Vehicle Performance and Human Factors (1)

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Factors Influencing Highway Design

- Functional Classification of the Highway
- Urban/Rural
- Expected traffic volume and mix
- Design speed
- Topography
- Desired level of service (e.g. congestion level)
- Budget
- Safety
- Social and Environmental factors
Components of Highway Transport

- Driver
- Pedestrian
- Vehicle
- Road
- Environment (Weather, Time of Day (angle of sun), ...
Driver Characteristics

The sense most important in driving is sight, though others may play in to a lesser extent:

- the feel of the road,
- the sound of the siren,
- the smell of burning oil.

Sight is affected by

- brightness,
- background brightness, contrast,
- time,

Visual Reception has five principal characteristics important in driving:

- **Visual Acuity** - the ability to see fine details of an object:
  Very Clear 3-5° conical angle,
  somewhat clear within 10 – 12° conical angle

- **Peripheral Vision** - the ability to see objects beyond the cone of clearest vision, up to 160°

- **Color Vision** - the ability to differentiate colors

- **Glare Vision and Recovery** - seeing when subject to a bright light, recovery 3 sec from dark to light and 6 sec from light to dark

- **Depth Perception** - ability to differentiate objects by distance, difficult when moving at high speed
**Perception-Reaction Process**

- **Perception** - driver sees object
- **Identification** - driver identifies object (understands stimulus)
- **Emotion** - driver selects action
- **Reaction (Volition)** - driver executes action
Example: Perception-Reaction Time

A driver with a perception reaction time of 3 seconds is driving 100 km/hr when she sees a tree blocking the road and must stop. Determine the distance (in meters) the vehicle moves before the driver applies the brakes.

\[ D = v \cdot t = \left( \frac{100 \text{ km/hr}}{3600 \text{ sec/hr}} \right) \times 3 \text{ sec} \times \frac{1000 \text{ m/km}}{1} = 83.33 \text{ meters} \]
Each process takes time. As a result, time beyond simple braking time is required to avoid collision, and advanced warnings are given in signs, and minimum sight distances become engineering design constraints.

AASHTO stipulates assuming at least 2.5 seconds for stopping sight distance.
Pedestrian Characteristics

How fast do pedestrians walk? It depends.

The average walking speed at intersections has been estimated at 1.5 m/sec for males and 1.41 m/sec for females.

But it may be less than 1 m/sec for elderly and disabled.

This is important for designing traffic signal phasings, and for estimating stopping sight distance (will a sighted pedestrian clear the road?).
Vehicle Characteristics

_static: Mass, Length, Width, Height._ In general, the maximum allowed are 36,000 kg (80,000 lb), 2.59 m wide, 14.63 m long for trailers, though these vary by state, some allow larger vehicles. Truck weight is a critical issue in highway finance, as it is truck weight per axle that does the most damage to the roadway.

_dynamic: Acceleration, Velocity_
Highway Design Standards

- **Design speed** - "the maximum safe speed that can be maintained over a specified section of highway when conditions are favorable such that the design features of the highway govern."

- **Running speed** - speed vehicles are actually traveling (running distance over time).

- **Design vehicle** - the largest vehicle that uses the facility with any frequency
Cross-Section Elements

- Centerline
- Travel lane
- Shoulder
- Foreslope
- Ditch
- Backslope
Travel Lanes

- Lane widths of 3.6 m (12 feet) are preferred for designing arterials.

- For two-lane highways, a 7.2 m (24-foot) wide roadway is necessary for large vehicles (trucks and buses) to have sufficient clearance.

- Lane width affects highway capacity. Anything less than 3.6 m leads to reduced speed.

- At times existing rights of way and land development will control lane widths. Historically, roads were narrower.
Cross-Slopes

- Slopes are important to remove water from the roadway. Inadequate drainage becomes apparent after heavy rain, and more so after sleet and freezing rain.

- The trade-off is draining away water, which suggests steeper, and keeping vehicles from sliding, which suggests flatter.

- Two-Lane Highways – Slopes generally fall away from the centerline on both directions.

- Divided Roadways – Each roadbed is sloped individually and may be crowned separately as well (especially on divided highways).

- Drivers barely perceive cross slopes up to 2 percent; 1.5 to 2 percent are common cross slope values. Higher values may be unsafe, the same issues as with superelevation ensue.
Shoulders

• The roadway shoulder lies between the outer edge of the travel lane and the inside edge of the ditch, gutter, curb, slope or median (in divided roadways). Shoulders provide lateral support for pavement subbase, base and surface courses. Shoulders are sloped so that water runs off from the travel lane. In general,

  ‣ asphalt or concrete-paved shoulders are sloped from 2 to 6%,
  ‣ gravel shoulders from 4 to 6% and
  ‣ turf shoulders at about 8%.

• Shoulder widths are usually determined by the traffic volume and the percent of heavy vehicles. AASHTO recommends 3.0 m widths as normal on freeways and minimum of 0.6 m on lowest highways. At least 1.2 m should be available from the edge of the roadway to a roadside barrier. From a safety and flexibility standpoint, more shoulder is better than less, but some shoulder is better than none. On non-freeways, shoulders can also be used as bicycle lanes.
Side-Slopes

- **Sideslopes** provide a transition from the roadway shoulder to the original ground surface.

- **Foreslopes** extend from the shoulder edge to a drainage ditch or directly to the ground surface, depending on the terrain.

- **Backslopes** extend from the outside edge of the drainage ditch to ground surface or to the "cut" surface of a roadside.

- AASHTO states that foreslopes steeper than 3:1 (33%) are recommended only where conditions do not permit the use of flatter slopes. Backslopes steeper than 3:1 may be difficult to maintain and need to be evaluated with regard to slope stability.
Medians

- The median is the section of a divided highway that separates the lanes in opposing directions. The width is the distance between the edge of the inside lanes in the respective roadways.

- They can be raised, flush, or depressed. They may be protected by guardrails or jersey barriers. Depressed medians should have a sideslope of 6:1 or 4:1. Widths vary from 0.6 m to much larger. All else equal, medians are good things. However they add to the land cost of the road, while their benefits are hard to quantify.

- Its functions:
  - Recovery area for out-of-control vehicles
  - Separating opposing traffic
  - Stopping area for emergencies
  - Storage area for turning vehicles
  - Refuge for pedestrians
  - Reducing the effects of headlight glare
  - Providing temporary lanes and cross over areas during construction/maintenance
  - Land for future roadway expansion
Barriers (Median, Roadside)

- **Median Barrier** – a longitudinal system used to prevent an errant vehicle from crossing the portion of a divided highway separating the traveled ways for traffic in opposite directions.

- **Roadside barrier** – protects vehicles from hazards on the side of the roadway (protects things on the side of the roadway from the hazards caused by vehicles).

- **Guard rails** – longitudinal barriers placed on the outside of sharp curves or sections with steep slopes (greater than 4:1).

- Roadside and other barriers should only be implemented when other design options have been considered (for instance, a wider, flatter median or shoulder), as they can be hazardous when collided with. Cases to include them are especially steep roadside slopes.
Curbs and Gutters

• Curbs, short raised structures, delineate the edge of pavement, and help control drainage. Curbs can be barriers if sufficiently tall (.3 m), or can be considered mountable if less tall. Barrier curbs should be avoided on high speed roads.

• Gutters are located on the drainage side of the curb to provide the principal drainage for the highway.
Sidewalks

- Generally provided in urban but not in rural areas. Suburban use is mixed.

- Suggested minimum width 1.25 m, wider more urban areas. When shoulders are absent, sidewalks are important to separate the pedestrian from the vehicle mix.
Right of Way

- The total land area acquired for the construction of the highway (where private property ends and public begins). It must be wide enough to include all elements of the cross-section.
Horizontal Alignment

- Highways are measured along the centerline, rather than Cartesian coordinates.

- Stations are measured in km (there are also Imperial units for stationing) along a horizontal plane.

- So 2+302.250 should be read as 2 kilometers and 302.250 meters from the point of origin on the roadway, which is at 0+000.000.

Vertical Alignment

- Elevations are measured from the horizontal plane.
Key Terms

- Design Speed
- Running Speed
- Design Vehicle
- Travel lane
- Cross-slope
- Shoulder
- Side-slope

- Median
- Barrier
- Curb and Gutter
- Sidewalk
- Right-of-Way
- Stationing
Questions

Questions?
Abbreviations

- PRT - Perception Reaction Time
- AASHTO - American Association of State Highway and Transportation Officials (succeeded AASHO)
- AASHO - American Association of State Highway Officials
Key Terms

- Perception-reaction time
- Perception, Identification, Emotion, Reaction
- Visual Acuity
- Peripheral Vision
- Color Vision
- Glare Vision and Recovery
- Depth Perception
Variables

- $D = $ distance
- $r = $ rate (speed)
- $t = $ time
- $v = $ velocity
- $v_0 = $ velocity at time 0
- $a = $ acceleration
- $x = $ position
- $C = $ constant
- $\alpha, \beta = $ coefficients
In physics you dealt with numerous cases where acceleration is assumed constant. You will recall the following formulae:

\[ \frac{\partial v}{\partial t} = a \]
\[ v = at + C_1 \]
\[ x = 0.5at^2 + C_1t + C_2 \]

However in actual transportation applications, as opposed to simple falling bodies, acceleration can be a function of velocity. A model that is often used is:

\[ \frac{\partial v_t}{\partial t} = \alpha - \beta v_t \]

Integrating gives:

\[ -\frac{1}{\beta} \ln(\alpha - \beta v_t) = t + C \]
If the velocity is $v_0$ at time zero

\[ C = -\frac{1}{\beta} \ln(\alpha - \beta v_0) \]

\[ v_t = \left( \frac{\alpha}{\beta} \right) (1 - e^{-\beta t}) + v_0 e^{-\beta t} \]

\[ x = \left( \frac{\alpha}{\beta} \right) t - \left( \frac{\alpha}{\beta^2} \right) (1 - e^{-\beta t}) + \left( \frac{v_0}{\beta} \right) (1 - e^{-\beta t}) \]
Problem: Acceleration and Velocity

Suppose the acceleration of a vehicle can be represented by the equation

\[ \frac{\partial v}{\partial t} = 5 - 0.05v \]

where \( v \) is the vehicle speed in m/sec. If the vehicle is traveling at 90 km/hr, determine the velocity after 5 sec of acceleration and the distance traveled during that time. (work in pairs and solve)
Solution (1)

- $t=5$ sec,
- $\alpha=5$,
- $\beta=0.05$,
- $v_0 = 90$ kph

Solve for velocity

$$v_t = \left(\frac{\alpha}{\beta}\right)(1 - e^{-\beta t}) + v_0 e^{-\beta t}$$

$$v = \left(\frac{5}{0.05}\right)(1 - e^{-0.05\times5}) + 90\left(\frac{1000}{3600}\right)e^{-0.05\times5}$$

$$= 41.5 \text{ m/sec}$$
Solution (2)

Solve for position

\[ x = \left( \frac{\alpha}{\beta} \right) t - \left( \frac{\alpha}{\beta^2} \right) \left( 1 - e^{-\beta t} \right) + \left( \frac{v_0}{\beta} \right) \left( 1 - e^{-\beta t} \right) \]

\[ x = \left( \frac{5}{0.05} \right) 5 - \left( \frac{5}{0.05^2} \right) \left( 1 - e^{-0.05 \cdot 5} \right) + \left( \frac{90 \left( \frac{1000}{3600} \right)}{0.05} \right) \left( 1 - e^{-0.05 \cdot 5} \right) = 168.2m \]