The meaning and limits of the fundamental diagram

Dr. Ana Tsui Moreno Chou

Graz, Austria, 29.05.2024

Learning outcomes

a) Describe the relationships between the macroscopic variables speed, volume and density
b) Define the types of traffic regimes according to the US Highway Capacity Manual
c) List limitations of the fundamental diagram

Recap

Basic flow parameters:

- **Volume q**: the total number of vehicles passing over a given point or section of a lane or roadway during a given time interval

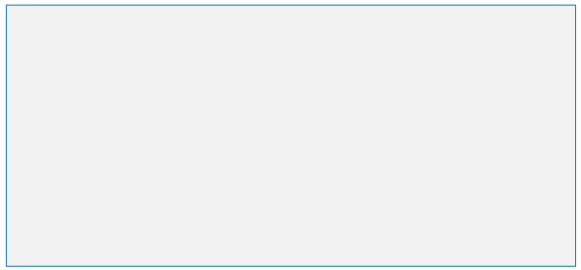
- **Density k**: number of vehicles occupying a given length of a lane or roadway at a particular instant

- **Speed V**: rate of motion expressed as distance per unit of time. ***Space mean speed*** is calculated as the average speed of vehicles traversing the segment at a particular instant

Relationships

Fundamental equation of traffic

The **fundamental equation of traffic** describes the general relationship between speed, volume and density as:

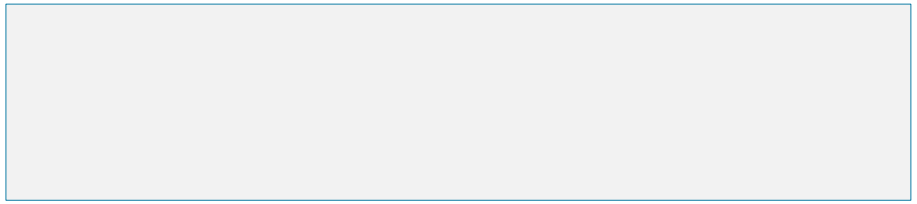


Where: $q = volume\ (veh/h)$

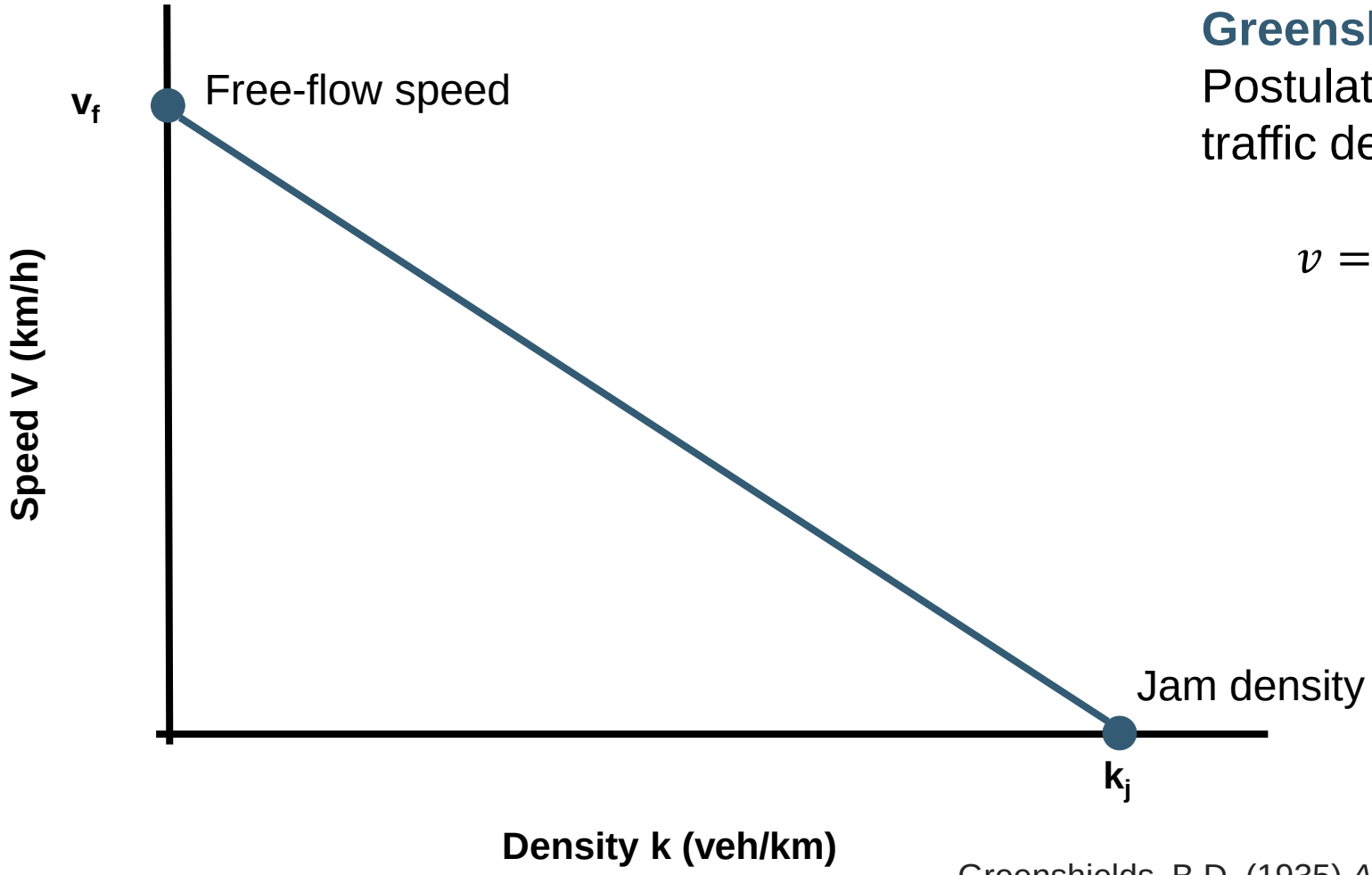
$k = density\ (veh/km)$

$v = speed\ (km/h)$

This is valid for homogeneous, stationary traffic flow within each traffic regime

The  displays the fundamental equation of traffic

Density and speed

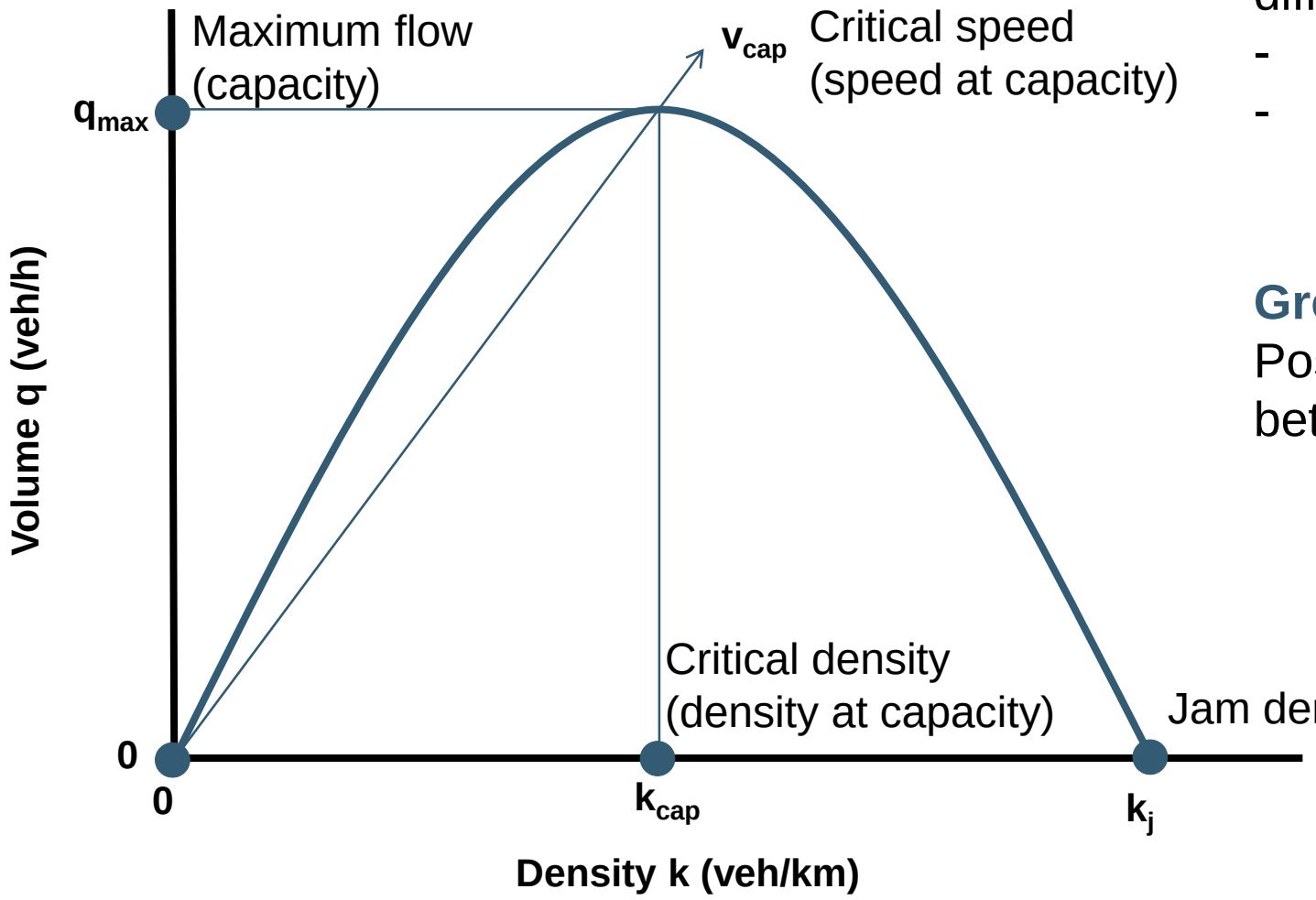


Greenshields (1935)
Postulated a **linear** relationship between traffic density and speed

$$v = v_f(1 - \frac{k}{k_j})$$

Greenshields, B.D. (1935) *A Study of Traffic Capacity*. Highway Research Board, 14, 448-477.

Density and volume



Zero volume occurs under two different conditions:

- No vehicles on the segment
- Density is so high that all vehicles must stop (jam density)

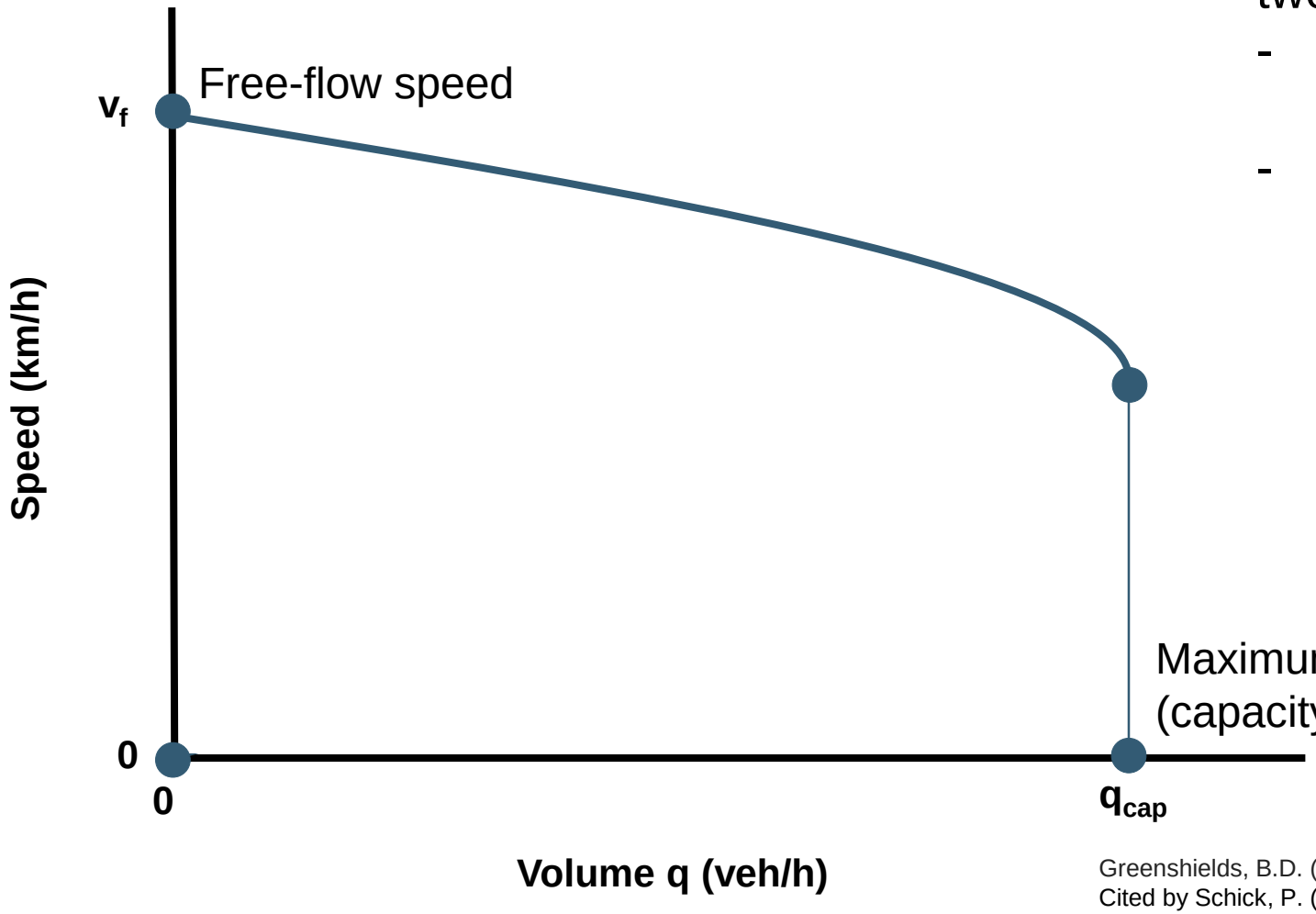
Greenshields (1935)
Postulated a **parabolic** relationship between density and volume

$$k_{cap} = \frac{k_j}{2}$$

$$q_{cap} = k_j \cdot v_{cap}$$

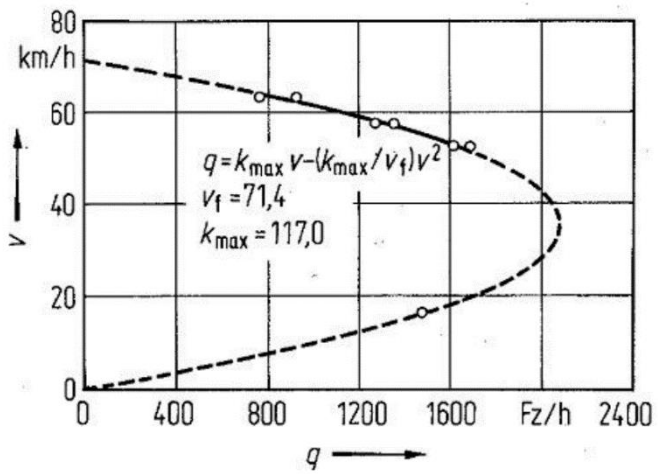
$$v_{cap} = \frac{v_f}{2}$$

Volume and speed



Close to zero volume occurs under two different conditions:

- No vehicles moving on the segment
- One vehicle is moving at its desired speed (free-flow)



Greenshields, B.D. (1935) *A Study of Traffic Capacity*. Highway Research Board, 14, 448-477. Cited by Schick, P. (2003) Einfluss von Streckenbeeinflussungsanlagen auf die Kapazitaet von Autobahnabschnitten sowie die Stabilitaet des Verkehrsflusses. Dissertation, University of Stuttgart (Figure 3.3)

Exercise

On a particular road, the Greenshields fundamental diagram holds with a free flow speed of 75 km/h and a jam density of 100 veh/km.

Does this determine the capacity with no further assumptions?

If so, calculate capacity.

If not, explain why not.

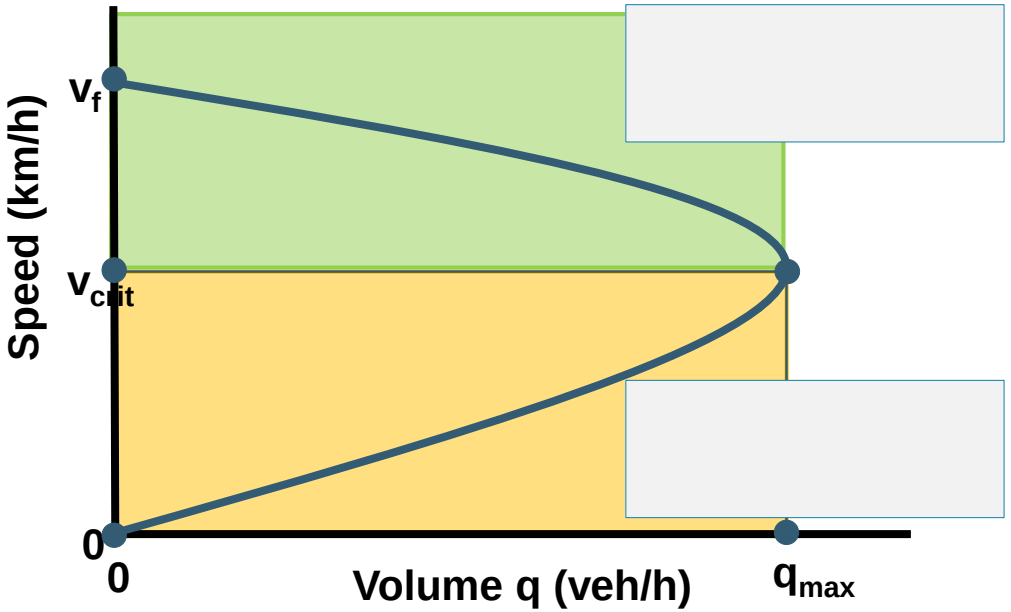
Traffic regimes

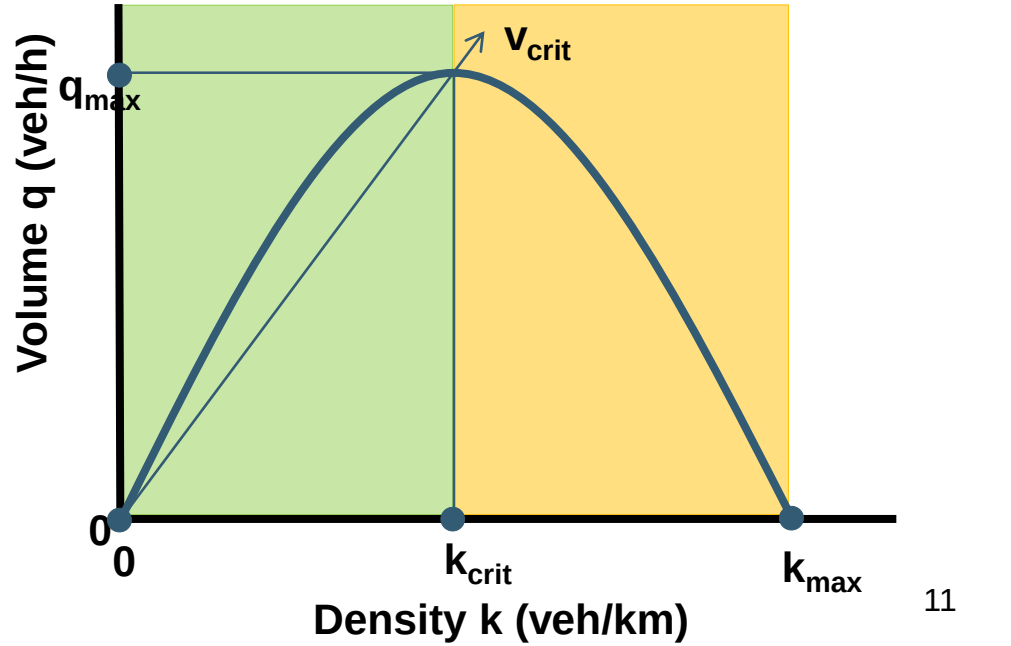
Traffic regimes

There are two basic types of traffic regimes:

1) **Undersaturated flow**: Traffic flow where the volume is lower than the capacity

2) **Oversaturated flow**: Traffic flow where the volume exceeds the capacity

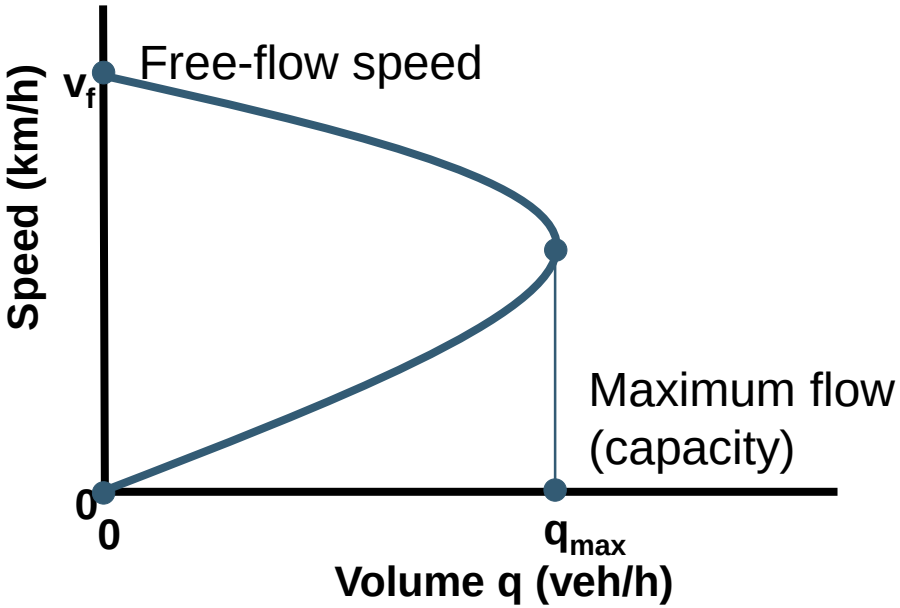




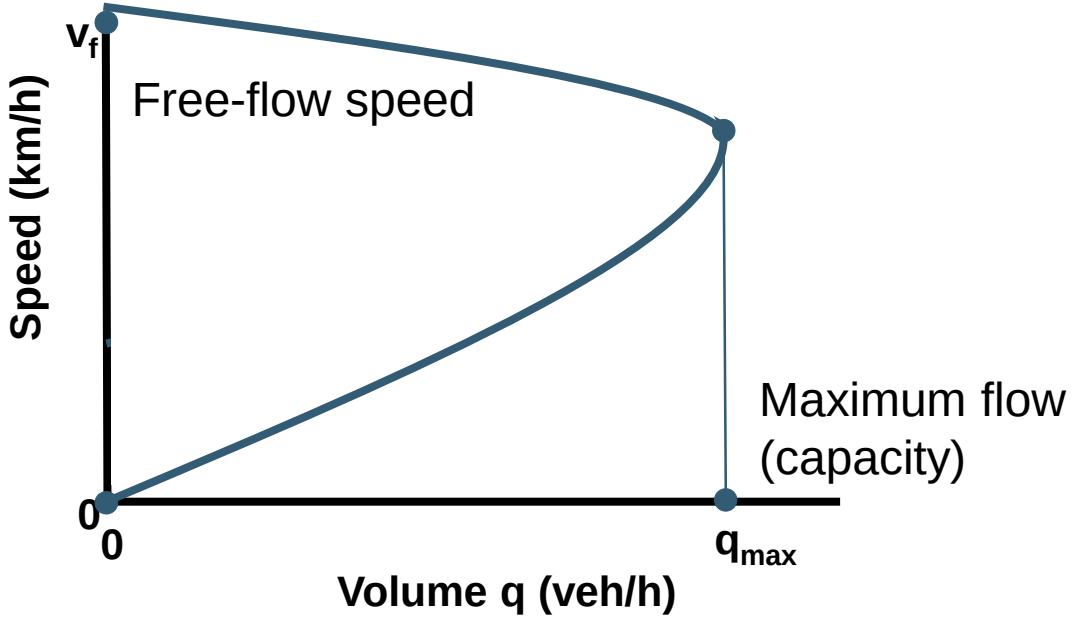
Limitations

Main limitations

- The form of the relationships depends on roadway conditions and on the segment length:
  - Different facilities will have different forms



Facility: _____

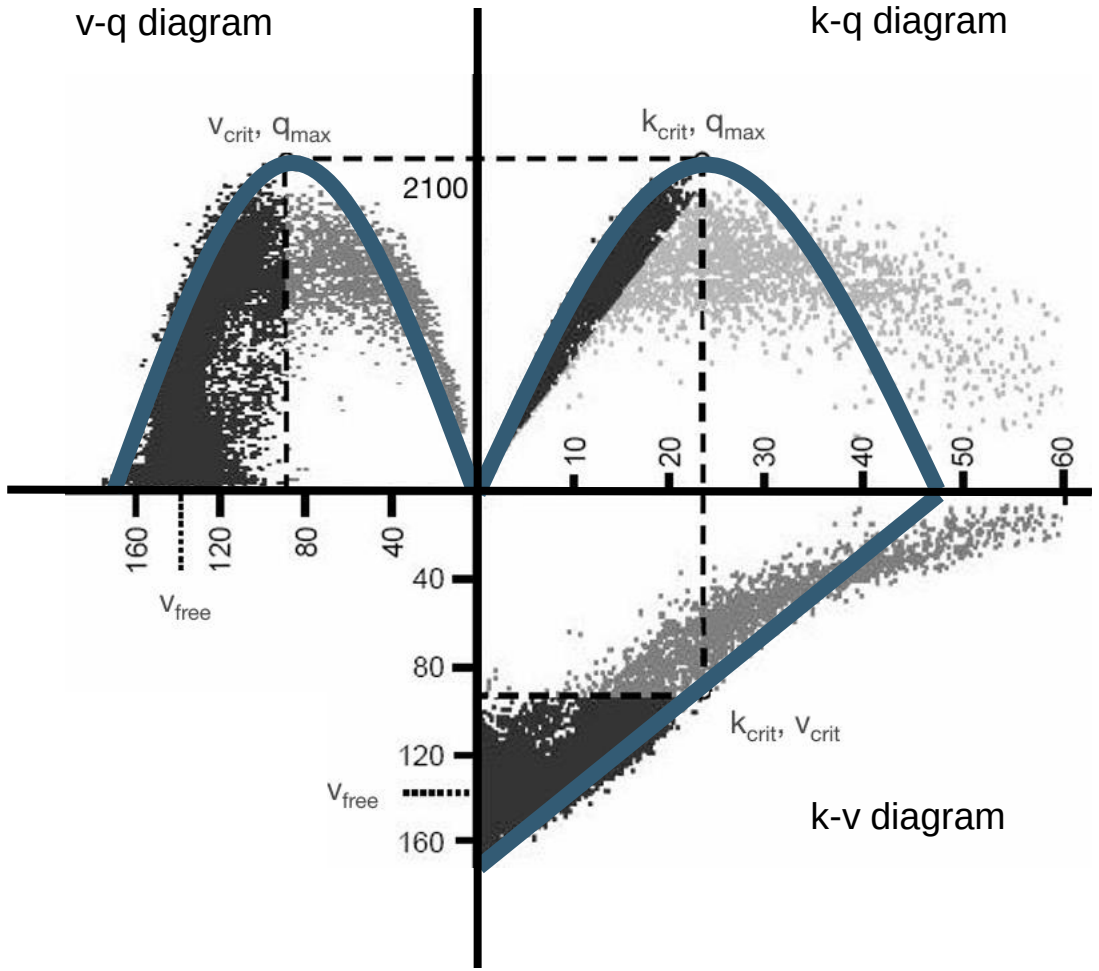


Facility: _____

Main limitations

- Traffic must be stationary and homogeneous:
  - Real-world data is affected by prevailing traffic or weather conditions
  - The idealized parabola may not be reached in freeway real-world data
  - Real-world data usually show discontinuities

Data from A9 between Munich and Nuremberg (MQ 316)



Translated from Schick, P. (2003) Einfluss von Streckenbeeinflussungsanlagen auf die Kapazitaet von Autobahnabschnitten sowie die Stabilitaet des Verkehrsflusses. Dissertation, University of Stuttgart (Figure 3.1)

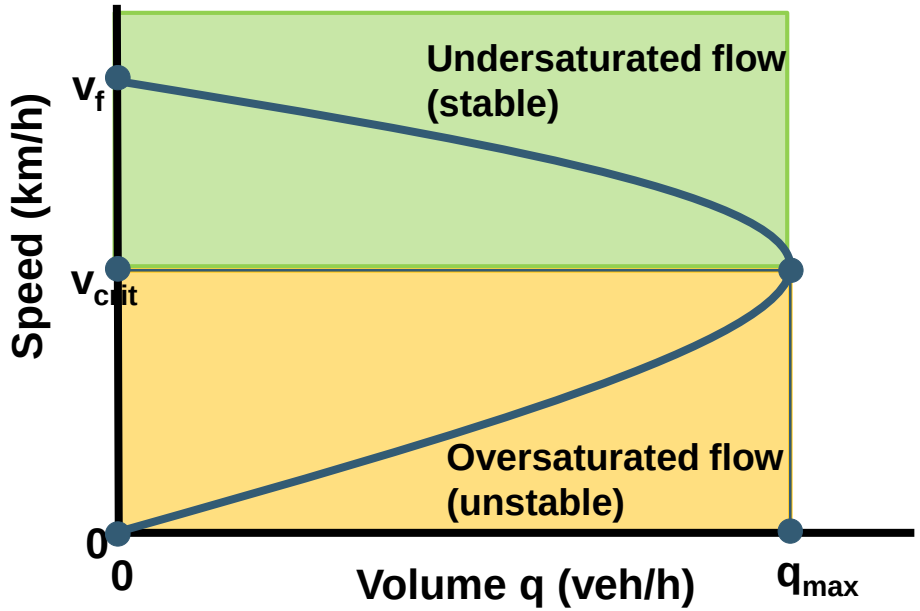
Main limitations

- Traffic analysis is constrained to the analyzed period and facility:
  - A queue created from a prior breakdown of a facility may have not yet been dissipated
  - Traffic conditions may be affected by downstream conditions

The US Highway Capacity Manual (TRB, 2023) defines two types of traffic regimes:

1) **Undersaturated flow**: Traffic flow where (*a*) the arrival flow rate is lower than the capacity, (*b*) no residual queue remains from a prior breakdown of the facility, **and** (*c*) traffic flow is unaffected by downstream conditions

2) **Oversaturated flow**: Traffic flow where (*a*) the arrival flow rate exceeds the capacity, (*b*) a queue created from a prior breakdown of a facility has not yet dissipated**, or** (*c*) traffic flow is affected by downstream conditions



Source: Transportation Research Board (2023). Highway Capacity Manual 7.0

Recap test

- Greenshields (1935) found that the relationship between traffic density and speed is:
  a) Parabolic
  b) Linear
  c) Log-linear

- According to the basic equation of traffic states, volume (q) is equal to:
  a) Speed divided by density
  b) Density divided by speed
  c) Speed times density

- The US Highway Capacity Manual defines oversaturated flow conditions when:
  a) Traffic flow is affected by downstream conditions
  b) The arrival flow rate is lower than the capacity
  c) No residual queue remains from a prior breakdown

The meaning and limits of the fundamental diagram

Dr. Ana Tsui Moreno Chou

ana.moreno@tum.de

Further materials

Take-home exercise

Describe qualitatively and quantitatively the macroscopic parameters:

- Traffic density **k,**
- Traffic volume **q** and
- Average velocity $\mathbf{v_m}$

On a two-lane rural highway with good weather conditions and adverse weather conditions for the traffic states

- **Undersaturated and**
- **Oversaturated.**

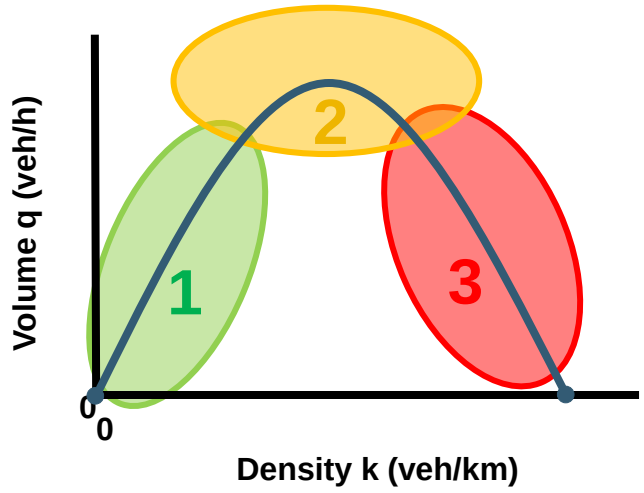
Plot your results in the fundamental diagrams and deduce relationships between these parameters on the two weather conditions.

Traffic regimes

Other examples

May (1990) defines three types of traffic regimes:

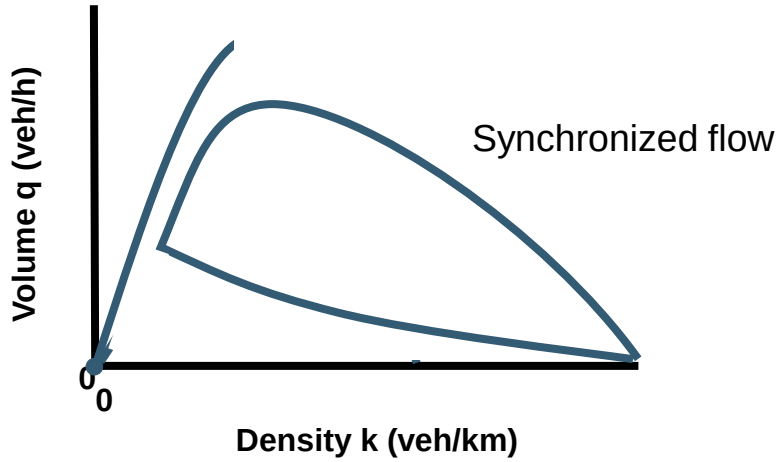
1) **Free flow**: high speed with low traffic flow and density
2) **Impeded free flow**: maximum traffic flow at optimum (critical) density and speed
3) **Impeded flow**: high traffic density with low traffic flow and speed



May, A. D., (1990). *Traffic Flow Fundamentals*. Prentice Hall, Englewood Cliffs, N.J.

Kerner (2004) defines two areas and three phases:

1) **Free flow**: no interrelation between vehicles, overtaking possible at any time
2) **Synchronized flow**: occurs behind a bottleneck. Few stops, comparable speed on lanes
3) **Wide moving jam**: front-end and rear-end of jam are described by shock waves against the traffic direction



Kerner, B. Kerner, (2004) Three-phase traffic theory and highway capacity, *Physica A: Statistical Mechanics and its Applications* 333, 379-440.

Applications of the fundamental diagram theory

- Design of road sections (e.g. determination of capacity)
- Traffic control (e.g. optimizing stable flow conditions)
- Traffic flow simulation (e.g. macroscopic models)
- Traffic state estimation (e.g. congestion propagation)