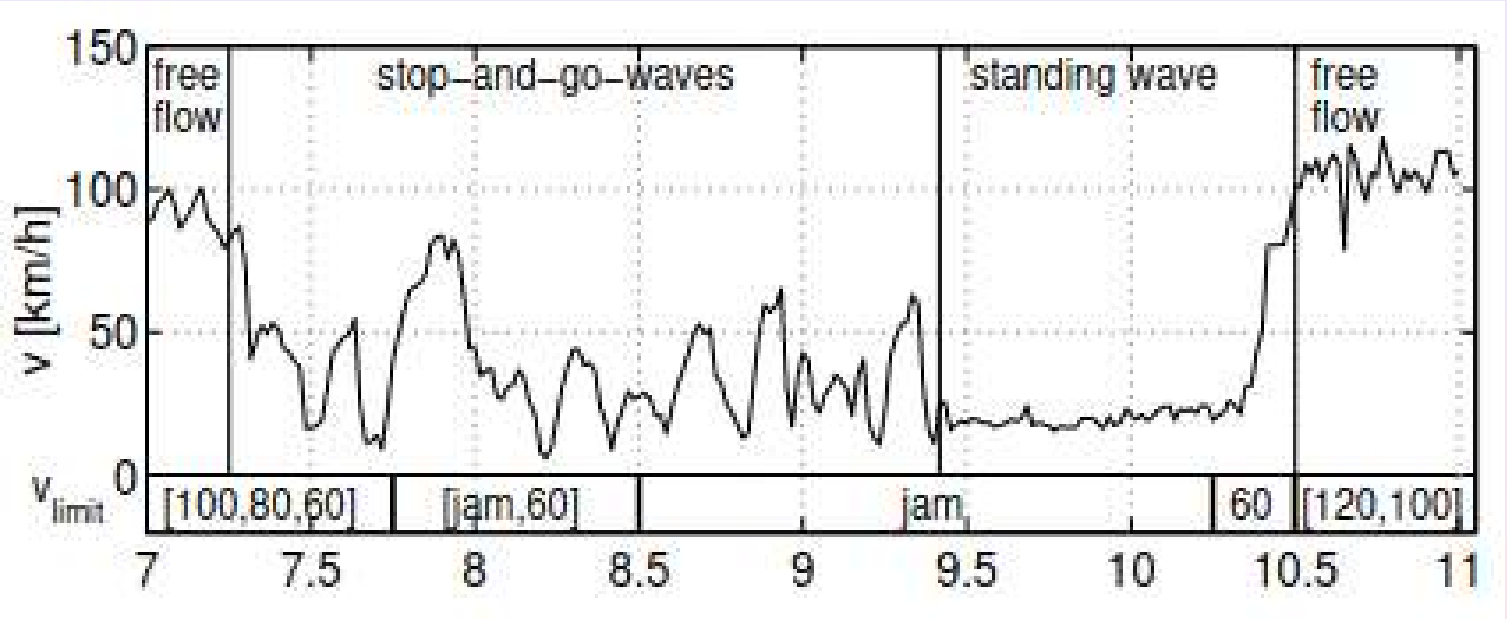
Ex: traffic light becomes green in $x = 0.6$.

Stop and Go waves

From [Sugiyama et al, New J. Phys. (2008)]

Drivers were asked to cruise at about 30 km/h.

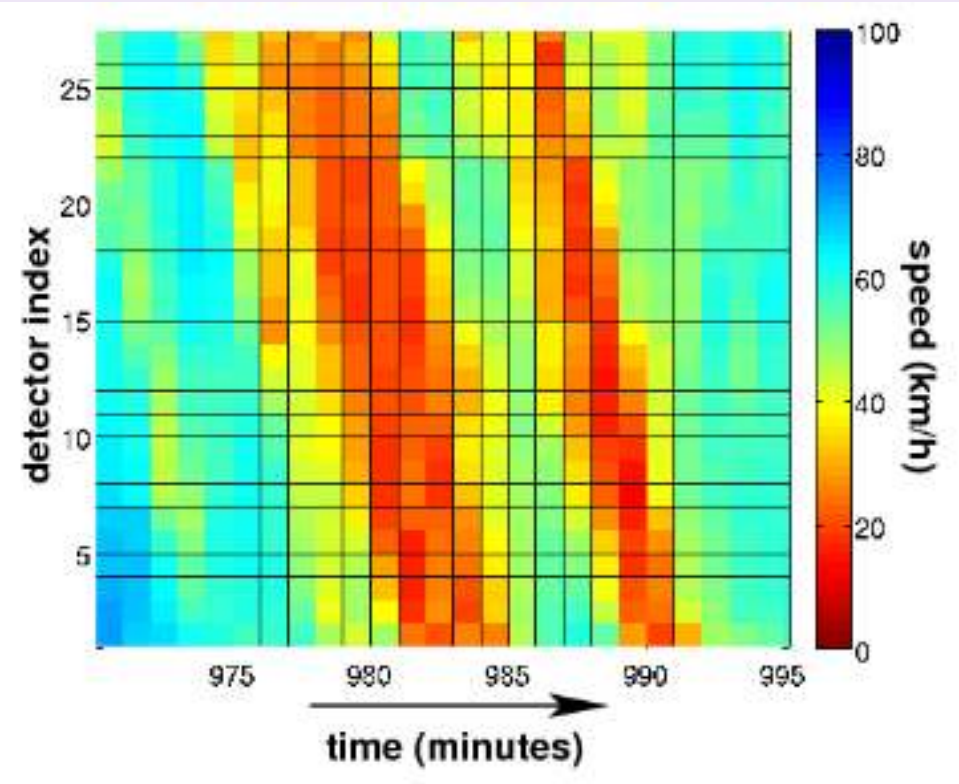
Stop and Go waves



From [Lenz et al, ECC, 2001 APCA]

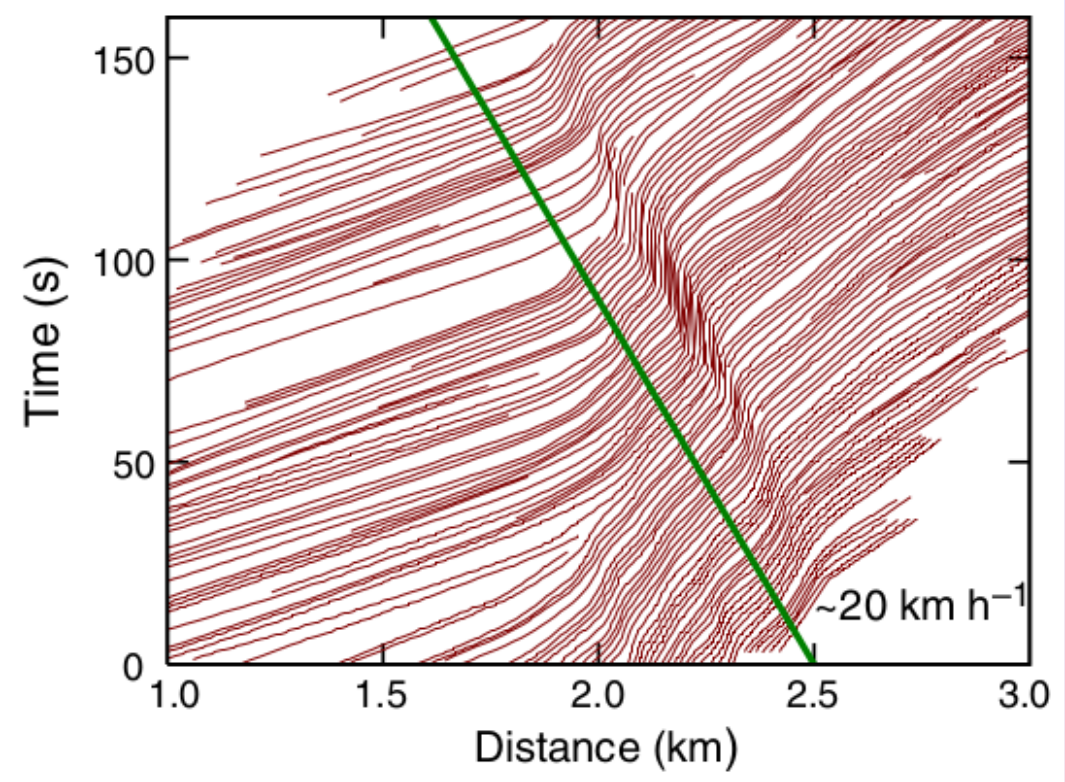
Stop and Go waves

Spatiotemporal plot of speed (averaged across three running lanes) for the high coverage section of M42 ATM showing two stop-and-go waves.



From [E. Wilson (2011), 75 Years of FD]

Stop and Go waves



From [Sugiyama et al, New J. Phys. (2008)]

- Trajectories of vehicles on the highway (aerial photograph taken in 1967). From [Treiterer and Myers, Transp. Traffic Theory (1974)]
- Green line : corresponds to a backward cluster velocity of 20 km/h, as measured in [Sugiyama (2008)].

Macroscopic Models for road traffic

1st order macroscopic model

- Modèle LWR (1955-1956)

2nd order macroscopic model

- Payne-Whitham model (1971)
  - ➥ “Requiem for second-order fluid approximations of traffic flow”
    [Daganzo 1995]