Fundamental parameters of traffic flow

To design a smooth, safe and economical operation of traffic a thorough knowledge of traffic stream parameters and their mutual relationships is of utmost important.

The fundamental stream characteristics are speed, flow, and density.

Density and flow parameters define **quantity of flow**, and speed parameter defines the **quality of flow**.

The traffic flow parameters can be:

1. **Microscopic** - studies the behavior of indl veh in the stream with respect to each other.

   measures of separation, i.e. the headway, can be either time or space headway.

2. **Mesoscopic**- stream characteristics are speed, flow, and density.

3. **Macroscopic** - characterizes the quantity or quality traffic as a whole

   flow, density, and speed.

Fundamental parameters of traffic flow

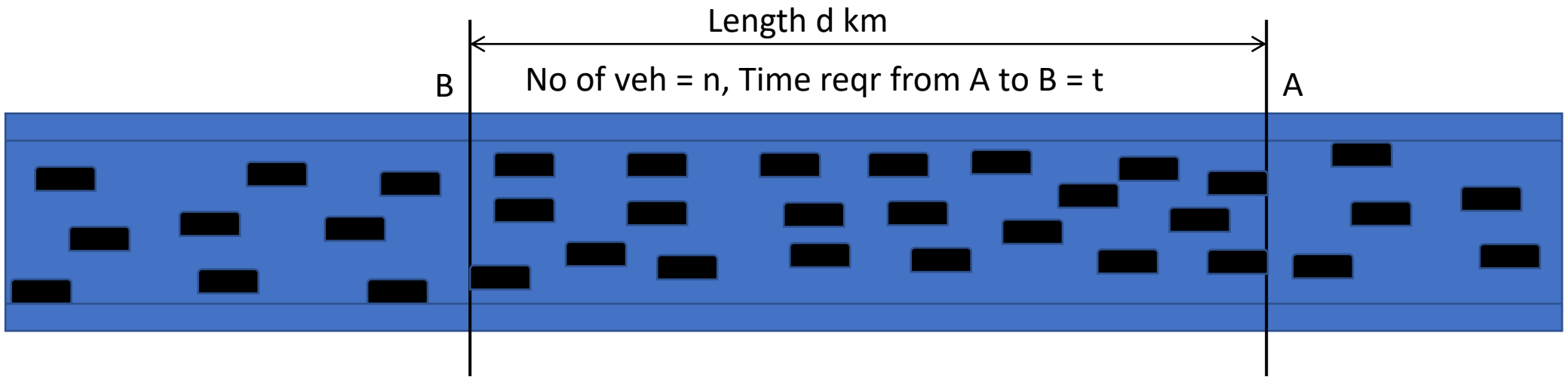
Speed: It is the total dist traversed divided by the total time. Usually expressed in mph or kmph, fps or m/s.

Volume / Flow: Total number of veh that pass over a given point or sec of a roadway (in one lane) during a given time interval. May be expressed in term of annual, monthly, daily, hourly or sub hourly periods, usually in vpd or vph.

Traffic Volumes directly affect the geometric design - Number of lanes, widths, etc.

Density: The number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per km or veh per mile.

Traffic Flow Parameters and Fundamental Relationship



Mathematically,

Speed, $v = \frac{d}{t}$, **in mph, kmph, fps, m/s etc**

Flow, $\mathrm{q} = \frac{n}{t}$, **in vph, vpd etc**

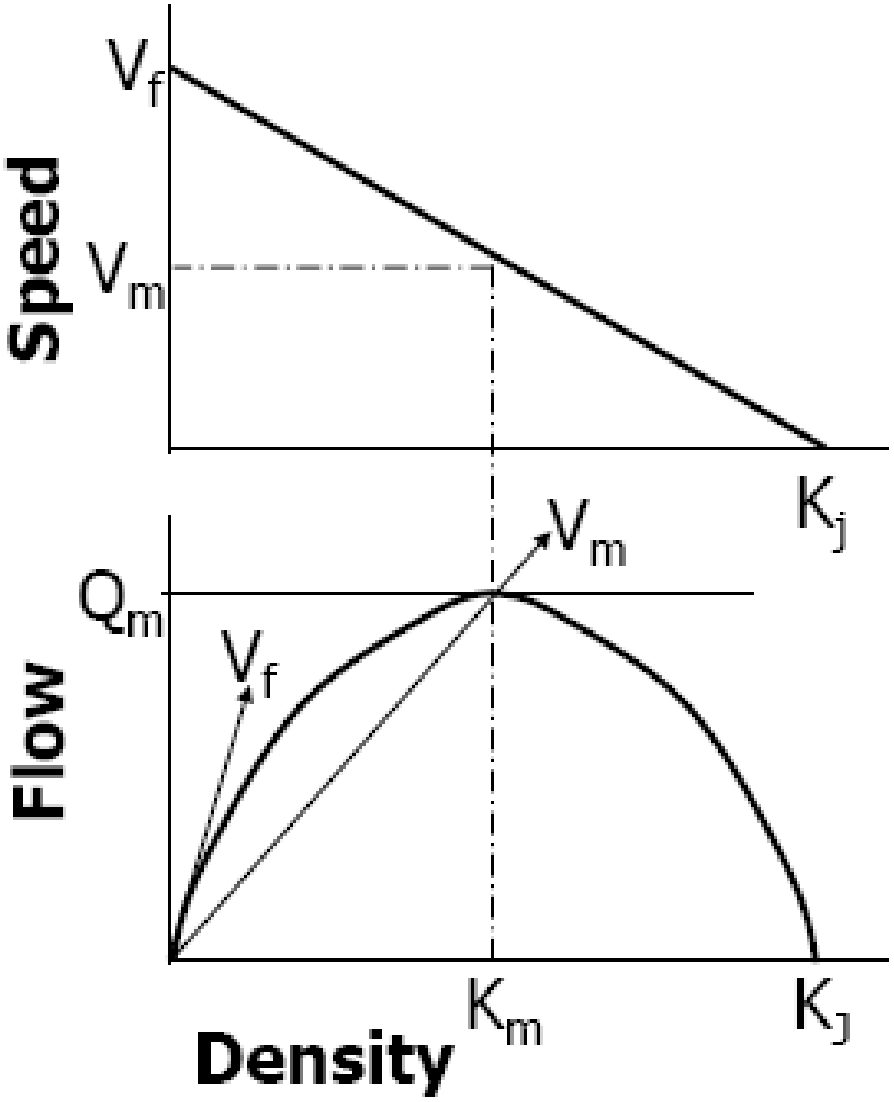
Density, $\mathrm{k} = \frac{n}{d}$, **in vper mile, v per km etc**

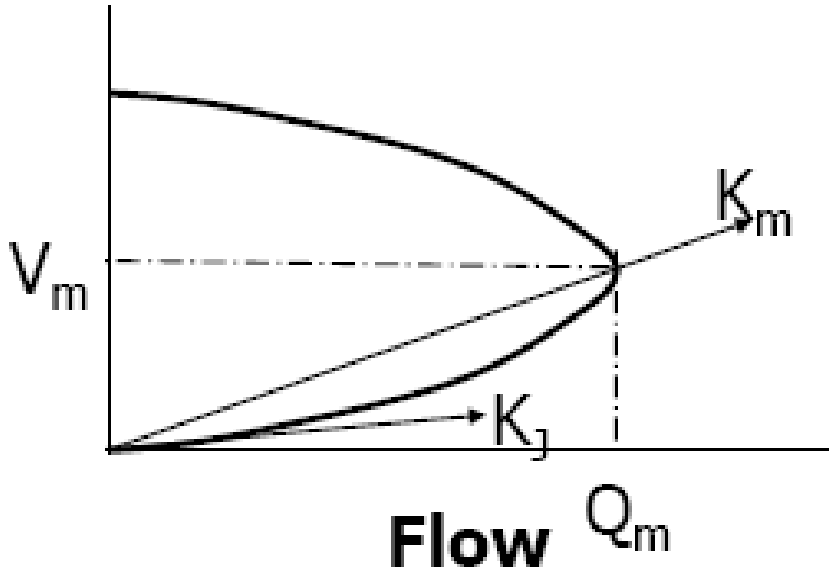
Fundamental Relationship

Flow (veh/hr) = Density (veh/mile) x Speed (miles/hr)

Q = K x V

Fundamental Relationship – Speed, Flow and Density





Q_m = Max Flow or Capacity

V_f= Free Flow Speed

V_m= Optimal Speed under Max Flow

K_j = Jam Density

K_m= Optimal Density under Max Flow

Fundamental Relationship – Speed, Flow and Density

Greenshield's model:

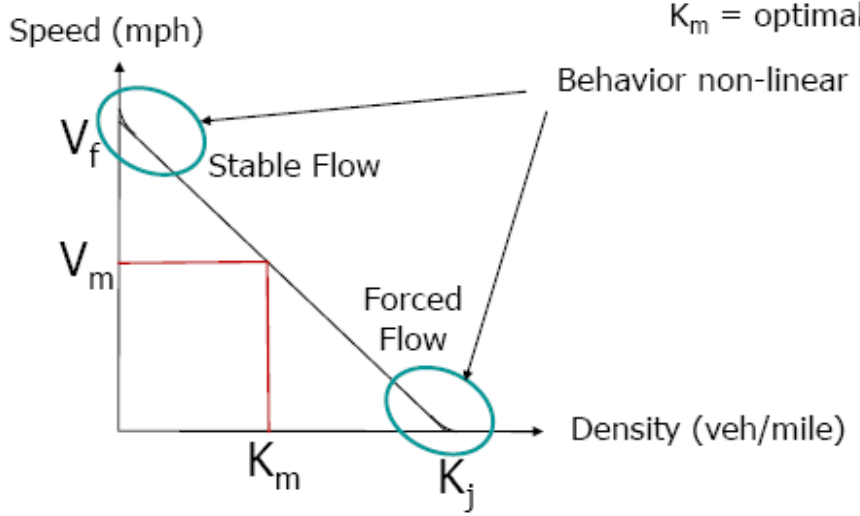
I. When the density is zero, the flow is zero because there are no vehicles on the roadway.

II. As the density increases, the flow also increases to some maximum flow conditions.

III. When the density reaches a maximum, generally called *jam density*, the flow must be zero because the vehicles tend to line up end to end (parking lot conditions).

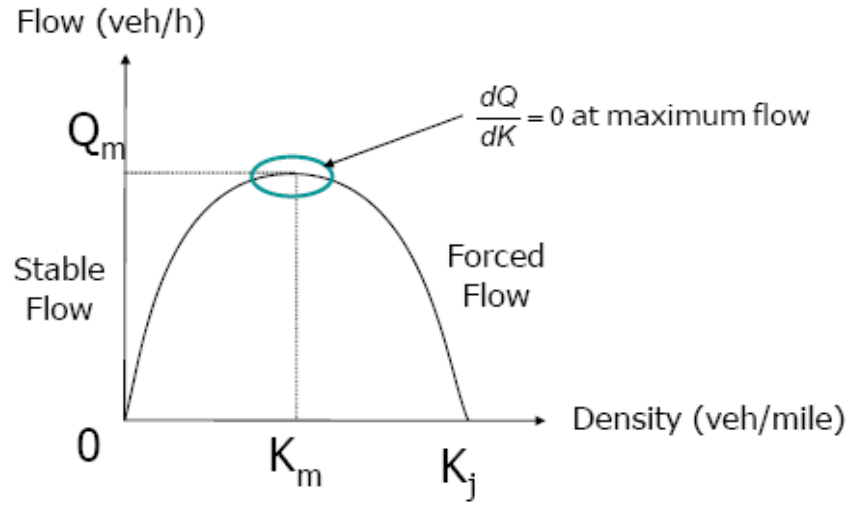
Speed and Density

V_f = free flow speed
V_m = optimal speed
K_j = jam density
K_m = optimal density



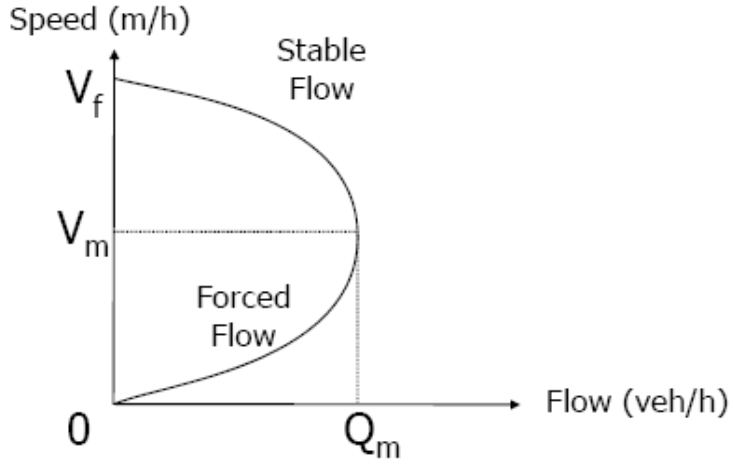
Flow and Density

Q_m = maximum flow
K_m = optimal density



Flow and Speed

Q_m = maximum flow
V_m = optimal speed



Major Traffic Elements (Principal Factors) Influencing Highway Design

- Traffic volume (ADT and AADT)
- Design Hour volume (DHV)
- Directional distribution
- Design speed
- Design vehicle
- Percentage of trucks
- LOS

Various Types of Traffic Volumes

Volume / Flow: Total no of veh that pass over a given point or sec of a roadway during a given time interval.

Average Annual Daily Traffic (AADT): Average 24-hour traffic volume at a location over a full 365-day of the year.

$$= \frac{\text{total no of veh passing a location in whole year}}{365}$$

Average Annual Weekday Traffic (AAWT): Average 24-hour traffic volume on weekdays over a full year.

$$= \frac{\text{total no of veh passing a location only on weekdays in whole year}}{260}$$

Average Daily Traffic (ADT): Average 24-hour traffic at a location for any period less than a year (e.g. six months, a season, a month, a week or even two days)

$$= \frac{\text{total no of veh passing a location in days < 365 days}}{no\ of\ days\ traffic\ counted}$$

Average Weekday Traffic (AWT) : Average 24-hour traffic volume on weekdays for any period less than a year

Various Types of Traffic Volumes

Peak Hour Traffic: Traffic volume collected in a time shorter than one day (e.g. rush hour volume). Peak-hour traffic is used to determine the design hourly volume (DHV), which is often expressed as a percentage of the AADT.

DHV (Design Hourly Volume): Volume projected to use a facility during the design year, it is the 30^{th} highest hourly vol of the design yr, generally 20 years in the future

Directional Distribution: It is the one-way volume in the predominant direction of travel, expressed as a proportion of the volume in two-way DHV.

For rural two-lane road ranges from 0.5 to 0.7, typically assumed 0.6 (60%)

PHF (Peak Hour factor)

PHF is the ratio of total hourly vol to the max rate of flow within the hour.

For Intersection, $PHF = \frac{Hourly\ Vol}{4 \times 15\ \min\ count}$

For Freeway, $PHF = \frac{Hourly\ Vol}{12 \times 5\ \min\ count}$

Types of Flow for quality/LOS

Interrupted: flow at stop and go situation

Uninterrupted flow: when the flow is smooth

Saturation flow: max hourly rate of an approach at a signalized junction

Service flow rate: max hourly rate of a roadway section during a given period under prevailing roadway condition

Free flow: when dvr face no restriction in driving and can maintain their desired speed

Forced flow: when dvr are forced to follow slow leader and lane changing opportunity decreases with increased traffic vol

Types of Flow for quality/LOS

Stable/steady Flow: when demand is well below the road way capacity and avg rate of flow almost remains constant

Unstable flow: when demand is at or near or exceed the capacity and avg rate of flow fluctuate largely with time

Peak / Off peak flow: flow at peak or off peak period

Contra flow: an arrangement on a large road by which traffic going in both direction uses only one side of the road (for repair work)

An arrangement on a one way street by which only bus is allowed to go in opposite dir.

Tidal flow: when traffic flows in both direction exhibit unbalanced characteristics at peak periods

Induced flow: flow that is generated because of new or improved road way facility.

Levels of Service (LOS)

Level of service is a qualitative measure used to relate the quality of traffic service.

LOS is used to analyze highways by categorizing traffic flow and assigning quality levels of traffic based on performance measure like speed, density etc.

A – Free flow

B – Reasonable free flow

C – Stable flow

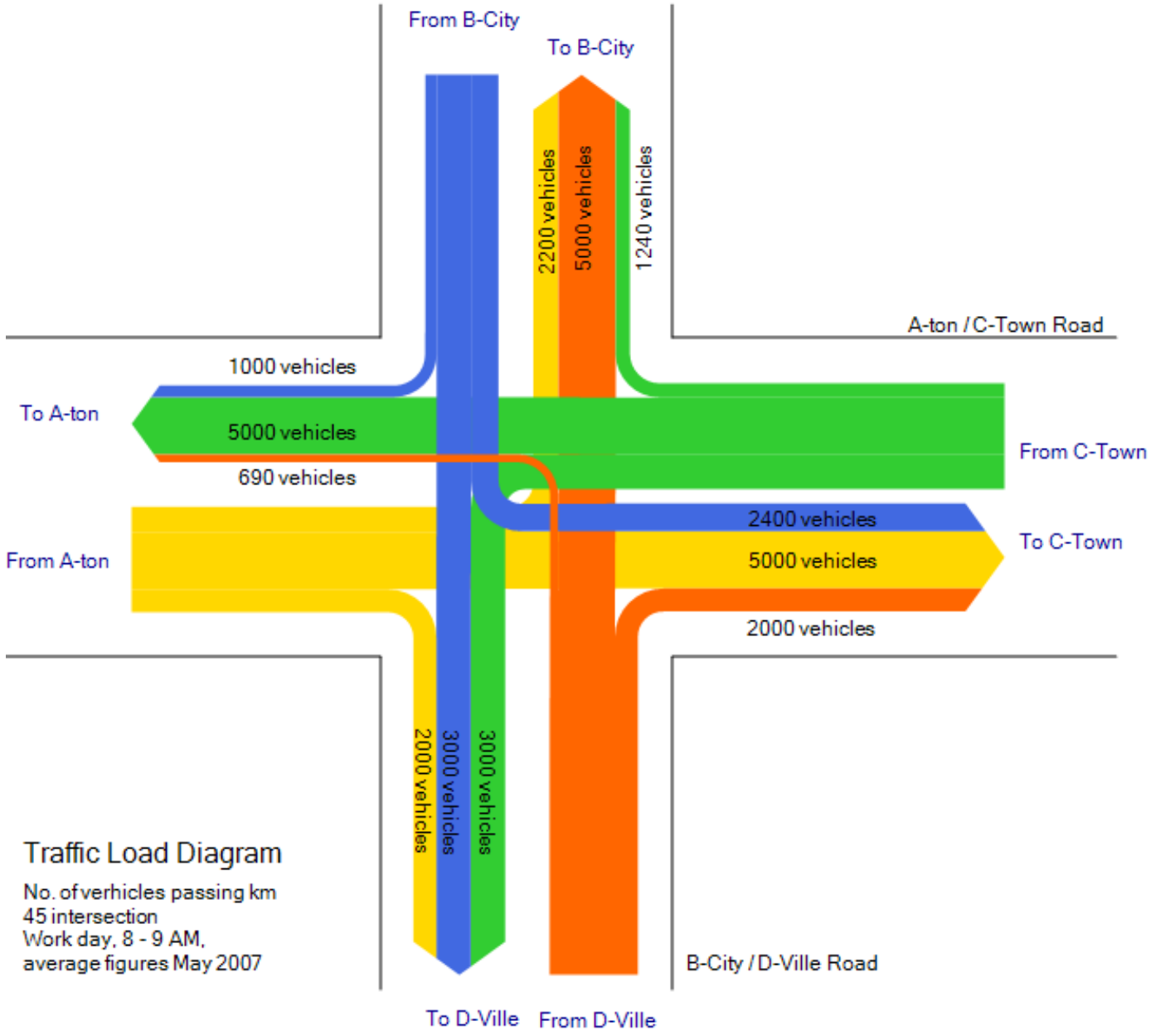
D – Approaching unstable flow

E – Unstable flow

F – Forced or breakdown flow

Level of Service	Flow Conditions	Operating Speed (mph)	Technical Descriptions
A		60	Highest level of service. Traffic flows freely with little or no restrictions on maneuverability. **No delays**
B		60	Traffic flows freely, but drivers have slightly less freedom to maneuver. **No delays**
C		60	Density becomes noticeable with ability to maneuver limited by other vehicles. **Minimal delays**
D		57	Speed and ability to maneuver is severely restricted by increasing density of vehicles. **Minimal delays**
E		55	Unstable traffic flow. Speeds vary greatly and are unpredictable. **Minimal delays**
F		<55	Traffic flow is unstable, with brief periods of movement followed by forced stops. **Significant delays**

Traffic Load Diagram



Vehicle Characteristics

Static Characteristics: Weight, Size (Length, Width)

Weight : Pavement Depths, Maximum Grades

Size : Lane Width, Shoulder Width, Length and Width of Parking, Lengths of Vertical Curves

Kinematic Characteristics: Acceleration and Deceleration Capabilities.

Determine dimensions of Intersections, Freeway Ramps, Climbing or Passing Lanes, Turnout Bays for Buses

Dynamic Characteristics: Air Resistance, Grade Resistance, Rolling Resistance, Curve Resistance, Friction Resistance etc.

How and what elements they affects?

Design Vehicles

- Design vehicles have **dimensions or operating characteristics** that are critical and will **control the design and/or operation** of the roadway.
- **The largest vehicle** likely to use that facility on a frequent basis
- Design vehicles selected for each class with representative : Weight, Dimensions, Operating characteristics
- Key Vehicle Dimensions: Height, Length, Width, Wheelbase, Turning Radius
- Design vehicles based upon general class groupings. Four General Classes are:
  - **Passenger Cars** : Cars, Sport/utility vehicles, minivans, vans, pick-up trucks
  - **Buses** : Intercity motor coaches, city transit, school bus, articulated buses
  - **Trucks** : Single-unit trucks, semi-trailer tractors
  - **Recreational Vehicles** : Motor homes, cars with camper trailers, boat trailers
  - ***Bicycle considered as needed***

What should be the design Vehicle?

Relationship between vehicular and facility characteristics	
Vehicular characteristics	**Related facility characteristics**
Length	**Parking stall length** **Transit station platform length**
Width	**Lane width** **Parking stall width** **Lateral clearance**
Height	**Vertical clearance** **Minimum vertical curve length**
Wheel base (turning radius)	**Lateral clearance on curves** **Intersection edge radii**
Weight	**Structural design of surface** **Structural design of guideway** **Structural design of bridges**
Acceleration / deceleration	**Maximum grade** **Minimum vertical curve length** **Horizontal curve radius**
Speed	**Horizontal curve radius** **Minimum vertical curve length** **Maximum superelevation**

Driver Characteristics

Important physical characteristics

- Vision
- Hearing
- Other senses
- Strength
- Coordination

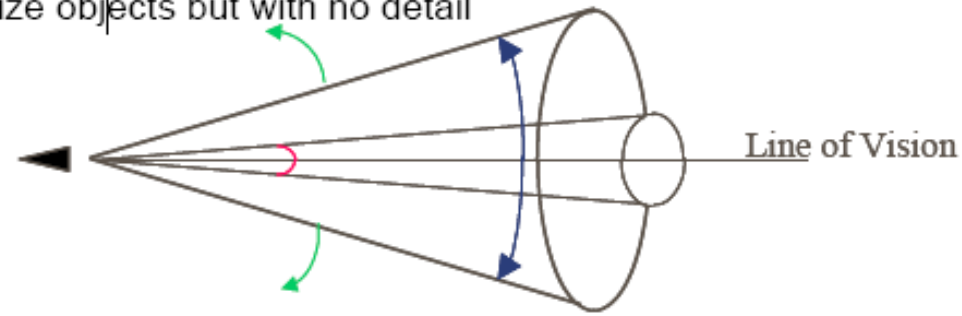
Visual Components

- Visual Acuity
- Glare Vision and Recovery
- Depth Perception
- Color Vision

Varying Skill, Varying Perceptual Abilities

Varying Circumstances

- Cone of Vision
  - Acute Vision Cone (3° to 5)
    - Recognize legends
  - Clear Vision: (10° to 12°)
    - Recognize shape and color
    - Use for signs and signals
  - Peripheral Vision (120° to 180°)
    - Recognize objects but with no detail



Driver Characteristics-Visual Components

Visual Acuity: Ability to discern object / Sharpness with which a person can see an object

Changes with age

Affected by various factors

- Contrast and brightness of object
- Level of illumination
- Relative motion between the observer and the object

Optimal time for identification = 0.5 to 1.0 seconds

Signs and Markings placed within 10 degree cone of clear vision

Glare recovery - Glare impairs ability to see

Depth perception - Ability to estimate distance, speed

Color Vision

Ability to differentiate one color from another

Color is a factor in traffic control devices

Driver Performance

Considers the following:

- **The driving task**
- **The guidance task**
- **The information system**
- **Information handling**

The Driving Task

Consists of three components, ordered on scales of complexity and importance for safety

1. **Control:** Steering and speed control
2. **Guidance:** Road-following and safe-path maintenance in response to road and traffic conditions
3. **Navigation:** Trip planning and route following

Con and guidance errors dir contribute to accdt

Nav error resulting in delay contribute to inefficient op and may indir lead to accdt.

Driver Performance

The Guidance Task

Lateral placement and road following

Car following

Passing Maneuvers

Other guidance activities : Merging, Lane changing, Response to traffic control devices

The Information System

Formal sources of information - Traffic control devices

Informal sources - Roadway and roadside design features, Pavement joints, Tree lines

Information Handling

Dvr use many senses to gather info, Feel rd surface texture through vibration in the steering wheel, hear the sirens of emergency veh, see alignment, markings and signs.

Throughout the driving tasks they perform several function almost simultaneously. They look a info system, make numerous decisions and perform nec con actions.

Sources of info compete for their attention

Driver Perception and Reaction Time

Is defined as the interval between seeing, feeling, or hearing a traffic or HW situation and making an initial response to what has been perceived.

Perception - Reaction Time is termed as PIEV time.

Perception: recognition of a stimulus

Identification: interpretation of stimulus

Emotion: determination of appropriate response (decision-making)

Volition: physical execution of a decision

PIEV time varies from less than **0.5 sec to 3 sec** or more.

Varies pers to pers, time to time, changes with age, with physical condition, situation, and so on.

Primacy

Relates the relative importance to safety of competing information

- Control and guidance information has high primacy
- Navigation information has lower primacy

Expectancy

Formed by the experience and training of drivers

Relates to the likelihood that a driver will respond to common situations in predictable ways that the driver has found successful in the past

Affects how drivers perceive and handle information

In situations where driver expectancies are violated, longer response times, inappropriate responses or errors may result

Base condition of uninterrupted flow facilities

1. Lane width = 12 ft or 3.6m
2. Min 6 ft lateral clearance
3. Min 2 ft median lateral clearance
4. All passenger cars in the traffc stream
5. Regular and familiar dvr
6. Five or more lanes in one direction
7. Interchange spacing $\geq$ 2 mile or 3 km
8. Gen level terrain (grade $\leq 2\%$

Base condition of Signalized intersection

1. Lane width = 12 ft or 3.6m
2. Level terrain
3. All passenger cars in thr tfc stream
4. No curb parking allowed
5. No turning mov at intersec
6. No Ped or bisysles at the intersec
7. Intersec loc outside the CBD
8. Green signal aval at all times

Prevailing condition are seldom available. The condition are gp into three cat:

1. **Roadway condition**
2. **Traffic condition and**
3. **Control condition**

Roadway factors:

1. The type of facility and its dev env
2. Lane widths
3. Shoulder width and lateral clearance
4. Design speed
5. Hor and vertical alignment

Traffic Comditions:

1. The type of vehicle: truck, bus etc
2. Lane wise tfc distr
3. Dir distr of tfc (cap declines if dir distr become unbalance

Control Comditions:

1. Time aval
2. Type of control

Capacity for a Freeway Segment/Uninterrupted flow condition

Free Flow Speed **(FFS)=BFFS-f_{LW}-f_{LC}-f_N-f_{ID}**

Hourly flow rate estimation

$$v_p = \frac{V}{PHF \times N \times fHV \times f_P}$$

Peak Hour Factor, $PHF = \frac{V}{4 \times V_{15}}$

N= no of free lane in one direction

Hy veh adjustment factor, $f_{HV} = \frac{1}{1+PT(ET-1)+PR(ER-1)}$

Dvr population factor, f_P varies from 0.85 (unfamiliar) to 1.00 (familiar)

LOS for a basic freeway segment: Determine the expected LOS for a section of a four-lane urban freeway (two lane in each direction) with 12 ft lanes and a right-shoulder lateral clearance of 3 ft. The section has 4 percent gradient 0.8 mile long. It is to accommodate 10% heavy trucks and buses and 2% recreational vehicles. Based on local studies an adjustment factor f_P of 0.90 is indicated. The peak hour volume 2230 vph in the peak direction only and the facility has one interchange per mile on average with a peak hour factor of 0.93.

Solution First, calculate the heavy vehicle factor:

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} = \frac{1}{1 + 0.1(2.5 - 1) + 0.02(3.0 - 1)} = 0.84$$

with $E_T = 2.5$ (per Table 6-9) and $E_R = 3.0$ (per Table 6-10).

Next, determine the peak flow rate:

$$v_P = \frac{V}{PHF \times N \times f_{HV} \times f_P} = \frac{2{,}230}{0.93 \times 2 \times 0.84 \times 0.90} = 1{,}586 \text{ pc/h/ln}$$

with N = two lanes (number of lanes in each direction).

Calculate the free-flow speed:

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} = 75 - 0.0 - 1.8 - 4.5 - 2.5 = 66.2 \text{ mph}$$

A value of 75 mph for *BFFS* was used for urban freeway condition.

Finally, determine the level of service (LOS) using Table 6-4 or Figure 6-8:

For *FFS* = 66.2 mph: LOS = C (greater than B and less than C, so classify as C)

TABLE 6-3 Freeway Level of Service and Density

Level of Service	Density Range (pc/mi/ln)
A	0–11
B	>11–18
C	>18–26
D	>26–35
E	>35–45
F	>45

Source: Highway Capacity Manual, U.S. Customary Units, Transportation Research Board, 2000.

TABLE 6-5 Freeway Adjustments for Lane Width

Lane Width* (ft)	Reduction in Free-Flow Speed, f_{LW} (mph)
12	0.0
11	1.9
10	6.6

*Interpolation may be used for lane width values between those provided in tab

Source: Highway Capacity Manual, U.S. Customary Units, Transportation Res 000.

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TABLE 6-6 Freeway Adjustments for Right-Shoulder Lateral Clearance

Right-Shoulder Lateral Clearance* (ft)	Reduction in Free-Flow Speed, f_{LC} (mph) Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

*Interpolation may be used for lateral clearance values between those provided in table.

Source: Highway Capacity Manual, U.S. Customary Units, Transportation Research Board, 2000.

TABLE 6-7 Freeway Adjustments for Number of Lanes

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (mph)
≥5	0.0
4	1.5
3	3.0
2	4.5

Note: For all rural freeway segments, $f_N = 0.0$

Source: Highway Capacity Manual, U.S. Customary Units, Transportation Research Board, 2000.

TABLE 6-8 Freeway Adjustments for Interchange Density

Interchanges per Mile	Reduction in Free-Flow Speed, f_{ID} (mph)
≥0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.50	5.0
1.75	6.3
2.00	7.5

Source: Highway Capacity Manual, U.S. Customary Units, Transportation Research Board, 2000.

TABLE 6-4 Level of Service for Basic Freeway Segments and Varying Free-Flow Speed

Level of Service	Maximum Density (pc/mi/ln)	Minimum Speed (mph)	Maximum v/c Ratio	Maximum Service Flow Rate (pc/hr/ln)
Free-Flow Speed = 75 mph				
A	11	75.0	0.34	820
B	18	74.8	0.56	1,350
C	26	70.6	0.76	1,830
D	35	62.2	0.90	2,170
E	45	53.3	1.00	2,400
F	varies	varies	varies	varies
Free-Flow Speed = 70 mph				
A	11	70.0	0.32	770
B	18	70.0	0.53	1,260
C	26	68.2	0.74	1,770
D	35	61.5	0.90	2,150
E	45	53.3	1.00	2,400
F	varies	varies	varies	varies
Free-Flow Speed = 65 mph				
A	11	65.0	0.30	710
B	18	65.0	0.50	1,170
C	26	64.6	0.71	1,680
D	35	59.7	0.89	2,090
E	45	52.2	1.00	2,350
F	varies	varies	varies	varies
Free-Flow Speed = 60 mph				
A	11	60.0	0.29	660
B	18	60.0	0.47	1,080
C	26	60.0	0.68	1,560
D	35	57.6	0.88	2,020
E	45	51.1	1.00	2,300
F	varies	varies	varies	varies
Free-Flow Speed = 55 mph				
A	11	55.0	0.27	600
B	18	55.0	0.44	990
C	26	55.0	0.64	1,430
D	35	54.7	0.85	1,910
E	45	50.0	1.00	2,250
F	varies	varies	varies	varies

Source: Adapted from *Highway Capacity Manual,* U.S. Customary Units, Transportation Research Board, 2000.

TABLE 6-9 Passenger-Car Equivalents for Trucks and Buses on Upgrades

Grade (%)	Length (Miles)	E_T Percent Trucks and Buses								
		2	4	5	6	8	10	15	20	25
<2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥2–3	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.50–0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.75–1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	>1.00–1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
>3–4	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	>0.50–0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	>0.75–1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	>1.00–1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	>1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
>4–5	0.00–0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.50–0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	>0.75–1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	>1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
>5–6	0.00–0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	>0.25–0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	>0.30–0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	>0.50–0.75	5.0	4.5	4.0	3.5				3.0	3.0
	>0.75–1.00	5.5	5.0	4.5	4.0				3.0	3.0
	>1.00	6.0	5.0	5.0	4.5				3.5	3.5
>6	0.00–0.25	4.0	3.0	2.5	2.5				2.0	2.0
	>0.25–0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	>0.30–0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	>0.50–0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	>0.75–1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	>1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

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