# Lecture 5.37

## 5.4 Street Lighting

# Need and Objectives of Highway Street Lighting

Although traffic volumes are typically lower at night, night-time fatality rates per vehicle kilometer are significantly higher due to restricted visibility and glare.

The primary objectives of street lighting include providing adequate visual distance for drivers at operating speeds, revealing obstacles/pedestrians clearly, outlining road alignment and geometric hazards, reducing night-time crash frequency, and enhancing personal security in urban corridors.

- Night Crash Reduction: Studies show proper lighting reduces night crashes by 30% to 40%
- Obstacle Detection: Ensuring drivers perceive hazards beyond vehicle headlight range
- Delineation of Geometry: Highlighting curves, intersections, and lane drops
- Pedestrian & Urban Security: Discouraging crime and improving pedestrian confidence

# Fundamental Photometric Definitions and Units

Understanding lighting design requires familiarity with core photometric quantities used to measure light energy, illumination density, and road surface brightness.

Key metrics include Luminous Flux (measured in lumens, the total light emitted by a source), Illuminance ($E$, measured in lux, light falling per unit surface area), Luminance ($L$, measured in $cd/m^2$, brightness reflected into the driver's eye), and Luminous Efficacy (lumens/watt).

| **Quantity** | **Unit** | **Description** |
|---|---|---|
| Luminous Flux | Lumen ($lm$) | Total light emitted by a lamp fixture |
| Illuminance ($E$) | Lux ($lx$) | Flux density on road surface ($1lx = 1lm/m^2$) |
| Luminance ($L$) | $cd/m^2$ | Surface brightness perceived by the eye |
| Luminous Efficacy | $lm/W$ | Ratio of light output to power consumed |

# Visual Principles: Seeing by Silhouette vs Contrast

At night, a driver perceives objects on the roadway primarily through brightness contrast between the object and its background background pavement surface.

Two main visual mechanisms are used: Seeing by Silhouette (where the object appears darker than the bright pavement background behind it) and Seeing by Reverse Silhouette / Surface Detail (where the object is directly illuminated to appear brighter than the dark background).

- Silhouette Seeing: Road surface is made bright so dark objects stand out in stark contrast
- Reverse Silhouette: High direct light renders object bright against dark background
- Design Standard: Highway lighting primarily relies on Silhouette Seeing for economic efficiency
- Contrast Sensitivity: Ability of human eye to detect small luminance differences under low light

# Glare: Types and Control Techniques

Glare is an objectionable visual condition caused by high brightness contrasts or improperly shielded light sources, reducing visual performance or causing visual discomfort.

Glare is divided into Disability Glare (which physically reduces visual contrast and seeing distance) and Discomfort Glare (which causes visual annoyance and eye fatigue). Control is achieved through proper luminaire cutoff angles and mounting heights.

- Disability Glare: Stray light scattered in the eye, reducing object visibility instantly
- Discomfort Glare: Produces eye fatigue and discomfort without necessarily obscuring vision
- Cutoff Luminaires: Shielding light rays emitted above $80^{\circ}$ from vertical downward axis
- Mounting Height Influence: Higher mounting heights remove fixtures further from driver line of sight

# Factors Influencing Street Lighting Design

Designing an effective street lighting system involves balancing traffic operational requirements, road geometry, and economic efficiency.

Key factors include Road Classification (expressway, arterial, collector, local), Traffic Volume and Operating Speed, Pavement Surface Reflectivity (dry vs wet asphalt/concrete), Carriageway Width, surrounding land use brightness, and presence of pedestrian crossings.

- Road Category: Higher class roads (arterials) require higher average luminance $(1.5 - 2.0 cd/m^2)$
- Pavement Reflectivity: Dark asphalt requires higher illuminance than light-colored concrete
- Traffic Speed: Higher speeds demand longer visual sight distances and glare control
- Environmental Context: Commercial city centers require higher light levels than rural highways

# Types of Street Lamps and Luminaires

The selection of light source directly impacts system energy consumption, color rendering, lifecycle cost, and maintenance schedules.

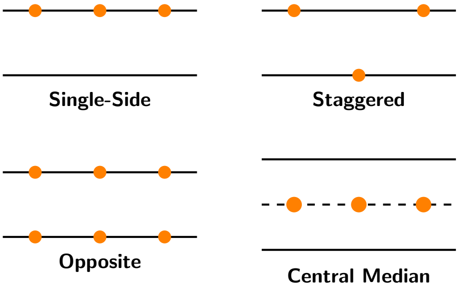
Historical High-Pressure Sodium Vapor (HPSV) and Metal Halide lamps have been largely replaced by Solid-State LED (Light Emitting Diode) technology, which offers superior energy efficiency (¿130 lm/W), long lifespan (¿50,000 hours), dynamic dimming capability, and excellent color rendering.

- High-Pressure Sodium Vapor (HPSV): Yellowish light, high efficacy, poor Color Rendering Index (CRI)
- Metal Halide (MH): White light, good CRI, moderate lifespan and energy efficiency
- LED Luminaires: High energy efficiency, directional light control, long life, white light
- Optical Distribution: Asymmetric beam spreads tailored to wide carriageways

# Luminaire Arrangement Patterns

Luminaires are installed along the roadway in specific geometric layouts determined by carriageway width ($W$) relative to mounting height ($H$).

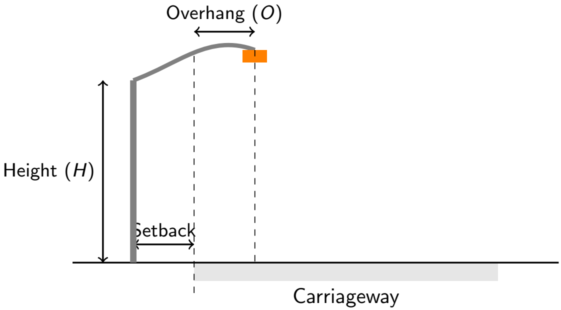
Standard arrangements include Single-Side Arrangement (for narrow roads, $W \leq H$), Staggered Arrangement (for medium roads, $H < W \leq 1.5H$), Opposite Arrangement (for wide roads, $W > 1.5H$), and Central Median Arrangement (for dual carriageways with median dividers).



# Geometric Parameters: Spacing, Height, and Overhang

The placement geometry of lighting poles determines the uniformity of illuminance and prevents dangerous 'zebra-striping' dark patches on the pavement.

Key parameters include Mounting Height ($H$, typically $8m - 12m$), Spacing between poles ($S$, typically $3H - 5H$), Overhang ($O$, distance luminaire extends from pole toward carriageway), and Pole Setback from curb edge (minimum $0.6m - 1.5m$ for roadside safety).



# Uniformity Ratios and Quality Requirements

Average light intensity alone is insufficient; light must be distributed uniformly across the entire road surface to ensure eye comfort and continuous object detection.

Quality standards dictate the Overall Uniformity Ratio ($U_0 = L_{min}/L_{avg} \geq 0.40$) and Longitudinal Uniformity Ratio ($U_l = L_{min}/L_{max} \geq 0.60$ along the lane center line).

- Overall Uniformity ($U_0$): Minimum luminance divided by average luminance ($L_{min}/L_{avg}$)
- Longitudinal Uniformity ($U_l$): Minimum divided by maximum luminance along lane center
- Preventing Patchiness: Eliminating dark spots where pedestrians or debris could be hidden
- Wet Surface Performance: Maintaining uniform reflectivity during rainy conditions

# Lighting at Special Road Locations

Complex highway features demand specialized lighting designs to guide drivers through sudden geometric transitions and conflict areas.

Special locations include Intersections and Rotaries (requiring 50% higher illuminance than approach roads), Pedestrian Crossings, High-Mast Lighting at complex interchange loops ($20 - 30m$ poles with ring arrays), Toll Plazas, and Tunnel Portals (requiring daytime adaptation lighting).

- Intersections & Conflict Points: Increased lux levels to highlight turning maneuvers
- High-Mast Lighting: Ring arrays mounted on 30m masts for spacious interchanges
- Pedestrian Crossings: Positive contrast lighting to illuminate pedestrians clearly
- Tunnel Entrances: High daytime illumination at portals to prevent 'black hole' effect

# Summary of Street Lighting

This lecture detailed the principles, photometrics, luminaire technology, and geometric layouts of highway street lighting.

Designing safe street lighting requires selecting proper luminaire types (LEDs), establishing appropriate mounting height and spacing ratios ($S/H = 3 - 5$), ensuring high uniformity ratios ($U_0 \geq 0.40$), and shielding against glare.

- Street lighting dramatically reduces night-time crash frequency and enhances security
- Silhouette seeing is the primary visual mechanism for highway pavement illumination
- Cutoff LED luminaires provide high energy efficacy with minimal glare scatter
- Arrangement patterns (single, staggered, opposite, median) depend on carriageway width
- Uniformity ratios ($U_0$, $U_l$) ensure smooth continuous visibility without dark patches