Adaptive Signal Control Technology
Evolution of Traffic Signal Control
Pretimed or Fixed Time

- Same green time every cycle
- No phase skipping
- Adjacent signals with same cycle length will have green time start the same relative to each other every cycle

Components

| Controller |
• Green time varies between minimum and maximum times based on vehicle demand
• Phases without demand may be skipped
• Cycle length varies – green times random relative to adjacent intersections

<table>
<thead>
<tr>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller</td>
</tr>
<tr>
<td>Detection</td>
</tr>
</tbody>
</table>
Achieving Coordination

- Common cycle length
- Define offset between intersections based on travel time
- Synchronize clocks
- Pretimed
- Actuated-Coordinated

**Components**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Local Controller</td>
<td></td>
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<tr>
<td>Master Controller or Server</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td></td>
</tr>
<tr>
<td>Detection (optional)</td>
<td></td>
</tr>
</tbody>
</table>
Coordination: Basics

- **Clocks**
  - Real time
  - Local
  - Master

- **Cycle**
  - same at all intersections on corridor

- **Offset**
  - Local clock offset from master clock

- **Split**
  - Max time for each phase
Coordination: Progression

- **Green band** defined based on cycle, main street split, and offset
- Offset based on assumed travel time (speed, distance) between intersections

Offset reference point is beginning of first coordinated phase yellow.
Coordination: Cycle Length

- Time required for complete sequence of signal phases
Coordination: Splits

- Portion of cycle allocated to each phase (green + clear)
- Selected based on phasing & expected demand
- Sum of phase splits = cycle length
- Splits must be long enough to service phase parameters (min green, yellow, red, ped walk, ped clear)
Coordination: Force-Offs

- Used to enforce phase splits
- Define time in cycle when uncoordinated phases must end
- Control must return to coordinated phase no later than programmed time
Coordination: Force-Offs

- **Floating force-offs**
  - Limit a phase to the programmed split time
  - All unused time reverts to coordinated phase

- **Fixed force-offs**
  - Maintains phase’s force off point in the cycle
  - Unused time can be used by following phases
• **Permissives**
  - Windows of time when the controller can leave the coordinate phase(s) to serve the uncoordinated phases
  - Define the earliest and latest points at which an uncoordinated phase can **begin**
  - When a permissive period is active, the first uncoordinated phase in sequence with demand will begin (earlier phases in sequence with no demand will be skipped)
  - Simultaneous vs. sequential permissive periods

• **Yield Point**
  - Beginning of the first (or all) permissive periods
  - Determines the earliest point at which the coordinated phase(s) can begin termination and transition to uncoordinated phase(s)
Coordination: Actuated Coordinated

Actuated phase can gap out

- $\phi$ = Phase Number
- $\rightarrow$ = Permitted Movement
- $\rightarrow$ = Protected Movement
- $\leftrightarrow$ = Pedestrian Movement
Coordination: Transitions

• Process to get local & master clocks in sync
• Causes
  – Time-of-day scheduled changes
  – Manual operator selection
  – Traffic-responsive pattern selection
  – Emergency vehicle, railroad, or other preemption
  – Adaptive control system pattern selection
  – Corrections to the controller clock
  – Pedestrian time exceeds split time
  – Power loss and restoration
• Transition logic independent at each controller
• Transition logic is vendor-specific
• No coordination exists until transition is complete!
Controllers typically limit the amount of adjustment that can occur in one cycle → multiple cycles needed to finish

Lengthening the cycle
- Dwell: holds green for coordinated phase until new offset reference point if achieved.
- Max Dwell: modified dwell limits amount of extra green each cycle
- Add: Shifts start of cycle progressively later by increasing green time on all phases in the sequence rather than just coord phase

Shortening the cycle
- Subtract: Shifts start of cycle progressive earlier by subtracting time from one or more phases in the sequence (subject to min green and ped time requirements). Good for small corrections.

Shortway (aka bestway, fastway, or smooth)
- Finds shortest path to transition using either lengthening or shortening transition logic. Varies by controller vendor.
Methods for Selecting Coordination Plan

• **Time-of-day schedule**
  – Transitions between plans occur at set time of day

• **Traffic responsive**
  – Uses system detector thresholds to pick from a predefined set of plans on some recurring basis (typically > 15 minutes)
  – Requires engineering to determine cycle/offset/split for the predefined patterns

• **Central system/Manual**
  – User command to run a particular pattern until further notice

• **All of these methods require transition**
  – Due to transition, Signal Timing Manual recommends plan changes no more often than every 30 minutes
  – Avoid plan changes during congested conditions when signals need to operate at maximum efficiency
Adaptive Signal Control Technology
ASCT: Timing Methods

- **Pattern-based**
  - Controller operates in **coordination** using cycle, split, and offset
  - Adaptive system downloads new cycle, split and/or offset settings for the active timing plan
  - Unconstrained by algorithm processing time, but limit breadth of search to a limited range around current settings
    - Minimize transitions
    - Minimize overreaction to short-term anomalies

- **Non-pattern-based**
  - Controller generally runs **free**
  - Adaptive system uses phases calls, detector calls, and/or phase holds to provide time to desired phases by overriding the local controller
ASCT: Data Sources

• Controller: Binned detector data
  – Controller stores detector volume & occupancy
  – Adaptive system vol/occ from controller on recurring basis
  – Most pattern-based ASCT use this method

• Controller: High-resolution data
  – 1/10 second resolution data (basis of ATSPM)
  – Econolite Edaptive

• Direct detection data to ASCT
  – Detector system communicates directly with adaptive algorithm
  – Most non-pattern-based ASCT use this method
Pattern-Based ASCT
ACS-Lite Family
ASCT: ACS-Lite

- FHWA sponsored development in mid-2000s with four vendors
  - Econolite
  - McCain
  - Peek
  - Siemens (formerly Eagle)

- Pattern-based

- Designed to minimize cost of installation
  - Leverage existing detection & closed loop system technology

- Current products with ACS-Lite foundation
  - Econolite: Centracs Adaptive
  - McCain: Transparity Adaptive
  - Siemens: ACS-Lite
ASCT: ACS-Lite

- **Split tuning:**
  - Occupancy data → average phase utilization
  - Optimizes to balance phase utilization by adjusting splits
- **Offset tuning:**
  - Volume & occupancy using upstream detection
  - Develops flow profile
  - Optimizes offset to maximize arrival on green
- **Cycle length:**
  - Original ACS-Lite could not “tune” cycle length
    - Controller would select cycle length from time of day plan
    - Base plans required
  - Some vendors have enhanced ACS-Lite algorithms by selecting cycle length using traffic responsive thresholds
    - Econolite Centracs Adaptive
    - McCain Transparity
SCOOT
• Stands for **Split Cycle and Offset Optimization Technique**
• Originally developed in 1980s; currently owned by Siemens
• Pattern-based
• On-line, real-time simulation model
  – Entire intersection for cycle lengths
  – Each approach for splits/offsets
• User can favor movements, directions, or phases

<table>
<thead>
<tr>
<th>Optimizer</th>
<th>Frequency of changing</th>
<th>Change values (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split</td>
<td>Every phase change</td>
<td>+4, 0, -4</td>
</tr>
<tr>
<td>Offset</td>
<td>Once per cycle</td>
<td>+4, 0, -4</td>
</tr>
<tr>
<td>Cycle time</td>
<td>Every 5 or 2.5 minutes</td>
<td>+4, 0, -4 (32-64)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+8, 0, -8 (64-128)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+16, 0, -16 (128-240)</td>
</tr>
</tbody>
</table>
SynchroGreen
SynchroGreen

- Developed by Trafficware
- Optimizes cycle length, splits and offsets (3 modes)
  - Main corridor
  - Balance mode – who needs time most this cycle
  - Critical intersection mode
- Can pick different travel paths through the system to optimize
- No base plans required
1. Green Utilization from detector occupancy data
2. Target Phase Allocation (ideal phase split)
3. Period Selection (global analysis of cycle length)
4. Timing Plan Distribution (proportions phase allocation according to targets and assigns critical period duration to all intersections in the system)
Centracs Edaptive
Centracs Edaptive

- Developed by Econolite based on Purdue research
- Uses 1/10 second high resolution data (ATSPM)
- Pattern optimizer
  - Purdue Link-Pivot & Volume/Capacity for Offsets & Cycle Opt.
- Updates coordination pattern in controller with recommended adjustments

<table>
<thead>
<tr>
<th>Setting</th>
<th>Initial</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>47</td>
<td>33</td>
</tr>
<tr>
<td>Cycle Length</td>
<td>120</td>
<td>115</td>
</tr>
<tr>
<td>Sequence/Splits</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>
• Cycle-based calculations every 3 cycles to create a pattern that gets written to controller
• Based on Purdue metrics using high resolution data
  – Offsets based on Purdue link-pivot
  – Splits based on split failures
• Collects data from peer intersections to calculate timing plan, shares plans across field network
  – Each intersection runs the adaptive optimization algorithm using software on the local controller
  – Results compared between intersections & scored
  – Highest score gets selected for the whole network
Non-Pattern-Based ASCT
In|Sync: Overview

• **Digitize operations**
  – Consider compatible phase pairs (states) instead of traditional sequences

• **Global optimizer**
  – Green waves/time tunnels
  – Tunnel start times calculated using assumed travel time between intersections (speed, distance) (similar to offset)
  – Tunnel start times relative to facilitator intersection (similar to closed loop system with master intersection having offset zero)

• **Local optimizer**
  – Schedules phase states outside of green tunnel (essentially non-coordinated phases)
• Green tunnels require consistent period (cycle length) at all coordinated intersections
  – Potential for period adjustment if local intersection “reports in” if it needs more time (like traffic responsive operation)

• Green tunnel is essentially a coordinated phase split with an offset set as beginning of green

• Tunnel truncation allows tunnel to gap out, which is essentially actuated coordinated operation
• Scheduling of states
  – If close to start of new tunnel, schedules main street sequence (could be left turns)
  – If tunnel has recently ended, cross street sequences have scheduling priority
  – Miscellaneous main state is scheduled for phases with queues that have been waiting the longest
    • If wait times are equal, then phase with largest queue is scheduled
    • Miscellaneous time used to schedule any phase with real-time demand including main street left turns
• Empty queues: Uses queue of 1 vehicle to schedule these phases last and will be skipped if no vehicles arrive
• State duration: continually modified to contain vehicles arriving after phase starts (similar to extension)
• State termination: percentage of capacity w/ time & gap
In|Sync: Local Optimizer

- Calculating a sequence
  - Data: current queues, pending pedestrian calls, upcoming tunnels
  - Queue converted to min. clearance time: phase time must be enough to clear the queue plus yellow/red to get to that phase
  - For ped, clearance time is time required for pedestrians to walk across the intersection
  - Tunnel plans converted into restrictions on beginning and ending times for the phase (beg. time <= beg. of tunnel – change time and end time >= end of tunnel)
  - For each sequence, minimum-total-time solution satisfying restrictions and total waiting time for queues calculated
    - Sequence with least total waiting time is chosen
    - If no solution, then lowest-priority of restrictions relaxed until solution
In|Sync: Local Optimizer

- **Early release**
  - Local optimizer can be configured to restrict early release of a tunnel phase at an intersection

- **Period length evaluation**
  - Analyzes queue lengths and % occupancy for each phase
  - If intersection doesn’t have enough time to adequately clear out queues, intersection reports this to the facilitator
  - If current 15-min. flow rates comparable to historically logged flow rate, then assumes current pattern of traffic can be served using a period that was adequate for historical traffic (period prediction)
• Picks compatible phase states from possible sequences
• Eliminates transitions (but may have similar functionality called “Recovery Mode”)
In|Sync: Interface

- Traditional controllers have detector calls on multiple phases at the same time; serve in sequential order.
- In|Sync intercepts detection and only places a call for the phases to provide the desired state at any time.
- Controller runs free
  - 1 second passage time beyond when In|Sync drops call
  - Controller still manages clearance times
  - Controller can respond to higher priority calls (preemption).
- In|Sync processor runs local optimizer function on Windows XP embedded computer in each cabinet.
• Recommend running in detector mode for 2 weeks prior to adaptive turn-on
  – Test input/outputs
  – Log historical queue data
• Configurations (similar to time of day schedules)
  – Must be manually configured using time-space diagram
  – Typically done by Rhythm during the 2-week detector period
  – Priority direction & tunnel offset & duration, tunnel truncation
  – Allowable phase sequences
  – Phase min green and limit (similar to programmed split time)
In|Sync Configuration: Time of Day Schedules

- Each “configuration” has settings for:
  - Direction priority
  - Permitted sequences (lead/lag, etc.)
  - Maximum wait time
  - Min green, yellow, red
  - Queue correction
  - Gap time
InSync Configuration: Direction Priority

- Tunnels can be associated with any movement
- Duration like coordinated split time
- Offset
- Tunnel truncation like actuating coordinated phase

60% truncation for 70 sec. tunnel means 42 sec. min tunnel

<table>
<thead>
<tr>
<th>Periodic Mode</th>
<th>Override Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Through</td>
<td>East Through</td>
</tr>
<tr>
<td>North Left</td>
<td>East Left</td>
</tr>
<tr>
<td>South Through</td>
<td>West Through</td>
</tr>
<tr>
<td>South Left</td>
<td>West Left</td>
</tr>
<tr>
<td>Global Offset</td>
<td>0</td>
</tr>
<tr>
<td>Global Duration</td>
<td>0</td>
</tr>
<tr>
<td>Local Offset</td>
<td>-36</td>
</tr>
<tr>
<td>Local Duration</td>
<td>70</td>
</tr>
</tbody>
</table>
InSync Configuration: Permitted Sequences

![Permitted Sequences Diagram]
In Sync Configuration: Queue Correction

When detector says queue is 5 or more, tell optimizer to assume 38 cars in queue

<table>
<thead>
<tr>
<th>Maximum Detection</th>
<th>Corrected Queue</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Bound Through</td>
<td>20</td>
</tr>
<tr>
<td>North Bound Left</td>
<td>20</td>
</tr>
<tr>
<td>South Bound Through</td>
<td>20</td>
</tr>
<tr>
<td>South Bound Left</td>
<td>12</td>
</tr>
<tr>
<td>East Bound Through</td>
<td>99</td>
</tr>
<tr>
<td>East Bound Left</td>
<td>99</td>
</tr>
<tr>
<td>West Bound Through</td>
<td>99</td>
</tr>
<tr>
<td>West Bound Left</td>
<td>5</td>
</tr>
</tbody>
</table>

When detector says queue is 5 or more, tell optimizer to assume 38 cars in queue
• CentralSync travel time between intersections
  – User-defined (*not* auto-calculated based on distance and speed)
  – Typically calculated by Rhythm during 2-week detector period
InSync Configuration: Green Tunnel
Rapid Flow Technologies
SURTRAC
Surtrac Overview

• Optimizes to minimize person delay
  – Treats intersection control as single machine scheduling problem
  – Aggregate representation of traffic flows to identify input jobs
  – Communicates schedules to downstream neighbors to give visibility of future input jobs

• Coordinates networks dynamically using vehicle arrival model with no fixed cycle

• Very few adaptive operational parameters

• Adaptive optimization runs on Linux computer in each cabinet (decentralized operation)

• Uses exit detection to find platoons for downstream intersections
Surtrac Key Technical Ideas

Aggregate Flow Representation

Startup lost time

Anticipated Queue

Platoon gap

Input Flow 1

Input Flow 2

Signal Sequence

Schedule $S = (1, 1, 2, 1, 2, 2, 1, 1)$
Adaptive Systems: Hardware
## Adaptive Infrastructure Comparison

<table>
<thead>
<tr>
<th>System</th>
<th>Optimization Engine</th>
<th>Stop Bar</th>
<th>Advance</th>
<th>Midblock</th>
<th>Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS-Lite*</td>
<td>Central Server</td>
<td>M, S</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SCOOT</td>
<td>Server</td>
<td>M, S</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SynchroGreen</td>
<td>ATMS.now Server</td>
<td>M, S</td>
<td>M (E)</td>
<td>M (I) – either location</td>
<td></td>
</tr>
<tr>
<td>Edaptive</td>
<td>Cloud-based</td>
<td>M, S</td>
<td>M (E), S(+)</td>
<td>M (I) – either location</td>
<td></td>
</tr>
<tr>
<td>Maxtime</td>
<td>In local controller</td>
<td>M, S</td>
<td>M</td>
<td>M(I) alt. to advance</td>
<td></td>
</tr>
<tr>
<td>In</td>
<td>Sync</td>
<td>Processor in cabinet</td>
<td>Proprietary detection for queue measurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surtrac</td>
<td>Processor in cabinet</td>
<td>M, S</td>
<td>M (E)</td>
<td>M (I)</td>
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</tr>
</tbody>
</table>

*Includes all ACS-Lite descendents: Centracs Adaptive, Transparity, Siemens ACS-Lite
Detection key: M = main street, S = side street, E = external links, I = internal links, + = critical intersections only

### Detection for arrival profiles
- Traditional advance detection (~400 feet upstream of stop bar)
- Midblock detection
- Exit detection from upstream intersection
Adaptive Implementation Considerations

- What happens when detection fails? How likely?
- What happens when communication to optimization engine fails? How likely?
- Are base timing plans required? Who is developing?
- Can existing detection be used?
- How does system respond to unpredictable changes in demand?
- Priority of corridor vs. side streets or grid
- How will performance be monitored to ensure system meets project objectives?
  - Does the adaptive system provide relevant performance measures out of the box
  - Does the adaptive system allow the controller to collect accurate high resolution data for ATSPM?
Adaptive Implementation Considerations

• Is existing system operating as designed?
  – Does detection work?
  – Are clocks synchronized?
  – Are controllers programmed correctly?

• Network configuration – IP address assignment

• Will the municipality promptly repair detection and communication issues? Are parts readily available from adaptive vendor? Can “off the shelf” components be used for repairs?
Adaptive Traffic Signal Control: Systems Engineering
• Issued February 15, 2013
• Simplifies systems engineering for adaptive following federal guidelines
• Systems engineering isn’t a boilerplate checklist to get a proprietary approval
• Municipal recognition of ongoing maintenance & operations costs
  – Provide letter signed by municipality
  – Make sure the municipality understands and commits to funding ongoing costs: Quote the dollar amount in the letter
  – Don’t hide the costs in small print of TE-153!
  – Don’t assume passing resolution for TE-160 means they understand the future costs

• Budget for equipment failures and replacement, not just vendor support

• Demonstrate what the problem is and why adaptive is the recommended solution
• **Existing characteristics of the corridor**
  – Provide data to support, using available sources if necessary
    • Probe data showing unreliable nature of corridor travel times
    • Volume data from existing loops (high res data, controller, or closed loop system)
  – If there are special events that cannot be accommodated with TOD plans, don’t pick an adaptive system that requires all these parameters to be human-set

The existing characteristics of the corridor are (check all that apply)

- [x] Corridor experiences large fluctuations (~20% change) in traffic volumes that are: daily
- Time period that fluctuations occur (check all that apply): [x] AM  [x] MID-DAY  [x] PM  [x] OFF-PEAK
- [x] Corridor handles a large amount of special events that cannot be accommodated with TOD plans, and contribute significantly to network delay.
- [x] Corridor is a PennDOT priority corridor.
- [x] Corridor is in the vicinity of and has access to interstate highways.
- [x] Corridor is an MPO priority corridor.
• **Major concerns**
  – Consider signal timing objectives and context
  – Identify priorities, not everything

The major concerns along the corridor are (check all that apply)..................

Which approach is of major concern: mainline

- [X] Progression along the corridor.
- [X] Delay on the corridor.
- [X] Capacity deficiencies along the corridor.
- [X] Queuing issues and/or left turn lane spillback.
- [X] Delay on the side streets approaches.
- [X] High number of crashes along the corridor.
## Traffic Signal Objectives

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<tr>
<th>Operations</th>
<th>Safety</th>
<th>Flow</th>
<th>Intersection</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Light</td>
<td>Minimize phase failures</td>
<td>Smooth flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uncongested</td>
<td>Equitable service</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Congested</td>
<td>Maximize throughput</td>
<td>Manage queues</td>
</tr>
</tbody>
</table>

### Organizational
- Responsiveness to stakeholder needs
- Comply with agency policies and standards

### Maintenance
- Minimize life cycle costs
- Sustain infrastructure state of good repair
- Sustain system and technology reliability/state of good repair

Source: Eddie Curtis & Rick Denney, FHWA
• Know when objectives apply
  – Intersection vs. network approach
  – Light flow vs. uncongested flow vs. congested flow

Corridor Objectives

The operational objectives for the signals to be coordinated are (check all that apply): (3.4).

- [x] Smooth the flow of traffic along coordinated routes.
- [x] Maximize the throughput along coordinated routes.
- [x] Equitably serve adjacent land uses.
- [x] Manage queues, to prevent excessive queuing from reducing efficiency.
- [x] Variable, with either a combination of these objectives, or changing objectives at different times.
- [x] For a critical isolated intersection, maximize intersection efficiency.
• Develop reasonable system requirements
  – Don’t pick requirements to purposely eliminate vendors for reasons that don’t affect operations
  – Don’t let existing, ancient controllers dictate decision making (replacing a timer for $3-4k per intersection is often cheaper than a proprietary bid premium and/or installing a separate processor in the cabinet)
  – Video detection may not be the most effective way to achieve remote monitoring. Consider CCTV mounted to signal pole.

• Consider multiple vendor’s systems
  – Eliminate systems that don’t meet requirements
• **TE-153 required**
  – Federally funded projects
  – State funded projects (includes GLG, ARLE, Multimodal)
  – Municipal projects
  – Developer projects (includes HOP)

• **Complete through Part H and submit to BOMO**
  – Department projects: prior to beginning of preliminary engineering
  – Municipal/developer projects: include with first traffic signal submission
  – Projects currently in design: submit ASAP

• **Part I (Verification and Validation)**
  – Cannot be completed by system designer (conflict of interest)
  – Recommend using RITIS/INRIX data for before/after analysis
  – Submit to BOMO
Adaptive Signal Control in Pennsylvania

Source: TSAMS
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