

# Adaptive Signal Control Technology Research in Illinois

Kyle Armstrong, Ray Benekohal, Hongjae Jeon



# Overview

- ASCT Overview and Installation
- First Year After Implementation Results
- Final Year (TBC 2017 and ASCT 2017) Results
- Safety Analysis
- Travel Time and Speed
- System Response to Heavy Volume and Special Events

# What is Adaptive Signal Control Technology (ASCT)?

- Continuously adjusts timings to accommodate real-time changes in traffic patterns and improve traffic flow
- Several products with different methodologies
- Some systems may only require software upgrades while others may require additional controller and detection hardware

# Benefits of ASCT

- Improves travel times through coordinated signal systems
- Adaptability to sudden changes in traffic patterns
- Reduce number of vehicle stops and wait times
- Reduce fuel consumption
- Reduced number of crashes?

# Purpose of ASCT Research

- Determine if there is a reduction in crashes due to ASCT implementation (rear-end crashes & left turn crashes)
- Develop a Crash Modification Factor (CMF) for ASCT implementation
- Measure improvements in traffic flow and efficiency

# Research Overview

- Initially 3-year project beginning in 2013
- Phase 1 – Select test site, perform systems engineering analysis, collect pre-implementation data
- Phase 2 – Purchase and install ASCT system, post-implementation data, develop benefit-cost and CMF information

# ASCT Installation

- Selected Neil St. corridor in Champaign
- Performed systems engineering analysis based on the needs of the Neil St. corridor to help select ASCT system
- Trafficware SynchroGreen system selected
- Installed April 2015 with full acceptance November 2015
- System required video detection installation
- Allowed vendor to adjust detection and timing programs
- Improved version installed April 2017

# Performance Indicator (PI)

- ❖ Examined changes in volume, delay and queue individually (with 97% confidence level)
- ❖ Then, considered volume, delay, and queue length combined and called it PI (with 91% confidence level)
- ❖ PI is:
  - Improved (Imp)  
Example: Delay and queue decreased with volume increase significantly
  - Unchanged (Unch)  
Example: Volume, delay, and queue remained unchanged
  - Deteriorated (Det)  
Example: Delay and queue increased without volume increase significantly



# First Year After Implementation Results (2013 vs 2015)

- ❖ Total 83 approaches from 6 intersections in 4 time periods  
 $4 \times [(4 \times 4 + 1 \times 3 + 1 \times 2)] = 84$ , minus off-peak of Windsor due to video failure
- ❖ Traffic volume
  - 33% increased, 65% unchanged, and 2% decreased significantly
- ❖ Delay
  - 17% increased, 72% unchanged, and 11% decreased significantly
- ❖ Queue length
  - 22% increased, 60% unchanged, and 18% decreased significantly

# First Year After Implementation Results (2013 vs 2015)

- ❖ Performance Indicator (PI)
  - 41% improved, 30% unchanged, and 29% deteriorated
  
- ❖ PI on Major-street
  - 34% improved, 26% unchanged, and 40% deteriorated
- ❖ PI on Minor-street
  - 50% improved, 36% unchanged, and 14% deteriorated
  
- ❖ ASCT seemed to make a compromise between the minor- and major-street

# Final Year Implementation Results (2017 TBC vs 2017 ASCT)

- ❖ Total 56 approaches from 5 intersections in 3 time periods  
 $3*(4*4+1*3)=54$ , but one lane group was excluded due to insufficient volume
- ❖ Traffic volume
  - 7% increased, 72% unchanged, and 21% decreased significantly
- ❖ Delay
  - 56% increased, 40% unchanged, and 4% decreased significantly
- ❖ Queue length
  - 35% increased, 65% unchanged, and 0% decrease significantly
- ❖ Performance Indicator (PI)
  - 5% improved, 32% unchanged, and 63% deteriorated

# Final Year Implementation Results (2017 TBC vs 2017 ASCT)

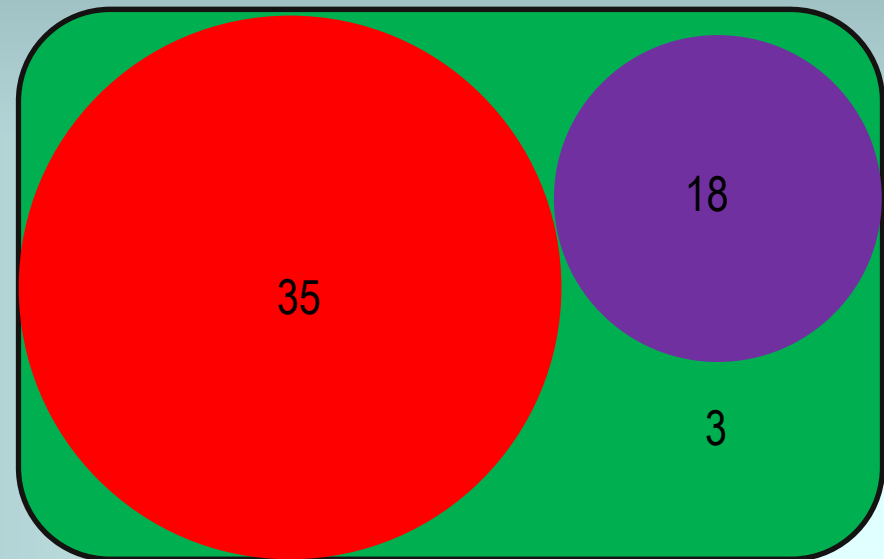
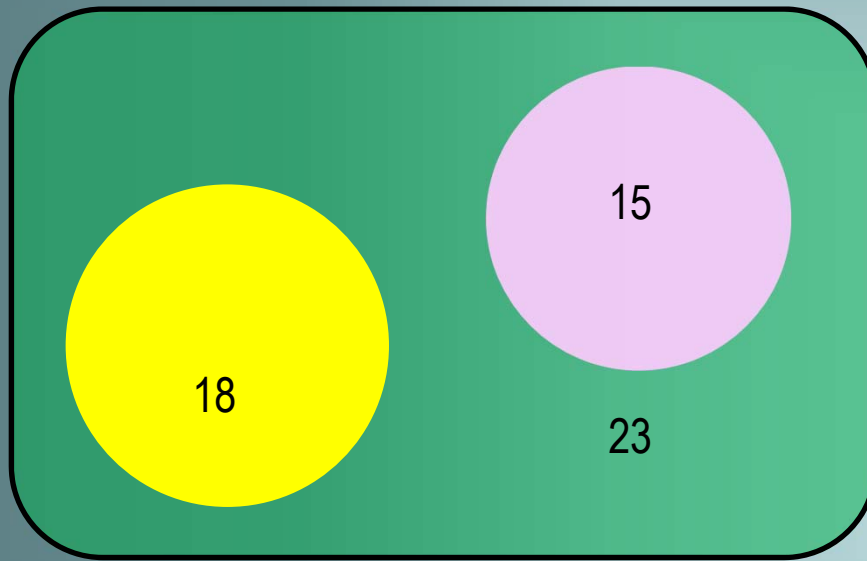
- ❖ PI on Major-street
  - 7% improved, 30% unchanged, and 63% deteriorated
- ❖ PI on Minor-street
  - 4% improved, 35% unchanged, and 61% deteriorated
- ❖ 35 out of 56 cases were deteriorated
- For 20 out of 35 cases could be explained, even though that does not justify the system performance deterioration
  - Unfavorable arrival types (8 cases), Insufficient response to volume increase (3 cases), Signal-timing changes (6 cases), Increase in proportion of vehicles stopped (13 cases). *Some cases had more than one explanation*
- For 15 cases no reasonable explanation

# Comparison between First Year and Final Year

❖ 56 cases that were in the first year and final year

First year after

Final year



Deteriorated

Improved

Unchanged

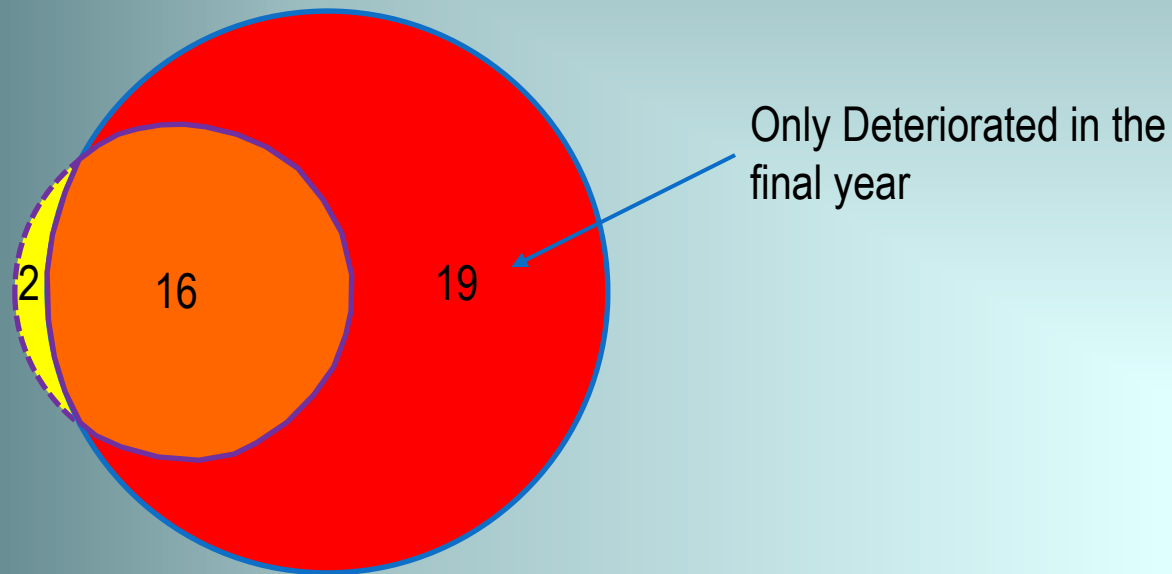
Deteriorated

Improved

Unchanged

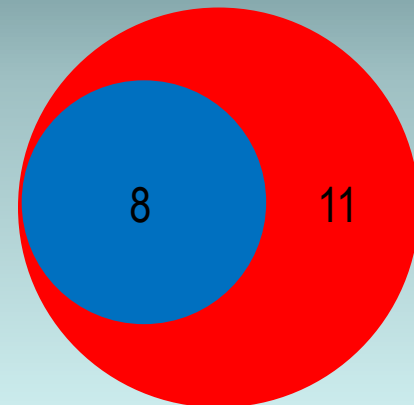
# Comparison between First Year and Final Year

- ❖ 16 deteriorated cases are common in both first year after and final year
- ❖ 19 cases are only deteriorated in final year



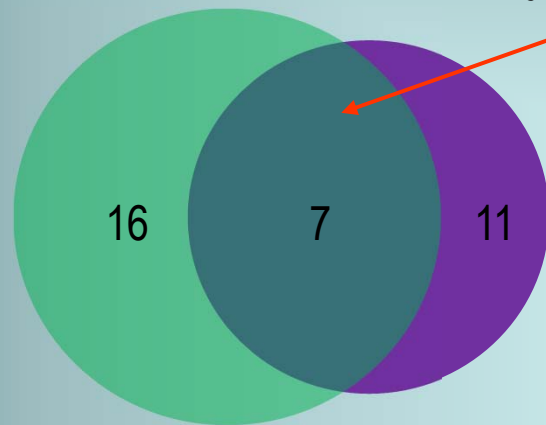
# Comparison between First Year and Final Year

- ❖ in 8 of the 19 cases, some explanation for deterioration was found, though the deterioration is not justified
  - Unfavorable arrival types
  - Signal-timing changes
  - Increase in proportion of vehicles stopped
- ❖ No explanation for the remaining 11



# Worsening in the Final Year

- ❖ If it was Imp. in the first year and Unch. in the final year, it is considered a worsening case.
  - PI improved in the first year after implementation (23 cases)
  - PI unchanged in the final year (18 cases)
  - 7 cases satisfy both condition



Additional worsening cases

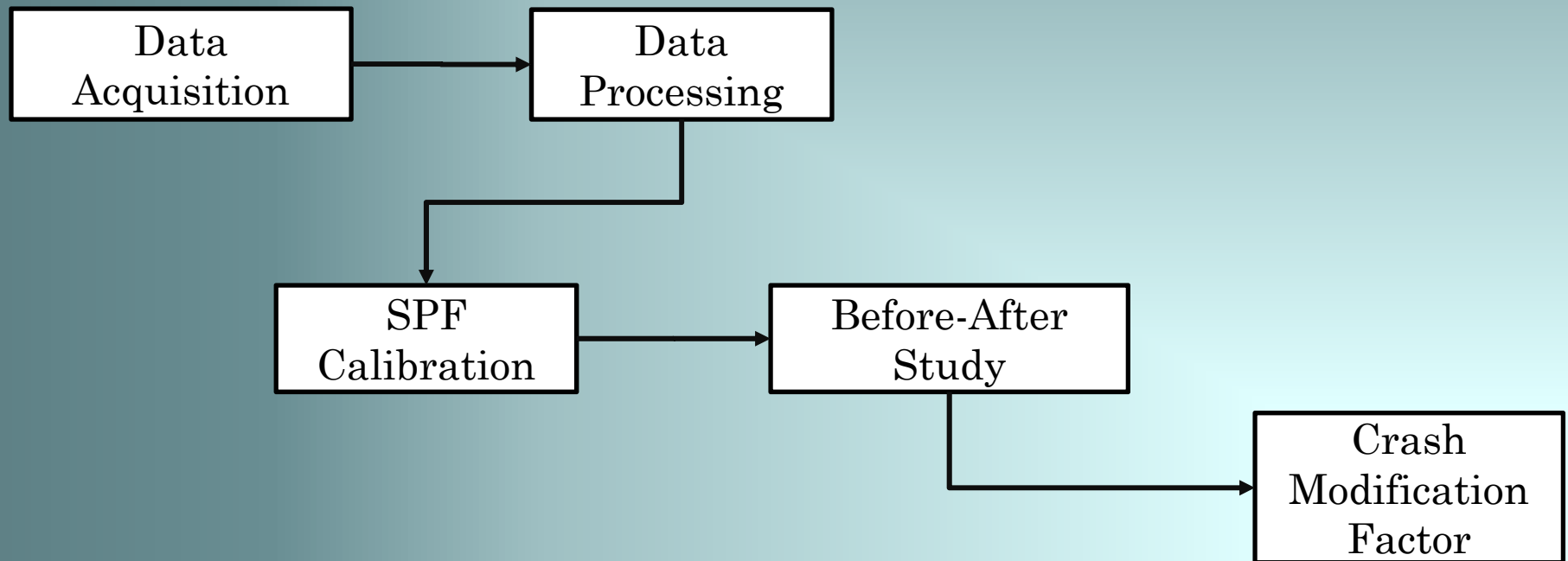
First year after improved

Final year unchanged



# Safety Analysis

- ❖ Quantify safety effects of ASCT system by developing CMF



# Safety Report

- ❖ Before & after study applying Empirical Bayes method
- ❖ Safety Performance Functions (SPF) were calibrated to local conditions.
  - Highway Safety Manual:
    - Multiple vehicle total crashes
    - Multiple vehicle fatal and injury (FI) Crashes
    - Multiple vehicle property damage only (PDO)
  - Illinois Specific SPF
    - Fatal, type A, and type B injury crashes (KAB)
    - Type A injury Crashes only
    - Type B injury crashes only

# Before and After Study

- ❖ Before period: 2012-2014 (36 months)
- ❖ After Period: May 2015 – Oct 2016 (18 months)
- ❖ Data requirements for SPF calibration by HSM procedures:
  - AADT of major and minor roads per intersection
  - Approaches with left-turn lanes
  - Intersection left-turn signal phasing (protected/permissive)
  - Approaches with right-turn lanes
  - Approaches with right turn on red prohibited
  - Presence of lighting
  - Presence of red-light cameras
  - Available pedestrian data

# Before and After Study Results

## Four-Legged Intersection (Only) CMF Results

| Crash Severity | CMF  | Standard Error |
|----------------|------|----------------|
| Total          | 1.00 | 0.16           |
| FI             | 0.67 | 0.23           |
| PDO            | 1.09 | 0.20           |

## Project level CMF (All Intersections) for Multiple-vehicle Crashes

| Crash Severity | CMF  | Standard Error |
|----------------|------|----------------|
| Total          | 0.96 | 0.15           |
| FI             | 0.67 | 0.22           |
| PDO            | 1.04 | 0.18           |

# Before and After Study Results

## Paired T-test Results for Crash Types and Severities

| Crash Type/Severity      | Avg. Difference per intersection (crashes/18month) | p-value | Interpretation             |
|--------------------------|--|---------|----------------------------|
| Angle                    | -0.25  | 0.67    | Decreasing trend, not sig. |
| Rear End                 | -0.083   | 0.923   | Decreasing trend, not sig. |
| Sideswipe Same Direction | 0  | 1.00    | No change                  |
| Turning                  | 0  | 1.00    | No change                  |
| Type A                   | -0.5   | 0.22    | Decreasing trend, not sig. |
| Type B                   | 0  | 1.00    | No change                  |
| Type C                   | -0.58  | 0.44    | Decreasing trend, not sig. |

# Safety Results

- ❖ Fatal and injury crashes showed decreasing trend ( $CMF < 1$ ), but was not significant
- ❖ Total and PDO crashes showed no change ( $CMF \sim 1$ ), but not significant
- ❖ Type A and C injury crashes showed decreasing trend but not significant
- ❖ Angle and rear end crashes showed decreasing trend but not significant

# Travel Time

- ❖ Travel-time data was collected using GPS
- ❖ Two sets of runs were collected with TBC
- ❖ Two sets were collected with ASCT

## Data Collection Days and Number of Runs

| Year            | Day of Data Collection          | AM |    | OP |    | NP |    | PM |    |
|-----------------|---------------------------------|----|----|----|----|----|----|----|----|
|                 |                                 | SB | NB | SB | NB | SB | NB | SB | NB |
| 2014 (TBC)      | Oct 28-29; Nov 18-19; Dec 3-4   | 24 | 24 | 16 | 16 | 17 | 16 | 17 | 15 |
| 2016 (ASCT)     | March 16, 30-31; April 7, 12-13 | 19 | 19 | 17 | 18 | 17 | 18 | 20 | 21 |
| 2017 (TBC)      | March 9; 15-16                  | 8  | 8  | -  | -  | 9  | 9  | 12 | 12 |
| 2017 (ASCT)     | April 12;18-19                  | 8  | 8  | -  | -  | 7  | 7  | 11 | 11 |
|                 |                                 |    |    |    |    |    |    |    |    |
| 2015 (Feedback) | May 5-7; July 14-15             | 20 | 20 | 18 | 18 | 19 | 19 | 20 | 20 |

# Travel Time

- ❖ Three main comparisons were performed:
  - Travel time data from 2014 (TBC) vs 2016 (ASCT)
  - Travel time data from 2017 (TBC) vs 2017 (ASCT)
  - Travel speed data from 2017 (TBC) vs 2017 (ASCT)
- ❖ The “preferred” directions were:
  - NB in AM peak (vehicles driving into downtown)
  - SB in PM peak (vehicles driving away from downtown)
- ❖ T-test at 90% confidence is used



# Travel Time (TT) and Speed

- ❖ TT were compared from each segment and for the corridor
- ❖ Corridor:
  - Stadium Dr. to Windsor Rd. (5 links and 6 intersections)
- ❖ TT were measured from the midpoints of intersections.
- ❖ Speeds found at the middle third of each segment

# Travel Time and Speed Results

- ❖ In both comparisons of travel time:
  - The preferred directions (AM NB and PM SB) experienced an average increase in travel time
  - The Noon-Peak experienced an increase in travel times for the SB direction
  - No changes in Off-Peak hours
- ❖ Speed Comparison:
  - The corridor experienced an overall decrease in speed in the PM SB direction
  - This is not beneficial for efficiency but may contribute to safety benefits (may decrease crash severity).

# System Performance

1. When heavy volume on WB Thru of Kirby Avenue
  - Observed in PM peak on three days right after the vendor did the “final fine tuning” of the system
2. During special events
  - Garth Brooks concerts at the State Farm Center
  - Pre-marathon

# Heavy Volume on WBT of Kirby Avenue

- ❖ Afternoon peak observations on three consecutive days
  - 4:28 PM to 5:43 PM on April 10, 2017
  - 4:31 PM to 5:37 PM on April 11, 2017
  - 4:35 PM to 5:00 PM on April 12, 2017
- ❖ Multiple cycle failures (WB queue did not clear during green time)
  - Nearly one-half to two-thirds of cycle failures
- ❖ During cycle failure on Minor street (Kirby Avenue)
  - Unused green on Major street
  - Most of cases receiving link of Minor link had space to receive more queued vehicles

# Heavy Volume on WBT

❖ Condition on competing directions (NBT/SBT at Neil) and receiving link on Apr 11, 2017

| Beginning of Cycle | Cycle Length (seconds) | WBT Green Time (seconds) | Field Observation                                    |  | Video Observation |  |
|--------------------|------------------------|--------------------------|--|--|-------------------|--|
|                    |                        |                          | Number of Vehicles in Queue on WBT at Start of Green | Number of Vehicles in Queue on WBT at End of Green | Receiving Link    | Unused Green Time on NBT/SBT (seconds) |
| 4:31:18 PM         | 112                    | 33.1                     | 7  | 0  | EMPTY             | 0-5                                    |
| 4:33:10 PM         | 108                    | 33.1                     | 15   | 0  | EMPTY             | 14                                     |
| 4:34:58 PM         | 114                    | 33.1                     | 16   | 4  | EMPTY             | 7-8                                    |
| 4:36:52 PM         | 117                    | 32.1                     | 19   | 5  | EMPTY             | 11                                     |
| 4:38:49 PM         | 119                    | 34.1                     | 24   | 13   | EMPTY             | 0                                      |
| 4:40:48 PM         | 117                    | 48.1                     | 25   | 8  | EMPTY             | 12-15                                  |
| 4:42:45 PM         | 121                    | 36.1                     | 22   | 2  | EMPTY             | 16                                     |
| 4:44:46 PM         | 132                    | 47.1                     | 24   | 0  | EMPTY             | 0                                      |
| 4:46:58 PM         | 117                    | 30.1                     | 11   | 0  | EMPTY             | 0                                      |
| 4:48:55 PM         | 110                    | 26.1                     | 16   | 5  | EMPTY             | 10-13                                  |
| 4:50:45 PM         | 118                    | 34.1                     | 21   | 5  | EMPTY             | 13-15                                  |
| 4:52:43 PM         | 119                    | 38.1                     | 17   | 1  | EMPTY             | 0                                      |
| 4:54:42 PM         | 126                    | 41.1                     | 22   | 2  | EMPTY             | 0                                      |
| 4:56:48 PM         | 126                    | 41.1                     | 15   | 0  | HALF FULL         | 0-4                                    |
| 4:58:54 PM         | 119                    | 45.1                     | 19   | 4  | HALF FULL         | 7-8                                    |
| 5:00:53 PM         | 117                    | 34.1                     | 23   | 3  | EMPTY             | 8                                      |
| 5:02:50 PM         | 115                    | 34.1                     | 25   | 8  | EMPTY             | 11                                     |
| 5:04:45 PM         | 117                    | 32.1                     | 22   | 6  | EMPTY             | 0                                      |
| 5:06:42 PM         | 112                    | 43.1                     | 21   | 0  | EMPTY             | 8-10                                   |
| 5:08:34 PM         | 127                    | 42.1                     | 18   | 0  | EMPTY             | 0                                      |
| 5:10:41 PM         | 126                    | 41.1                     | 17   | 1  | HALF FULL         | 0                                      |
| 5:12:47 PM         | 135                    | 57.1                     | 12   | 0  | HALF FULL         | 0                                      |
| 5:15:02 PM         | 120                    | 36.1                     | 25   | 5  | EMPTY             | 5                                      |
| 5:17:02 PM         | 122                    | 25.1                     | 24   | 10   | EMPTY             | 10                                     |
| 5:19:04 PM         | 125                    | 36.1                     | 28   | 14   | EMPTY             | 3-5                                    |
| 5:21:09 PM         | 122                    | 43.1                     | 28   | 12   | EMPTY             | 15-18                                  |
| 5:23:11 PM         | 128                    | 33.1                     | 35   | 15   | EMPTY             | 0                                      |
| 5:25:19 PM         | 128                    | 39.1                     | 32   | 17   | FULL              | 5-8                                    |
| 5:27:27 PM         | 135                    | 45.1                     | 26   | 7  | HALF FULL         | 9                                      |
| 5:29:42 PM         | 135                    | 49.1                     | 18   | 0  | EMPTY             | 18-20                                  |
| 5:31:57 PM         | 126                    | 39.1                     | 12   | 0  | EMPTY             | 5-7                                    |
| 5:34:03 PM         | 116                    | 36.1                     | 10   | 0  | EMPTY             | 10                                     |

Cycle failure

Available green time and storage space

Green time not available

Available green time, but no storage space

# Special-Event Traffic

- ❖ Garth Brooks concerts at UI's State Farm Center
  - Two concerts on April 29, 2017 and one concert on April 30, 2017
  - System inability to respond to volume increase on Kirby Avenue
  - Police took control of signal operation when both inbound and outbound had congestion
- ❖ Pre-marathon
  - Traffic pattern and traffic-signal operation were not normal
  - Data was not helpful to assess system performance
  - Police controlled traffic pattern and traffic-signal operation
- ❖ Marathon day
  - Flashing mode at the traffic signal of Stadium Drive
  - Traffic was closed at Neil Street between Kirby Avenue and Stadium Drive → traffic pattern changed and not operating in adaptive mode

# Garth Brooks concerts at the State Farm Center

❖ Inability to respond to volume increase on EBT (going to concert) on April 29, 2017

| Beginning of Cycle | Cycle Length (seconds) | EBT Green Time (seconds) | Video Observation                                    |  |                    | Unused Green Time on NBT/SBT (seconds) |
|--------------------|------------------------|--------------------------|--|--|--------------------|--|
|                    |                        |                          | Number of Vehicles in Queue on EBT at Start of Green | Number of Vehicles in Queue on EBT at End of Green | EBT Receiving Link |  |
| 1:35:46 PM         | 121                    | 17.1                     | 7+   | 5  | EMPTY              | 0                                      |
| 1:37:47 PM         | 115                    | 33.1                     | 8+   | 4  | EMPTY              | 3-5                                    |
| 1:39:42 PM         | 121                    | 21.1                     | 8+   | 4  | EMPTY              | 20                                     |
| 1:41:43 PM         | 125                    | 28.1                     | 5+   | 1  | EMPTY              | 0                                      |
| 1:43:48 PM         | 125                    | 28.1                     | 7+   | 5+   | HALF FULL          | 0                                      |
| 1:45:53 PM         | 128                    | 38.1                     | 5+   | 7+   | HALF FULL          | 0                                      |
| 1:48:01 PM         | 122                    | 29.1                     | 8+   | 2  | EMPTY              | 0                                      |
| 1:50:03 PM         | 125                    | 25.1                     | 8+   | 4  | EMPTY              | 5-6                                    |
| 1:52:08 PM         | 125                    | 24.1                     | 7+   | 7  | HALF FULL          | 0                                      |
| 1:54:13 PM         | 125                    | 28.1                     |  |  |                    |  |
| 1:56:18 PM         | 125                    | 18.1                     |  |  |                    |  |
| 1:58:23 PM         | 125                    | 17.1                     |  |  |                    |  |
| 2:00:28 PM         | 126                    | 28.1                     |  |  |                    |  |
| 2:02:34 PM         | 124                    | 21.1                     | 8+   | 5  | FULL               | 0                                      |
| 2:04:38 PM         | 125                    | 28.1                     | 7+   | 4  | HALF FULL          | 0                                      |
| 2:06:43 PM         | 125                    | 28.1                     | 8+   | 6+   | HALF FULL          | 0                                      |
| 2:08:48 PM         | 125                    | 28.1                     | 9+   | 6+   | FULL               | 0                                      |
| 2:10:53 PM         | 127                    | 28.1                     | 8+   | 5  | HALF FULL          | 0                                      |
| 2:13:00 PM         | 123                    | 28.1                     | 7+   | 7+   | FULL               | 0                                      |
| 2:15:03 PM         | 115                    | 37.1                     | 7+   | 6+   | HALF FULL          | 0                                      |
| 2:16:58 PM         | 127                    | 28.1                     | 7+   | 6+   | FULL               | 0                                      |
| 2:19:05 PM         | 112                    | 33.1                     | 7+   | 8+   | FULL               | 0                                      |
| 2:20:57 PM         | 114                    | 36.1                     | 8+   | 5+   | FULL               | 0                                      |
| 2:22:51 PM         | 117                    | 31.1                     | 7+   | 8+   | FULL               | 7                                      |
| 2:24:48 PM         | 107                    | 22.1                     | 8+   | 9+   | FULL               | 0                                      |
| 2:26:35 PM         | 117                    | 32.1                     | 9+   | 7+   | FULL               | 0                                      |
| 2:28:32 PM         | 110                    | 29.1                     | 7+   | 8+   | FULL               | 0                                      |
| 2:30:22 PM         | 125                    | 35.1                     | 8+   | 8+   | FULL               | 0                                      |
| 2:32:27 PM         | 114                    | 28.1                     | 8+   | 7+   | FULL               | 0                                      |
| 2:34:21 PM         | 110                    | 28.1                     | 7+   | 5+   | FULL               | 5-10                                   |
| 2:36:11 PM         | 114                    | 28.1                     | 8+   | 6+   | FULL               | 5-10                                   |
| 2:38:05 PM         | 117                    | 28.1                     |  |  |                    |  |
| 2:40:02 PM         | 116                    | 31.1                     | 7+   | 6+   | HALF FULL          | 0                                      |
| 2:41:58 PM         | 233                    | 95.1                     | 7+   | 1  | HALF FULL          | 30                                     |
| 2:45:51 PM         | 153                    | 47.1                     | 8+   | 0  | EMPTY              | 3-6                                    |
| 2:48:24 PM         | 186                    | 54.1                     | 7+   | 0  | EMPTY              | 40                                     |

Cycle failure

Available green time and storage space

Green time not available

Available green time, but no storage space

# Garth Brooks concerts at the State Farm Center

- ❖ Inability to respond to volume increase on EBT (going to concert) on April 29, 2017

| Beginning of Cycle | Cycle Length (seconds)                 | EBT Green Time (seconds) | Video Observation                                    |  |                    |                              |
|--------------------|--|--------------------------|--|--|--------------------|------------------------------|
|                    |  |                          | Number of Vehicles in Queue on EBT at Start of Green | Number of Vehicles in Queue on EBT at End of Green | EBT Receiving Link | Unused Green Time on NBT/SBT |
| 1:35:46 PM         | 121                                    | 17.1                     | 7+   | 6+   | EMPTY              | 0                            |
| 1:37:47 PM         | 115                                    | 33.1                     | 8+   | 4  | EMPTY              | 3-5                          |
| 1:39:42 PM         | 121                                    | 21.1                     | 8+   | 4  | EMPTY              | 20                           |
| 1:41:43 PM         | 125                                    | 28.1                     | 5+   | 1  | EMPTY              | 0                            |
| 1:43:48 PM         | 125                                    | 28.1                     | 7+   | 5+   | HALF FULL          | 0                            |
| 1:45:53 PM         | 128                                    | 38.1                     | 5+   | 7+   | HALF FULL          | 0                            |
| 1:48:01 PM         | 122                                    | 29.1                     | 8+   | 2  | EMPTY              | 0                            |
| 1:50:03 PM         | 125                                    | 25.1                     | 8+   | 4  | EMPTY              | 5-6                          |
| 1:52:08 PM         | 125                                    | 24.1                     | 7+   | 7+   | HALF FULL          | 0                            |
| 1:54:13 PM         | 125                                    | 28.1                     | No recording   |  |                    |                              |
| 1:56:18 PM         | 125                                    | 18.1                     |  |  |                    |                              |
| 1:58:23 PM         | 125                                    | 17.1                     |  |  |                    |                              |
| Cycle failure      | Available green time and storage space |                          | Green time not available                             |  |                    |                              |



# Conclusion

- ❖ First year implementation, ASCT seemed to favor minor-street over major-street
- ❖ Final year implementation deteriorated cases (63%) were more than first year (29%)
- ❖ Some reasonable explanation(s) for deteriorated cases (20 out of 35 cases) in final year
- ❖ Decreasing trend on fatal and injury crashes ( $CMF < 1$ ), but not significant
- ❖ No change on Total and PDO crashes ( $CMF \sim 1$ )

# Conclusion

- ❖ Average travel time increased in preferred directions
- ❖ PM SB experienced decrease in speed, and it may contribute to safety benefits by compromising efficiency
- ❖ Nearly one-half to two-thirds of cycle failures during WBT PM peak observation on three days
  - Most cases had unused green on SBT/NBT with available storage space on WBT receiving link
- ❖ Garth Brooks concerts at the State Farm Center
  - System inability to respond to volume increase on Kirby Avenue
  - Cycle failures even for early arrivals with unused green on SBT/NBT with available storage space on WBT receiving link
    - Could have created worsened situation for late arrivals with unused green on SBT/NBT with NO available space

Thanks!

Questions?

Kyle Armstrong ([Kyle.Armstrong@illinois.gov](mailto:Kyle.Armstrong@illinois.gov))

Ray Benekohal ([rbenekoh@illinois.edu](mailto:rbenekoh@illinois.edu))

Hongjae Jeon ([hjeon17@Illinois.edu](mailto:hjeon17@Illinois.edu))