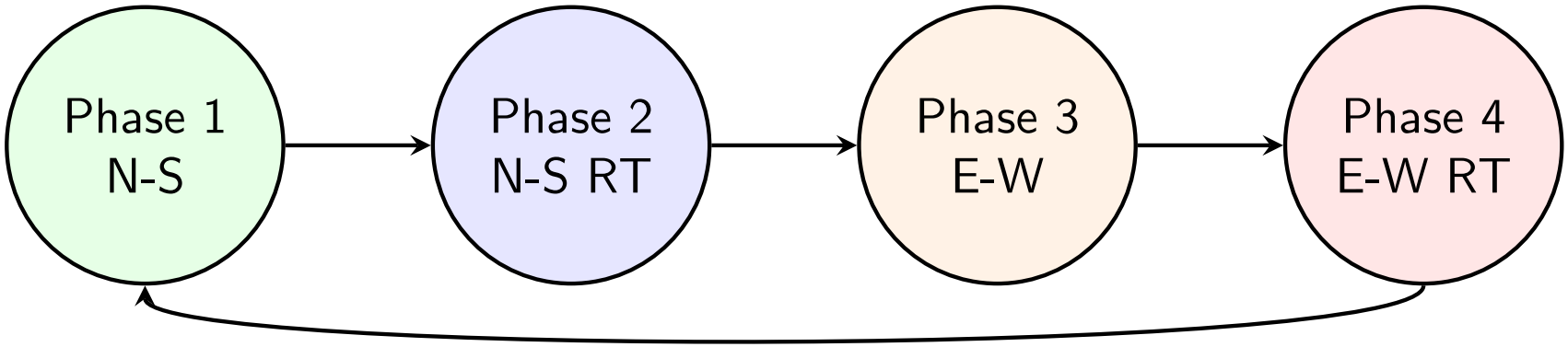
Lecture 3.23

3.3 Traffic Signals

Multi-Phase Signal Layouts and Conflict Point Elimination

Complex 4-legged intersections with heavy right-turning volumes cannot operate safely on simple 2-phase timing plans due to severe right-turn collision hazards.

Multi-phase signal layouts eliminate crossing conflicts by providing dedicated green arrows for right turns.



Inter-Green and Clearance Interval Math

The inter-green period is the transition buffer between the end of green for one phase and the start of green for the next phase.

It comprises Amber time (A) and All-Red clearance time (AR). Amber allows approaching drivers to stop safely, while All-Red clears vehicles trapped inside the intersection box.

- **Amber Duration**: $A = t + \frac{v}{2a+2gG}$ (t=reaction $\sim$1s, v=speed, a=decel)
- **All-Red Formula**: $AR = \frac{w+L_v}{v}$ (w=width, L_v=vehicle length $\sim$6m)
- **Dilemma Zone**: Zone where vehicle can neither stop safely before stop line nor clear intersection before red
- **Minimum Inter-Green**: Typically 4 to 8 seconds total clearance

Pedestrian Phasing Strategies and Pelican Crossings

Pedestrians at signalized junctions require explicit signal protection to prevent collisions with turning vehicles.

Engineers use concurrent pedestrian phasing, exclusive pedestrian phases, or mid-block Pelican/Puffin push-button signals.

- Concurrent Phasing: Pedestrians cross parallel to straight vehicular movement stream
- Exclusive Pedestrian Phase (Barnes Dance): All vehicles stopped; pedestrians cross in any direction including diagonally
- Pelican Crossing: Pedestrian Light Controlled Signal with push-button actuator
- Puffin Crossing: Infrared sensors detecting pedestrian presence to adjust crossing duration

Signal Controller Architecture and Hardware

Modern traffic signal controllers are industrial-grade microcomputers housed in weather-proof roadside cabinets.

Controllers execute complex signal timing logic, monitor detector inputs, enforce conflict safety monitoring, and log operational telemetry.

- Microprocessor CPU: Runs multi-plan signal timing logic and actuated algorithms
- Conflict Monitor Unit (CMU): Failsafe hardware that immediately drops signal into flashing amber if conflicting green lights occur
- Solid-State Switches: Power switches driving high-efficiency LED aspect lamps
- UPS Battery Backup: Uninterruptible Power Supply ensuring 4 to 8 hours operation during grid outages

Vehicle Detection Technologies

Traffic-actuated and adaptive signal systems rely on accurate real-time vehicle detectors to register arrivals, queues, and headway gaps.

Engineers choose between sub-surface pavement sensors and non-intrusive overhead sensors based on installation and maintenance constraints.

Detector Type	**Placement**	**Sensing Mechanism**
Inductive Loop (ILD)	Sub-surface	Wire coils sensing metallic mass
Video Image (VIP)	Overhead	Cameras with AI queue detection
Microwave Radar	Overhead	Radar sensing approach speed/count
Infrared/Thermal	Overhead	Detects heat signatures

Coordinated Signal Systems and Green Waves

When signalized intersections are closely spaced along an arterial corridor (less than 1 km apart), isolated signal operation causes stopping platoons at every junction.

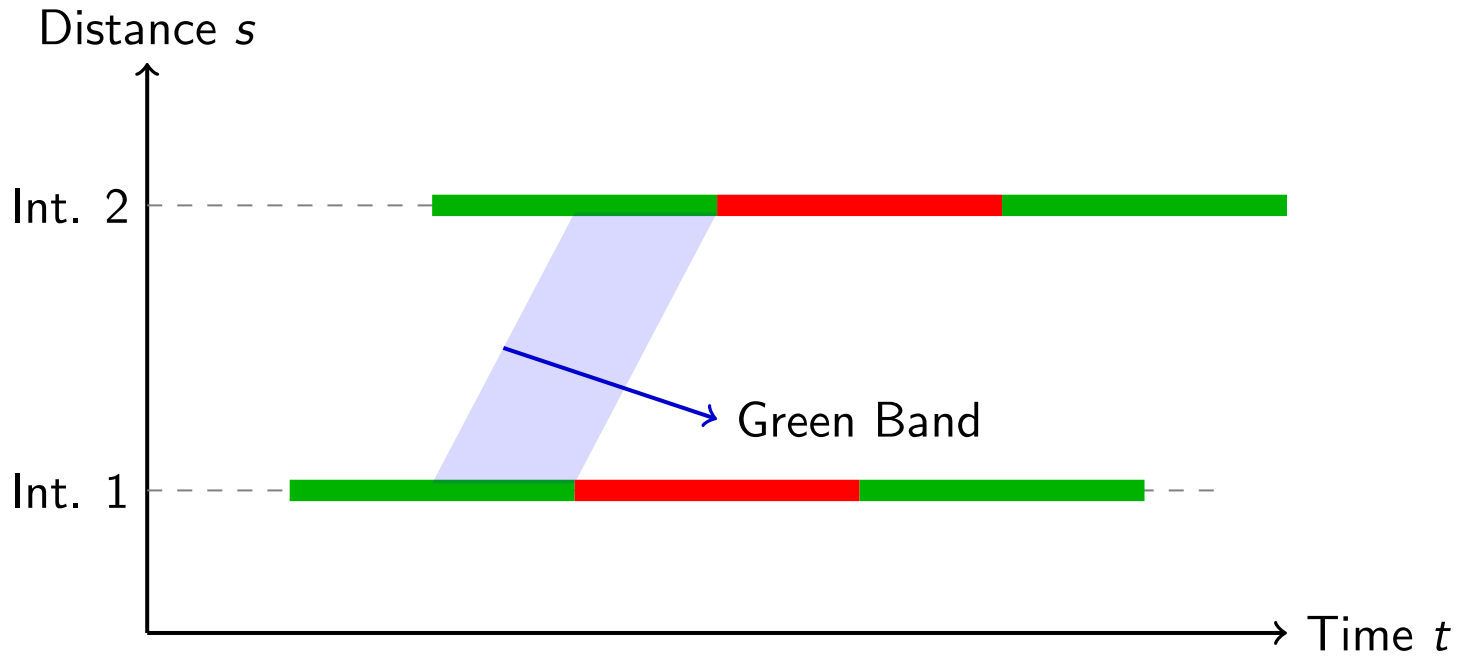
Signal coordination synchronizes adjacent signals so that vehicle platoons traveling at design speed hit green lights continuously ('Green Wave').

- Common Cycle Length: All coordinated signals must share identical cycle length C
- Offset: Time difference (seconds) between start of green at consecutive intersections
- Platoon Propagation: Vehicles traveling together in tight cluster at steady speed
- Bandwidth: Width of green time window (seconds) available for uninterrupted progression

Time-Space Diagrams for Corridor Synchronization

A Time-Space Diagram plots distance along an arterial corridor on the vertical axis against time on the horizontal axis.

Signal aspect displays for each intersection are plotted vertically. Slope of the green band represents design progression speed ($v = \Delta s / \Delta t$).



Area Traffic Control Systems (ATCS)

Area Traffic Control Systems (ATCS) connect hundreds of signalized intersections across a city to a centralized master computer network.

Adaptive ATCS continuously recalculates cycle lengths, splits, and offsets every few minutes based on real-time detector data from across the city.

- SCOOT (Split Cycle Offset Optimisation Technique): Adaptive system continuously adjusting timing in small increments
- SCATS (Sydney Co-ordinated Adaptive Traffic System): Selects preset timing plans dynamically based on degree of saturation
- TRANSYT: Offline optimization software for determining arterial offsets
- Benefits: 15-25% reduction in city-wide travel time, fuel consumption, and emissions

Transit Priority and Emergency Vehicle Preemption

Transit Signal Priority (TSP) and emergency preemption alter signal timing to favor high-occupancy buses or priority vehicles.

Preemption immediately overrides normal signal phasing to grant emergency vehicles green lights upon approach.

- Transit Priority (TSP): Extends green or truncates red to clear BRTS buses
- Emergency Preemption: Infrared / GPS / acoustic sensors detecting ambulances or fire engines
- Preemption Sequence: Immediate green for emergency approach; red for all conflicting legs
- Recovery Phase: Controller safely transitions back to normal timing program after passage

Signal Maintenance, Audit, and Failure Protocols

Signal failures (blackouts, conflict trips) freeze intersection flow and cause major accidents. Maintenance systems must include hardware safety redundancies.

Controllers must automatically revert to a safe default mode during power loss or logic errors.

- Default Fallback Mode: Flashing Amber on major street / Flashing Red on minor street
- Conflict Trips: Instant shutdown to flashing mode within 500 milliseconds of conflict
- LED Lamp Reliability: LED aspect life exceeds 50,000 hours with low power draw
- Preventive Maintenance: Quarterly cabinet cleaning, detector tuning, and CMU testing

Summary of Advanced Traffic Signal Control

In this lecture, we covered multi-phase signal design, inter-green clearance math, vehicle detection, signal coordination, time-space diagrams, and adaptive ATCS.

Advanced signal engineering optimizes network capacity and reduces city-wide congestion.

- Multi-Phase: 3 and 4-phase layouts eliminate right-turn crossing conflicts
- Inter-Green Math: Amber ($A = t + v/2a$) + All-Red ($AR = (w + L)/v$) clear intersection
- Detectors: Inductive loops (ILD) and Video Image Processing (VIP) feed actuated controllers
- Signal Coordination: Shared cycle length C and offsets ($t = d/v$) create Green Waves
- ATCS Systems: SCOOT and SCATS provide real-time adaptive city-wide control