Lecture 6.43

6.3 Smart Traffic Management System (STMS)

Urban Congestion Challenges and Need for STMS

Conventional traffic signals operate on pre-timed, fixed signal plans derived from historical traffic counts. However, actual urban traffic fluctuates dynamically due to weather, accidents, special events, peak hour shifts, and roadwork.

Fixed-time signals lead to wasted green light time on empty approaches while adjacent heavily congested approaches suffer from massive queues and spillbacks across upstream intersections.

STMS continuously measures real-time queue lengths and vehicle arrival rates at intersection approaches, automatically adjusting green split times, cycle lengths, and phase sequences to minimize total network delay.

- Inflexibility of pre-timed fixed signal plans during non-recurrent congestion
- Inefficient green light allocation causing unnecessary vehicle idling
- Queue spillback causing gridlock across adjacent urban intersections
- Real-time dynamic adjustment of green split, cycle time, and phase sequence
- Reduction of fuel consumption, vehicle emissions, and travel delays

Evolution of Traffic Signal Control Strategies

Traffic signal control technology has evolved through four distinct generations over the past decades.

First Generation: Isolated fixed-time signals. Second Generation: Time-of-Day (TOD) coordinated systems switching pre-stored plans based on historical morning/evening peak data.

Third Generation: Actuated signal control responding to local vehicle detectors. Fourth Generation (STMS): Fully adaptive, network-wide coordinated real-time optimization powered by central algorithms and AI.

Gen	**Control Type**	**Key Characteristics**
1st	Isolated Fixed-Time	Pre-timed controllers, no responsiveness
2nd	Time-of-Day (TOD)	Pre-stored plans based on historical data
3rd	Actuated Control	Responds to local vehicle detectors
4th	Fully Adaptive	Real-time network optimization (SCOOT/SCATS)
Next	AI & Self-Learning	Reinforcement learning, continuous adaptation

SCOOT (Split Cycle Offset Optimisation Technique)

SCOOT is a world-renowned real-time adaptive traffic control system developed in the United Kingdom, widely deployed in major cities globally.

SCOOT uses inductive loops or video sensors installed far upstream from the stop line (at the entrance to the link) to measure approaching vehicle profile queues (Cyclic Flow Profiles - CFPs).

A central computer continuously runs a traffic model to make frequent, small adjustments (a few seconds at a time) to green split, offset, and cycle time every cycle to minimize network stops and delays.

- Developed by TRL (UK); centralized network-wide adaptive architecture
- Sensors positioned upstream at link entrances to capture approach profiles
- Calculates Cyclic Flow Profiles (CFPs) predicting arrival times at stop lines
- Makes incremental, frequent adjustments to green split, cycle time, and offsets
- Highly effective in dense urban networks with predictable queue buildup

SCATS (Sydney Co-ordinated Adaptive Traffic System)

SCATS is an adaptive traffic control system developed in Australia, widely implemented in Asia, Australia, and parts of India.

Unlike SCOOT, SCATS uses sensors (typically inductive loops or camera zones) positioned directly at the intersection stop line. It measures lane degree of saturation (DS) and space re-claim during the green phase.

SCATS operates on a decentralized hierarchical architecture where local controllers make rapid cycle-by-cycle phase length adjustments, while regional computers coordinate offsets between adjacent signals.

- Developed in Sydney, Australia; decentralized hierarchical architecture
- Sensors placed at the stop line to measure lane Degree of Saturation (DS)
- Dynamic cycle length and green split adjustment based on space utilization
- Fast adaptation to sudden traffic drops or emergency vehicle overrides
- Comparison: SCOOT requires central traffic modeling; SCATS relies on stop-line saturation

AI & Computer Vision for Real-Time Traffic Density

Modern STMS implementations increasingly replace traditional inductive loops with AI-powered Computer Vision cameras.

High-definition cameras mounted at intersections feed live video into Edge AI processing units running Deep Learning algorithms (e.g., YOLO or CNN models). The software detects, counts, and classifies vehicles in real time.

Computer vision accurately measures queue lengths in each lane, identifies vehicle types (cars vs heavy buses), detects illegal turns or gridlock, and adjusts signal timing dynamically without cutting road surfaces.

- Replacement of physical pavement sensors with camera-based AI vision
- Deep Learning object detection (YOLO/CNN) for counting and classification
- Real-time measurement of lane queue length and vehicle density
- Detection of traffic violations (red-light jumping, stop line cross)
- Lower maintenance cost and non-intrusive installation

Priority Signaling for Emergency and Transit Vehicles

Emergency Vehicle Priority (EVP) and Transit Signal Priority (TSP) are critical features of modern Smart Traffic Management Systems.

When an approaching ambulance, fire tender, or police vehicle is detected via GPS tracking or optical/acoustic sensors, the STMS controller overrides normal signal sequencing to immediately clear the path with a green signal.

Similarly, TSP provides green light extensions or early green returns for public transit buses carrying high passenger volumes, encouraging transit usage and improving schedule adherence.

Feature	**Emergency Vehicle Priority (EVP)**	**Transit Signal Priority (TSP)**
Target Vehicles	Ambulances, Fire Engines, Police	Public Buses, BRTS
Mechanism	Preemption (immediate green override)	Green extension / early return
Objective	Minimize life-saving response times	Improve schedule adherence

Dynamic Corridor Control & Green Wave Synchronization

A 'Green Wave' is achieved when a series of sequential traffic signals along an arterial street are synchronized to allow a platoon of vehicles traveling at the design speed to pass through without stopping.

Traditional green waves use static progression offsets calculated for fixed speeds. STMS creates Dynamic Green Waves that adjust signal offsets dynamically based on real-time traffic speeds and queue clearance times.

Dynamic corridor control smooths arterial flow, minimizes vehicle stop-and-go acceleration cycles, and drastically reduces urban fuel consumption and tailpipe emissions.

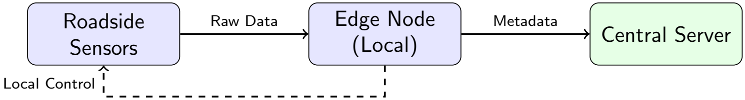
- Concept of progression offset and Bandwidth in signal coordination
- Dynamic Green Wave adaptation based on real-time travel speed
- Reduction of stop-and-go cycles along major urban arterial corridors
- Improvement of corridor Level of Service (LOS) during peak hours
- Significant reduction in vehicle carbon footprint and brake wear

IoT-Enabled Traffic Sensors & Edge Computing Nodes

The Internet of Things (IoT) architecture in STMS links distributed roadside sensors, smart signals, pedestrian push-buttons, and environment monitors to local edge computing nodes.

Edge computing processes video feeds and sensor data locally at the intersection cabinet rather than sending massive raw video streams across the network to central servers, reducing network latency and bandwidth costs.

Only processed metadata (such as vehicle counts, queue lengths, and signal status) is transmitted to the central cloud or command center.



- Local processing reduces bandwidth and ensures fault tolerance.

Integrated Command & Control Centre (ICCC) Integration

Under the Smart Cities Mission in India, Smart Traffic Management Systems are integrated into municipal Integrated Command and Control Centres (ICCC).

The ICCC serves as a unified digital platform connecting traffic control, city surveillance, emergency services, solid waste management, public transit, and disaster response.

Inter-agency coordination enabled by ICCC allows traffic police, municipal engineers, and emergency services to share live video feeds, coordinate joint responses during major events, and analyze urban mobility trends.

- Role of ICCC in the Indian Smart Cities Mission framework
- Integration of traffic management with city-wide municipal surveillance
- Cross-departmental data sharing: Traffic Police, Municipal Corporation, Emergency Services
- Unified dashboard displaying traffic incidents, signal health, and air quality
- Data-driven urban transport policy and infrastructure planning

Implementation Challenges: Infrastructure & Cybersecurity

While STMS offers transformative benefits, deployment in developing urban environments faces technical and operational challenges.

Infrastructure challenges include frequent road digging damaging fiber cables, power outages disrupting controllers, heterogeneous non-lane disciplined traffic (mixed traffic of auto-rickshaws, bikes, and trucks), and high capital expenditure.

Cybersecurity is a growing concern, as unauthorized hacking of smart signal networks could cause deliberate gridlocks or accidents. Robust encryption, firewalls, and air-gapped backup controls are mandatory.

- Handling heterogeneous, non-lane-disciplined traffic unique to Indian roads
- Vulnerability of field fiber cables to physical road construction damage
- Power supply fluctuations requiring UPS and solar backup power
- Cybersecurity threats: unauthorized signal override and data tampering
- Need for standardized maintenance contracts and trained municipal staff

Summary: Transforming Urban Mobility with STMS

In this lecture, we explored Smart Traffic Management Systems (STMS) for urban signalized networks.

We covered the drawbacks of fixed-time signals, the mechanisms of adaptive algorithms (SCOOT and SCATS), AI computer vision detection, priority signaling (EVP/TSP), dynamic green waves, edge IoT architecture, and ICCC integration.

STMS equips civil engineers with smart tools to solve urban traffic gridlock and create sustainable, liveable smart cities.

- STMS replaces rigid fixed-time plans with real-time adaptive signal control
- SCOOT (upstream profiles) and SCATS (stop-line saturation) lead adaptive technology
- AI vision enables non-intrusive queue length and vehicle class detection
- EVP and TSP prioritize emergency vehicles and public transit buses
- Smart City ICCC integration enables multi-agency urban operational control