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Flashing Yellow Arrow Signal Indications – A Case Study (Kingsport, TN)

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KINGSPORT
TENNESSEE

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ENGINEERS • SURVEYORS


GOOD LUCK
45
M.P.H.

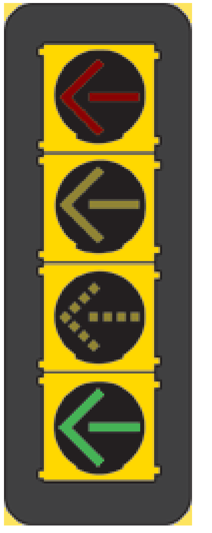

CORRECTIONAL
FACILITY
AREA
DO NOT PICK UP
HITCHHIKERS


NOT A
WALKWAY


KEEP
RIGHT

Background

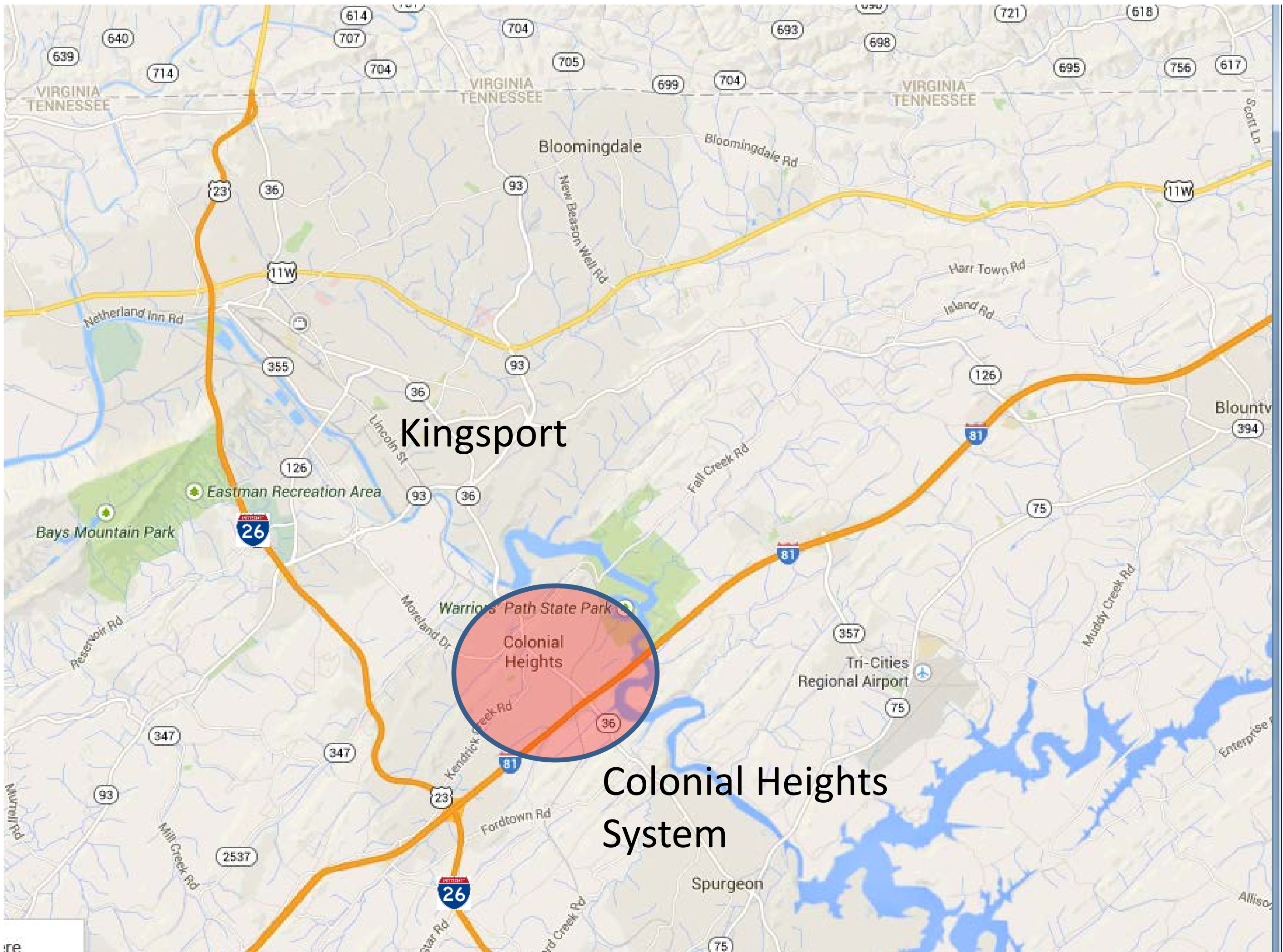
- NCHRP 493 (2003)
  – Concluded that the flashing yellow arrow (“FYA”) was safer and more effective than circular green
- 2009 MUTCD
  – Included the flashing yellow arrow as an allowable signal display
- City of Kingsport, TN
  – Population 50,000
  – Maintains 103 traffic signals
  – 2012: City Traffic Engineering staff began to investigate replacing five-section protected/permissive signal indications with four-section FYA indications
  – Spring 2013: City hired Mattern & Craig to update coordinated timing plans for the “Colonial Heights” system, and use this system as a pilot project for FYA implementation



Background (cont.)

- Colonial Heights system
  - 6 interconnected signals
  - Fort Henry Drive (S.R. 36), major arterial carrying 25,000 vpd
  - Sept. 2013: City replaced all five-section heads at these intersections with FYA, and concurrently implemented the updated coordinated timing plans
  - City staff collected travel time data along corridor shortly before and shortly after the change

Location

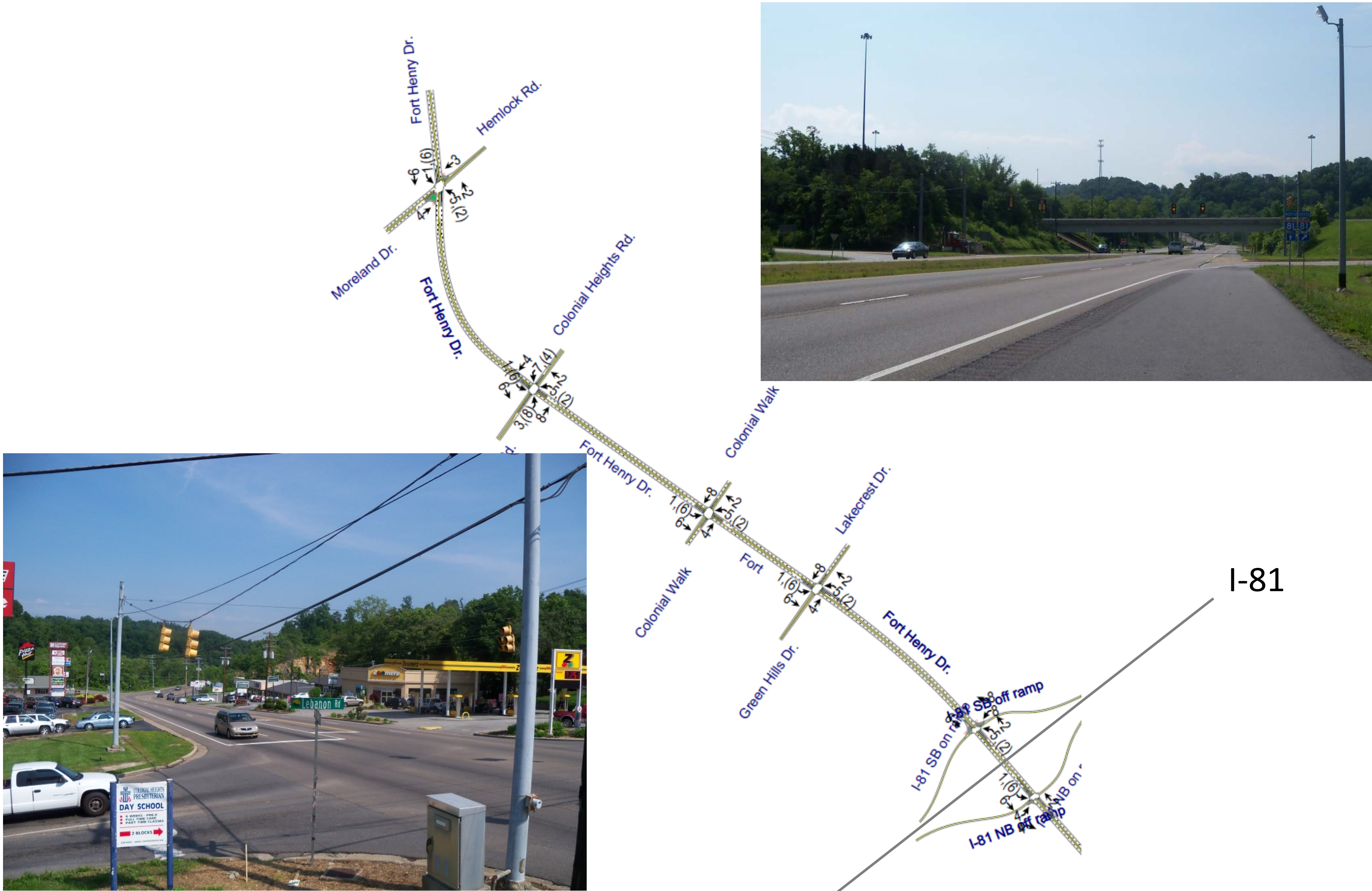


Bristol

Knoxville

Johnson City

Location


Fort Henry Dr.
Hemlock Rd.
Moreland Dr.
Colonial Heights Rd.
Colonial Walk
Lakecrest Dr.
Green Hills Dr.
I-81 SB off ramp
I-81 NB off ramp
I-81
Lebanon Rd
DAY SCHOOL

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FYA installation

Crash Rate Analysis

- City staff compiled crash data for the 6 intersections from Sept. 2011 to Dec. 2014 (24 months prior to implementation, 15 months after)
- At each intersection, angle crashes and rear-end crashes were tabulated, with a separate tally of angle crashes involving a left-turning vehicle on Ft. Henry Dr. and rear-end crashes involving vehicles on Ft. Henry Dr.

Before/After Crash Data

INTERSECTION	CRASHES BEFORE IMPLEMENTATION (24 MONTHS)				CRASHES AFTER IMPLEMENTATION (15 MONTHS)			
	ANGLE (TOTAL)	ANGLE (FT HENRY LEFT TURN)	REAREND (TOTAL)	REAREND (FT HENRY)	ANGLE (TOTAL)	ANGLE (FT HENRY LEFT TURN)	REAREND (TOTAL)	REAREND (FT HENRY)
I-81 NB Ramps	4	3	9	8	2	1	4	3
I-81 SB Ramps	4	1	6	6	1	1	4	4
Green Hills/Lakecrest	7	2	12	10	1	0	5	4
Colonial Walk	3	0	4	4	1	0	2	2
Lebanon/Col. Heights	3	1	20	16	3	0	8	5
Moreland/Hemlock	3	1	39	19	3	3	26	12

Crash Rate Analysis (cont.)

- Total intersection volumes were calculated:
  - 12-hour (0700-1900) turning movement counts were collected in Feb. 2013 for timing update
  - TDOT has a permanent count station along S.R. 36 (north of I-81)
  - Expansion factor was calculated to extrapolate 24-hour intersection volumes from turning movement counts

Crash Rate Analysis (cont.)

- Crash rates (per million entering vehicles) for each crash type, at each intersection, were calculated:

$$R = \frac{1{,}000{,}000 \times C}{365 \times N \times V}$$

R = crash rate per million entering vehicles

C = # of crashes in study period

N = # of years of data

V = total intersection traffic volume (vpd)

Before/After Crash Rates

INTERSECTION	CRASH RATES PER MILLION ENTERING VEHICLES							
	ANGLE (TOTAL)		ANGLE (FT HENRY LEFT TURN)		REAR-END (TOTAL)		REAR-END (FT HENRY)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
I-81 NB Ramps	0.2439	0.1951	0.1829	0.0976	0.5488	0.3903	0.4878	0.2927
I-81 SB Ramps	0.1986	0.0794	0.0496	0.0794	0.2979	0.3177	0.2979	0.3177
Green Hills/Lakecrest	0.3311	0.0757	0.0946	0.0000	0.5676	0.3784	0.4730	0.3027
Colonial Walk	0.1363	0.0727	0.0000	0.0000	0.1818	0.1454	0.1818	0.1454
Lebanon/Col. Heights	0.1107	0.1772	0.0369	0.0000	0.7382	0.4724	0.5906	0.2953
Moreland/Hemlock	0.1137	0.1819	0.0379	0.1819	1.4777	1.5762	0.7199	0.7275
Mean=	0.1891	0.1303	0.0670	0.0598	0.6353	0.5467	0.4585	0.3469
Std. Dev.=	0.0870	0.0599	0.0644	0.0741	0.4587	0.5161	0.1945	0.1969

Crash Rate Analysis (cont.)

- Before/after crash rates (for each type) were analyzed for statistical significance.
  - Data sets were analyzed to determine if normally distributed (done by visual observation of histograms). Data did ***not*** follow a normal distribution.
  - Wilcoxon Rank-Sum test was applied to each before/after paired data set.

Crash Rate Analysis (cont.)

- Wilcoxon Rank-Sum test:
  - Non-parametric test
  - Tests if difference in the median value for each paired set is significant
  - All values in a paired data set are ranked in increasing numerical order
  - Sums the ranks for each set (i.e. “before” and “after”)
  - Smaller sum becomes the W-statistic, and is compared to the critical W-statistic for a given sample size and confidence level
  - If W-statistic for a given pair is less than W-critical, then the difference in median values is statistically significant

Wilcoxon Rank-Sum Test Results

	ANGLE (TOTAL)		ANGLE (FT HENRY LEFT TURN)		REAR-END (TOTAL)		REAR-END (FT HENRY)	
	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
	11	9	12	10	8	6	9	3
	10	3	7	8	3	4	5	7
	12	2	9	2.5	9	5	8	6
	6	1	2.5	2.5	2	1	2	1
	4	7	5	2.5	10	7	10	4
	5	8	6	11	11	12	11	12
Rank sum, R =	48	30	41.5	36.5	43	35	45	33
W =	30		36.5		35		33	
α (two-tail)=	0.05	0.20						
W_{crit} =	26	30						
$W < W_{crit}$?		**Y**		**N**		**N**		**N**

- Rear-end collision crash rates decreased, but the difference is ***not*** statistically significant
- Angle collision crash rates also decreased. The difference in total angle crash rates ***is*** statistically significant at the 80% confidence level. The difference in left-turning angle crashes is ***not*** statistically significant, likely due to small sample size.

Operational Analysis

- Updated coordinated timing plans for the system were implemented in Sept. 2013.
  - Previous timings were developed in 2006 (also by Mattern & Craig)
  - Plans employ 3 patterns (AM, mid-day, PM) for weekday traffic; run free from 2200 to 0630
  - Timing updates were minor:
    - Slight (5-second) changes in cycle lengths (all are 80-100 seconds)
    - Clearance intervals adjusted
    - Minor (1-3%) changes in splits
    - Lead/lag left-turn phasing employed for phases 1 & 5, varies by time of day

Example timings

Intersection No./Zone	Int., Channel, Address	Location	Printed	Developed By	Installed On
410 / 1	6,1,6	Fort Henry Drive at Moreland/Hemlock	05/29/13	Mattern & Craig	

FREE RUN TIMING INFORMATION

○ All phase timing information can be found in the field controller.
● Modify field controller timing information with provided table values.

PHASE(S)	1	2	3	4	5	6	7	8
MINIMUM GREEN								
PASSAGE/GAP								
YELLOW								
RED			2.0	2.0				
MAX GREEN 1								
MAX GREEN 2								
WALK								
FLASHING DON'T WALK								
RECALL								
VEHICLE CALL MEMORY								

TIME OF DAY FUNCTIONS

● All TOD information can be found in the field controller.
○ Modify field controller TOD data with provided table values.
○ Replace field controller data with provided table values

TIME		FUNCTION	DAY OF WEEK						
Start	End		S	M	T	W	R	F	S

COORDINATION PLANS AND TIME-OF-DAY SCHEDULE

○ All coordination data, including splits, offsets, and schedule information can be found in the field controller.
● All coordination data, including splits, offsets, and schedule information should be installed as shown in the following tables.
○ The required coordination data includes information from both the field controller and the following tables. Where conflicts exist, table values have precedence.

COORDINATION TIMING PLAN INFORMATION

PLAN:	1	2	3	4	5	6	7	8
PATTERN	1	2	3					
CYCLE LENGTH	85	90	95					
SPLITS: PHASE 1	14/12	13/12	13/12					
PHASE 2	46/39	49/44	51/48					
PHASE 3	15/13	14/13	14/13					
PHASE 4	25/21	23/21	23/22					
PHASE 5	24/20	23/21	21/20					
PHASE 6	36/31	39/35	42/40					
PHASE 7	-	-	-					
PHASE 8	-	-	-					
COORDINATED PHASES	2,6	2,6	2,6					
LAG PHASES	1,4,5	1,4	1,4					
OFFSET 1	82/70	83/75	84/80					
OFFSET 2								
OFFSET 3								
OFFSET 4								

TIME BASED COORDINATION SCHEDULE

TIME		PATTERN	C/O/S	DAY OF WEEK						
Start	End			S	M	T	W	R	F	S
6:30	9:30	1	1/1/1		X	X	X	X	X	
9:30	14:30	2	2/1/1		X	X	X	X	X	
14:30	19:00	3	3/1/1		X	X	X	X	X	
19:00	22:00	2	2/1/1		X	X	X	X	X	
22:00	6:30	FREE	FREE		X	X	X	X	X	
8:00	21:00	2	2/1/1	X						X
21:00	8:00	FREE	FREE	X						X

Notes:
1. All splits and offsets are given in PERCENT/SECONDS.
2. Offsets are referenced to the end of the first coordinated green.

Operational Analysis (cont.)

- City staff completed travel time runs shortly before implementation, and several months after, using the "floating car" technique
- Multiple runs in each direction and for each pattern, both before and after, were completed
- Mean travel time ("T") and space-mean speed ("S") were calculated

Operational Analysis (cont.)

TIME PERIOD / PATTERN	TRAVEL TIME RUN #	SOUTHBOUND			NORTHBOUND		
		BEFORE	AFTER	Δ	BEFORE	AFTER	Δ
		TRAVEL TIME, T (sec)			TRAVEL TIME, T (sec)		
AM	1	156	144		190	151	
	2	182	157		191	157	
	3		141		190	194	
	4		153			152	
	ΣT	338	595		571	654	
	n	2	4		3	4	
	T_{mean}	169	149	-20	190	164	-27
	S (mph)	31.1	35.3	4.2	27.6	32.1	4.5
MID	1	156	148		230	183	
	2	188	172		151	209	
	3	146			132		
	4						
	ΣT	490	320		513	392	
	n	3	2		3	2	
	T_{mean}	163	160	-3	171	196	25
	S (mph)	32.2	32.9	0.7	30.7	26.8	-3.9
PM	1	154	156		163	142	
	2	179	151		146	156	
	3	145	150		179	177	
	4	224				158	
	ΣT	702	457		488	633	
	n	4	3		3	4	
	T_{mean}	176	152	-23	163	158	-4
	S (mph)	29.9	34.5	4.6	32.3	33.2	0.9

Conclusions

- Previous studies have demonstrated the *safety* benefits of flashing yellow arrow indications (*i.e. NCHRP web-only document 123*)
- This study has shown that their implementation in Kingsport has improved *both safety and operations* (although statistical significance is low, due to sample size)
- Recommendations:
  - Study this corridor further (collect 3+ years before/after crash data)
  - Study other locations in Kingsport

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Questions?

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