B.Sc - Road & Railway Design I. *Lecture 5.*

TRAFFIC FLOW ANALYSIS, CAPACITY & LEVEL OF SERVICE

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IMPORTANCE OF TRAFFIC IN ROAD PLANNING & DESIGN

- Traffic data collection and projections thereof of traffic volumes and traffic flow patterns are basic requirements for planning of road development and management schemes
- Traffic data are important in planning of a particular section of the road network and for its subsequent maintenance as well
- Traffic flow pattern appears to be random in distribution, as it reflects people's motivation in terms of different composition of vehicles on different types of roads under varying environmental (weather) conditions

DEFINITIONS

- *Traffic flow*: the movement of individual vehicles between two points and the interactions they make with one another
- *Traffic volume* or simply *flow*: the total number of vehicles passing a given point during a given time interval (interval may be an hour, day, week, or even a year)

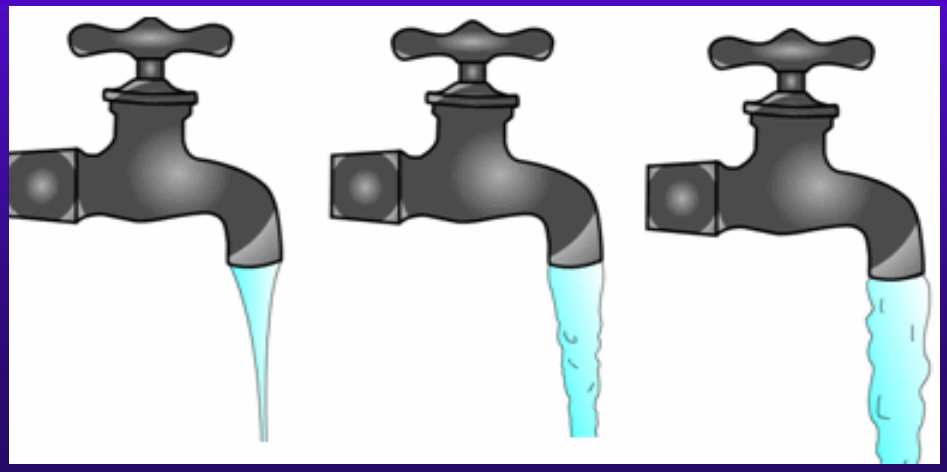
- Studying traffic flow is difficult because driver behaviour is something that cannot be predicted with one-hundred percent certainty
- Fortunately, drivers tend to behave within a reasonably consistent range, thus, traffic flows tend to have some reasonable consistency and can be roughly represented mathematically

FLOWS

Glacier ice flow

Water flowing from a bottle & from a drainage pipe

River water flow

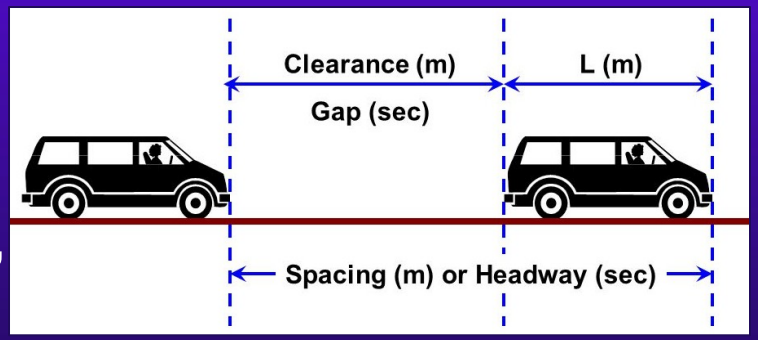


Growing turbulence as flow rate is increased

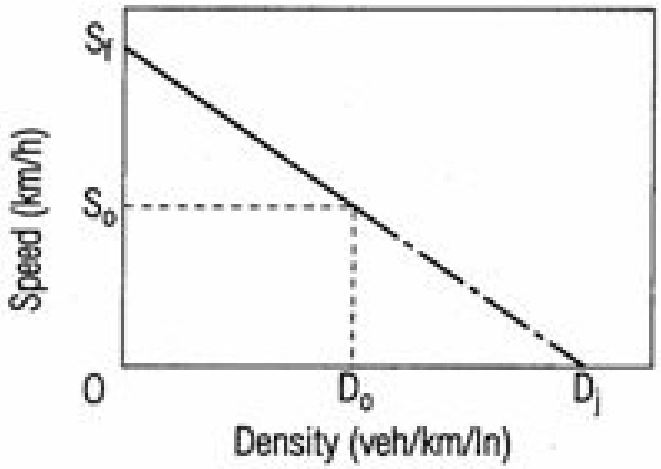
Lava flow from a volcano

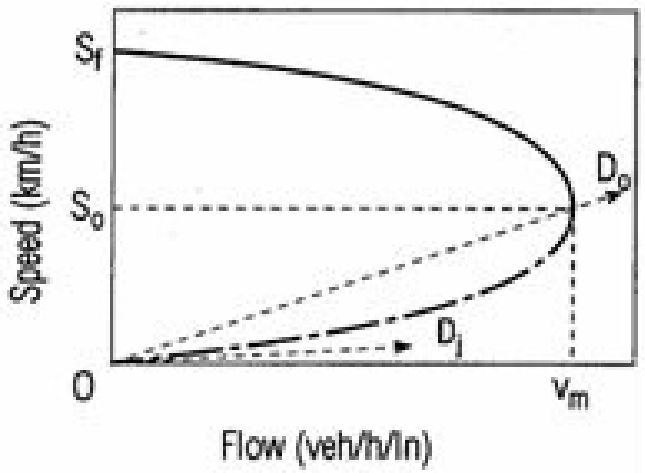
BASIC RELATIONSHIPS 1

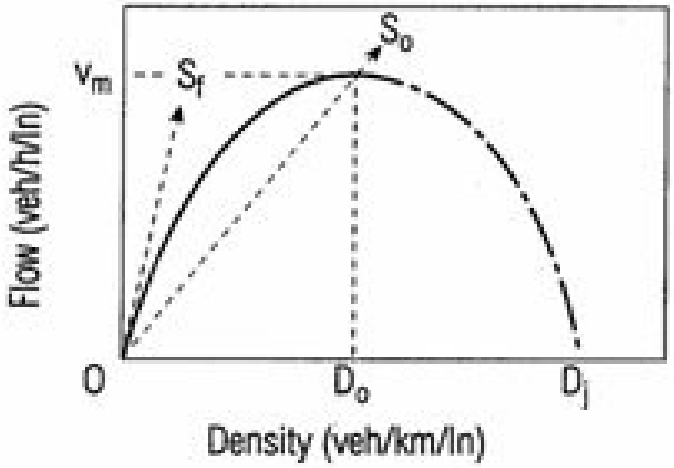
- To represent traffic flow, basic relationships have been established between it's three main characteristics: *(q)* volume, *(k)* density, and *(v)* speed
- *Rate of flow*: equivalent hourly rate at which vehicles pass a given point during a given time interval less than one hour
- *Density* of flow: number of vehicles occupying a given length of roadway, averaged over time
- *Spacing* is the inverse of density, measured as the distance (m) from the tip of one vehicle to the tip of the next one behind it
- *Headway* is the inverse of flow, which is the time that elapses between the tip of the i_{th} vehicle passing a reference point in space and that of the $(i + 1)_{th}$ vehicle



BASIC RELATIONSHIPS 2







Legend

Oversaturated flow

Flow = Density * Speed

TRAFFIC DATA BASE

- Key areas in which traffic data are needed:
  - Determination of a programme of road widening needs and general improvement or strengthening of existing road through a programme of reconstruction and construction of new roads
  - To check the efficiency of the road network by comparing current traffic volume with the level of service or the calculated capacity
  - To establish the relationship between traffic volume and composition, number of accidents and causes thereof, as well as determination of the probable occurrences
  - To plan prioritisation of roads improvement schemes based on economic efficiency assessment
  - To study future traffic trends and assisting in predicting traffic flows in the future for a given period

TYPES OF TRAFFIC SURVEYS

- There are 2 main types of determining appropriate data by *traffic surveys*:
  - Executing serial *traffic counts* by each traffic lane at selected cross sections and intersections of the road network under scrutiny, aiming to determine the volume, composition and variation in time of all traffic flows observed
  - Carrying out *enquiries* among drivers and vehicle owners or households, freight haulers aiming to extend the scope of data obtained by counts to the *origin* and *destination*, purpose and frequency (among others) of the trips observed within prealably defined (assumed homogenous) zones served by the road network under scrutiny

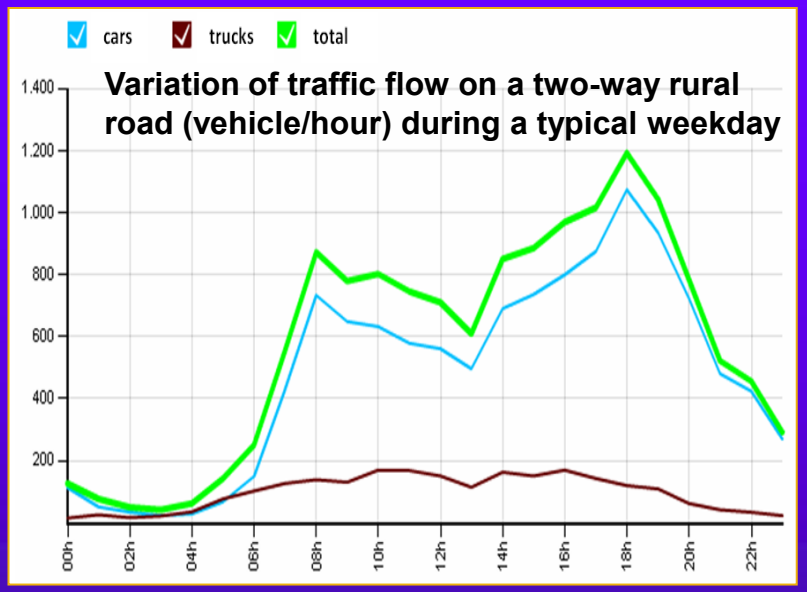
TRAFFIC COUNTS

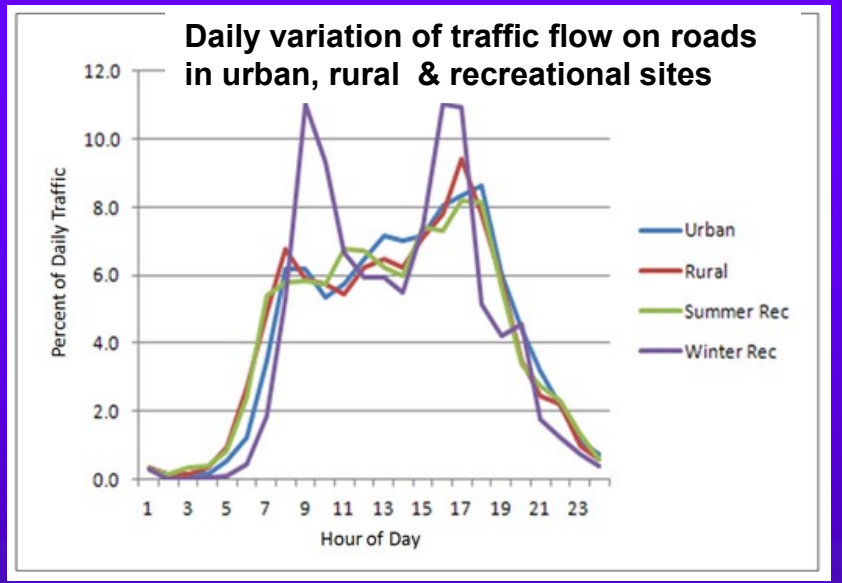
- A traffic count is a count of vehicular or pedestrian traffic, which is conducted along a particular road, path, or intersection
- A traffic count is commonly undertaken
  - *manually* by observers who visually count and record traffic on a hand-held electronic device or tally sheet; or
  - *automatically* with the installation of a temporary or permanent traffic recording device
- Traffic counts provide the source data used to calculate the Annual Average Daily Traffic (AADT), which is the common indicator used to represent traffic volume

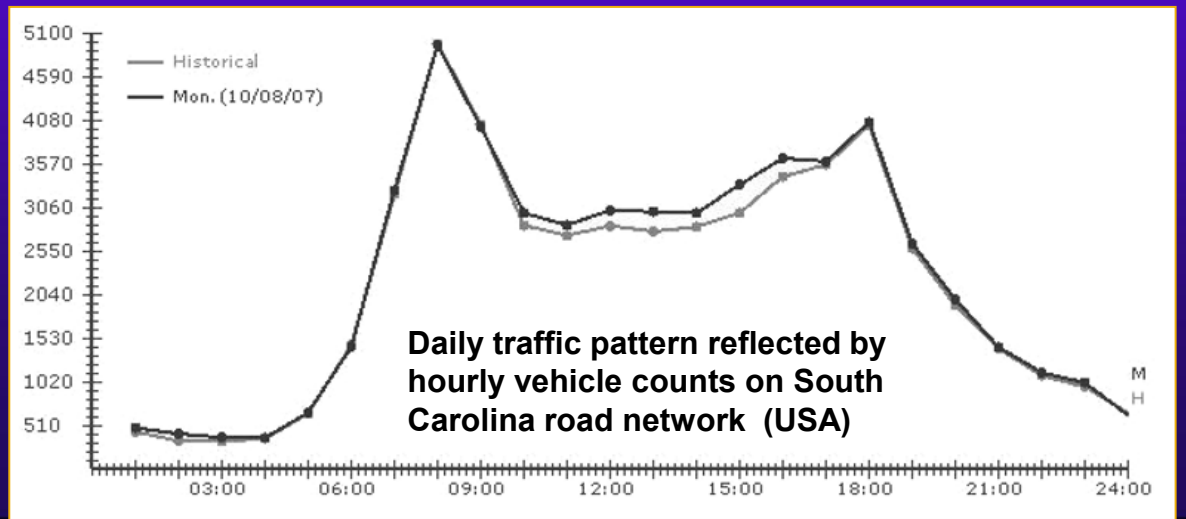
TRAFFIC COUNTING PERIODS 1

- The selection of counting method should be determined using the *counting period*
- Since traffic volumes changes considerably in time, the counting period should be *representative* of the time of day, day of month and month of year for the study area
- There are three cyclical variations that are of particular interest:
  - *Hourly pattern*: The way traffic flow characteristics varies throughout the day and night
  - *Daily pattern*: The day-to-day variation throughout the week
  - *Monthly* and *yearly pattern*: The season-to-season variation throughout the year

DAILY TRAFFIC PATTERN



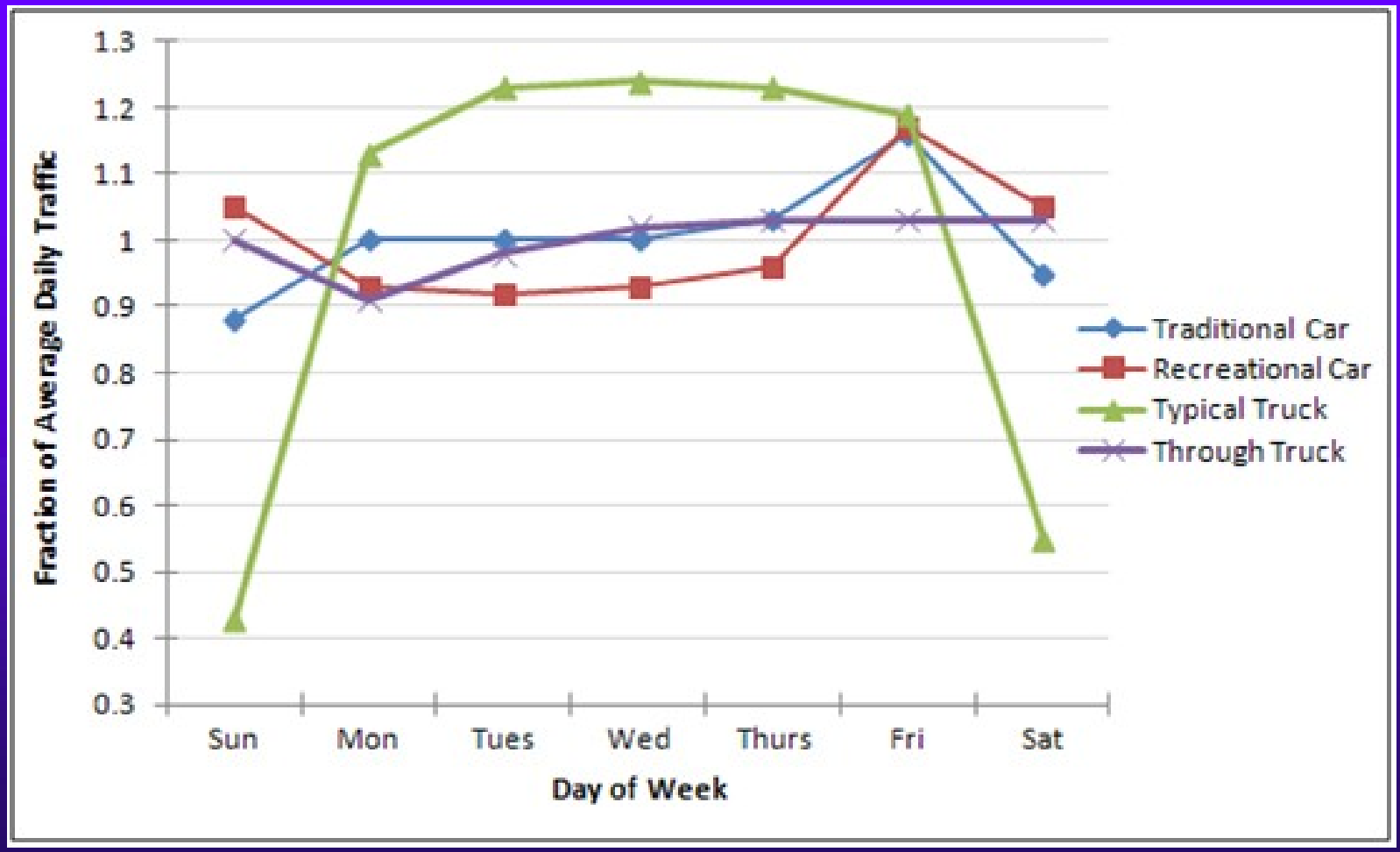




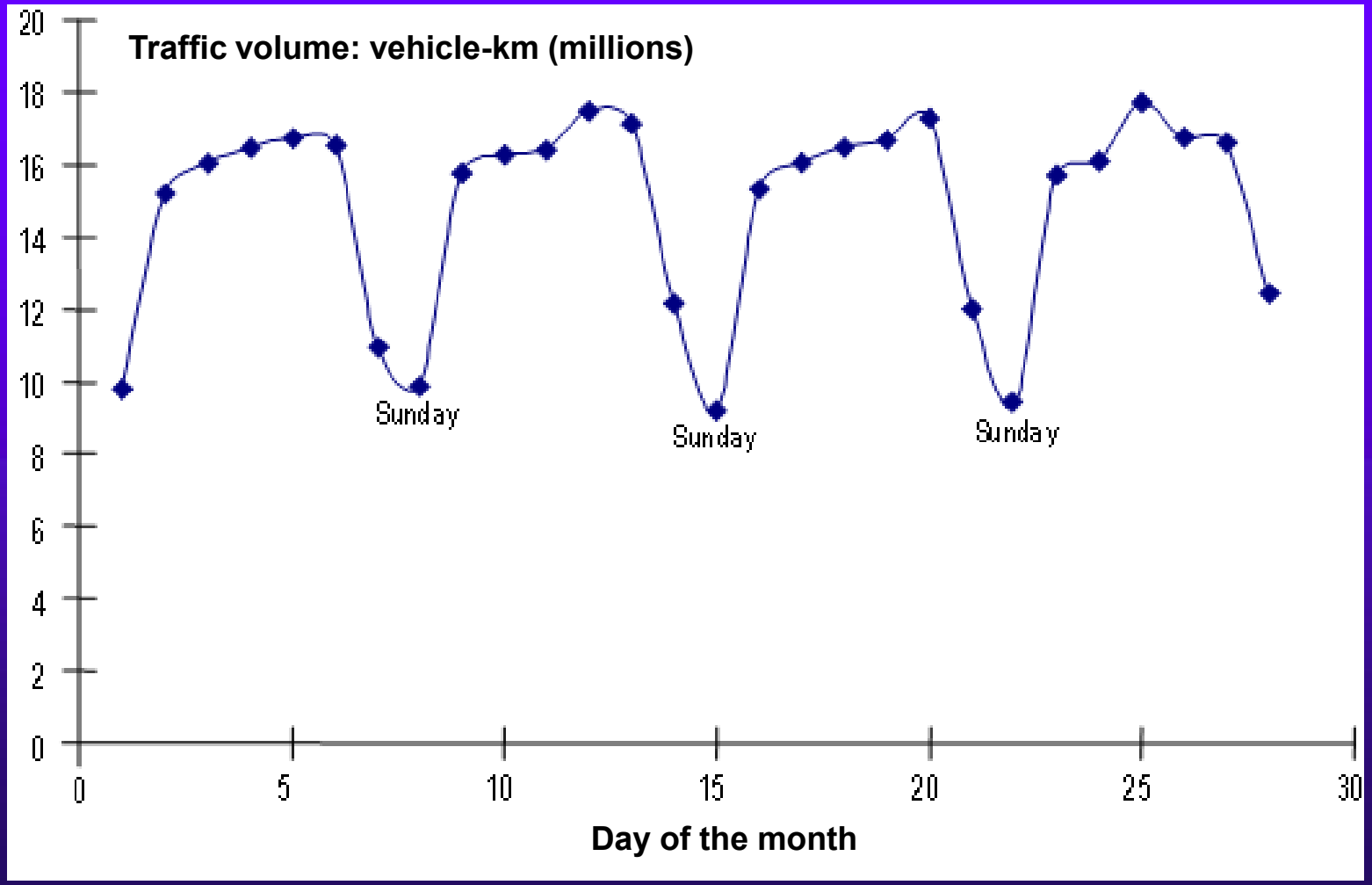
WEEKLY TRAFFIC PATTERN 1

- Typical hourly patterns of traffic flow, particularly in urban areas, generally show a number of distinguishable peaks: that in the morning followed by a lean flow until another peak in the afternoon
- Experience shows that although traffic volumes may grow over time, the relative variations of traffic at the various hours of the day of a month are often quite consistent year after year
- The traffic volume generally varies throughout the week too, during working days (Monday to Friday) may not vary substantially, but during the weekend is likely to differ from the working days on different type of roads & in different directions

WEEKLY TRAFFIC PATTERN 2



MONTHLY TRAFFIC PATTERN



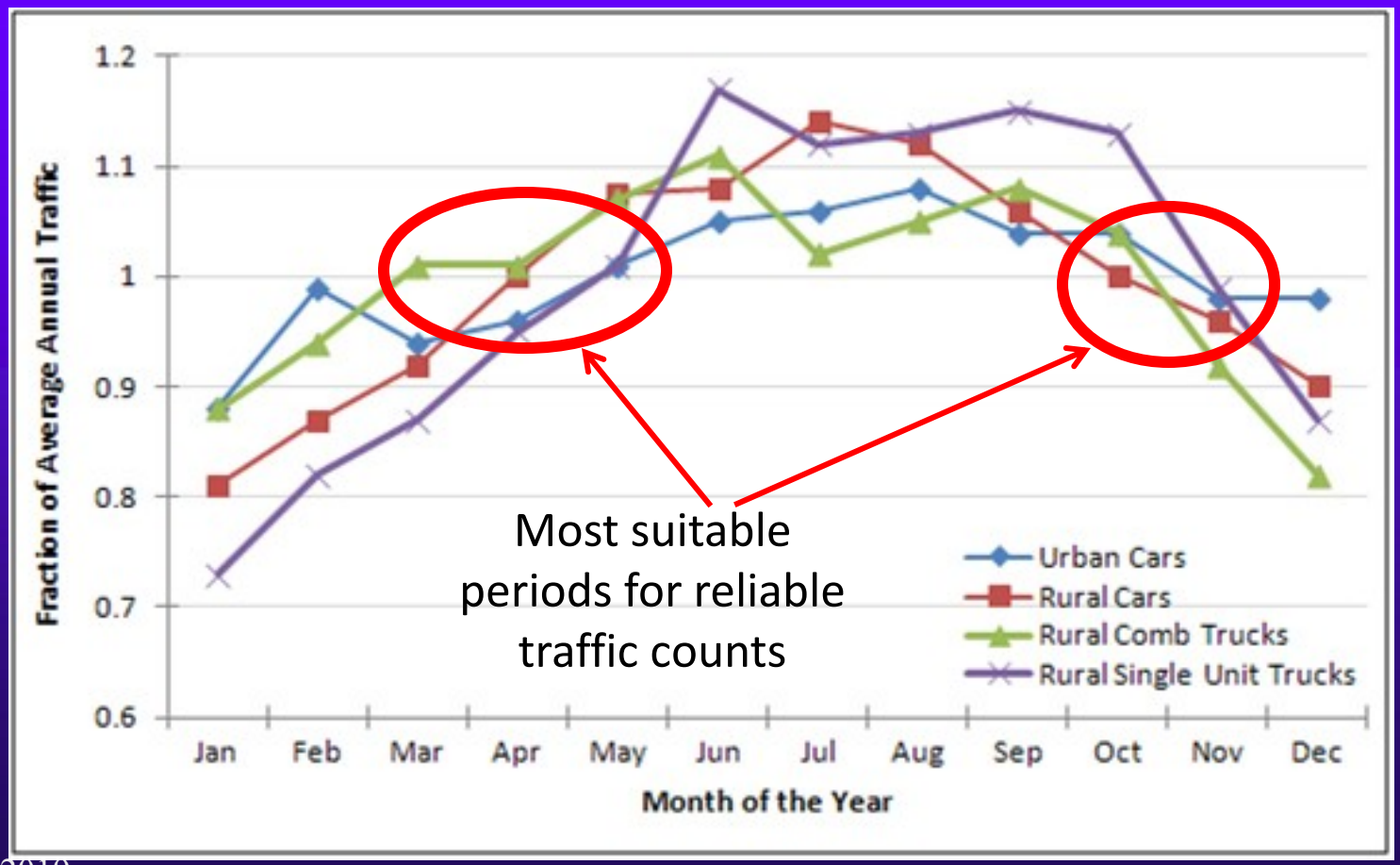
MONTHLY & YEARLY TRAFFIC PATTERN

- Monthly and yearly pattern normally reflects the seasonal variation of traffic flow: it may vary for passenger cars and vehicles transporting goods
- Knowledge of how traffic flows varies for different vehicle categories may be useful when scheduling traffic counts, designing road improvement schemes and setting maintenance programmes
- Since traffic volume is closely related to economic growth, *yearly increase of traffic volume* (ΔV; vehicle fleet/year) is expressed as ΔV= *f*(ΔGDP) and *traffic performance* (P=V*Yearly Distance Run; vehicle-km/year, or ton-km/year, or passenger-km/year) is generally increasing steadily in time

YEARLY TRAFFIC PATTERN

$$AADT = q_{count} * a_{day} * a_{week} * a_{month} * a_{year}$$

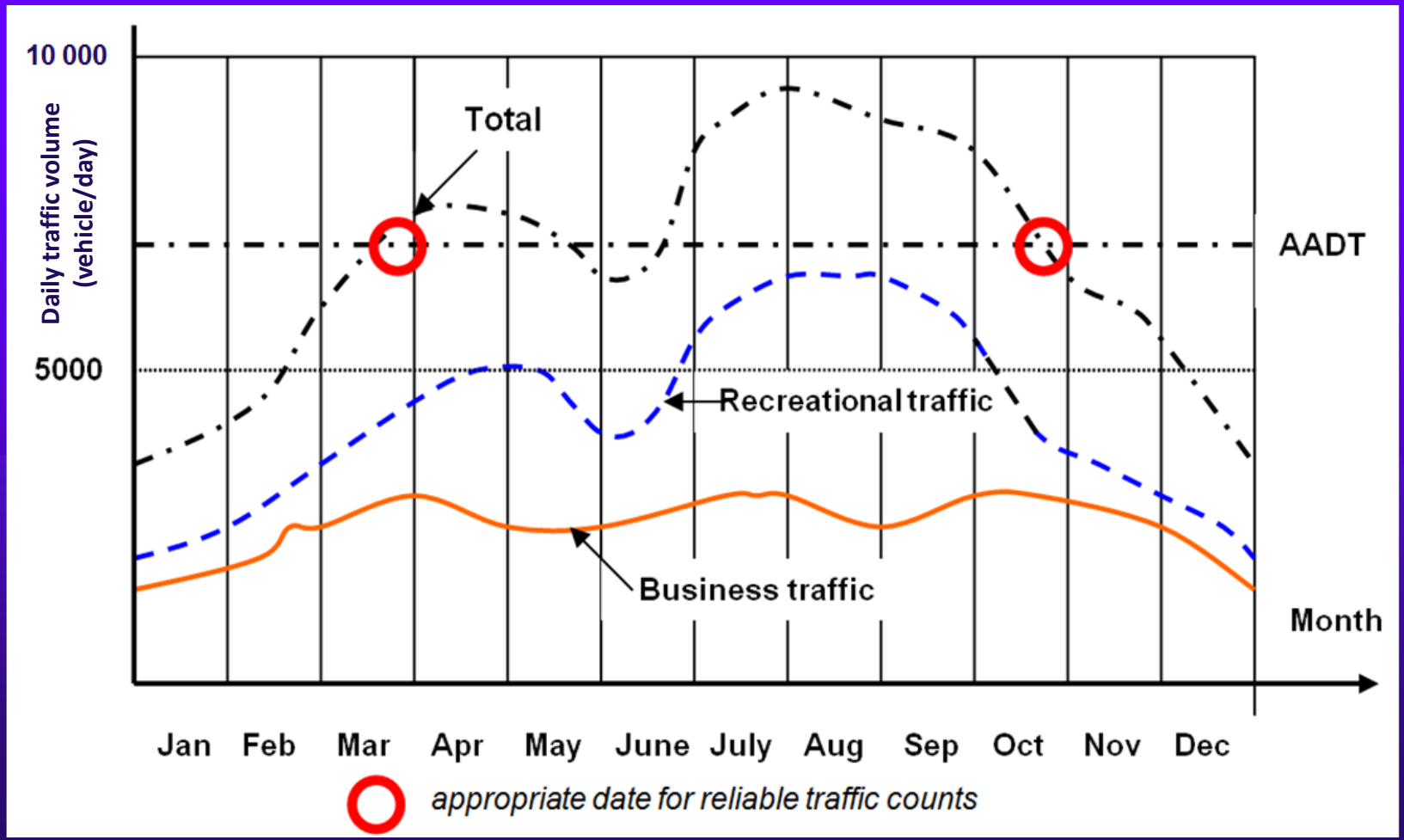
a – adjustment factor



ESTIMATING AADT 1

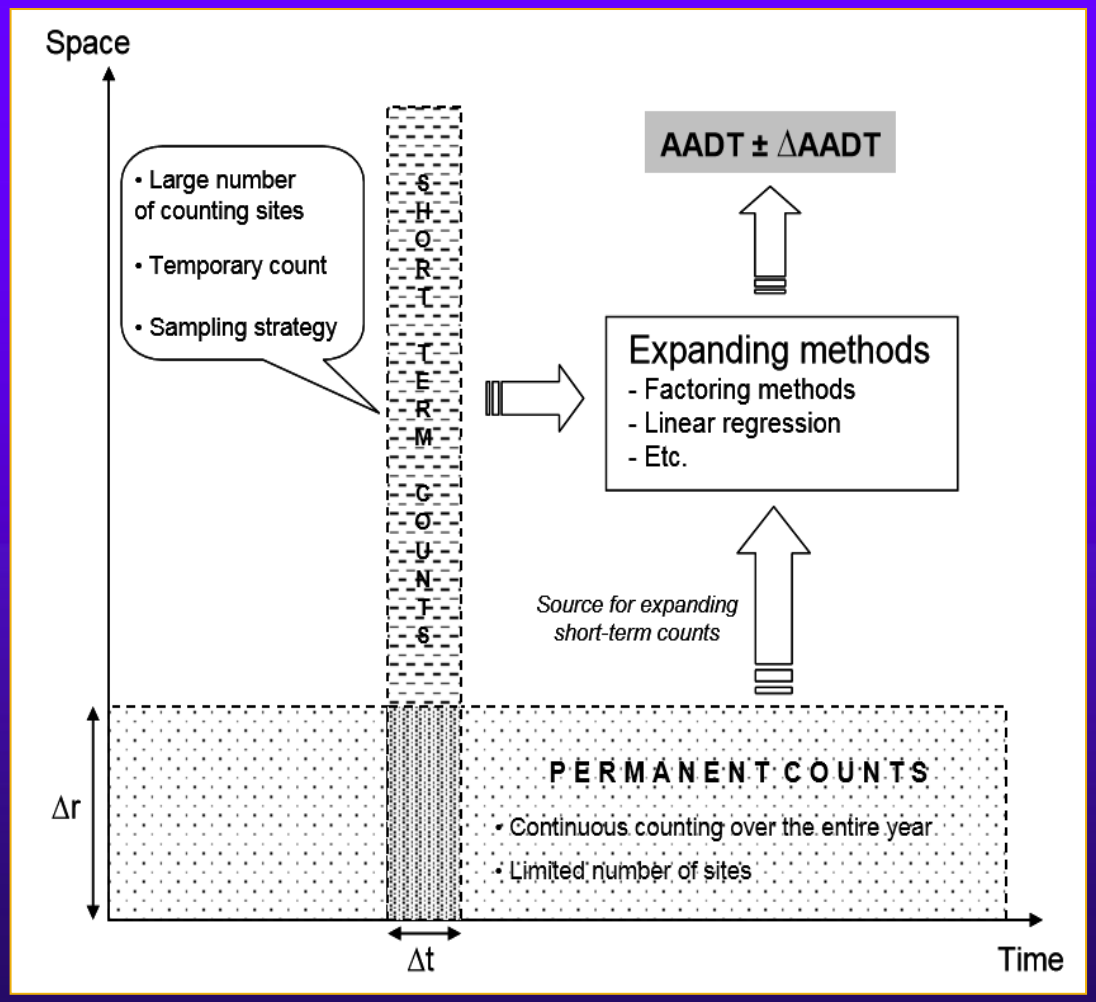
- Counting periods are 15 minutes or 2 hours for peak periods, 4 hours for morning and afternoon peaks and 12 hours for daytime periods, preferably on mid-week days in April or October
- Determination of the AADT from 12-hour traffic count is achieved by converting to 16-hour flow (the volume of traffic flow counted in hours) by using applicable *conversion factors* defined by permanent counting stations
- A further conversion to 24-hour flow may be carried out to obtain an Average Daily Traffic flow ADT) and subsequently to define the Annual Average Daily Traffic (AADT)

YEARLY TRAFFIC PATTERN (seasonal variations)



ESTIMATING AADT 2

- Annual average daily traffic: AADT, (annual traffic averaged on a daily basis) is a measure used primarily in transportation planning, road design and traffic engineering
- Traditionally, it is the total volume of vehicle traffic of a road for a calendar year divided by 365 days

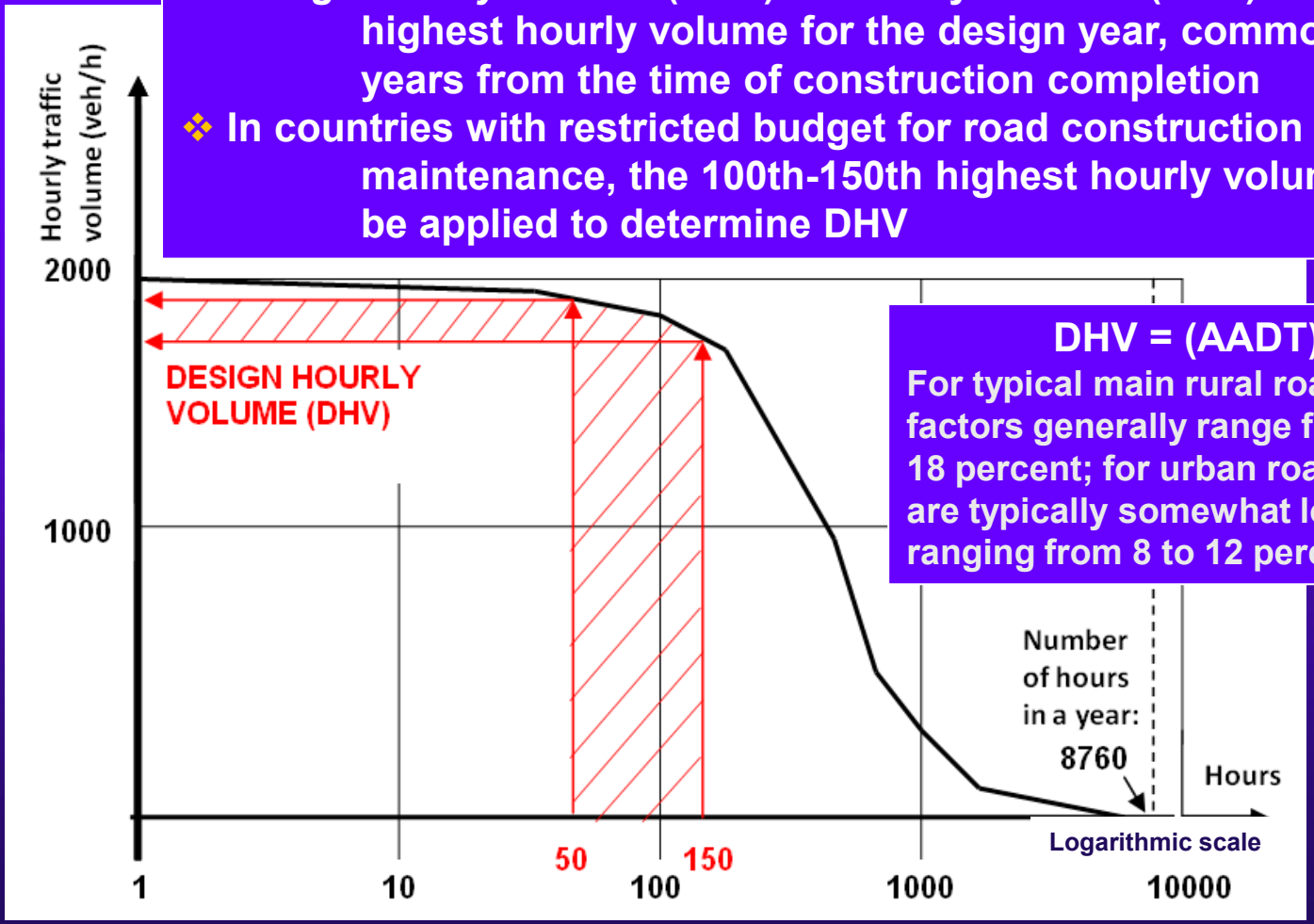


Schematic view of the main procedure for estimating AADT

YEARLY DISTRIBUTION OF HOURLY VOLUMES

(values in decreasing order)

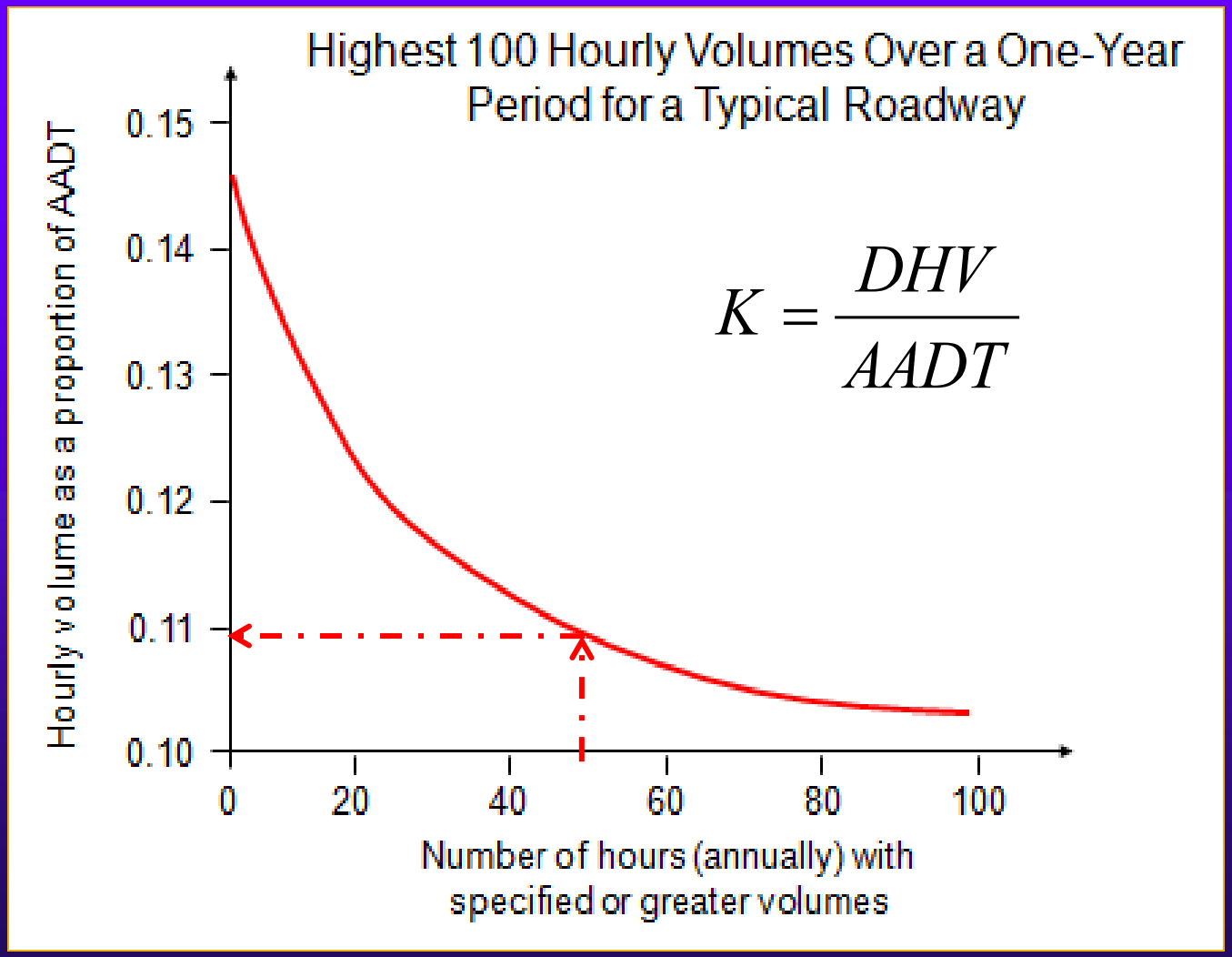
- *Design Hourly Volume* (DHV) is usually the 30th (USA) or 50th (EU) highest hourly volume for the design year, commonly 20 years from the time of construction completion
- In countries with restricted budget for road construction & maintenance, the 100th-150th highest hourly volume may be applied to determine DHV



DHV = (AADT)*(*K*)

For typical main rural roads, *K*-factors generally range from 12 to 18 percent; for urban roads they are typically somewhat lower, ranging from 8 to 12 percent

RELATIONSHIP BETWEEN *AADT & DHV*



MANUAL TRAFFIC COUNTS 1

- Manual counts are recorded using one of three methods: tally sheets, mechanical, or electronic counting boards
  - Recording data onto *tally sheets* is the simplest means of conducting manual counts: the data can be recorded with a tick mark on a pre-prepared field form (a watch or stopwatch is necessary to measure the desired count interval)
  - *Mechanical counting boards* consist of counters mounted on a board that record each direction of travel (they are push button devices: each button represents a different stratification of type of vehicle being counted)
  - *Electronic counting boards* are battery-operated, hand-held devices, similar to mechanical counting boards, but equipped with an internal clock that automatically separates the data by time interval; the data can be downloaded to a computer, which saves time

VEHICLE CLASSIFICATION

- A crucial element of all traffic counts is the *classification* of the observed vehicles
- Traditional classification (example):
  1. Passenger car
  2. Pick-up or van <1.5 tons
  3. Truck (2 axles) more than 1.5 and less than 3.5 tons
  4. Light lorry (commercial vehicle with max 3 axles), more than 3.5 and less than 7.5 tons
  5. Medium lorry (commercial vehicles with max 4 axles), more than 7.5 and less than 12 tons
  6. Heavy (articulated) lorry (Heavy Goods Vehicle or HGV) (more than 4 axles), >12 tons
  7. Minibus (max 9 seats, including driver)
  8. Bus (>9 seats)
  9. Agricultural Machines

MANUAL TRAFFIC COUNTS 2

ROADS AND HIGHWAYS DEPARTMENT — TRAFFIC COUNT TALLY SHEET — Sheet : ..... of .....

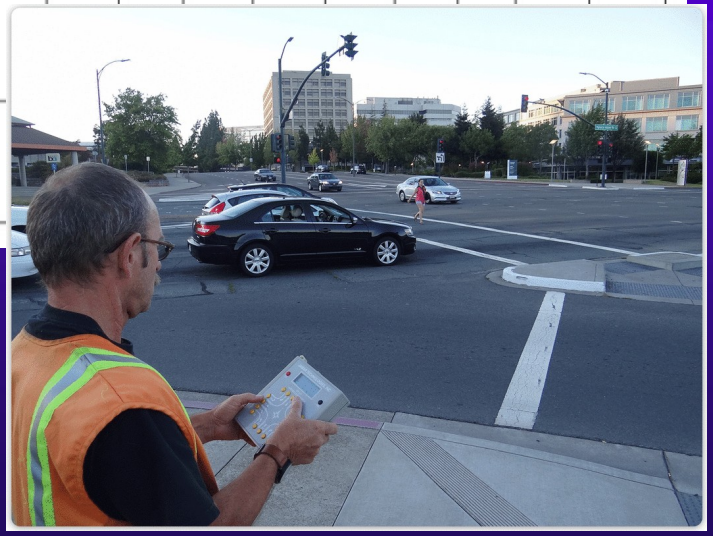
Name of Road ..... Road No. : ..... Direction From : ..... To : .....

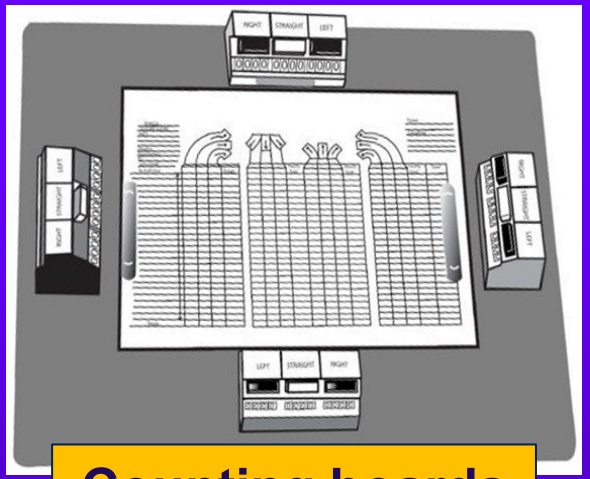
Station Name ..... Station Number : ..... Date : ...../...../..... (DD MM YY)

Enumerator : ..... Supervisor : .....

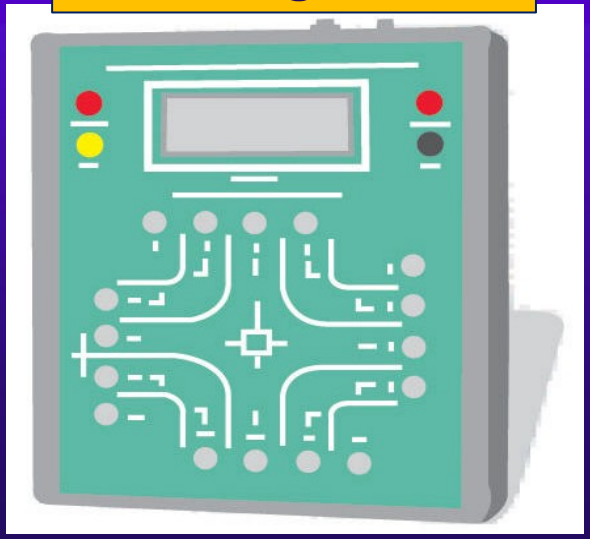
	MOTORISED										NON-MOTORISED		
HOURS COUNTED	1 Heavy Truck	2 Medium Truck	3 Small Truck	4 Large Bus	5 Mini Bus	6 Microbus	7 Utility	8 Car	9 Auto Rickshaw	10 Motor Cycle	11 Bicycle	12 Cycle Rickshaw	13 Animal/Push Cart
: to :													
: to :													
: to :													
: to :													

Tally sheet





Counting boards

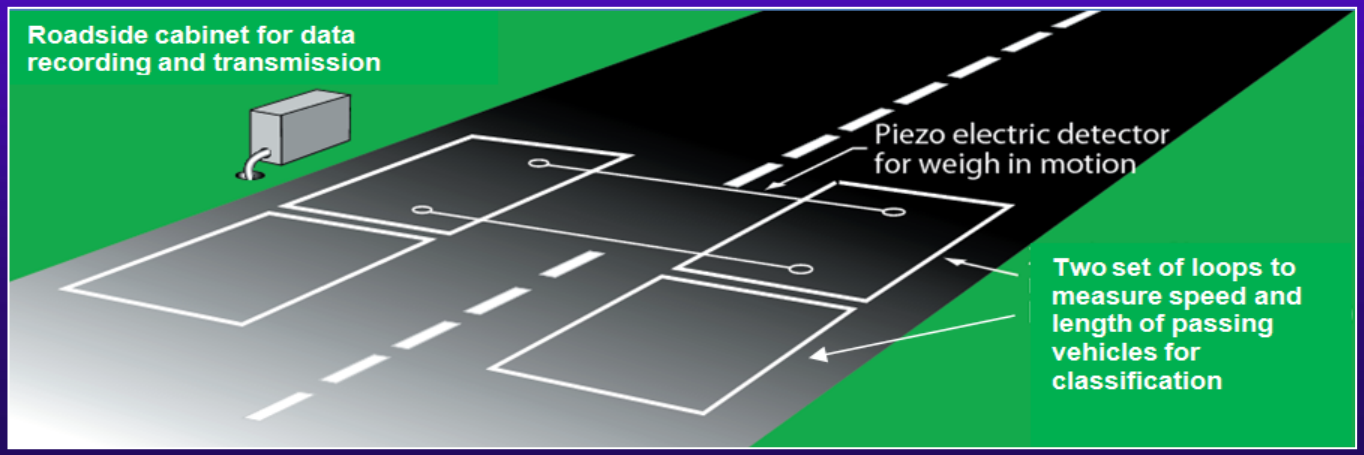


AUTOMATIC TRAFFIC COUNTING TECHNOLOGIES 1

- Automatic traffic count technologies refer to traffic data measured by the means of detectors located on the pavement (contact system) or along the roadside (contactless)
  - *Pneumatic road tubes*: rubber tubes are placed across the traffic lanes to detect vehicles from pressure changes that are produced when a vehicle tyre passes over the tube. The pulse of air that is created is recorded and processed by a counter located on the side of the road. This technology has limited lane coverage and its efficiency is subject to weather, temperature and traffic conditions
  - *Inductive loops*: it is the most conventional technology used to collect traffic data, the loops are embedded in roadways in a square formation that generates a magnetic field changing when a vehicle passes over the loop – this information is transmitted to a counting device placed on the side of the road

AUTOMATIC TRAFFIC COUNTING TECHNOLOGIES 2

Pneumatic (rubber) traffic counting
Tubes laid across the road surface



Typical layout of magnetic loops on the road surface

AUTOMATIC TRAFFIC COUNTING TECHNOLOGIES 3

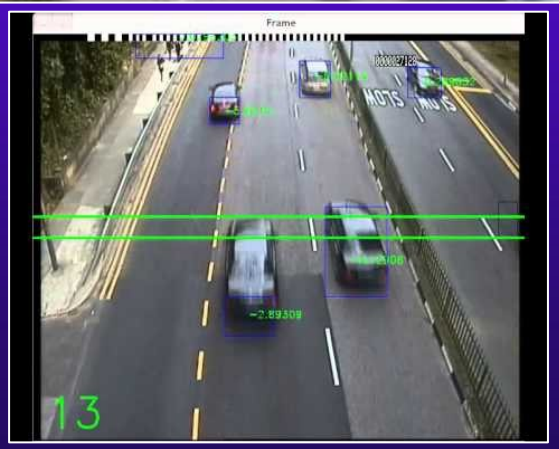
- *Piezoelectric sensors*: the sensors are placed in a groove along roadway surface of the lane(s) monitored; mechanical deformation of the piezoelectric material modifies the surface charge density of the material so that a potential difference appears between the electrodes - the amplitude and frequency of the signal is directly proportional to the degree of deformation (this system can be used to measure both, weight *and* speed)

- Contactless systems are based on electrical or optical principle (activated by interruption of current or light beam); radar, microwave (Doppler principle), ultrasound or infrared, CCTV or video image processing methods, etc.

AUTOMATIC TRAFFIC COUNTING TECHNOLOGIES 4

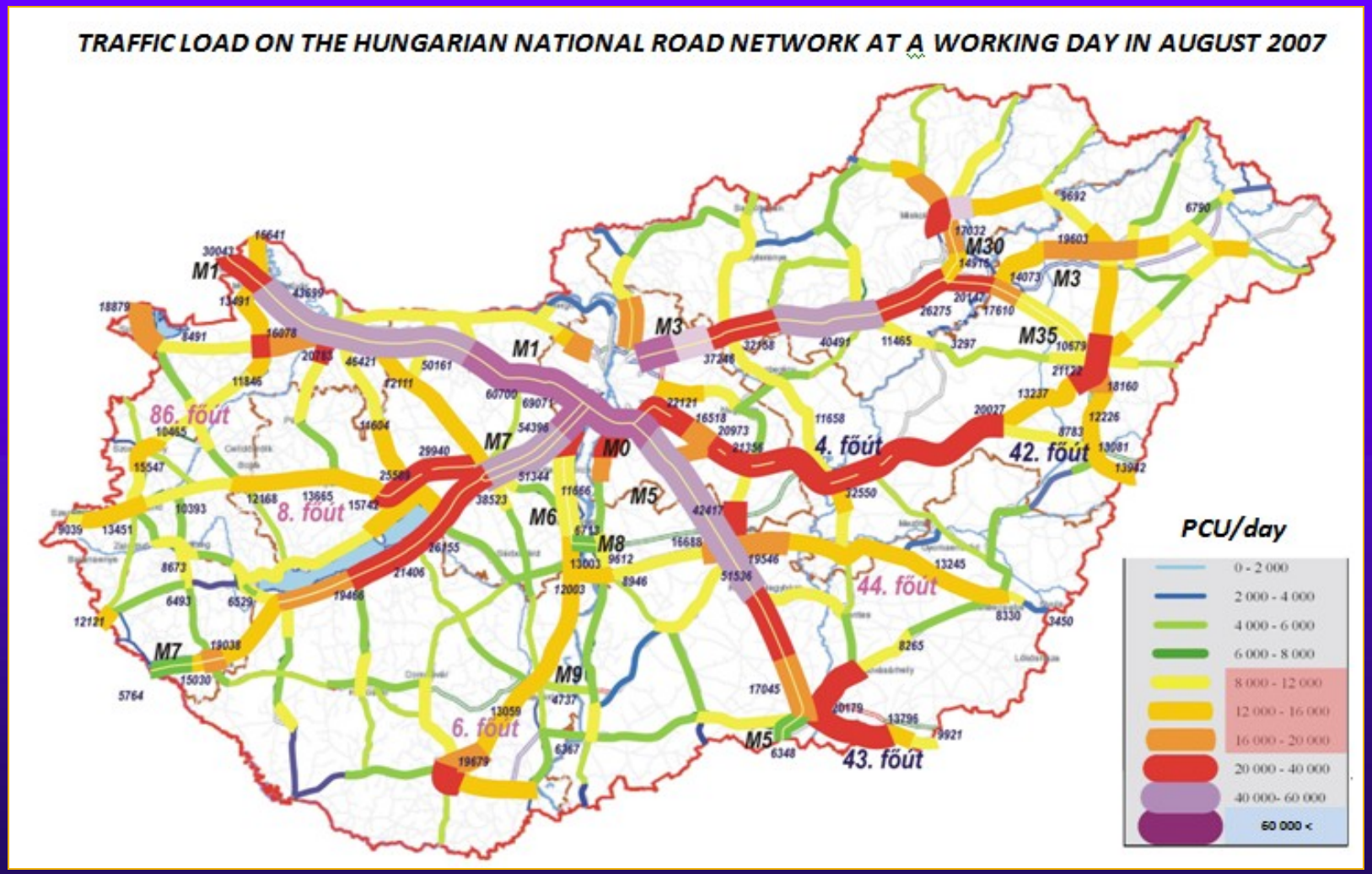
Doppler principle based automatic traffic counting radar device

Infrared vehicle detection and count



Traffic counts by video cameras & image processing

TRAFFIC LOAD MAP



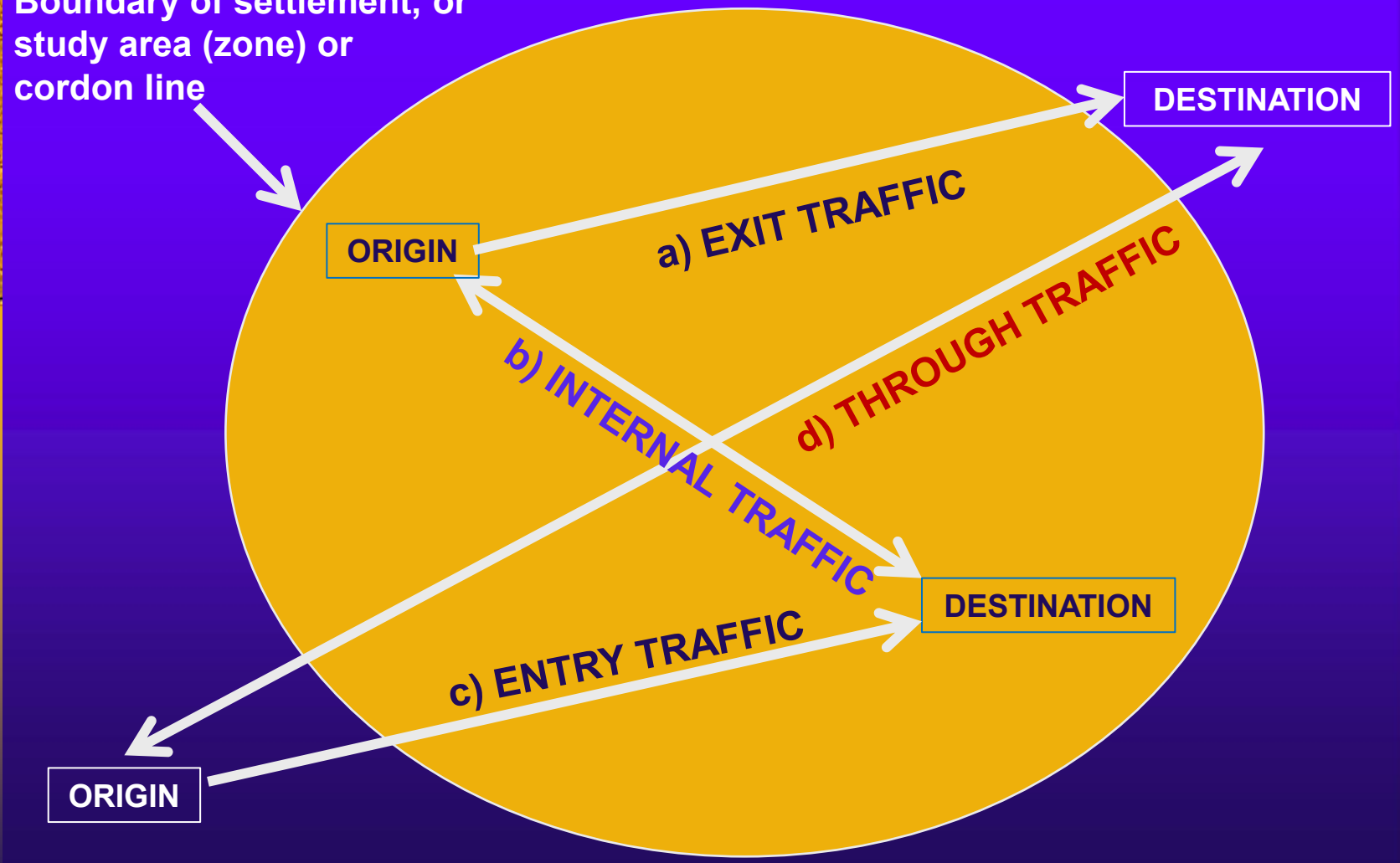
ORIGIN-DESTINATION SURVEYS 1

- Origin-destination (O-D) surveys provide a detailed picture of the trip patterns and travel choices of a city's or region's residents
- These surveys collect valuable data related to households, individuals and trips, allowing to understand travel patterns and characteristics and providing input to travel demand model development, traffic forecasting and planning for area-wide transportation needs and services
- The purpose for which an O-D survey is required determines the extent of preliminary preparations for organizing the survey

ORIGIN-DESTINATION SURVEYS 2

- *Origin* is the location where a trip begins, *destination* is the location where it ends
- Origin-destination describes both 'ends' of a single trip; it is commonly abbreviated to *O-D*
- *Trip* is a single or one-directional movement of one person or vehicle) from one point (origin) to a second point (destination), for a single purpose (e. g. commute to work or school)
- Purpose describes the reason that the trip is made
- Household is the basic analytical unit of the survey sample (group of people, whether related or unrelated, who live together in the same location)

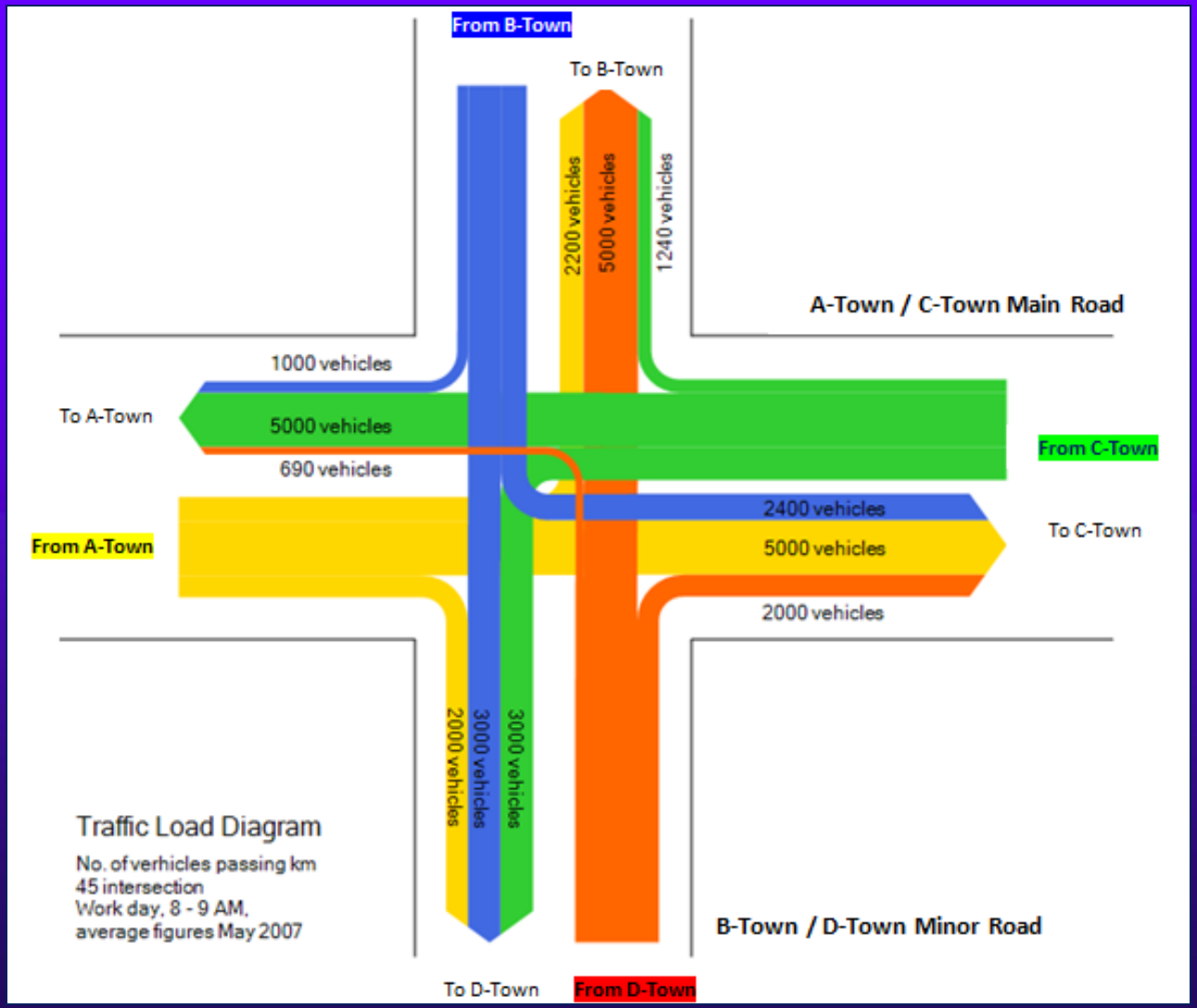
TRAFFIC FLOWS OBSERVED BY AN *O-D* SURVEY



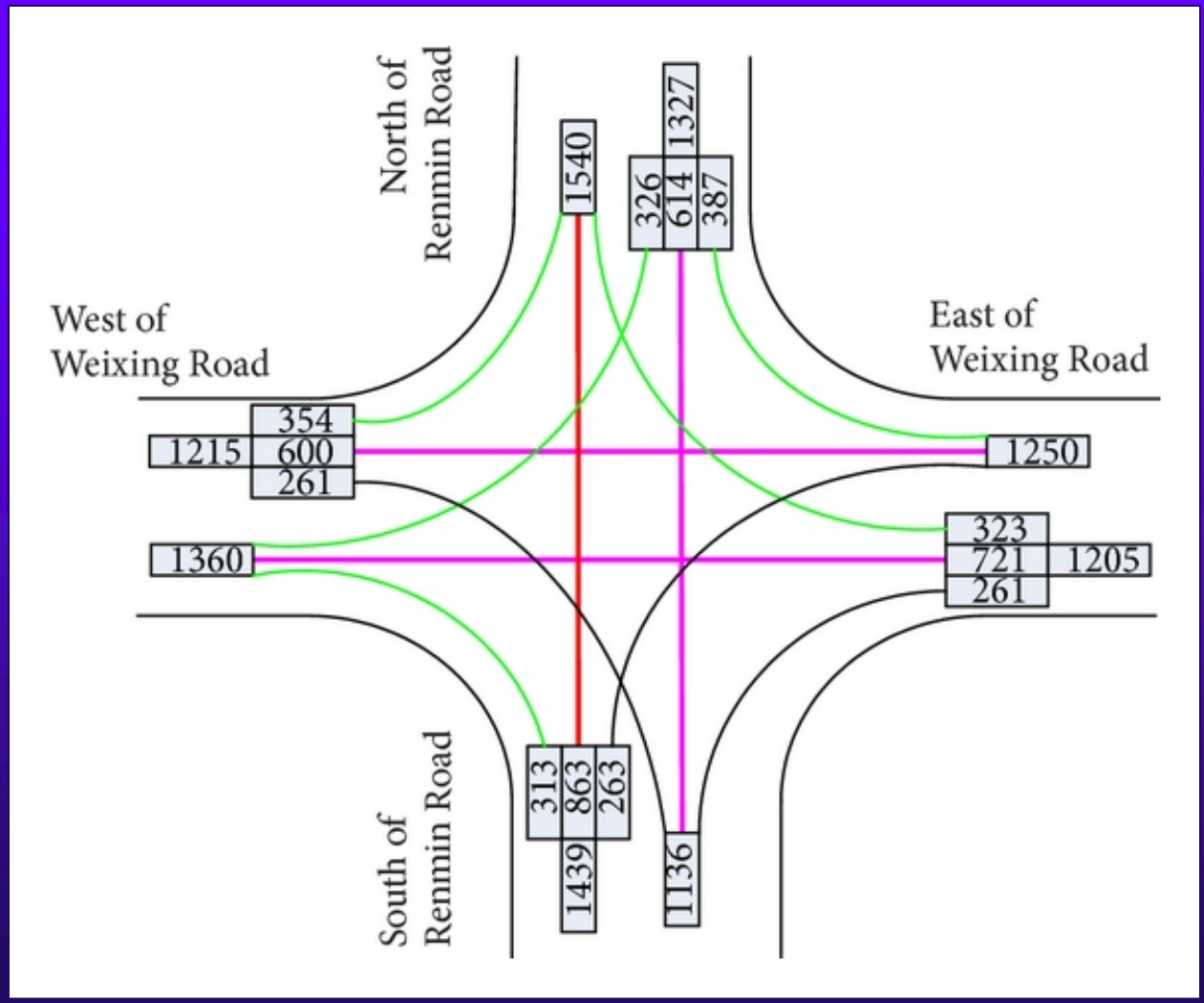
TECHNIQUES FOR *O-D* SURVEY

- ***Home interview survey:*** **size of sample is determined on the basis of population layers of the study area and according to statistical standards related to representativity**
- ***Road-side interview survey:*** **directly interviewing drivers of vehicles at selected survey points**
- ***Post-card questionnaire survey:*** **reply-paid questionnaires are handed over to each of the drivers or a sample of them at the survey points and requesting them to complete the information and return by post**
- ***Registration number plate survey:*** **recording the registration numbers of vehicles entering or leaving an area at survey points located on the cordon line**
- ***Tags on vehicles:*** **at each point where the roads cross the cordon line, vehicles are stopped and a tag is affixed, usually under a windscreen wiper (different survey stations have different shapes and/or color to identify the survey stations), and the vehicles are stopped again at the exit points where the tags are removed**

O-D TRAFFIC LOAD DIAGRAM



O-D TRAFFIC LOAD GRAPH



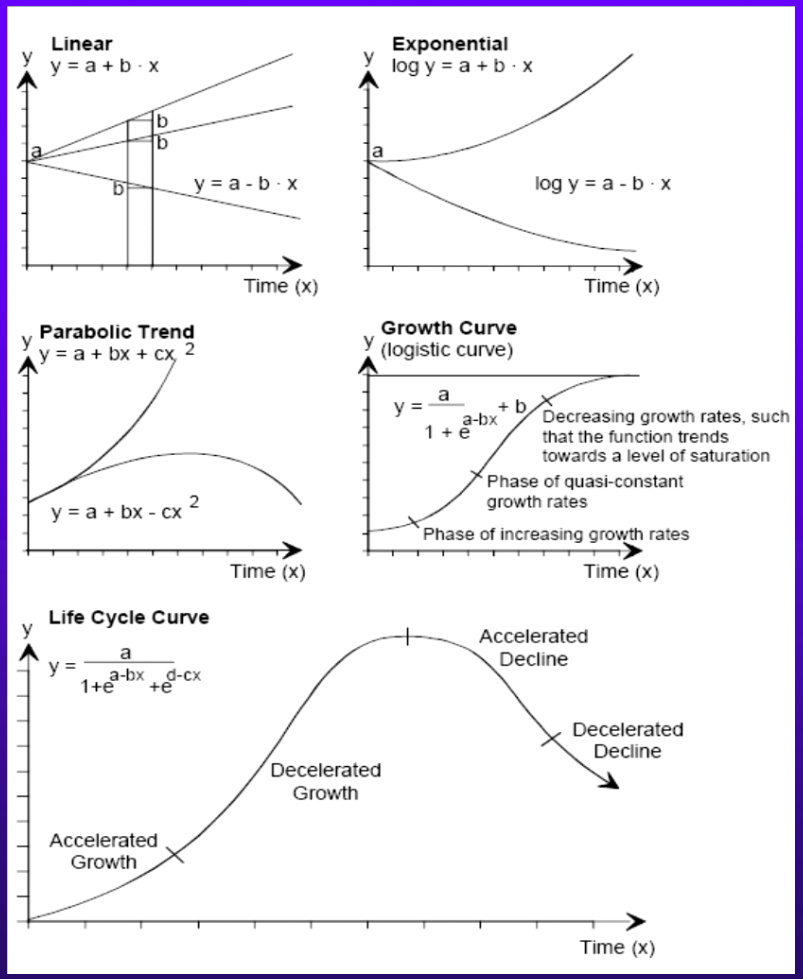
ECONOMY AND DEMAND FOR ROAD TRANSPORT

- Reliable research found a strong correlation between economic growth and road traffic growth, without revealing the exact causes of this correlation
- In most countries traffic has been growing steadily and faster than the economy as a whole during several decades
- The result is that the *'transport intensity*' of the economy has been increasing, i. e. each unit of economic output is associated with a greater amount of movement of people or goods
- Income growth does have a strong effect on traffic growth, but that the amount of traffic is also influenced by the price, speed and quality of transport

TRAFFIC FORECAST 1

- Forecasting traffic flows between O-D pairs, a section, or a part of the road network, it may be possible to *extrapolate* the past trends derived (using *linear*, *exponential* or other *smoothing functions*), from historical traffic counts/surveys
- This would normally yield satisfactory estimates of short to medium term traffic growth (5-10 years)
- If such historical records are not available or are unreliable, alternative methods should be used to determine the expected growth of traffic between O-D pairs during the forecast (design) period (20 years)
- In order to specify this growth a scale factor known as a *composite growth factor* is to be determined; this relates the present to the predicted traffic flow

TRAFFIC FORECAST 2



Functions used for extrapolation

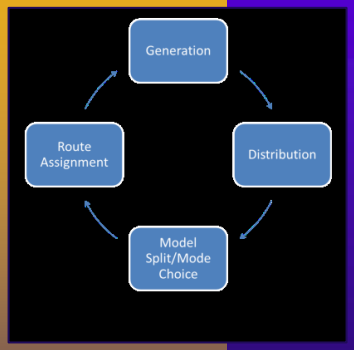
Year	Car	Motor-cycle	Bus	Lorry
2015	1,0	1,0	1,0	1,0
2020	1,2	1,0	1,14	1,27
2025	1,3	0,98	1,41	1,41
2030	1,6	0,97	1,56	1,56
2035	1,8	0,95	1,74	1,74
2050	2,0	0,93	1,48	1,88

Growth factors used for traffic forecast

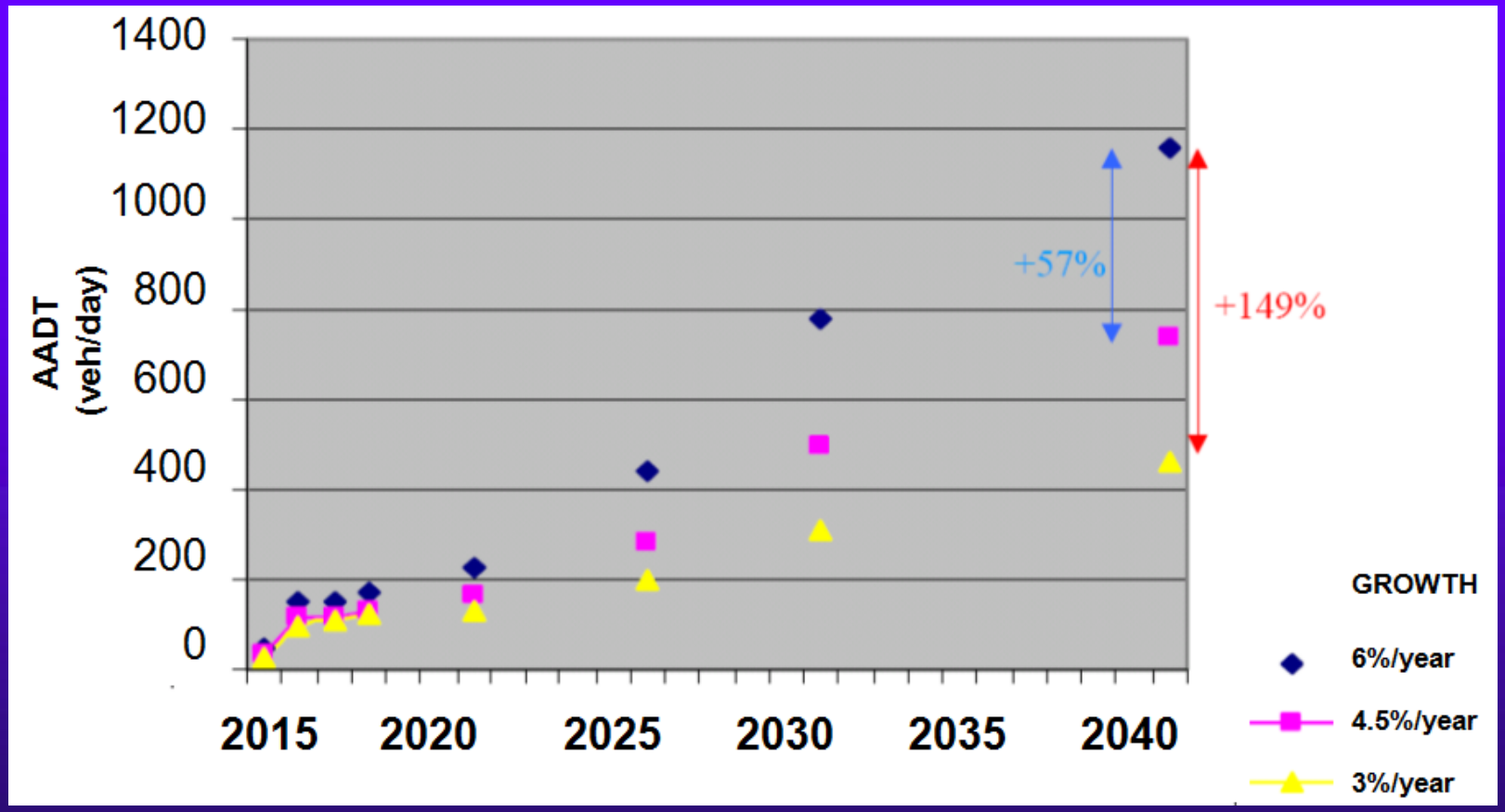
- The driving force behind traffic growth is *mobility*
- *Mobility* is the ability to travel to many different destinations
- *Accessibility* is to gain entry to a particular site or area using (e. g.) *roads*

PASSENGER TRAFFIC FORECASTING MODEL

- Travel demand models are based on the following four-step process and using fresh traffic counts' data aiming to provide more reliable results:
  - *Trip generation*: determines the frequency of origins and destinations of trips in each zone by trip purpose, typically as a function of household demographics, land uses and other socio-economic factors (gravity model)
  - *Trip distribution*: pairs trip origins with destinations
  - *Mode choice*: calculates the proportion of trips between each origin and destination that use different transport modes
  - *Traffic (route) assignment*: allocates trips between an origin and destination by a particular mode via different travel routes; usually, route assignment is calculated under the assumption that each driver will choose the shortest travel time between origin and destination, subject to every other driver doing the same

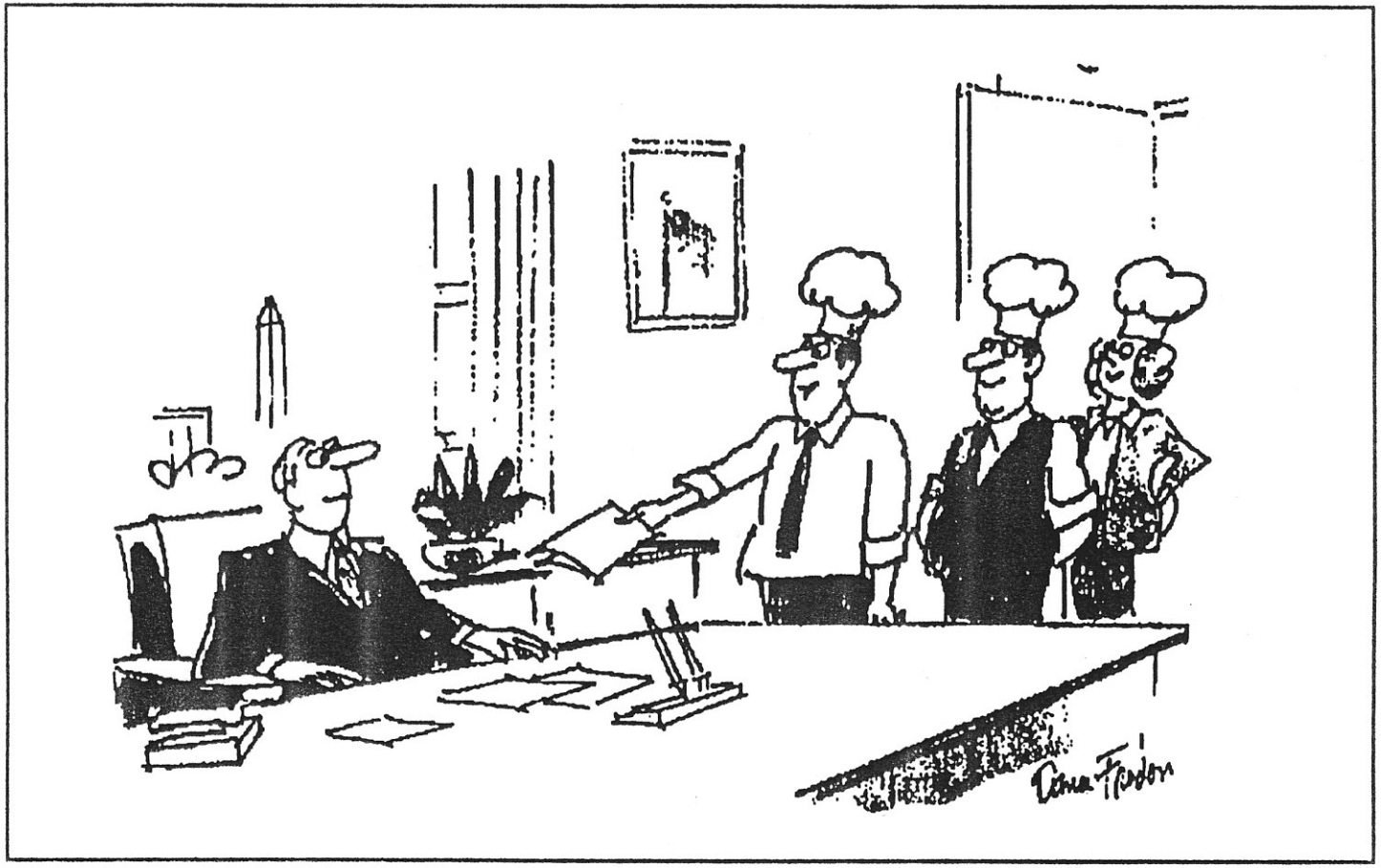


UNCERTAINTY OF LONG TERM FORECAST



Long term consequences of different assumptions

TRAFFIC FORECAST UNDER POLITICAL PRESSURE



"Here are the numbers you wanted cooked, sir."

PASSENGER CAR UNIT

- *Passenger Car Unit* (PCU) is a metric used in traffic engineering to assess traffic flow rate on a road (PCU/hour; PCU/day) for comparison
- PCU as *equivalency factor* reflects essentially the impact that a given type of vehicle has on traffic variables (such as headway, speed, density) compared to that of a single passenger car
- Using PCU-s a mixed traffic stream can be easily transformed into a *hypothetical* passenger-car stream used to measure road *capacity*
- *Typical values* of PCU:

passenger car, pickup, van	- PCU=1.0	motorcycle	- PCU=0.7
trucks and buses	- PCU=2.5	articulated HGV, bus	- PCU=2.5

CAPACITY & LEVEL OF SERVICE

- *Capacity* and *level of service (LOS)* are two related terms: capacity analysis tries to give a clear understanding of *how much* traffic a given road section or intersection can accommodate, while LOS tries to answer how good is the present traffic situation on a given road or intersection
- Thus LOS gives a *qualitative measure* of traffic, where capacity gives a *quantitative* measure of a road or intersection
- Capacity and level of service *varies* with the type of road or intersection, prevailing traffic and road conditions etc.

CAPACITY

- Capacity is usually defined as the maximum hourly rate (PCU/h) or jam density (k_{jam}) at which vehicles can reasonably be expected to traverse a point or uniform section of a traffic lane or a two-way road during a given time period under prevailing roadway, traffic and control conditions
- Capacity is independent of the demand, however, it depends on traffic composition and conditions, geometric design of the roadway, drivers behaviour, weather conditions (visibility), etc.
- For a given road, capacity could be constant; for a two-way rural road, or a single traffic lane on a motorway, usually C = 2000 PCU/h is assumed

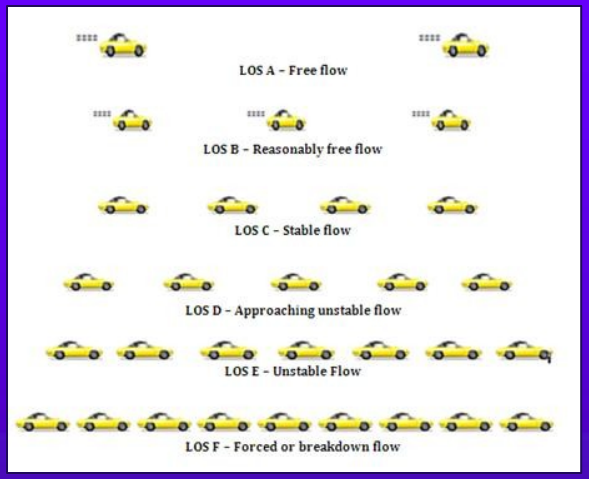
LEVEL OF SERVICE 1

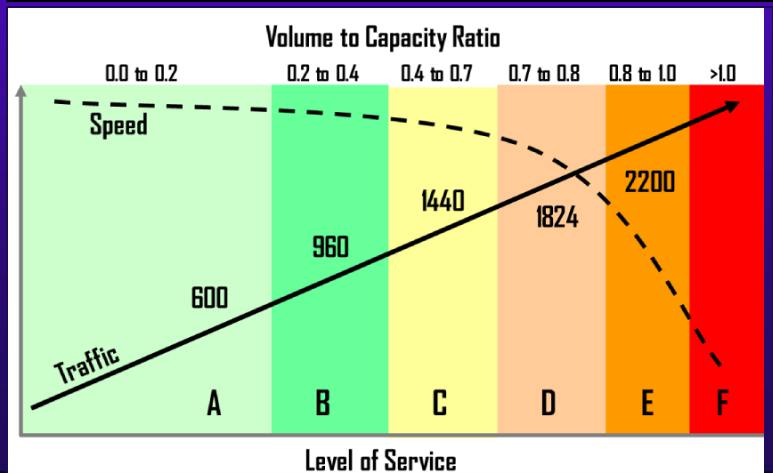
- LOS is related to the traffic *service quality* to a given *flow rate* of traffic; it is a term that designates a range of operating conditions on a particular type of road
- A term closely related to capacity and often confused with it, is *service volume*
- A service volume is the *maximum number of vehicles*, which can be accommodated by a given road or intersection under well defined conditions at a given level of service (LOS)
- US Highway Capacity Manual (HCM) divides the quality of traffic into six levels ranging form level *A* (best) to level *F* (worst)

LEVEL OF SERVICE 2

Level of Service (LOS)		Density (veh/km/lane)	Free flow speed (km/h)	V/C	Upper limit of flow rate (veh/h)
A	Free flow	0-7	120	0.35	700
B	Reasonably free flow	7-11	120	0.55	1100
C	Stable flow	11-16	114	0.77	1540
D	Approaching unstable flow	16-22	99	0.92	1840
E	Unstable flow	22-28	85	1.0	2000
F	Forced or breakdown flow (congestion)	>28	<85	>1.0	2150

LOS for a typical motorway segment (USA)





LOS for an inter-section (USA)

Level of Service (LOS)	Control Delay sec/vehicle (signalised)	Control Delay sec/vehicle (unsignalised)
A	≤10	≤10
B	10-20	10-15
C	20-35	15-25
D	35-55	25-35
E	55-80	35-50
F	>80	>50

LEVEL OF SERVICE 3

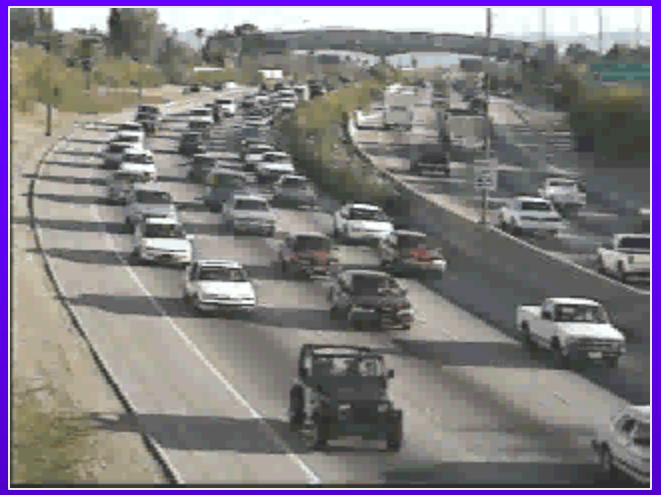
- LOS *A*
  - Free-flow operation
  - Free-flow speed (FFS) is the mean speed of passenger cars that can be accommodated under low to moderate flow rates on a uniform road segment under prevailing roadway and traffic conditions
- LOS *B*
  - Reasonably free flow
  - Ability to maneuver is only slightly restricted
  - Effects of minor incidents still easily absorbed

LEVEL OF SERVICE 4

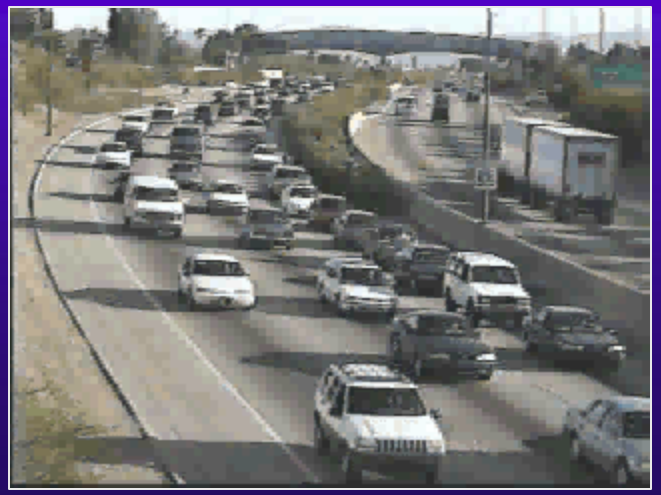
- LOS *C*
  - Speeds at or near FFS
  - Freedom to maneuver is noticeably restricted
  - Queues may form behind any significant blockage
- LOS *D*
  - Speeds decline slightly with increasing flows
  - Density increases more quickly
  - Freedom to maneuver is more noticeably limited
  - Minor incidents create queuing

LEVEL OF SERVICE 5

- LOS *E*
  - Operation near or at capacity
  - No usable gaps in the traffic stream
  - Operations extremely volatile
  - Any disruption causes queuing

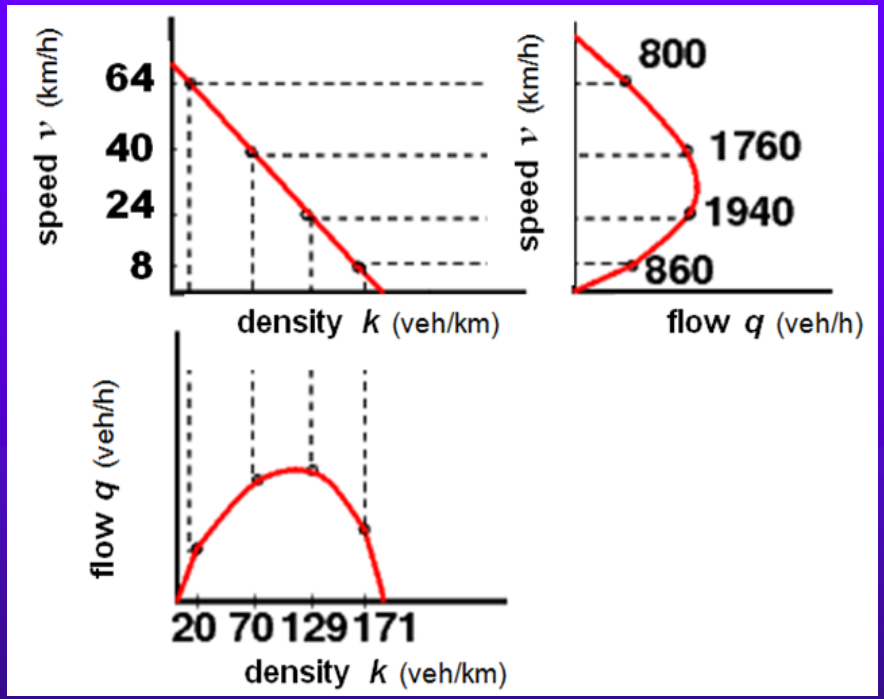


- LOS *F*
  - Breakdown in flow
  - Queues form behind breakdown points
  - Demand > Capacity



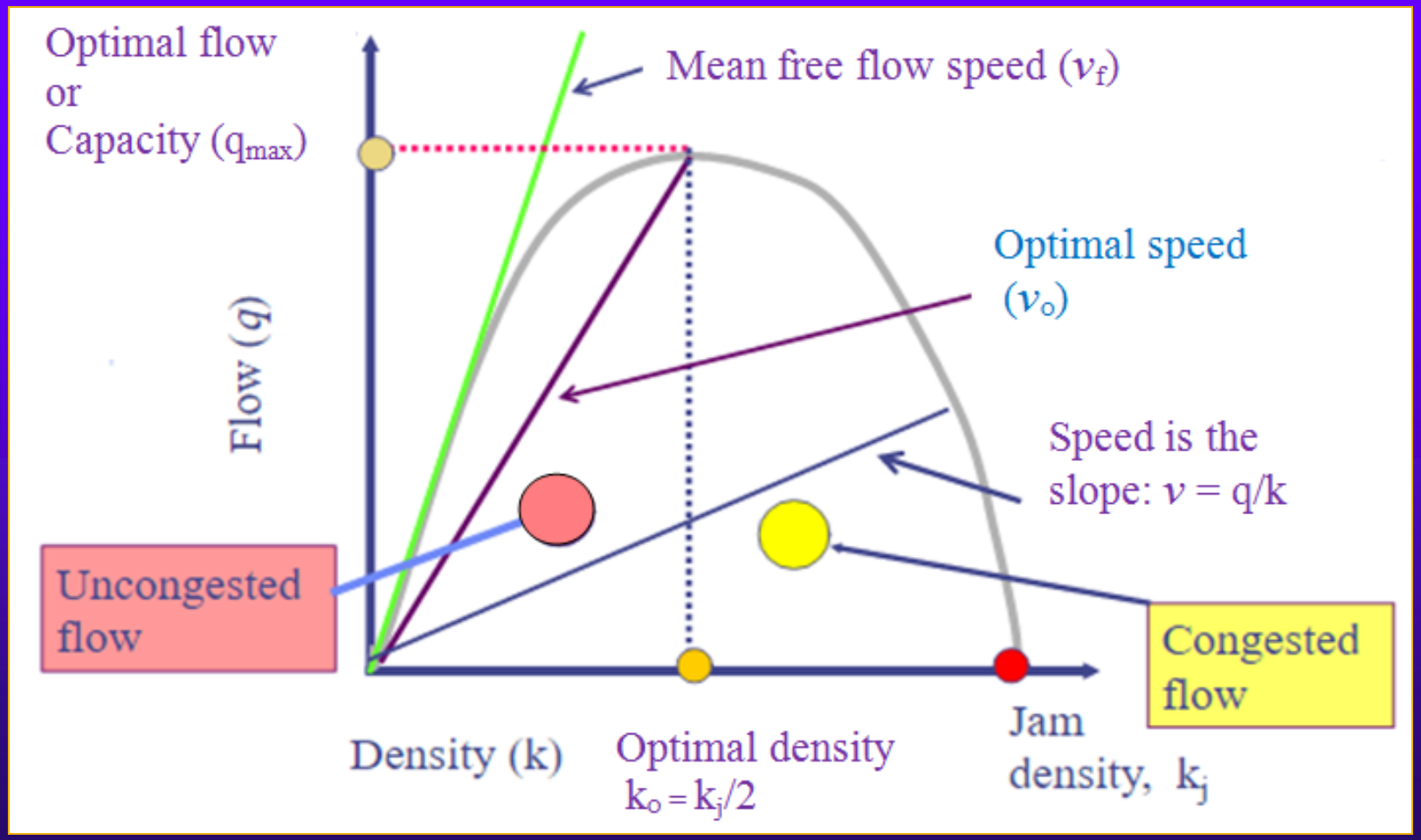
TRAFFIC FLOW, SPEED & DENSITY (REMINDER)

- The three basic parameters used to describe traffic flow states are *volume/flow, speed* and *density*
- For uninterrupted traffic flow, the theoretical relationships between these parameters are generally referred to as *fundamental diagrams* of traffic flow

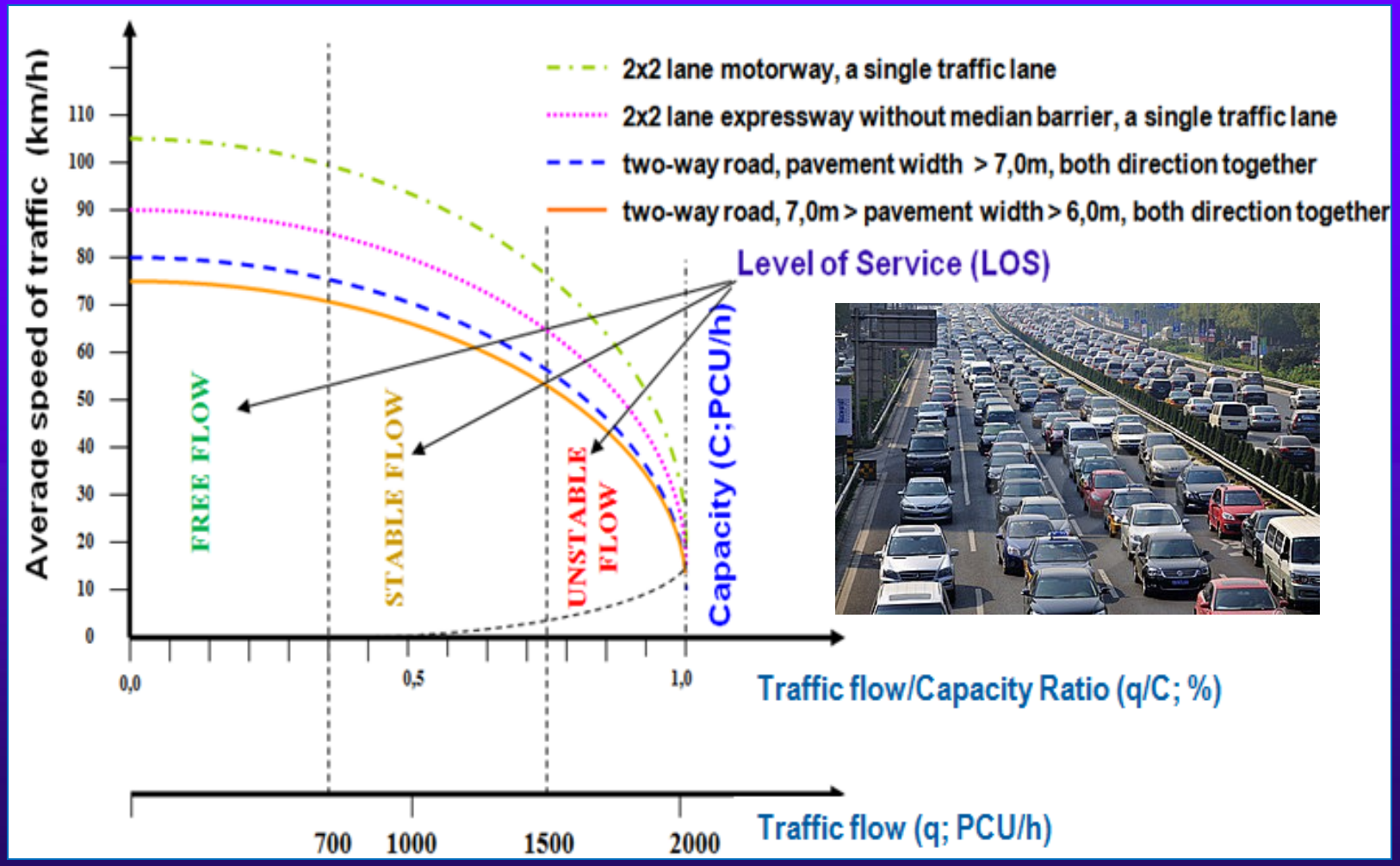


Fundamental diagrams for traffic flow

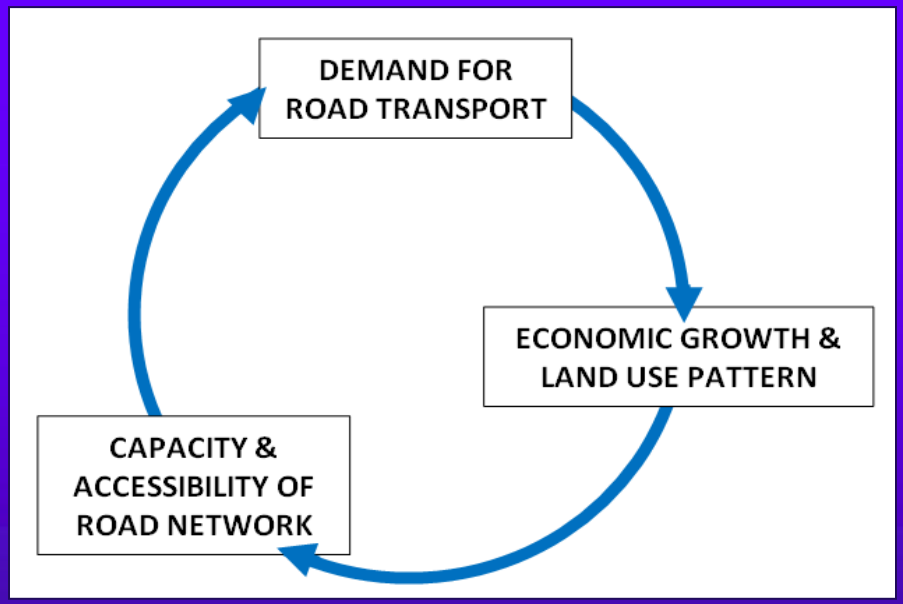
FLOW-DENSITY FUNDAMENTAL DIAGRAM

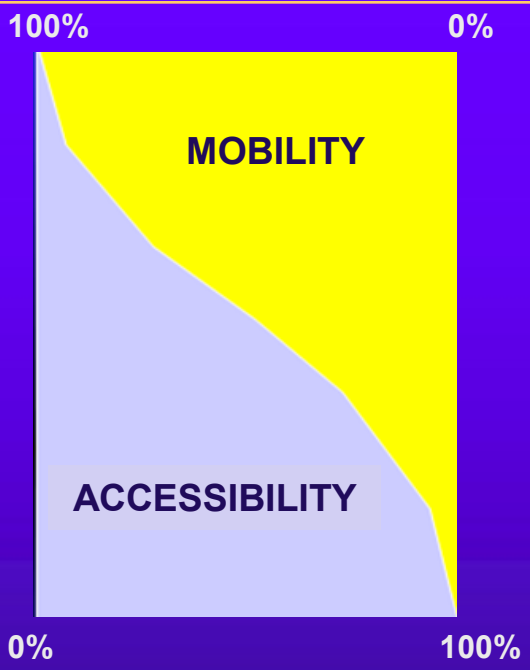


SPEED-FLOW FUNDAMENTAL DIAGRAM



EVER GROWING TRANSPORT DEMAND?





This circular, self-reinforcing characteristics of transport demand creates a central dilemma: building additional capacity (improving roads and extending the network) invariably leads to incrementally increased transport demand...

Timár 2019