Lecture 1.3

1.3 Vehicular Characteristics

Classification of Vehicular Characteristics

Vehicular characteristics are broadly divided into two major categories: Static Characteristics and Dynamic Characteristics.

Static characteristics remain fixed regardless of vehicle motion (dimensions, weight, wheel configuration). Dynamic characteristics govern the vehicle while in motion (acceleration, speed, power-to-weight ratio, braking efficiency, turning radius, and off-tracking).

- Static Characteristics: Width, height, length, gross weight, axle loads, tire contact area
- Dynamic Characteristics: Maximum speed, acceleration capability, power output, braking distance
- Geometric Impact: Governs lane width, overhead clearance, turning radii, and sight distance
- Structural Impact: Governs flexible and rigid pavement structural design

Static Characteristics: Vehicle Dimensions

Vehicle dimensions (width, height, overall length) establish the physical boundary constraints for highway geometric elements.

Vehicle width determines the required traffic lane width, shoulder width, and bridge roadway width. Vehicle height governs vertical clearance under flyovers, underpasses, electric lines, and tunnels. Vehicle length dictates minimum turning radii, parking bay dimensions, and overtaking distance.

- Width -¿ Dictates standard lane width (e.g., 3.5 m single lane / multi-lane per IRC)
- Height -¿ Dictates minimum vertical clearance under structures (IRC standard 5.0 m to 5.5 m)
- Length -¿ Governs minimum turning radii, intersection storage bays, and overtaking sight distance
- Overhangs -¿ Front and rear bumper overhangs influence clearance on steep vertical curves

Static Characteristics: Weight and Axle Loading

Vehicle gross weight and individual axle load configurations determine the stress distribution transferred to pavement structures and bridge decks.

Axle configurations include single axle with single wheels, single axle with dual wheels, tandem axles, and tridem axles. Pavement structural design relies on the Standard Axle Load concept (81.6 kN or 8.16 tonnes single axle dual wheel).

- Gross Vehicle Weight (GVW): Total weight of vehicle chassis, engine, cargo, and passengers
- Axle Load: Portion of vehicle weight carried by a single axle assembly
- Standard Axle Load: 80 kN / 81.6 kN (8.16 tonnes) single axle with dual wheels (IRC:37)
- Fourth Power Law: Pavement damage increases exponentially with axle load ratio $(\text{Load} / \text{Standard Load})^4$

IRC Standard Design Vehicle Dimensions

The Indian Roads Congress (IRC) specifies standard maximum dimensions for design vehicles operating on Indian road networks to ensure uniform infrastructure design.

According to IRC guidelines, maximum allowable vehicle dimensions are: Width = 2.50 m (2.60 m for reefer trucks), Height = 3.80 m for normal goods vehicles (4.75 m for double-decker buses / container carriers), and Length = 12.0 m for single-unit trucks, 18.0 m for semi-trailer combinations.

Dimension	**Standard Limit**	**Special/Maximum Limit**
Width	2.50 m	2.60 m (ISO Containers)
Height	3.80 m (Normal goods)	4.75 m (Double-decker/Container)
Length	12.0 m (Single Unit)	18.0 m (Tractor-trailer)

Note: Design Vehicle Selection is based on the largest vehicle expected to use the facility in significant numbers.

Dynamic Characteristics: Power, Speed, and Acceleration

A vehicle's power output (horsepower or kW) relative to its total weight defines its acceleration capability, speed maintenance on steep upgrades, and overall maneuverability.

Heavy trucks have significantly lower power-to-weight ratios compared to passenger cars, causing them to decelerate sharply on steep uphill gradients. This speed differential necessitates climbing lanes on mountainous highways.

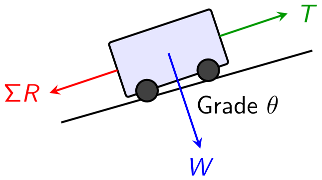
- Power-to-Weight Ratio: High in passenger cars (80-150 hp/tonne); Low in heavy trucks (6-10 hp/tonne)
- Acceleration Rate: Governs gap acceptance at intersections and overtaking maneuvers
- Critical Length of Grade: Maximum upgrade length a heavy truck can navigate before speed drops unacceptably
- Climbing Lanes: Additional uphill lanes provided to segregate slow heavy vehicles from fast cars

Dynamic Characteristics: Tractive Resistance to Motion

To maintain motion at a target speed, a vehicle's engine tractive effort must overcome four primary resistive forces: Rolling Resistance, Air (Aerodynamic) Resistance, Grade Resistance, and Inertial/Curve Resistance.

Total Resistance R = R_r + R_a + R_g + R_i. Understanding resistive forces allows engineers to calculate maximum allowable highway gradients and fuel consumption rates.

- **Rolling (R_r):** Tire-pavement friction
- **Air (R_a):** Aerodynamic drag $\propto v^2$
- **Grade (R_g):** Gravity component $W \sin\theta$
- **Inertial (R_i):** $m \cdot a$ (acceleration)



Braking Performance and Skid Resistance

Braking performance determines the distance required to bring a moving vehicle to a complete stop once the brakes are applied. It depends on brake system efficiency, tire tread condition, pavement surface texture, and tire-pavement friction coefficient (f).

The theoretical braking distance equation is d_b = v^2 / (2 * g * f), where v is speed in m/s, g is gravitational acceleration (9.81 m/s^2), and f is the longitudinal coefficient of friction (IRC specifies f = 0.35 to 0.40).

- Braking Distance Formula: d_b = v^2 / (2 * g * f) [v in m/s] or d_b = V^2 / (254 * f) [V in km/h]
- Coefficient of Longitudinal Friction (f): IRC recommended value ranges from 0.35 (at 100 km/h) to 0.40 (at 30 km/h)
- Braking Efficiency (eta): Actual deceleration achieved compared to maximum theoretical deceleration
- Skid vs Slip: Skidding occurs when wheels lock completely and slide over road surface

Vehicle Turning Geometry and Off-Tracking

When a long vehicle negotiates a sharp horizontal curve at low speed, the rear wheels do not follow the exact path of the front steering wheels; instead, they track inward toward the curve center. This phenomenon is called Off-tracking.

Mechanical extra widening (E_m) required on horizontal curves to accommodate off-tracking is calculated using the IRC formula E_m = (n * L^2) / (2 * R), where n is number of lanes, L is wheel base length (m), and R is curve radius (m).

- Off-tracking: Inward path deviation of rear wheels relative to front steering wheels
- Wheel Base (L): Distance between front steering axle and rear axle center
- Mechanical Widening Formula: E_m = (n * L^2) / (2 * R)
- Psychological Widening (E_ps): E_ps = V / (9.5 * sqrt(R)) to account for driver steering inaccuracy at speed
- Total Extra Widening (E): E = E_m + E_ps

Passenger Car Unit (PCU) Concept

Traffic streams in developing nations contain diverse vehicle types (cars, buses, trucks, auto-rickshaws, 2-wheelers, bullock carts) with varying sizes and speeds. To express mixed traffic in a uniform measure, traffic engineers convert all vehicles into equivalent Passenger Car Units (PCU).

One PCU represents the relative space and performance impact of a given vehicle type compared to a standard passenger car under prevailing roadway and traffic conditions.

Vehicle Type	**PCU**	**Vehicle Type**	**PCU**
Two-Wheelers	0.5	Heavy Buses/Trucks	2.2 - 3.0
Car / Auto-Rickshaw	1.0	Agricultural Tractors	4.0 - 6.0
LCV	1.4	Animal Carts	4.0 - 6.0

PCU Definition: Relative measure converting heterogeneous vehicles into equivalent standard cars.
Factors: Physical dimensions, speed, acceleration, lane width, traffic density.

Heterogeneous Mixed Traffic Flow Dynamics

Unlike homogeneous traffic in Western countries where vehicles follow strict lane discipline and uniform speeds, Indian road traffic is highly heterogeneous.

Key characteristics of mixed traffic include wide speed differentials (10 km/h to 100 km/h), absence of lane discipline, lateral seepage of smaller vehicles into small road gaps, and complex vehicle-pedestrian interactions.

- Heterogeneity: Co-existence of fast motorized vehicles and slow non-motorized transport (NMT)
- Lack of Lane Discipline: Vehicles occupy any available lateral space across road width
- Capacity Reduction: Friction between high-speed cars and slow auto-rickshaws/bicycles reduces highway capacity
- Modelling Complexity: Standard highway capacity models must be modified using local PCU factors

Summary: Vehicular Characteristics

In this lecture, we studied static vehicular characteristics (dimensions, axle weights, IRC limits) and dynamic characteristics (power, resistances, braking distance, off-tracking).

We learned the theoretical formulas for braking distance ($d\_b = v^2 / 2gf$), mechanical curve widening ($E\_m = nL^2 / 2R$), and the conversion of mixed traffic into Passenger Car Units (PCU) per IRC:106.

- Static dimensions dictate lane width (3.5 m), clearance (5.0 m), and pavement design
- Braking distance depends squarely on initial speed: $d\_b = v^2 / (2 * g * f)$
- Off-tracking requires mechanical extra widening on horizontal curves
- PCU factors convert mixed traffic streams to equivalent standard car units
- Next Lecture: Detailed analysis of Driver Reaction Time and PIEV Theory