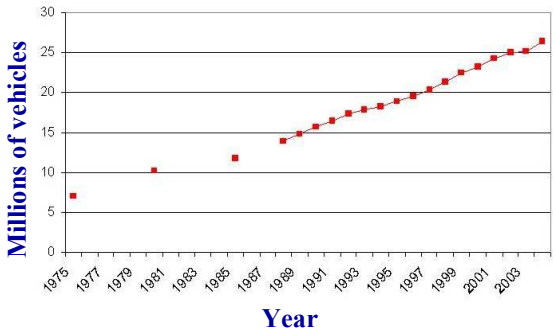
Mechanical Engineering Department
Carlos III University of Madrid

TRAFFIC ENGINEERING.

TRANSPORTATION

INTRODUCTION

Transport: change of geographical position of people or goods → **Traffic: transport related exclusively to vehicle movement**



→ **Traffic Engineering**

Traffic evolution in Spain

INTRODUCTION

TRAFFIC ENGINEERING:

Engineering branch associated with the planning, monitoring, geometric design and traffic operations of roads and their networks, so that people and goods move:

- **Safe.**
- **Fast.**
- **Efficient.**

INTRODUCTION

Two concepts can be outlined:

- **Design of road network for future needs.**

- **Traffic regulation to solve actual problems or foreseeable short-dated.**

INTRODUCTION

The traffic from a scientific-technical point of view demands the definition of a series of concepts, variables and parameters that allow understanding and approach the solutions to solve the problems generated

Laboratory

Road

TRAFFIC FLOW

- **Continuous traffic:**

No external fixed regulation devices to traffic flow exist, like for example, traffic lights, that oblige vehicles to stop. The possible stoppage is caused by internal reasons of traffic flow (accident, collision, break down, etc.)

- **Discontinuous traffic:**

Fixed elements interrupt periodically traffic (traffic lights, stops, …). These elements significantly diminish vehicle speed in certain instant.

FUNDAMENTAL TRAFFIC PARAMETERS

- **Traffic flow**
- **Speed**
- **Density**

TRAFFIC FLOW

Rate of vehicles that pass a given cross section of a road per unit time

Number of vehicles that pass a given road cross section (x)

$$I = \frac{n(x)}{t}$$

Time interval considered

Units:

- **Vehicles / hour (hour flow).**
- **Vehicles / day (daily flow).**

TRAFFIC FLOW

t<1 hour | 1 hour | 1 day | 1 year | t

TRAFFIC VOLUME

Number of vehicles that pass a given road cross section during a time interval

EQUIVALENT HOUR FLOW

$$I = \frac{n(x)}{t}$$

t< 1 hour expressed in hours

TRAFFIC FLOW

Traffic volume and equivalent hour flow:

Time interval	Volume (v)	Traffic Flow (v/h)
5:00 – 5:15	1000	4000
5:15 – 5:30	1200	4800
5:30 – 5:45	1100	4400
5:45 – 6:00	1000	4000

TRAFFIC FLOW

t<1 hour | 1 hour | 1 hour | 1 year | t

HOUR TRAFFIC FLOW

PEAK HOUR FLOW

Hour traffic flow measured during the peak hour

It is used to: calculate the capacity of roads, intersection characteristics, traffic control, coordination between traffic lights, etc.

TRAFFIC FLOW

t<1 hour | 1 hour | 1 day | 1 year | t

DAILY TRAFFIC FLOW

Number of vehicles that pass by a given point during a complete day

PEAK DAILY TRAFFIC FLOW

Number of vehicles that pass during the day of the year in which traffic is heavier

TRAFFIC FLOW

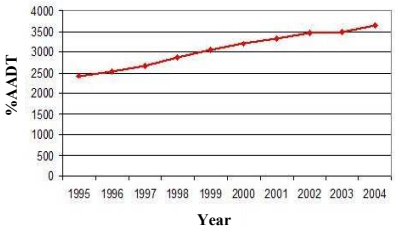
t<1 hour | 1 hour | 1 day | 1 year | t

AVERAGE ANNUAL DAILY TRAFFIC (AADT)

Total number of vehicles that passed by a road cross section during a given year divided by 365

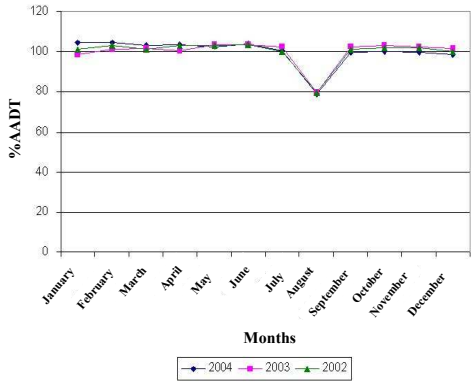
It is used to: Classify roads, number of of accidents, improvement of roads, economic studies…

CYCLES OF TRAFFIC FLOW



Generic tendency (Navarra)

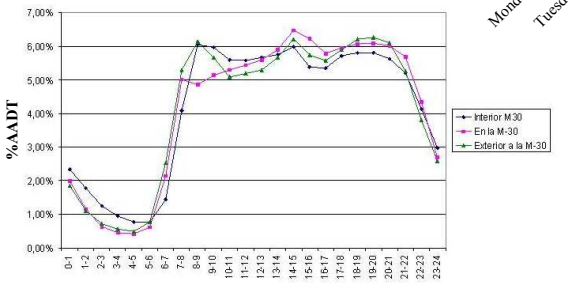
Annual cycle (Madrid)

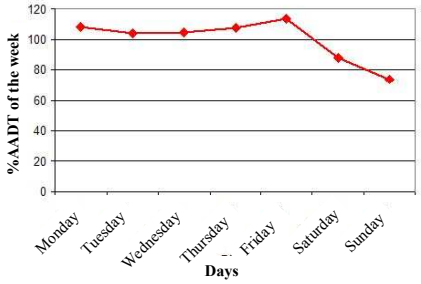


CYCLES OF TRAFFIC FLOW

Distribution of daily traffic flow

(Madrid)





Week cycle

(Gernika)

PEAK HOUR FACTOR (PHF)

Volume of traffic during an hour

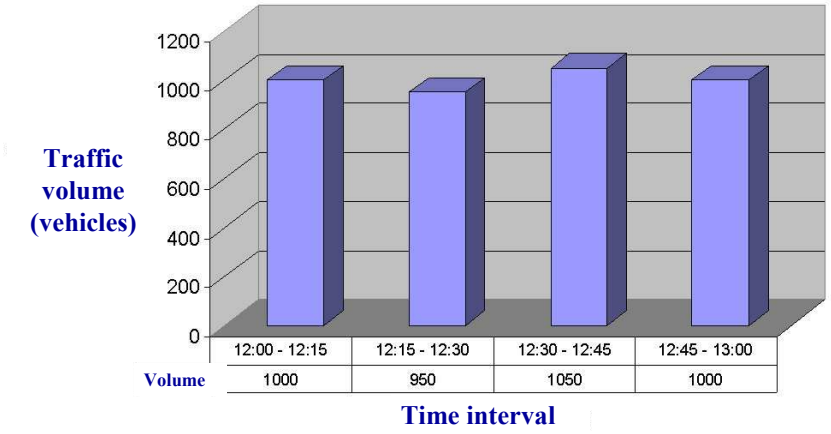
$$FHP = \frac{Q}{4Q_{15MAX}}$$

Maximum volume registered during the 15 minutes within the hour

In highway:

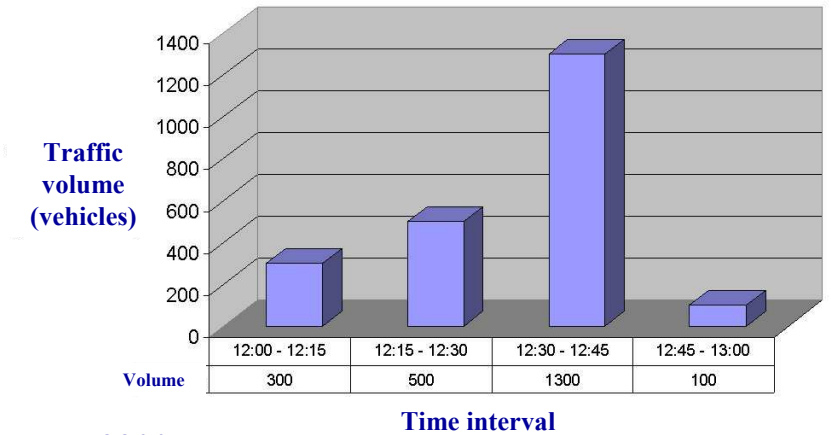
$$FHP = \frac{Q}{12Q_{5MAX}}$$

PEAK HOUR FACTOR (PHF)



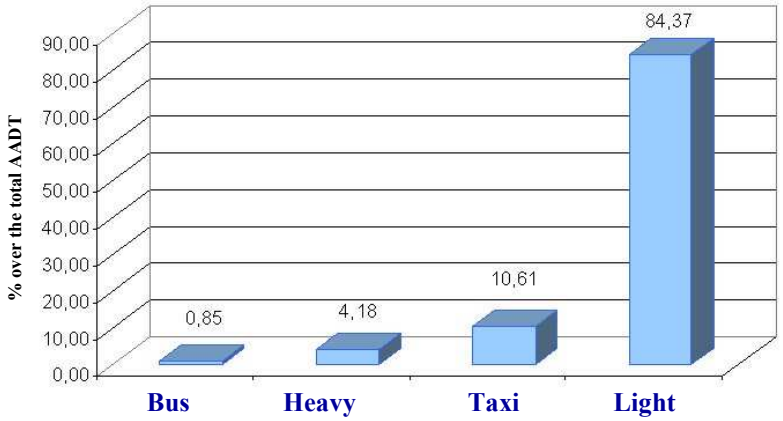
$$FHP = \frac{4000}{4200} \approx 0,95$$ ➡ **Homogeneous traffic**

PEAK HOUR FACTOR (PHF)



$$FHP = \frac{2200}{5200} \approx 0,42$$ ➡ **Non homogeneous traffic**

TRAFFIC COMPOSITION



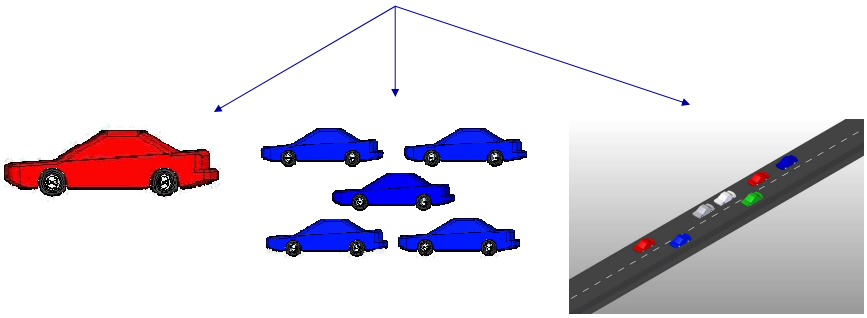
And: Pedestrian, motorbikes, non motor vehicles, agricultural vehicles…

FUNDAMENTAL TRAFFIC PARAMETERS

- **Traffic flow**
- **Speed**
- **Density**

- **Traffic volume**
- **Equivalent hour flow**
- **Hour flow**
- **Peak hour flow**
- **Daily flow**
- **Maximum daily flow**
- **Annual average daily traffic (AADT)**
- **Flow cycles**
- **Peak hour factor**
- **Traffic composition**

SPEED



Local instantaneous speed
Running speed
Travel speed

Mean instanteneous speed
Time mean speed
Space mean speed

85 percentile speed
Project speed
Service speed

SPEED OF A VEHICLE

Local instantaneous speed:

Speed of a vehicle when it passes through a certain road cross section

Running speed (V_c):

$$V_c = \frac{\text{travelled distance}}{\text{time spent to cover the distance}}$$

Travel speed (V_r):

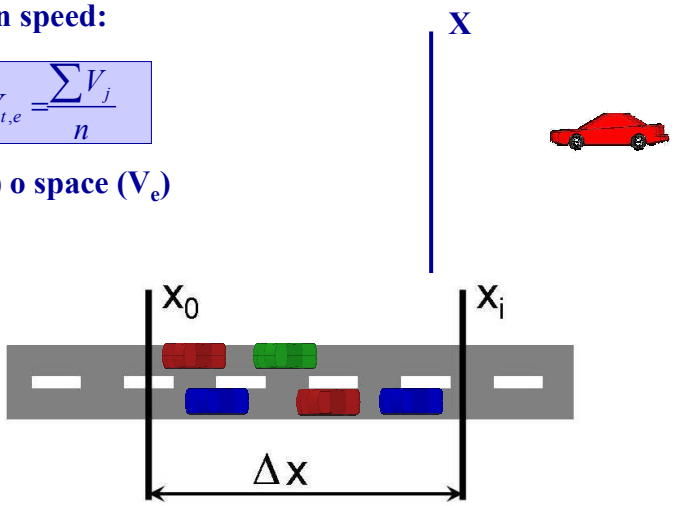
$$V_r = \frac{\text{travelled distance}}{\text{total time spent to cover the distance}}$$

SPEED OF A GROUP OF VEHICLES

Time mean speed:

$$V_{t,e} = \frac{\sum V_j}{n}$$

Local (V_t) o space (V_e)



SPEED OF A GROUP OF VEHICLES

Space mean speed (V_r):

$$V_r = \frac{\text{distance}}{\text{average of the time spent to cover the distance}}$$

$$V_r = \frac{L}{\frac{\sum t_j}{n}} = \frac{nL}{\sum t_j}$$

Running speed:

$$\frac{\text{distance}}{\text{average of the time in movement to cover the distance}}$$

SPEED OF A GROUP OF VEHICLES

Local instantaneous speed (km/h)	Time		Time without stops	
	Seconds	Hours	Seconds	Hours
36	5	0,00138889	5	0,00138889
60	45	0,0125	3	0,00083333
45	4	0,00111111	4	0,00111111
45	4	0,00111111	4	0,00111111
36	5	0,00138889	5	0,00138889
30	6	0,00166667	6	0,00166667
60	3	0,00083333	3	0,00083333
22,5	8	0,00222222	8	0,00222222
30	6	0,00166667	6	0,00166667
30	6	0,00166667	6	0,00166667

$$V_t = \frac{\sum V_j}{n} = \frac{394,5}{10} = 39,45\,km/h$$

$$V_r = \frac{nL}{\sum t_j} = \frac{0,5}{0,02555} = 19,56\,km/h$$

$$V_{rm} = \frac{nL}{\sum t_j} = \frac{0,5}{0,01389} = 36\,km/h$$

$$V_{rm} \leq V_t$$

OTHER SPEED CONCEPTS

85 percentil speed:

Speed that is only exceeded by the 15 % of the vehicles, considering only motor cars due to their high speed

This speed usually exceeds the mean speed in 20 %

Project speed:

Speed that is used to define geometric road elements: radius of curves, banking of curves

Service speed:

Speed at which vehicles could travel in a given road in favourable atmospheric conditions, for a given traffic stream and in a safety way

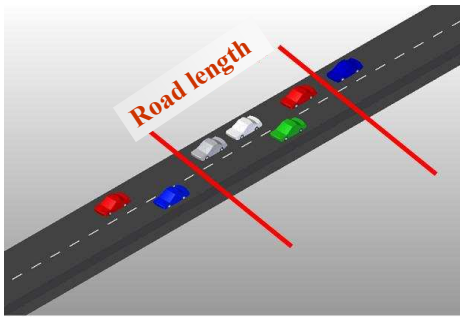
FUNDAMENTAL TRAFFIC PARAMETERS

- **Traffic flow**
- **Speed**
- **Density**

- **Speed of a vehicle**
  - Local or instantaneous
  - Running
  - Travel
- **Speed of a group of vehicles**
  - Instantaneous mean (local or spatial)
  - Time mean speed
  - Space mean speed
- **Other speed concepts**
  - 85 percentile speed
  - Project speed
  - Service speed

DENSITY

Number of vehicles in a road lane per unit length at a given instance



Usually measured in vehicles/km.

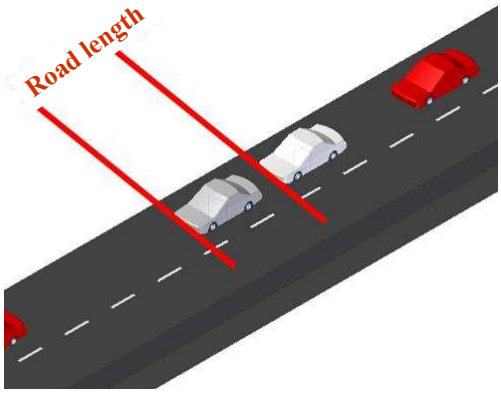
Maximum value ⇒ There is no space between the vehicles.

It is function of the mean vehicle length.

It is a measure of the manoeuvre.

SPACING

Distance between the front of two consecutive vehicles travelling in the same road lane at a given distance



Mean value

$$s_m = \frac{1}{D}$$

SPACING

The safety mean spacing that vehicles should have to guarantee that traffic flow is developed in safety conditions

$$s_s = 6 + \left(\frac{V}{3,6}\right) \cdot t_{perception}$$

- s_s: **Vehicle length**
- V: **Mean speed of the vehicles implied**
- $t_{perception}$: **Time gone by between the moment the preceding vehicle brakes until the consecutive perceives it**

$$s_s = a + b \cdot V + c \cdot V^2$$

- s_s: **Vehicle length**
- $b \cdot V$: **Reaction time of drivers**
- $c \cdot V^2$: **Brake distance**

SPACING

$$s_s = 6 + \left(\frac{V}{3,6}\right) \cdot t_{perception} \Rightarrow \begin{cases} t = 2/3s \Rightarrow s_s = 6 + 0,185V \\ t = 1s \Rightarrow s_s = 6 + 0,278V \end{cases}$$

$$s_s = a + b \cdot V + c \cdot V^2 \Rightarrow \begin{cases} s_s = 5,35 + 0,22V + 9,4 \cdot 10^{-4} V^2 \\ s_s = 8 + 0,2V + 0,003V^2 \end{cases}$$

Speed in (km/h)	40	60	80	100	120
$s_s = 6 + 0,185V$	13,4m	17,1m	20,8m	24,5m	28,2m
$s_s = 6 + 0,278V$	17,12m	22,68m	28,24m	33,80m	39,36m
$s_s = 5,35 + 0,22V + 9,4 \cdot 10^{-4} V^2$	15,65m	21,93m	28,97m	38,75m	45,29m
$s_s = 8 + 0,2V + 0,003V^2$	20,8m	30,8m	43,2m	58m	75,2m

GAP

Time gone by between two consecutive vehicles that pass by a given road cross section

$$\tau = t_2 - t_1 \qquad \tau = \frac{s(m)}{V(m/s)}$$

The mean value of the gap is:

$$\tau_m = \frac{\sum \tau}{n} = \frac{1}{I}$$

measured in s/vehicle

FUNDAMENTAL TRAFFIC PARAMETERS

- **Traffic flow**
  - Traffic volume and equivalent hour flow
  - Hour traffic flow, daily, MDF, …
  - Traffic flow cycle
  - Peak hour factor
  - Traffic composition
- **Speed**
  - Of a vehicle
  - Of a group of vehicles
  - Others: 85 percentile speed, project speed, service
- **Density**
  - Spacing
  - Time interval

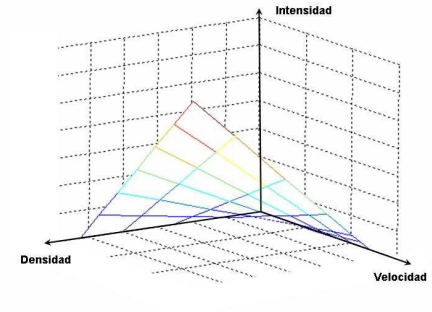
$$I = V \cdot D$$

FUNDAMENTAL TRAFFIC EQUATION

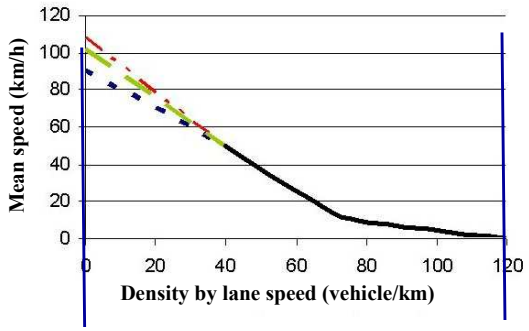
First approach:

Homogeneous traffic, mean speed V, spacing s

$$\left.\begin{aligned} \tau &= \frac{s}{V} \\ s &= \frac{1}{D} \\ \tau &= \frac{1}{I} \end{aligned}\right\} \Rightarrow \frac{1}{I} = \frac{1}{D \cdot V} \Rightarrow I = D \cdot V$$



FUNDAMENTAL TRAFFIC EQUATION



Highway with project speed of 100 km/h

Highway with project speed of 120 km/h

Two lane road with project speed of 120 km/h

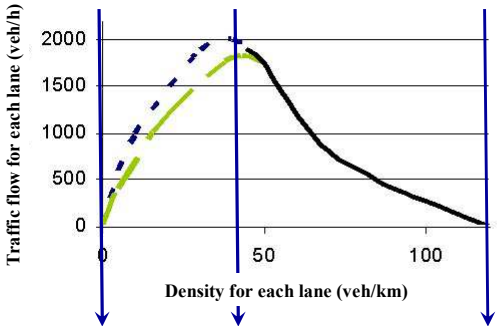
Unstable flow stream for every type of road

Few vehicles ⇩ **Free speed**

Increase of vehicles ⇩ **Conditioned speed**

Maximum density **Maximum density** ⇩ **Jam**

FUNDAMENTAL TRAFFIC EQUATION



Highway

Two lane road

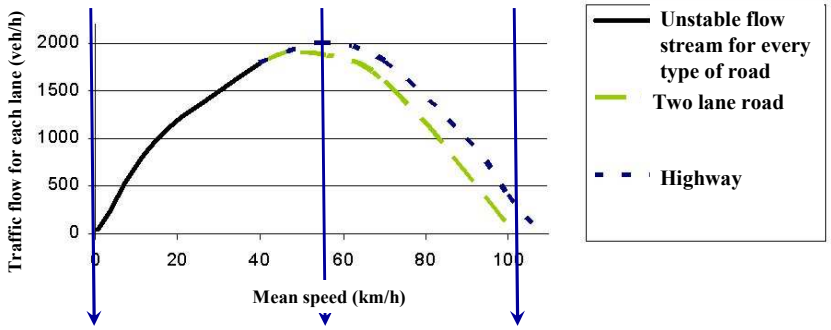
Unstable flow stream for every type of road

Zero density ⇩ **Zero traffic flow**

Critical density ⇩ **Maximum traffic flow**

Maximum density (jam) ⇩ **Zero traffic flow**

FUNDAMENTAL TRAFFIC EQUATION



Zero traffic flow ⇩ **Zero speed**

Increase of vehicles ⇩ **Conditioned speed**

Zero traffic flow ⇩ **Free speed**

CAPACITY OF A LANE

Maximum number of vehicles that can pass by a lane per unit time

$$C = \frac{V}{s_s} \cdot 1000$$ **(vehicles/hour)**

V = speed in km/hour

s = safety mean spacing in metres between the front of two consecutive vehicles, for a given speed

$$s_s = 6 + \left(\frac{V}{3,6}\right) \cdot t_{perception} \qquad s_s = a + b \cdot V + c \cdot V^2$$

LEVEL OF SERVICE

Traffic flow < Capacity

If the traffic flow equals the capacity:

- Low mean speed.
- Low spacing between vehicles.
- Frequent unexpected stoppage.

⇒ Collision between vehicles

Cualitative measure representative of the operation of a road for a given traffic flow, that has into account a group of factors (speed, manoeuvre, safety, comfort and cost) that take place in it.

LEVEL OF SERVICE

It is defined taking into account:

- Speed and time travel, taking into account not only the instantaneous speed but the time needed to cover a distance.
- Traffic interruptions, and the magnitude and frequency of the sudden changes in speed necessary to maintain the traffic flow stream.
- Liberty of manoeuvre to maintain the desired speed.
- Safety, including not only the number of accidents but the potential risk.
- Comfort while driving.
- Economy.

Service flow: maximum flow compatible with a certain level of service

LEVEL OF SERVICE

- **Level A**
  - **High level of functional freedom.**
- **Level B**
  - **Stable traffic although conditioned for the fastest vehicles.**
- **Level C**
  - **Stable traffic although considerably conditioned.**
- **Level D**
  - **Unstable traffic.**
- **Level E**
  - **Flow near capacity, frequent stops.**
- **Level F**
  - **Jammed road. The demand exceeds the capacity of the road.**

CAPACITY AND LEVEL OF SERVICE IN HIGHWAYS

Undesirable level of service ⇒ **Relation I/C**

Level of service	Service speed (km/h)	Specific road speed $\geq 110\,km/h$	I/C: Specific road speed $=100\,km/h$	I/C: Specific road speed $=80\,km/h$
A	≥ 100	$\leq 0,5-\frac{0,3}{n^{o}\ lanes}$	It is not possible to reach this level of service for any I/C	It is not possible to reach this level of service for any I/C
B	≥ 90	$\leq 0,75-\frac{0,5}{n^{c}\ lanes}$	$\leq 0,25$	It is not possible to reach this level of service for any I/C
C	≥ 80	$\leq\left[0,9-\frac{0,3}{n^{o}\ lanes}\right]\cdot PHF$	$\leq 0,45\ \cdot PHF$	It is not possible to reach this level of service for any I/C
D	≥ 65	$\leq 0,9\ \cdot PHF$	$\leq 0,8\ \cdot PHF$	$\leq 0,45\ \cdot PHF$
E	< 65	≤ 1	≤ 1	≤ 1

CAPACITY AND LEVEL OF SERVICE IN HIGHWAYS

Calculation of C and I_s

In ideal conditions, between 2200 and 2300 vehicles/hour

Traffic of only light vehicles
Lanes of, at least, 3,60m width and free shoulders of 1,80m

Lane width	Correction factor for two lane highway	Correction factor for 3 or 4 lane highway
3,60 m	1,00	1,00
3,30 m	0,97	0,96
3,00 m	0,91	0,89
2,70 m	0,81	0,78

Correction factors according to lane width and lateral obstacles (Fc, Fo)

TRAFFIC ENGINEERING

CAPACITY AND LEVEL OF SERVICE IN HIGHWAYS

Calculation of C and I_s

	Horizontal terrain	Ondulating terrain	Abrupt terrain
Trucks (E_c)	2	4	8
Buses (E_a)	1,6	3	5

Equivalent factors according to traffic composition

Flow service — **Number of lanes** — **Correction factors**

$$I_S = C_{CI} \cdot n \cdot \left(\frac{I}{C}\right)_S \cdot F_C \cdot F_O \cdot \frac{100}{100 - P_C - P_A + E_C P_C + E_A P_A}$$

Capacity for ideal conditions — **I/C for the level of service** — **Percentages of trucks and buses** — **Equivalent factors**

CAPACITY FOR DISCONTINUOUS TRAFFIC

Several factors have to be taken into account:

Level of service	Definition	Speed (km/h)	Jam index	Peak Hour Factor	I/C
A	Fluida	> 45	0	0,7	0,6
B	Estable/ligera	> 40	0,1	0,8	0,7
C	Estable/aceptable	> 35	0,3	0,85	0,8
D	Pre-inestable/tolerable	> 25	0,7	0,9	0,9
E	Inestable, congestionada/intolerable	25	0,85 - 1	0,95	1
F	Forzada, congestión total	< 25	despreciable	despreciable	despreciable

TRAFFIC ENGINEERING

CAPACITY FOR DISCONTINUOUS TRAFFIC

- **Physic and operation conditions**
  - **Access width: The width of an access to an intersection is designed according to not only the street, but the road mark, traffic island and other obstacles.**
  - **Traffic in one or double direction :A city road that has two directions will have fewer capacity than a one direction road, due to the interaction between both directions.**
  - **Lateral parking: If parking is prohibited capacity will always be increased.**
  - **Road grade: If the grade is positive the vehicle's speed and capacity will be decreased.**

CAPACITY FOR DISCONTINUOUS TRAFFIC

- **Environmental conditions**
  - **Load index: It evaluates the time usage when the traffic light is green.**
  - **Peak hour factor: Shows the variations in traffic flow.**
  - **Urban area: Between two intersections with the same layout and regulation it has more capacity the one situated on the bigger city.**
  - **Urban position: Also, for different positions of the intersection within the same city capacity is different. Generally, it can be distinguished three areas: town centre, the outskirts and intermediate between the other two.**

TRAFFIC ENGINEERING

CAPACITY FOR DISCONTINUOUS TRAFFIC

- **Traffic features:**
  - **Right and left turn: These manoeuvres produce a partial obstruction of traffic stream and may influence capacity greatly when used to much.**
  - **Buses and heavy vehicles: Due to their low speed and difficulty in carrying out manoeuvres, capacity tends to be diminished.**
  - **Urban bus transport: In addition, urban buses carry out a lot of stops and starts for passengers. Its effect depends on the number of stops, the city zone, the stop time and their location.**
- **Traffic control devices:**
  - **Traffic lights: Distributes and gives out the time traffic light cycle.**
  - **Vertical and road signs: They organize traffic stream and improve capacity.**

CAPACITY FOR DISCONTINUOUS TRAFFIC

Example: Australian method or Ackelik

Total capacity of the road

$$C_r = \sum_{i=1}^{n} C_{ci}$$

Number of lanes

Capacity of the ith lane

Theorical capacity of a lane

Capacity of a lane

$$C_c = \frac{C_t \cdot f_w \cdot f_p}{f_c}$$

Correction factors

CAPACITY FOR DISCONTINUOUS TRAFFIC

Example: Australian method or Ackelik

Theorical capacity of a lane

Zone \ Type of lane	1	2	3
A Outskirts	1850	1810	1700
B Intermediate	1700	1670	1570
C Town centre	1580	1550	1270

1. **Straight lane**
2. **Lane with possible turn. Its radius has to be bigger than 15 metres. Pedestrians will not be allowed to cross.**
3. **Lane with possible turn. Its radius has to be less or equal to 15 metres or pedestrians would be allowed to cross.**

CAPACITY FOR DISCONTINUOUS TRAFFIC

Example: Australian method or Ackelik

Width lane correction factor

Lane Width, w (m)	f_w
$w \leq 3$	0,55+0,14w
$3 \leq w \leq 3,7$	1
$w > 3,7$	0,83+0,05w

Traffic composition correction factor

$$f_c = \frac{\sum_{i=1}^{n} e_i I_i}{\sum_{i=1}^{n} I_i}$$

Equivalent factor tabled according to the type of the lane turn

Traffic flow for every type of vehicle

Correction factor for road slope (p)

$$f_p = 1 + \left(\frac{0,5p}{100} \right)$$