Reliability, Flexibility, And Environmental Impact Of Alternative Arterial Offset Optimization Objective Functions

Christopher M. Day[1], Thomas M. Brennan Jr.[1], Alexander M. Hainen[1], Stephen M. Remias[1], Hiromal Premachandra[1], James R. Sturdevant[2], Greg Richards[2], Jason S. Wasson[2], and Darcy M. Bullock[1]

1: Purdue University; 2: Indiana Department of Transportation

Paper No. 11-0036

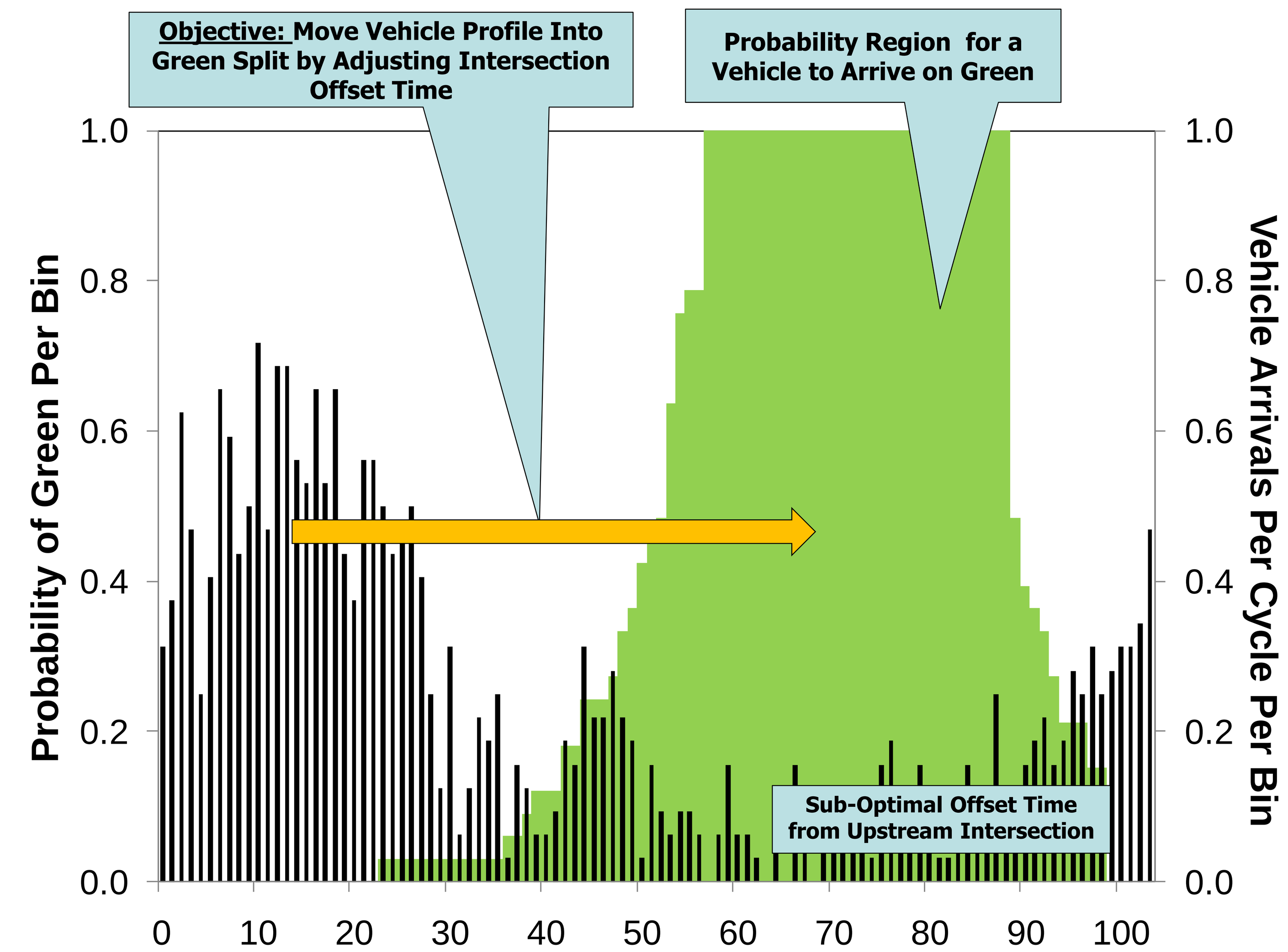
Motivation

There are a number of different opinions on which optimization objective function is best. It is desirable to use high resolution controller data and probe vehicle travel times to compare multiple objective functions to determine which function performs best on a coordinated arterial?

Approach

- Establish a baseline measurement of travel time along an arterial.
- Optimize offset times using four alternative objective functions:
  - Minimize delay
  - Minimize delay and stops
  - Maximize vehicle arrivals on green
  - Maximize vehicle arrivals on green without startup time
- Implement four optimized offsets at eight intersections
- Measure travel times of probe vehicles to assess travel time associated with each objective.
- Calculate the potential driver benefits for changing offset times to accommodate optimal travel time and platoon dispersion.

Offset Objective Function Concept



- Graph Shows Vehicle Flow Profile for a Single Intersection on a Coordinated Arterial
- Poor Progression is Shown with Majority of Vehicles Arriving on Red

- **Objective I:** Minimize delay (d)

$$d = w\sum_i q_i$$

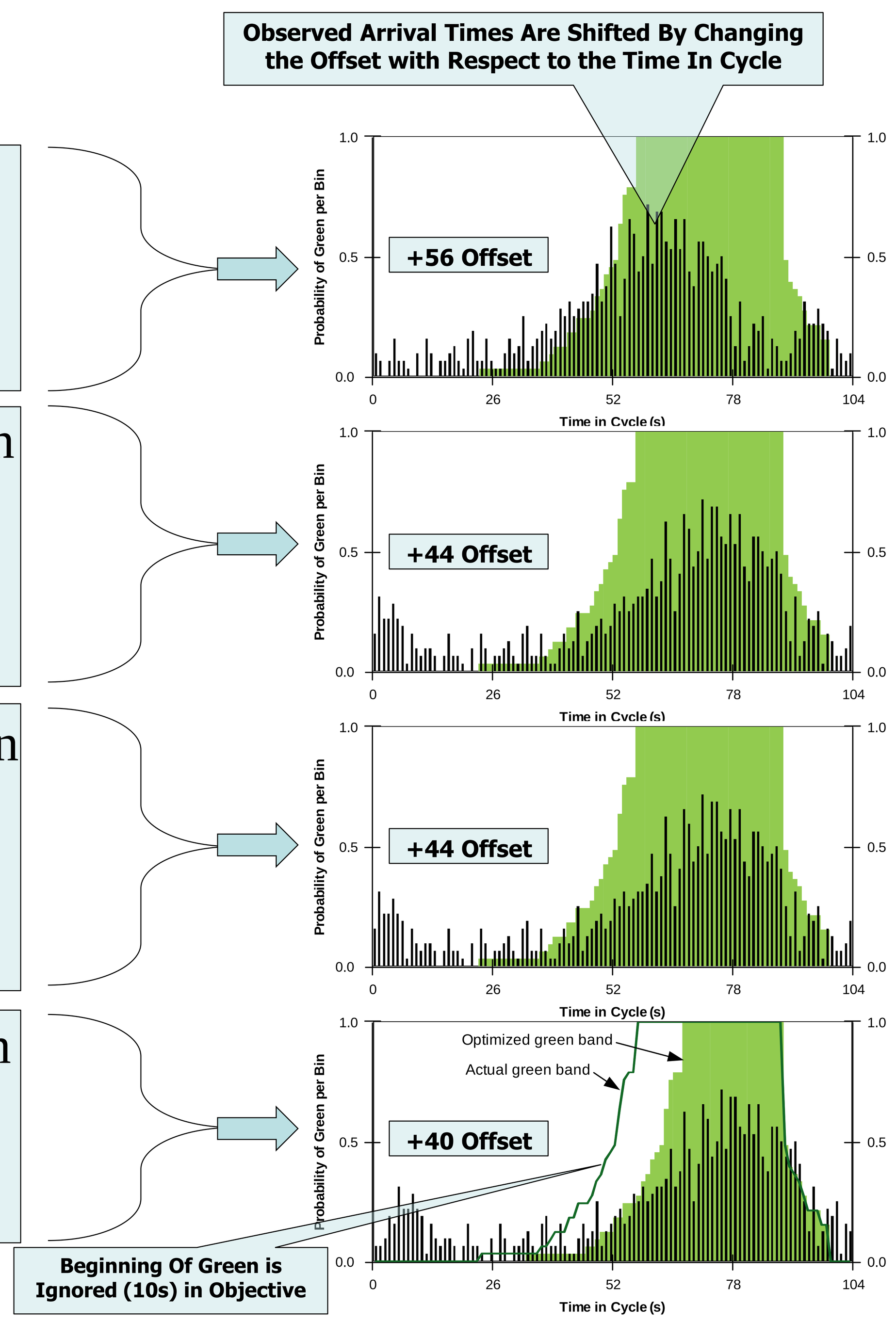
- **Objective II:** Minimize delay and stops in a performance index (PI).

$$PI = d + k\sum_i S_i$$

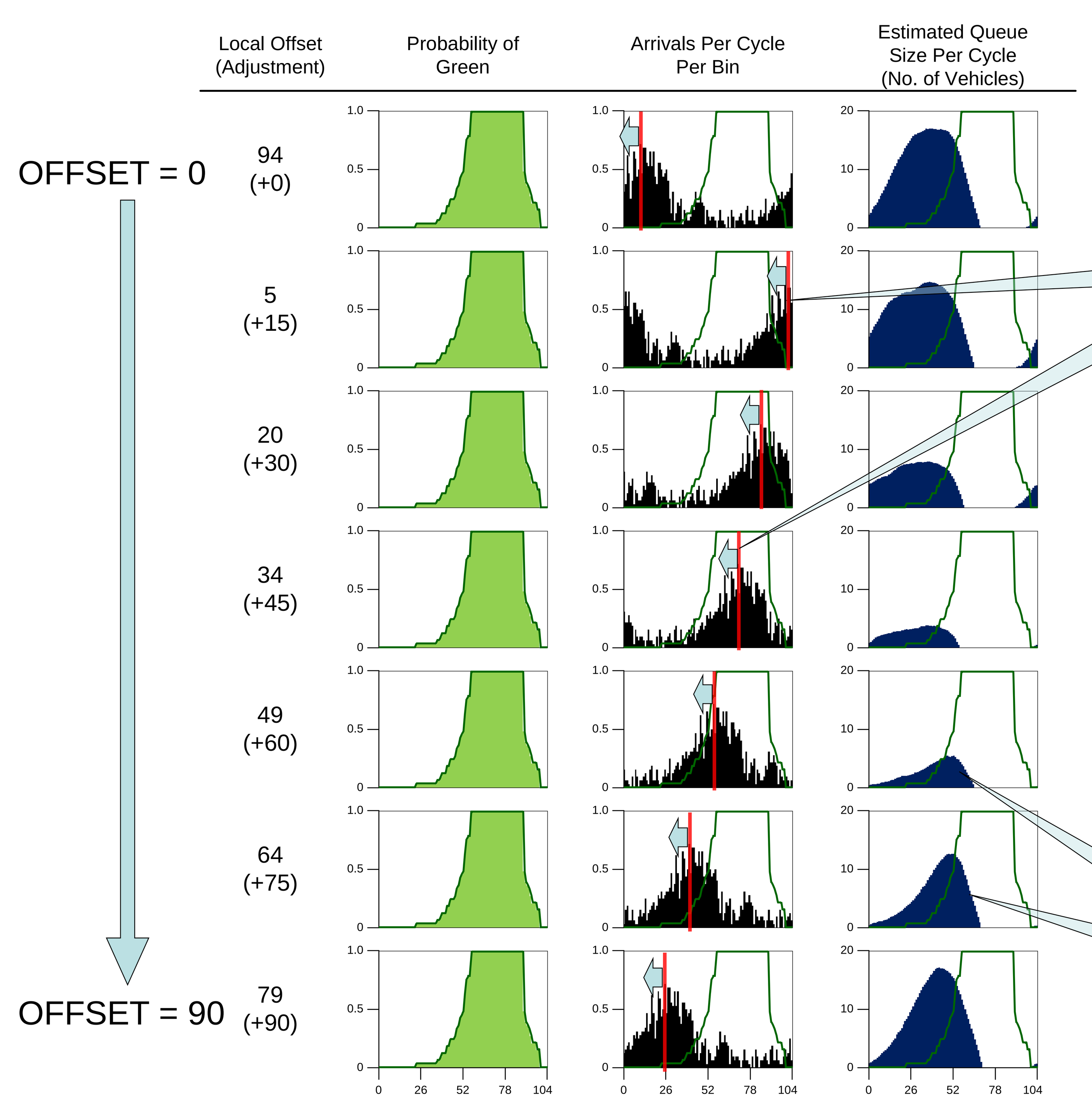
- **Objective III:** Maximize arrivals on green (N_g) [From **Pro-Tracts** & **ACS/lite**]

$$N_g = \sum_i G_i N_i$$

- **Objective IV:** Maximize arrivals on green with queue clearance time set at 10 seconds

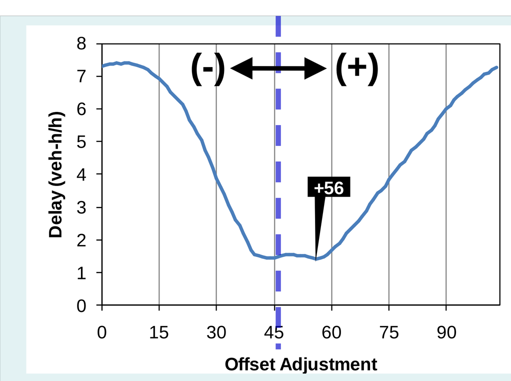


Effect Of Adjusting Local Offset To Shift Vehicle Arrivals With Respect To Green Time

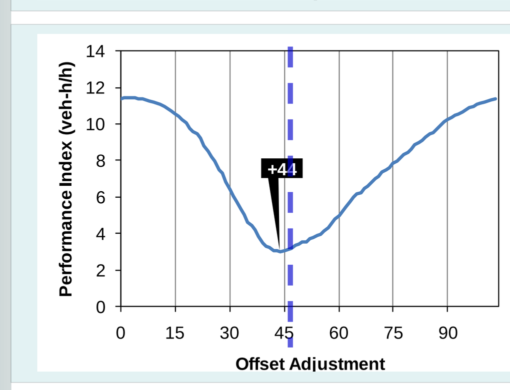


Optimal Offsets Calculated Based On Objective

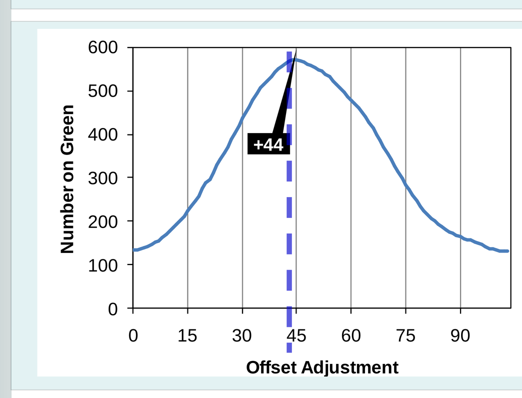
In General, Optimal Offsets Of Each Objective Functions Are Close



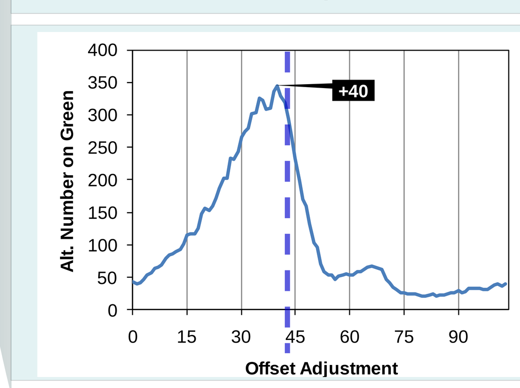
Objective I: Minimize Delay



Objective II: Minimize Delay & Stops

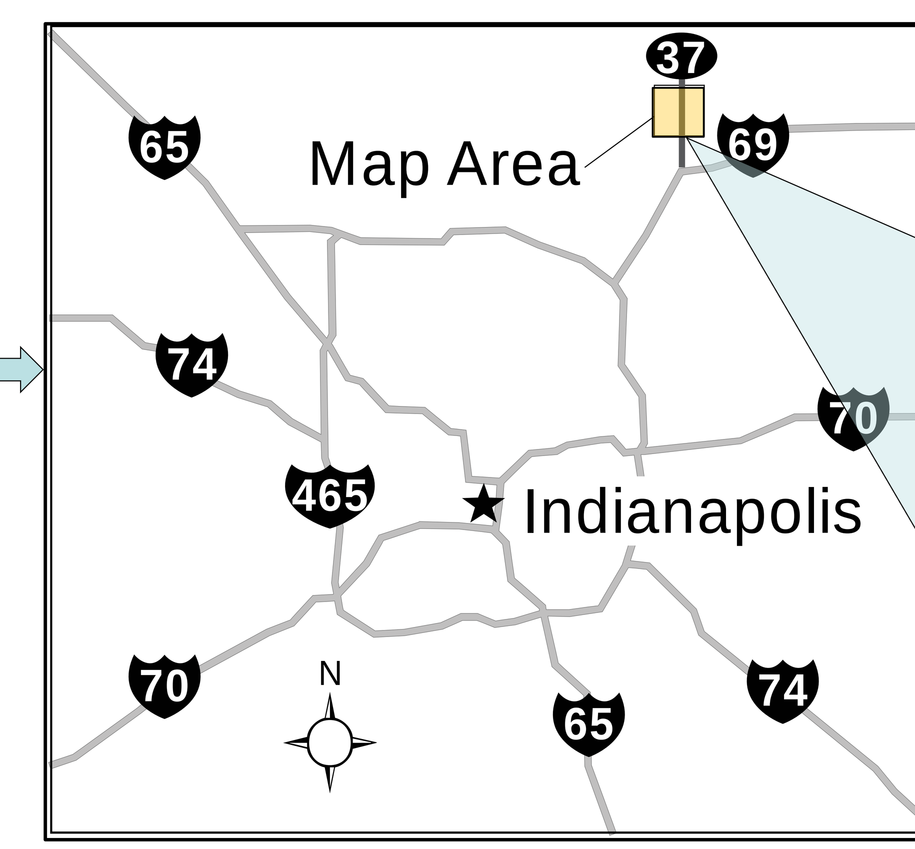


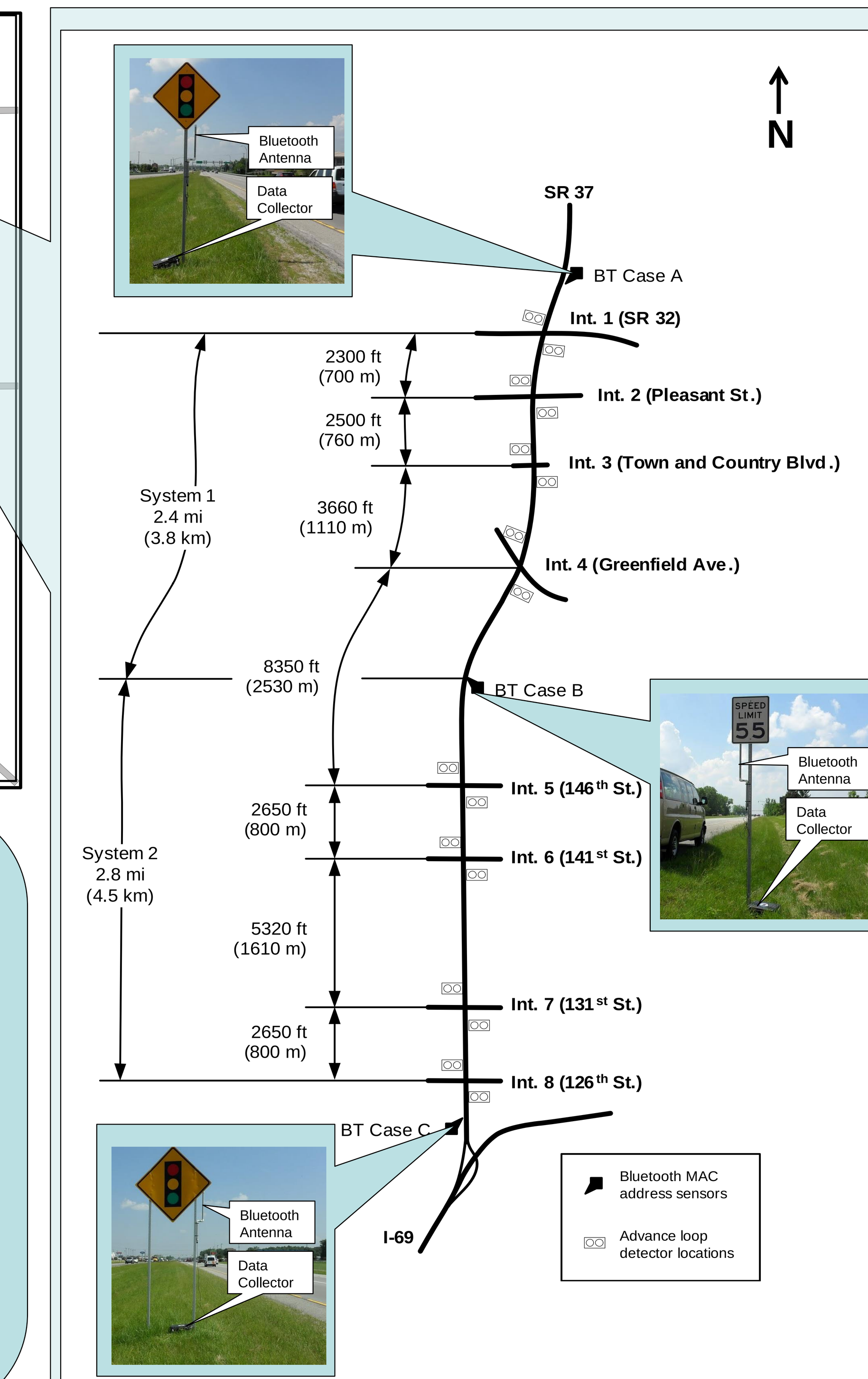
Objective III: Maximize Arrivals On Green



Objective IV: Maximize Arrivals On Green With 10s Queue Clearance

Calculated Optimal Offsets Tested On Weekend Plans Along Study Corridor





- FIVE SATURDAY DATA COLLECTION PERIODS

DATA COLLECTION DATE	OBJECTIVE
June 5th, 2010	BASE DATA
June 12th, 2010	I
June 19th, 2010	II
June 26th, 2010	III
July 3rd, 2010	IV

- AVERAGE SATURDAY VEHICLE VOLUME: ~30,000
- TIME OF DAY PLAN: 0600 – 2200
- INTERSECTIONS: 8
- CYCLE LENGTH: 114 Seconds

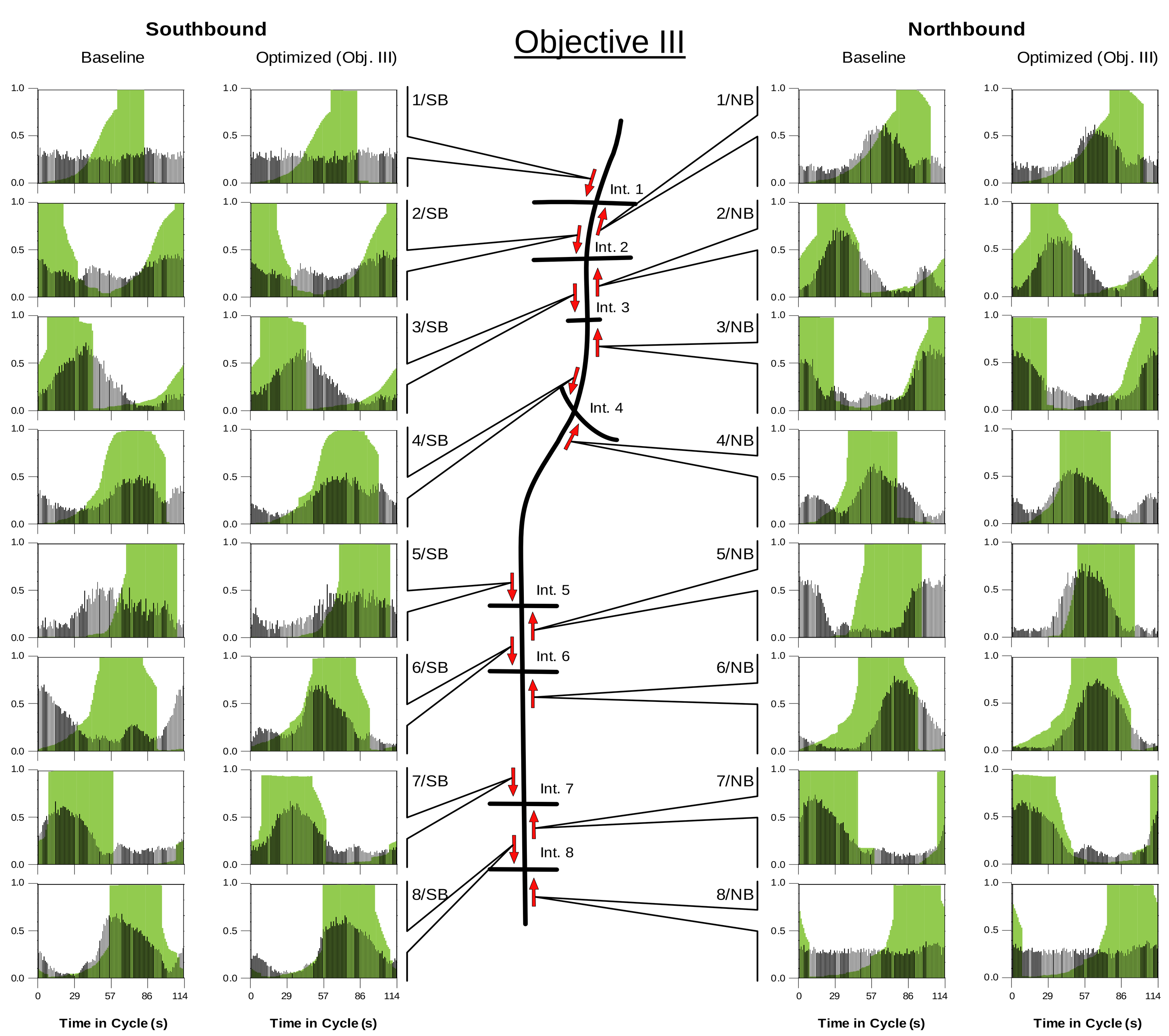
Reliability, Flexibility, And Environmental Impact Of Alternative Arterial Offset Optimization Objective Functions

Christopher M. Day[1], Thomas M. Brennan Jr.[1], Alexander M. Hainen[1], Stephen M. Remias[1], Hiromal Premachandra[1], James R. Sturdevant[2], Greg Richards[2], Jason S. Wasson[2], and Darcy M. Bullock[1]

1: Purdue University; 2: Indiana Department of Transportation

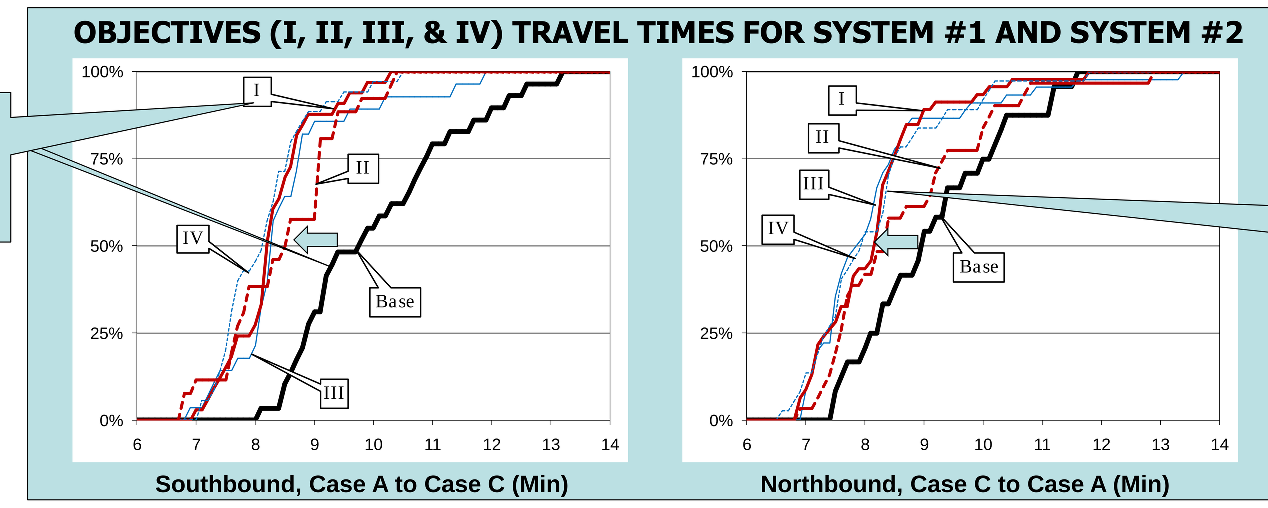
Paper No. 11-0036

Flow Profiles For Baseline And Optimized Offsets For The Saturday (0600 – 1800) TOD Plan



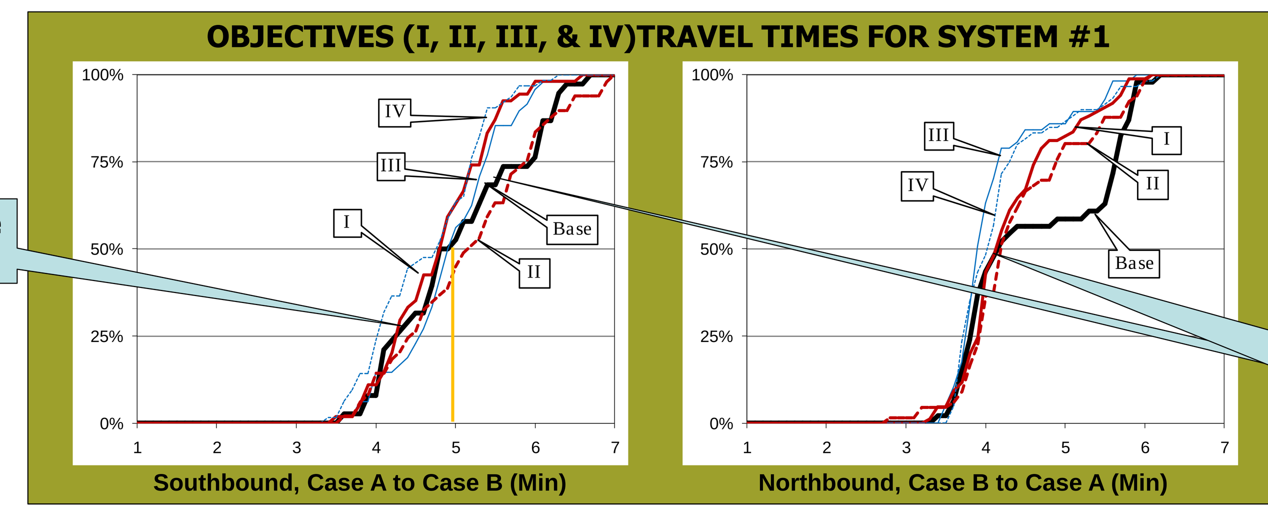
Flow Profiles Generated from High-Resolution ASC/3 Controller Data at Each of the 8 Intersections

Measured Travel Times Along Corridor To Assess The Effect Of Offset Change



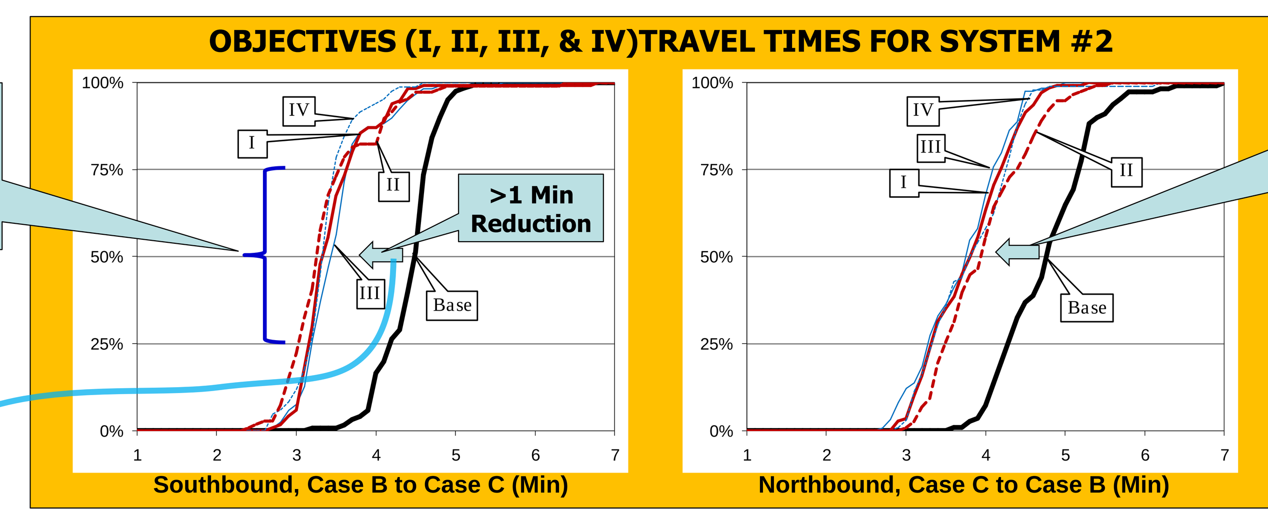
Each Objective (I, II, III, & IV) Travel Time Compared to the Base

Overall, the Travel Times Through Systems #1 & #2 Improved



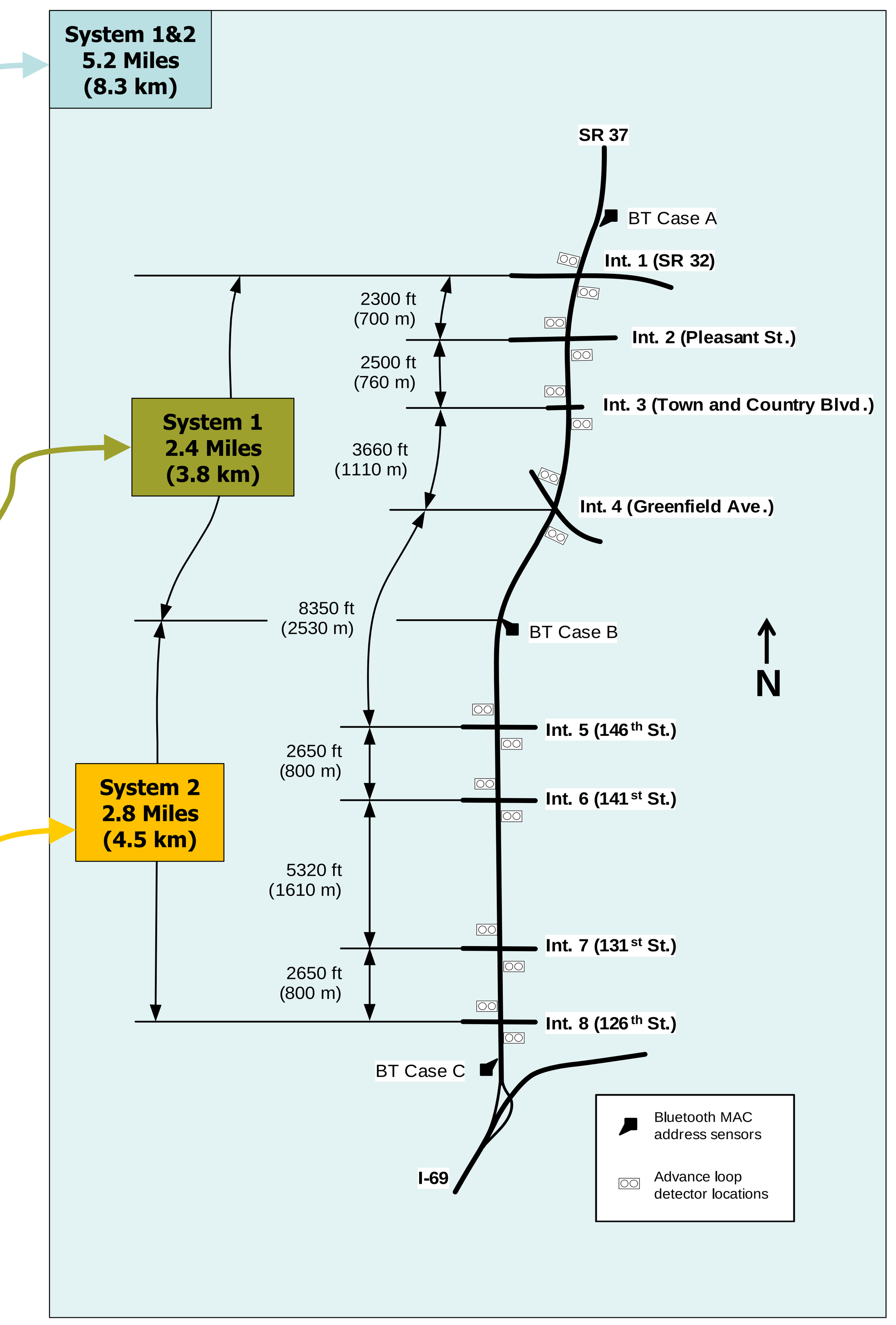
Median Travel Time ~5-Minutes

System #1 Had Been Previously Optimized, with Minimal Travel Time Improvement Measured



No Change in Travel Time Reliability (Slope of the line)

System #2 had Not Been Previously Optimized and it Showed the Most Improvement to the Travel Time



Quantifying The Potential Driver Benefit Gained By Adjusting Coordinated Signal Offsets For A Saturday Time-of-Day Plan

Travel Times Based For Each System and Each Objective

$$\Delta TT = TT_{Base(section)} - TT_{Objective(section)}$$

2% Trucks: $$USER_t = \Delta TT * Vol * \%T * PPV_t * \frac{\$102.12}{hr} * \frac{1\,hr}{60\,min}$$

98% Cars: $$USER_c = \Delta TT * Vol * \%C * PPV_c * \frac{\$15.47}{hr} * \frac{1\,hr}{60\,min}$$

$$FUEL = \Delta TT * Vol * \frac{0.87\,gal}{hr} * \frac{1\,hr}{60\,min}$$

$$CO_2 = FUEL * \frac{19.4\,lbs}{gal} * \frac{1\,ton}{2000\,lbs}$$

$$CC = CO_2 * \frac{\$22}{ton}$$

Hour Costs Obtained From TTI

Objective		Daily Total Time Saved (veh-min)	Daily CO_2 Emission Reduction (tons)	Daily CO_2 Savings	Daily User Benefits	Multi-plier	Annual CO_2 Emission Reduction (tons)	Annual CO_2 Savings	Annual User Benefits
System 1 and System 2, Arterial									
I	Min Delay	29418	4.14	$91	$9,920	52	215	$4,733	$515,847
II	Min Delay and Stops	29140	4.10	$90	$9,826	52	213	$4,689	$510,976
III	Max N_g	26907	3.78	$83	$9,073	52	197	$4,329	$471,817
IV	Alt. Max N_g	34221	4.81	$106	$11,540	52	250	$5,506	$600,073
System 1, Northern Section									
I	Min Delay	5032	0.71	$16	$1,697	52	37	$810	$88,233
II	Min Delay and Stops	3813	0.54	$12	$1,286	52	28	$614	$66,864
III	Max N_g	1760	0.25	$5	$593	52	13	$283	$30,855
IV	Alt. Max N_g	7883	1.11	$24	$2,658	52	58	$1,268	$138,229
System 2, Southern Section									
I	Min Delay	24386	3.43	$75	$8,223	52	178	$3,924	$427,614
II	Min Delay and Stops	25327	3.56	$78	$8,541	52	185	$4,075	$444,111
III	Max N_g	25147	3.54	$78	$8,480	52	184	$4,046	$440,962
IV	Alt. Max N_g	26338	3.70	$81	$8,882	52	193	$4,238	$461,845

- **All** Objectives Where Found to Have a Positive Financial and Environmental Impact on The Eight Intersection Study Corridor.
- The Improved Weekend Travel Times can be Equated to a Lower Bound Annual User Cost Saving of **$471,817.**
- The Improved Weekend Travel Times Reduce Fuel Consumption and Thus Decrease the Lower Bound Annual Carbon Cost Equivalent by **$4,329.**

Estimated Reduction in Fuel Consumption

20,300 – 25,500 Gallons

Estimated Reduction in CO_2 Output

197-250 Tons