ACS Lite Project Overview

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Adaptive Traffic Signal Control Workshop
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Outline

ACS = Adaptive Control Software

- Project goals and status
- What’s Lite about ACS Lite?
- ACS-Lite system architecture
- ACS-Lite algorithms overview
- Performance results
- Questions?
FHWA’s Motivation for the ACS-Lite Project

• **Limited U.S. deployment** of ACS
  - 8 agencies as of 1999

• FHWA ACS research
  - RHODES, OPAC, RTACL

• ACS survey & ITE roundtable
  - 70% say ACS too costly
  - 40% unconvinced of benefits over TOD/TRPS
  - ACS too sensitive/dependent on communications & detectors
  - Difficult to understand, configure, and maintain

• Closed-loop systems are prevalent in marketplace
  - Can we develop an adaptive solution augmenting existing hardware?
FHWA’s ASC-Lite Project Goals

**WIDELY DEPLOYABLE adaptive control**

- Low cost design
- Leverage existing infrastructure
  - Work with closed-loop systems & standard actuated controllers
  - Standard fully-actuated detector layouts
  - Communications bandwidth & protocols
  - Standard NTCIP interface
  - Field deployable without connection to TMC
- Meet performance expectations
Project Team

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Nils Soyke

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Sanjay Sridhar
Project Partners

TSIS/CORSIM integration & FHWA TReL testing

Charlie Stallard

Controller / Closed-Loop Signal System Vendors

Mark Hudgins
Gary Duncan
Peter Ragsdale
Ed Bertha
Project Summary

• Started in March 2002
  – Siemens ITS, Purdue, Arizona
  – Upgrade CORSIM (ITT Industries) for NTCIP interface
  – Partnership with NEMA controller manufacturers
    • Eagle, Econolite, McCain, PEEK
  – Focus on arterials in initial phase, networks at a later time

• Status
  – Initial software development complete
  – Initial simulation evaluation complete
  – Initial phase final report available March 2004

• Coming soon
  – Hardware-in-the-loop testing at Turner Fairbank Traffic Research Lab (TReL)
  – Field testing with participating NEMA systems
  – Additional R&D of algorithms and additional components
What’s “Lite” about ACS-Lite?

- Effective
- Inexpensive
- Compatible
- Easy to use
- “Low-Hanging Fruit”
Typical Closed-loop System

- Central System Software in <50% of deployed systems
- 9600 Baud Dial-up
- 1200 Baud, Twisted Pair ~50% of systems
- 9600 Baud ~50% of systems
- Master Controller
- Local Controller
- 3-7 Timing Plans on TOD Schedule Limited use of TRPS
- 8-10 Signals Per System
- Main Arterial
- Semi-Actuated Detection >50% of systems
- Fully-actuated Detection <50% of systems

9600 Baud Dial-up

1200 Baud, Twisted Pair ~50% of systems
9600 Baud ~50% of systems
ACS Lite System Architecture

- ACS-Lite API (NTCIP-protocol)
- ACS-Lite
- Protocol Translation Service
- Field Master
- Vendor-specific protocol
- Central System
- Laptop
Turner-Fairbank TReL Testing Configuration
Current Laboratory Configuration

ACS-Lite API (NTCIP-protocol)

ACS-Lite

CORSIM Simulation

Laptop
ACS-Lite Algorithms Architecture

- Time-of-Day Tuner
  - TOD Plans
    - cycle, splits, offsets
    - pattern switch times

- Run-time Refiner
  - Active Plan
    - cycle, splits, offsets
    - active pattern

- Transition Management
  - Plan Changes
    - transition method

Master Controller

Arterial

local

local

local
ACS-Lite Algorithms Architecture

- Time-of-Day Tuner
  - TOD Plans
    - cycle, splits, offsets
    - pattern switch times
  - Run-time Refiner
  - Transition Management
    - TOD Plans
    - Active Plan
      - cycle, splits, offsets
      - active pattern
    - Plan Changes
      - transition method
    - Large & fast parameter changes
    - Smooth, incremental parameter changes
    - Fast & non-disruptive parameter changes
    - Master Controller
      - local
      - Arterial
Run-Time Refiner

• Adjust **active** timing plan
  – Cycle (TBD), splits, offsets
  – Small, incremental adjustments (not permanent - TBD)
  – Switch earlier or later to next pattern (TBD)

• Monitor real-time status
  – Detector volume & occupancy
    • Sample every few seconds for cyclic flow profiles
    • Sample during green, yellow, & red intervals for phase utilization
  – Actual phase durations of actuated controller
  – Reasons for termination (max-out, gap-out, etc.)
Illustration of Run-Time Refiner

Average Daily Demand

Flow (vphpl)

Time of Day

AM

PM

12:00 2:00 4:00 6:00 8:00 10:00 12:00 2:00 4:00 6:00 8:00 10:00
Illustration of Run-Time Refiner

Month’s High-Low Range

Flow (vphpl)

Time of Day

AM

PM
Illustration of Run-Time Refiner

Flow (vphpl)

0 200 400 600 800 1000 1200

AM Plan
Mid-day Plan
PM Plan

Free

Time of Day

12:00 2:00 4:00 6:00 8:00 10:00
Illustration of Run-Time Refiner

- **Flow (vphpl)**
- **Time of Day**
  - AM
  - PM

- **TOD Plan Capacity**
Illustration of Run-Time Refiner

Today's Demand

This is a perfectly average day
Illustration of Run-Time Refiner

Run-Time Refiner adjusts active plan

Remove excess capacity of TOD plan

Flow (vphpl)

0 200 400 600 800 1000 1200

12:00 2:00 4:00 6:00 8:00 10:00 12:00 2:00 4:00 6:00 8:00 10:00

AM PM

Time of Day
Illustration of Run-Time Refiner

This is a perfectly "average" day
Illustration of Run-Time Refiner

This is today’s demand

This is a perfectly “average” day
Illustration of Run-Time Refiner

Run-Time Refiner reallocates time where needed

Better utilizes capacity of streets, but does not build new lanes
Transition Manager

• Manage controllers’ transition from one plan to next
  – Select existing transition mode
    • Dwell
    • Add
    • Subtract
    • Best way (of Add/Subtract)
  – Command sequence of changes (TBD)

• Transition Objectives
  – Timely return to coordination
  – Minimally disruptive
Illustration of Transition Manager

Plan 1

Offset 1

Dwell Only

Long Way

Short Way

Offset 2

Plan 2
Time-of-Day Tuner

- Periodically re-tune Time-of-day (TOD) plans (TBD)
  - Adjust cycle, offset, & splits
  - Changes are “permanent”
  - Fine-tune schedule of pattern switch times

- Benefits
  - Avoid additional 3-5% delay/year due to changing traffic patterns
  - Remain effective during controller comm. failure
  - Plans tailored to accommodate daily variability
  - Respond to seasonal changes in traffic conditions
Illustration of Time-of-day Tuner

Flow (vphpl)

Time of Day

AM Plan

Mid-day Plan

PM Plan

Free
Illustration of Time-of-day Tuner

What if variability changes?

Flow (vphpl)

Time of Day

AM

PM
Illustration of Time-of-day Tuner

What if variability changes?
Illustration of Time-of-day Tuner

Time-of-Day Tuner adjusts to handle extremes better
Illustration of Time-of-day Tuner

What if total flow changes?

Flow (vphpl)

Time of Day

AM

PM
Illustration of Time-of-day Tuner

What if total flow changes?
Illustration of Time-of-day Tuner

- Adjust TOD plan
- Hold AM plan later
- Start AM plan earlier
- Permanently increase max greens
ACS-Lite Algorithms Architecture

ACS-Lite is “ Appropriately” Adaptive within the data/communications environment of closed-loop systems
Run-Time Refiner Algorithm Details

- Splits
- Offsets
ACS Lite Split Adjustment Guidelines

1. “EQUISAT” is most popular adaptive split strategy
   - Volume & model parameters can be unreliable
   - Use phase timing & termination data (not alone)
   - Use lane independent green occupancy data

2. Account for early-return-to-green
   - Reduce stops with intelligently biased splits
   - Smart biasing requires arrival profile knowledge
Split Adjustment Algorithm

Extend EQUISAT concept to multi-ring controllers

- **STEP ONE**: Form reasonable estimates of degree of saturation
- **STEP TWO**: Minimize the maximum level of saturation on any phase
  - Ensure barrier alignment & cycle time constraints are satisfied
  - Accommodate progression by allowing lower level of saturation on coordinated phases
Detector Layout

Need detectors at stop-bar of coordinated phases

Phase Utilization Detectors

Flow Profile Detectors
Multi-ring Controller Terminology

- **Barrier group (or just group)**
  - The set of all phases (or ring-groups) between two barriers (or all phases if there are no barriers)
  - 2 groups below: \{1,2,5,6\} and \{3,4,7,8\}

- **A ring group is the set of phases on a ring in a group**
  - 4 ring-groups: \{1,2\}, \{5,6\}, \{3,4\}, and \{7,8\}

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\begin{array}{cccc}
  b & 1 & 2 & a \\
  5 & 6 & 7 & 8 \\
  a & 3 & 4 & b \\
\end{array} \]
Balance saturation within ring-group

- Less split time => higher saturation
- More split time => lower saturation

**Degree of saturation** estimates for each split allocation

<table>
<thead>
<tr>
<th></th>
<th>(1) 80%</th>
<th>(2) 80%</th>
<th>MAX 80%</th>
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</thead>
<tbody>
<tr>
<td>Better splits</td>
<td>(1) 80%</td>
<td>(2) 80%</td>
<td>80%</td>
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<tr>
<td>Original splits</td>
<td>(1) 70%</td>
<td>(2) 85%</td>
<td>85%</td>
</tr>
<tr>
<td>Worse splits</td>
<td>(1) 65%</td>
<td>(2) 90%</td>
<td>90%</td>
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</tbody>
</table>

← Duration of ring-group →
Balance saturation across barrier groups

Degree of saturation estimates for each barrier group duration:

-1
(1) 80%  (2) 85%
0  
(1) 80%  (2) 80%
+1  
(1) 75%  (2) 80%

-1
(3) 70%  (4) 85%
0  
(3) 70%  (4) 90%
+1  
(3) 70%  (4) 95%

↔ Duration of barrier-group →

85%
90%
95%
### Accounting for all rings

**Degree of saturation estimates for each barrier group duration**

<table>
<thead>
<tr>
<th>Duration</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<td>80%</td>
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<tr>
<td>+1</td>
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<td>95%</td>
<td>80%</td>
<td>Inf.</td>
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</tbody>
</table>

- **85%**
- **90%**
- **95%**
- **87%**
- **83%**
- **Inf.**

*Duration of barrier-group →*

**Infeasible**
Typical split adjustment profile
ACS Lite Offset Guidelines

• Measure cyclic flow profiles directly
• Account for travel time from the detector to the signal
• Account for variable start of green
• Account for both coordinated approaches and effect on downstream signals
• Maximize the total amount of captured flow
  - Two options:
    • On inbound and outbound movements at ALL signals on the arterial
    • On inbound and outbound movements at EACH signal on the arterial independently
• Make small incremental changes to minimize transitions
Detector Layout

**Detector Layout**

**Need detectors at stop-bar of coordinated phases**

**Phase Utilization Detectors**

**Flow Profile Detectors**
Local Offset Tuning

Shift to capture most arriving flow

Arrival Flow

Green Window

Cycle Counter (seconds)

Occuancy (%/sec)

0 20 40 60 80 100 120

0 20 40 60 80 100 120

0 90 180

U.S. Department of Transportation
Federal Highway Administration
FHWA Contract No.DTFH61-02-C-00047
Account for all coordinated approaches

Southbound

Northbound
Account for all downstream signals

Upstream shifting earlier reduces stops locally

Downstream shift would increase stops
Typical offset adjustment profile

Colors represent different CORSIM runs
Simulation Performance Testing

- **ITT Industries**
  - Developed NTCIP agent interface to CORSIM
  - Developed multi-pattern capability and realistic transition logic

- **Purdue**
  - Developed “real-world” test scenarios
  - Synchro-optimized timings
  - Many, many, many simulation runs and independent assessment of results
Simulation Performance Testing

- Evaluate algorithms parameters
  - Re-adjustment intervals (5 to 10 minutes)
  - Offset changes and max deviations (2 to 20 seconds, “any”)
  - Split adjustments and max deviations (2 to 20 seconds, “any”)
  - Results tend towards shorter re-adjustment intervals and larger flexibility of algorithm to make adjustments

- Start with optimized timings – can ACS-Lite improve?
- Start with bad/arbitrary offsets or splits – can ACS-Lite find a good solution?
- Change turning proportions and volumes to represent real-world traffic changes – can ACS-Lite adapt?
Simulation Performance Testing

Changes in volumes at side-street approaches to intersections 2, 4, and 7 impact the entire network
Evaluation Results – Total Control Delay

AM Scenarios  PM Scenarios  Off-peak Scenarios

Total Delay (veh-min)

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ACS-Lite

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Evaluation Results – Phase Failures

- **Total Number of Phase Failures:**
  - Synchro Baseline: 17
  - ACS-Lite: 24
  - Worst Case: 88

- **Improvement: ~70%**
## “Very High Altitude” Evaluation Results

<table>
<thead>
<tr>
<th>ACS-Lite test scenario</th>
<th>vs. “Do nothing”, initially as ACS-Lite</th>
<th>Conclusion</th>
</tr>
</thead>
</table>
| Start with optimized settings | Delay (-0.0%, +0.7%)  
Travel Time (-0.6%,+2.4%) | ACS-Lite “does no harm” |
| Start with bad Offsets (no split adjustment) | Delay (-4.2%, +0.9%)  
Travel Time (-4.0%,+1.3%) | ACS-Lite can find a good set of offsets |
| Start with bad side-street Splits (no offset adjustments and progression bias) | Delay (-3.3%, +2.2%)  
Travel Time (-4.9%,+6.8%) | ACS-Lite usually makes improvement |
| Changing volumes & turning proportions | Delay (-38%, -7.4%)  
Travel Time (-6.4%, +3.5%) | ACS-Lite provides consistent delay reduction |
Conclusions

• Core ACS-Lite development is complete
  – Run-Time Refiner
  – Transition Manager
  – Communications and algorithms software infrastructure

• Performance evaluation in simulation is encouraging

• Current configuration designed for up to 12 intersections on arterial

• Coming up
  – TReL testing with Hardware-in-Loop
  – Field testing
  – Time-of-day Tuner algorithms development
Questions?

Hunt us down for a demo