Traffic Flow – Seminar

28.04.2020

Relationships among characteristics

-

Application of speed-flow relationship

Miklós KÓZEL

kozel.miklos@mail.bme.hu

ST426

Content:

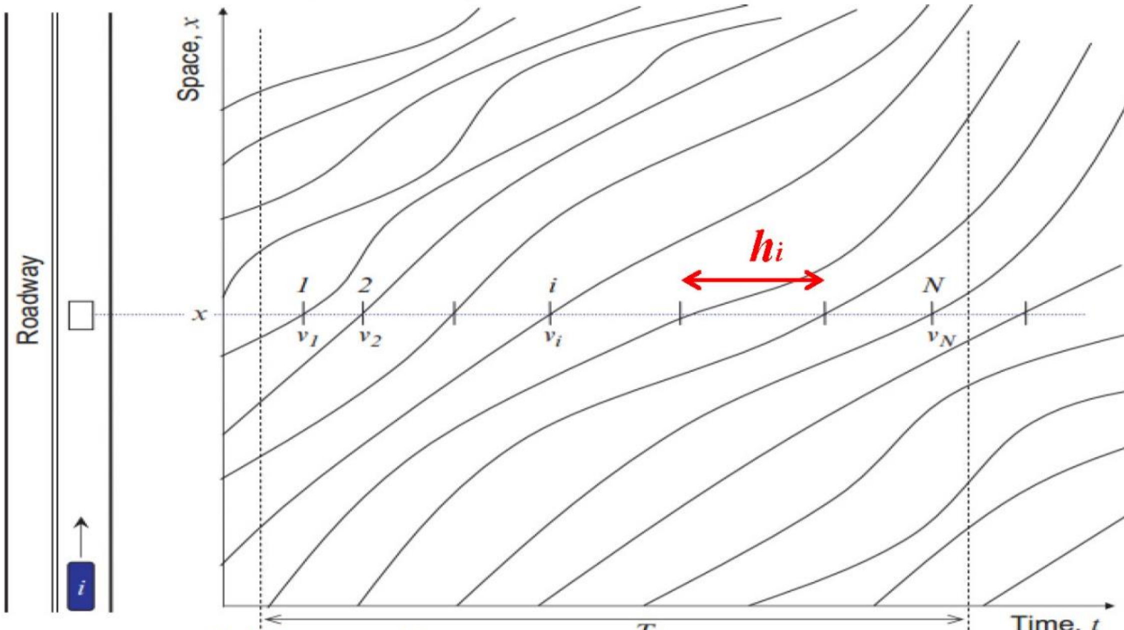
1. Previously on lectures:
   - important parts are highlighted
     - 6 basic parameters
     - reciprocal relations, $q = k \times v_s$
     - single regime models (as empirical models)
2. Previously on seminar:
     - reduced distance headway, h_R
3. Application of speed-flow relationship (as theoretical model) – **home assignment**

1. Basic parameters of road traffic

POINT SENSOR DATA

Lets consider:

A point sensor (such as a loop detector or a video camera) is installed on the road at location (x). **What kind of traffic flow characteristics can be determined from the time-space diagram?**



Point sensor data.

Traffic count (N): number of vehicles in traffic. (1,2,…,N)

Flow rate (q): number of vehicles per time period:

$$q = \frac{N}{T}$$

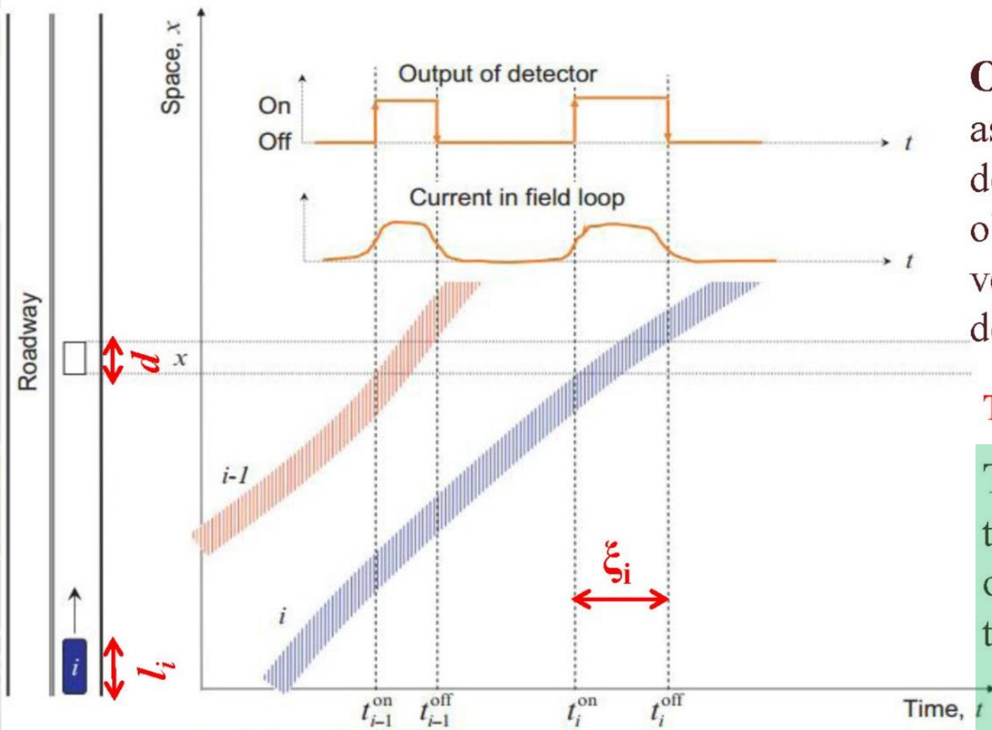
Headway (h_i): time distance between to consecutive vehicle: $h_i = t_i - t_{i-1}$

Observation duration $\cong T = \sum_{i=1}^{N} h_i$

1. Basic parameters of road traffic

POINT SENSOR DATA

What if we consider the physical dimensions of the vehicles and loop detectors?! **What kind of traffic flow characteristics can be determined?!**



Loop detector data.

Occupancy (o) = Occupancy is defined as the percentage of time when the loop detects vehicles above it. if the observation period is **T**, during which **N** vehicles are detected, the occupancy is determined as:

$$o = \frac{\sum_{i=1}^{N} \xi_i}{T}$$

Total on time

Time-mean speed (v_t) = Average of the vehicle speeds observed at a point of roadway in the time domain is termed "time-mean speed."

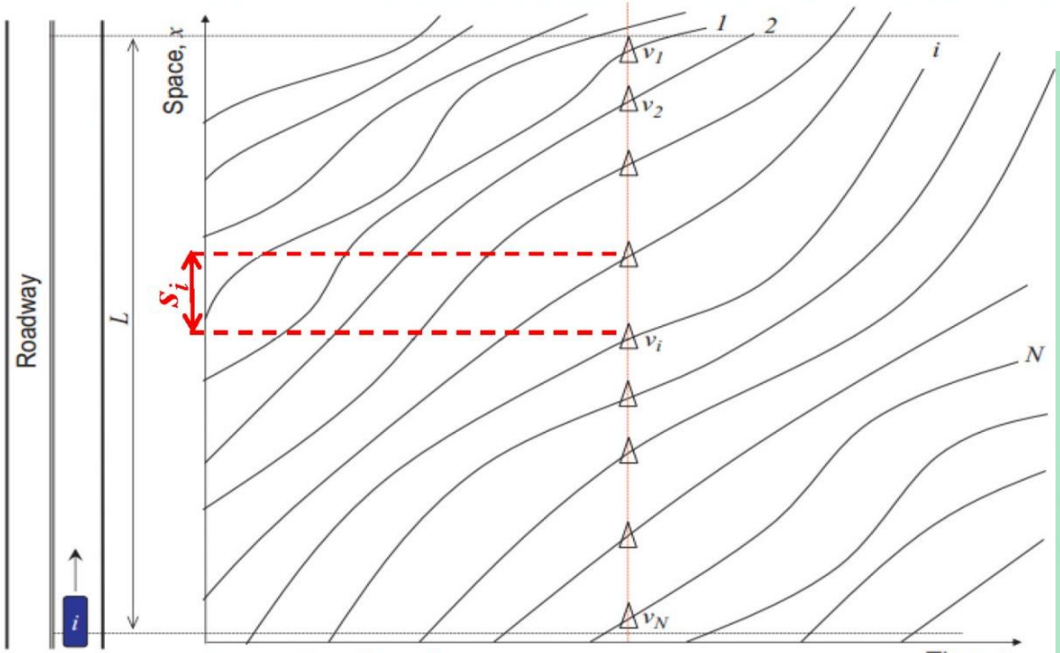
$$v_t = \frac{1}{N} \sum_{i=1}^{N} \dot{x}_i$$

1. Basic parameters of road traffic

SPACE SENSOR DATA

Lets consider:

We have taken a snapshot of roadway from the helicopter at time (t) and the vehicles are located and labeled as triangles in this snapshot. **What kind of traffic flow characteristics can be determined from these aerial photos?!**



A snapshot of roadway.

Spacing (s_i) = Spatial separation between two consecutive vehicles.

$$s_i = x_{i-1} - x_i$$

Density (k or D) = Number of vehicles observed on a unit length of road. $k = \frac{N}{L}$

Space-mean speed (v_s) = Average of the vehicle speeds in the space domain.

$$v_s = \frac{1}{N}\sum_{i=1}^{N}\dot{x}_i$$

1. Reciprocal relations

RELATIONSHIPS AMONG CHARACTERISTICS

Flow, Speed, and Density:

By definition, the following relationship holds as an identity:

$$q = k \times v_s$$

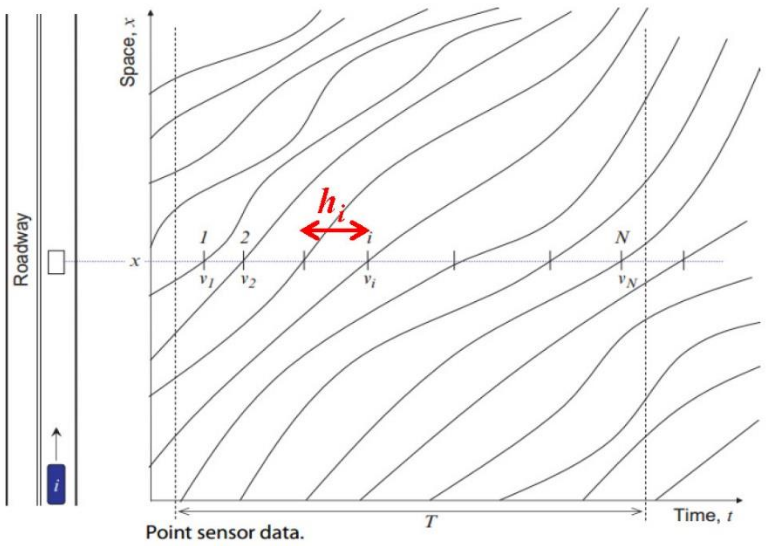
that is, ***flow q*** is the product of ***density k*** and ***space-mean speed v_s***.

Flow and Headway:

$$q = \frac{N}{T},$$

$$T = \sum_{i=1}^{n} h_i,$$

$$q = \frac{N}{\sum_{i=1}^{n} h_i} = \frac{1}{\frac{1}{N}\sum_{i=1}^{n} h_i} = \frac{1}{h}$$



Therefore, ***flow q*** is the **reciprocal** of ***average headway h***.

1. Reciprocal relations

RELATIONSHIPS AMONG CHARACTERISTICS

Flow and Headway:

For example, a flow of 1200 vehicles per hour suggests an average headway of:

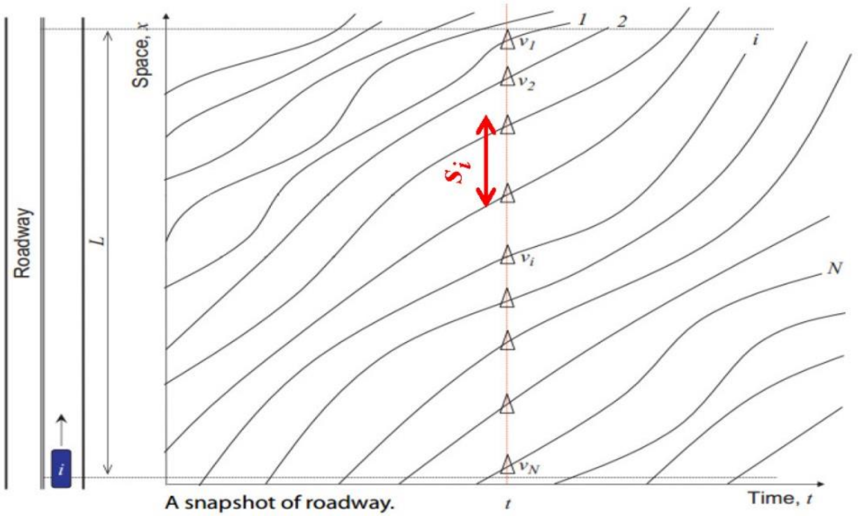
$$\frac{1}{1200 \text{ vehicles per hour}} = \frac{3600\,\text{s/h}}{1200 \text{ vehicles per hour}} = 3\,\text{s}$$

Density and Spacing:

$$k = \frac{N}{L},$$

$$L = \sum_{i=1}^{n} s_i,$$

$$k = \frac{N}{\sum_{i=1}^{n} s_i} = \frac{1}{\frac{1}{N}\sum_{i=1}^{n} s_i} = \frac{1}{s}$$

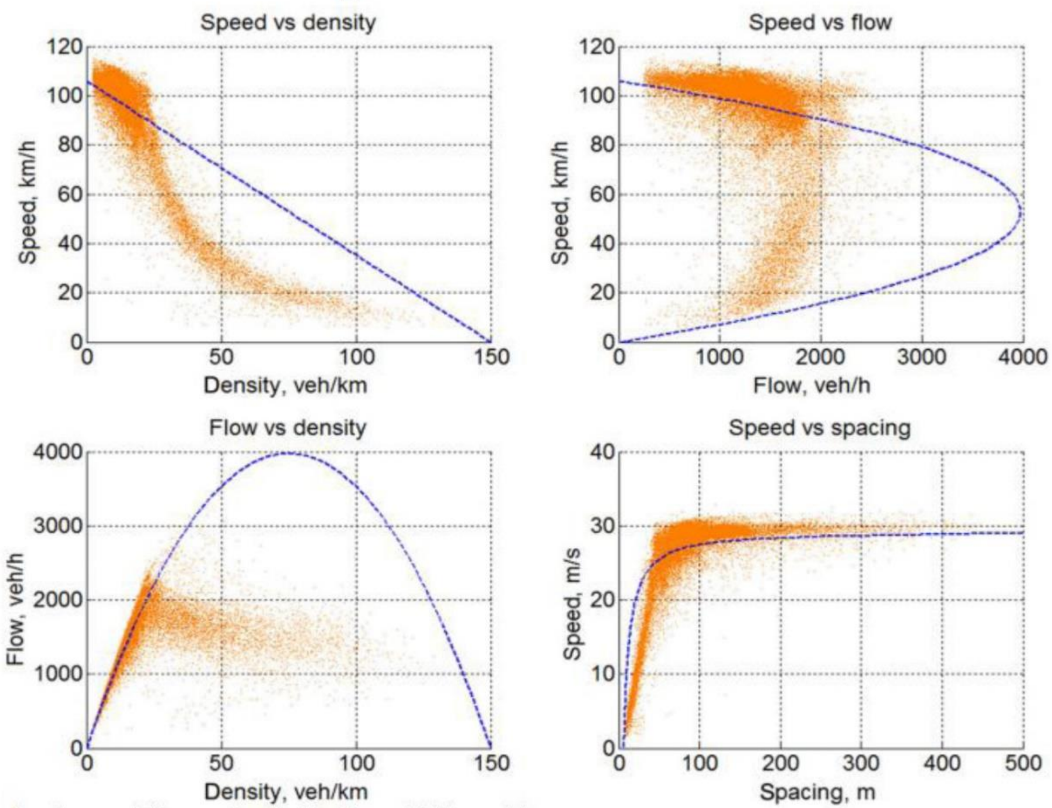


Therefore, ***density k*** is the **reciprocal** of ***average spacing s***.

1. Single regime models – based on measurement data

SINGLE REGIME MODELS

Evaluating the Greenshields Models:



Fundamental diagrams implied by Greenshields model.

- ✓ Model suffers from a lack of accuracy.
- ✓ e.g. the model predicts that the **capacity** of this road **($q = q_m$)** occurs at half the jam density ($k_m = 1/2k_j$) ≈ **82** (Veh/k). However, field observations suggest that k_m is most likely in the range of **25-40** vehicles per kilometer.
- ✓ Speed decreases linearly with density in the model, but we can have the free flow speed up to a density around 15 (veh/h) in this road before a noticeable speed drop can be observed.

1. Single regime models – based on measurement data

SINGLE REGIME MODELS

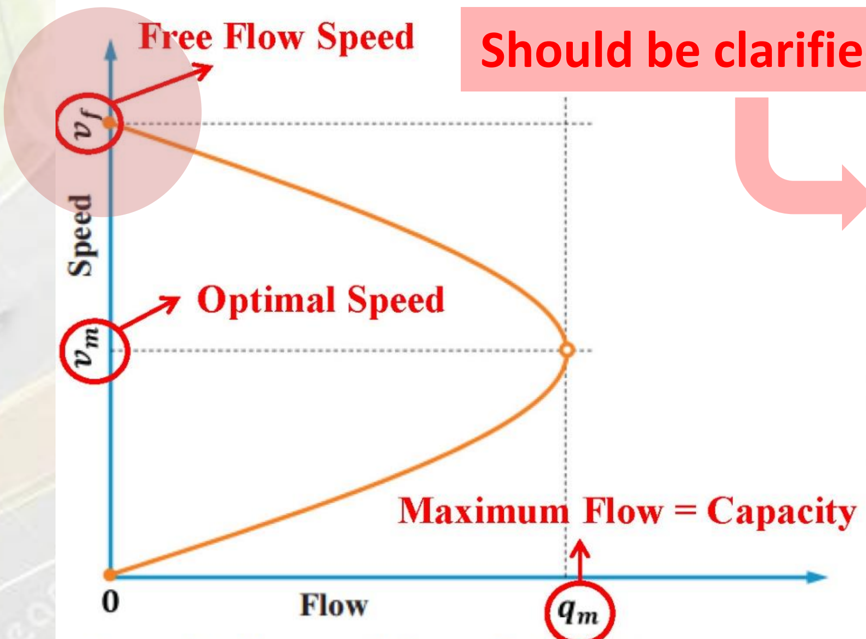
The Greenshields Model:

By **eliminating k** from the Greenshields model and using the identity **q = k × v** **speed-flow** relationship will be obtained:

$$q = k_j \left(v - \frac{v^2}{v_f} \right)$$

Should be clarified

It means speed is expressed as a function of flow: $v = U(q)$



Greenshields speed-flow relationship.

When the flow is close zero, two scenarios are possible: (1) the road is nearly empty and the few vehicles on the road are able to move at free flow speed; (2) the road is jammed, so that no one is able to move ($v \rightarrow 0$). When the flow reaches capacity ($q = q_m$), the two speeds become one, which is called the **optimal speed, v_m.**

2. Calculation of total distance headway

$$\boldsymbol{h_d > D_{total}}$$

$$D_{total} = D_b + D_r + l_{veh} + l_s$$

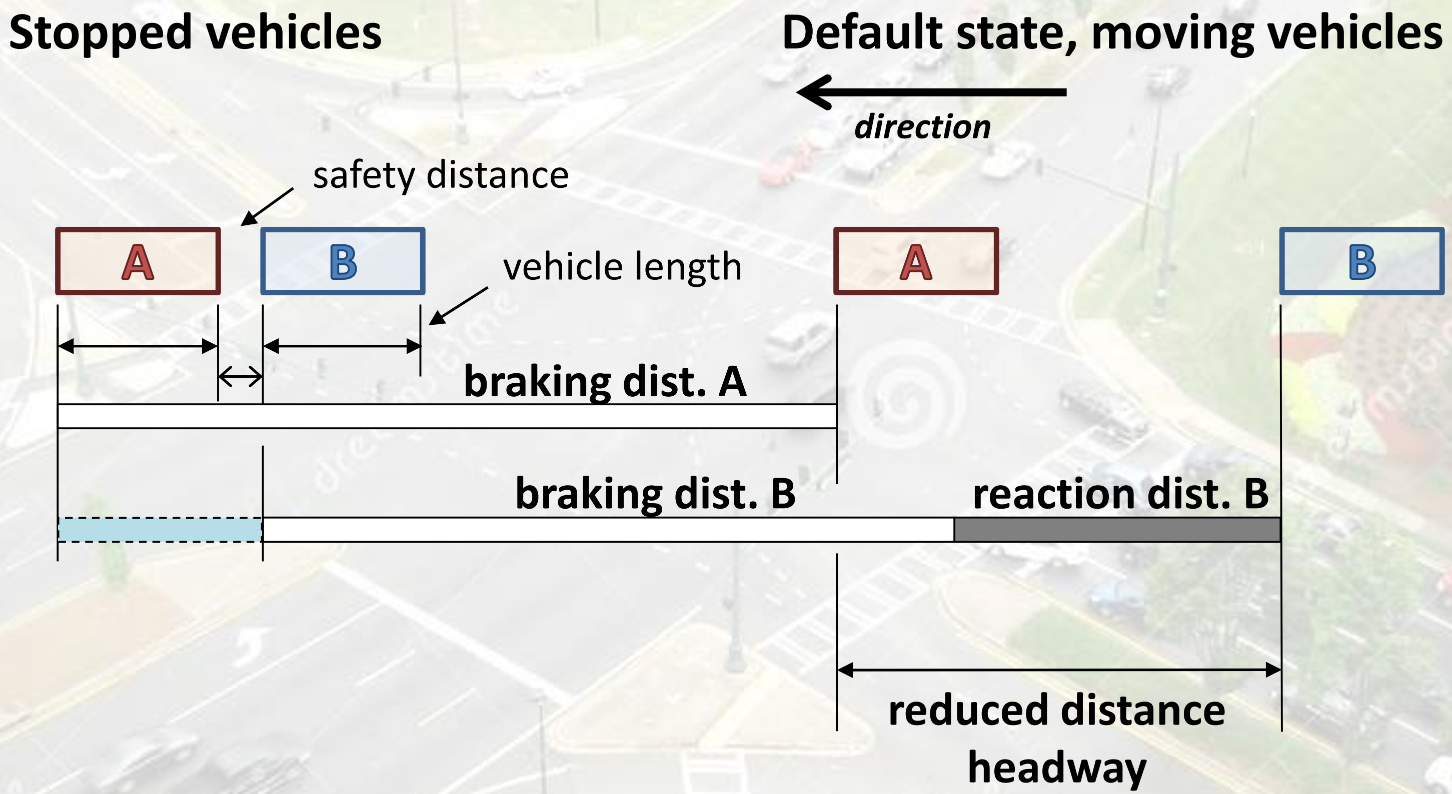
$$D_{total} = \underbrace{\frac{v^2}{2*g*(\varphi_1 \pm q)} + v*t_r}_{\text{stopping distance } (D_s)} + l_{veh} + l_s$$

stopping distance (D_s)

Description:

- v: speed;
- g: gravitational acceleration;
- φ_1: friction factor;
- t_r: reaction time;
- q: slope (tgα);
- l_{veh} : vehicle length;
- l_s : safety distance (spacing)

2. Calculation of reduced distance headway, h_R



Following vehicle:

Leading vehicle

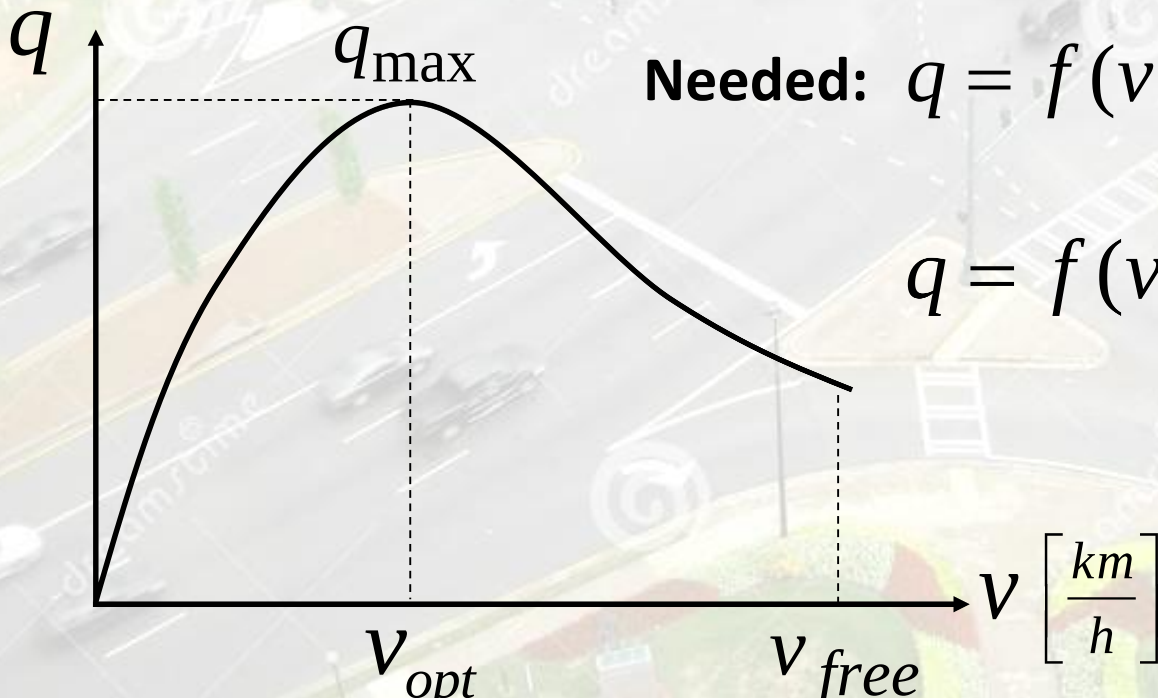
$$h_R = \frac{v_B^{\,2}}{2 * g * (\varphi_{1B} \pm q)} + v_B * t_{rB} + l_{vehA} + l_{sB} - \frac{v_A^{\,2}}{2 * g * (\varphi_{1A} \pm q)}$$

3.1 Application of speed-flow relationship (as theoretical model)

As a theoretical approach speed-flow relationship can be deducted from headway (t_h) and reduced distance headway (h_R).

$$q = \frac{T_H}{t_h} = \frac{3600}{t_h} = \frac{3600}{\frac{h_R}{v}} = \frac{3600 * v}{h_R} = \frac{3600 * v}{l_{veh} + l_s + t_r * v + \frac{v^2 * \alpha}{2 * g * (\varphi \pm q_{slope})}}$$

$\left[\frac{PCE}{h}\right]$



Needed: $q = f(v)$ $\quad \frac{dq}{dv} = 0 \Rightarrow v_{opt} \Rightarrow q_{\max}$

$$q = f(v) = \frac{c_1 * v}{c_2 + c_3 * v + c_4 * v^2}$$

$$v_{opt} = \sqrt{\frac{c_2}{c_4}}$$

3.2 Scaling (planning) the required capacity (supply)

During planning procedure different levels of capacity have to be distinguished:

Base capacity (ideal):
Theoretical maximum of passing vehicles in an hour [PCE/h]; it operates the previously defined formula with ideal (optimal) parameter values (e.g. vehicle length).

x 0,8 (c_s)

Possible capacity (real):
Possible maximum which considers real circumstances and operates with real parameter values; it takes spare capacity into consideration as well.

3.3 Scaling (planning) the required capacity (demand)

During planning procedure (and traffic counts) homogenization of traffic based on throughput (volume) is necessary.

In practice traffic volume (demand) is expressed in Passenger Car Equivalent (PCE):

„how many PCE could pass a cross-section if all the vehicles were passenger cars” [PCE/h]

Vehicle category	**PCE**
passenger car	*<u>1,0</u>*
light truck	1,4
heavy truck	1,8
trailer truck	2,5
non-articulated bus	1,8
articulated bus	2,5
motorcycle	0,7

PCE values depends on:

- classification of the road (nationwide roads or urban area),
- national regulation,
- clients expectations.

3.3 Scaling (planning) the required capacity (demand)

The time bases of – measured or calculated –traffic volume can be:

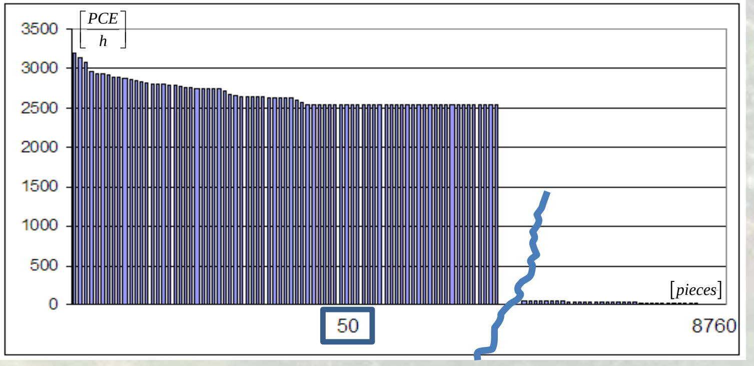
- one year
- one day – VPD (average daily traffic volume)
- one hour – PHT (peak hour traffic – usually basis of planning procedure)
- 15 min interval (see lecture)

VPD – One day average of a yearly traffic volume:

$$VPD = \frac{yearly\ traffic\ volume}{365}$$

PHT – The traffic of the fiftieth busiest hour. Usually presented as a proportion of VPD.

$$PHT = VPD * \omega$$



3.4 Scaling (planning) the required capacity

Interactions of parallel lanes should also be considered: the fact, that overtaking, turning, etc. maneuvers happens regularly the aggregate capacity (c_a) of multiple lanes never equals the capacity of 1 lane multiplied by the number of lanes.

Capacity utilization (CU) is the ratio of *demand* and *supply* in general.

Practically (in the meaning of aggregate road capacity utilization):

$$CU = \frac{PHT}{q * c_s * c_a}$$

Note: CU > 100% is not allowed! This determines the required number of lanes.

http://www.traffic-simulation.de/
https://www.youtube.com/watch?v=Suugn-p5C1M
https://futurism.com/watch-an-autonomous-car-prevent-a-traffic-jam-from-forming/
https://www.youtube.com/watch?v=iHzzSao6ypE