Addressing Bicycle-Vehicle Conflicts with Alternate Signal Control Strategies

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Work funded by NITC, the National Institute for Transportation and Communities
Portland State University

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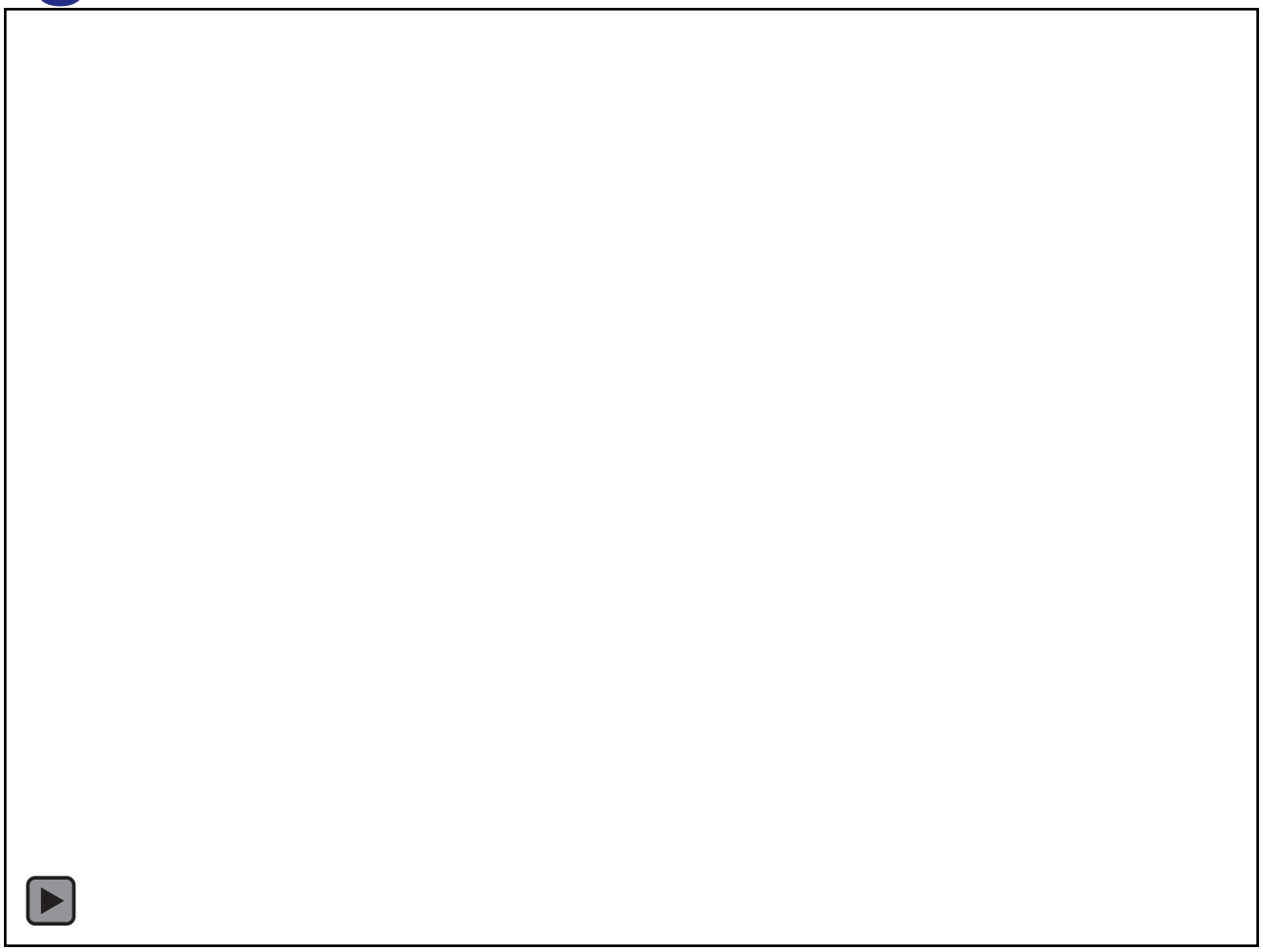
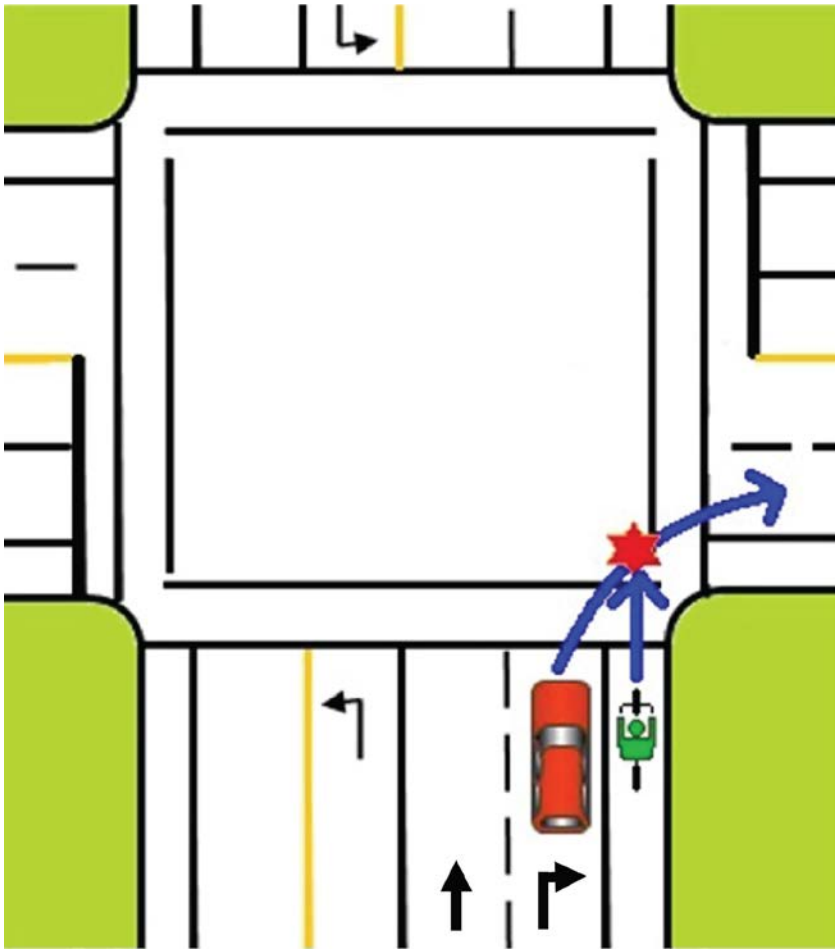
Right Hook Conflict



Project Objectives

- Assess the safety and efficiency impacts of various signal timing treatments that currently exist for right-hook bicycle-vehicle conflicts on all users
  - Traditional phasing
  - LBI
  - Exclusive Phasing
  - Split LBI (Emerging treatment)
- Field implementation of Split LBI treatment and evaluation of impacts

Motivation



- Intersection design treatments exist
  - Colored pavement markings
  - Enhanced curb radii
  - Signage
  - Protected intersections
- Limited research on signal control treatments

(Source: Hurwitz et al., 2015)

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Methodology

- Comprehensive Review of Conflict Treatments and Practitioner Survey
- SITL Simulation of Alternate Control Treatments
- Deployment and Field Data Collection

Split LBI Implementation in NYC

Source: NYCDOT

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Project Milestones

- Literature Review and Practitioner Survey ✓
- SITL Simulation of Alternate Control Treatments ✓
- **Identification of Field Deployment Sites**
  - **Phoenix** ✓
  - **Portland** ✓
  - **NYCDOT** ✓
- **Field Deployment of Split LBI/LBI –** ✓
- **Analysis of Field Deployment Data -** ✓
- Final Report ✓
- Guidance Document ✓

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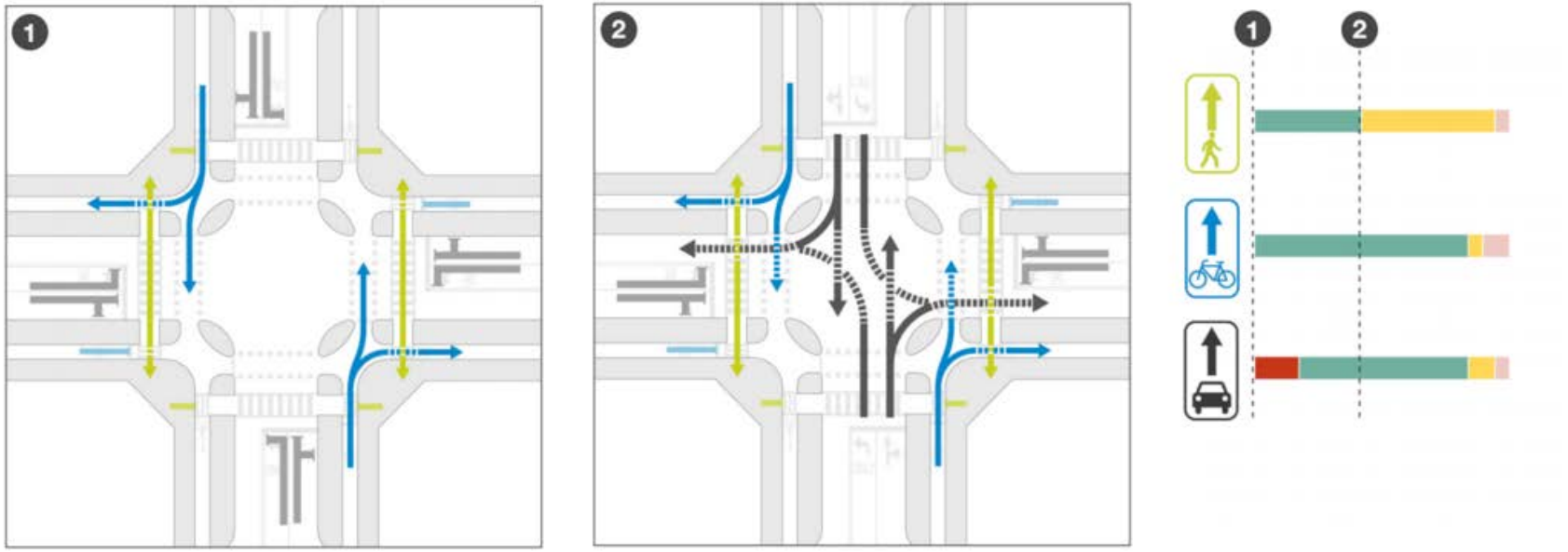
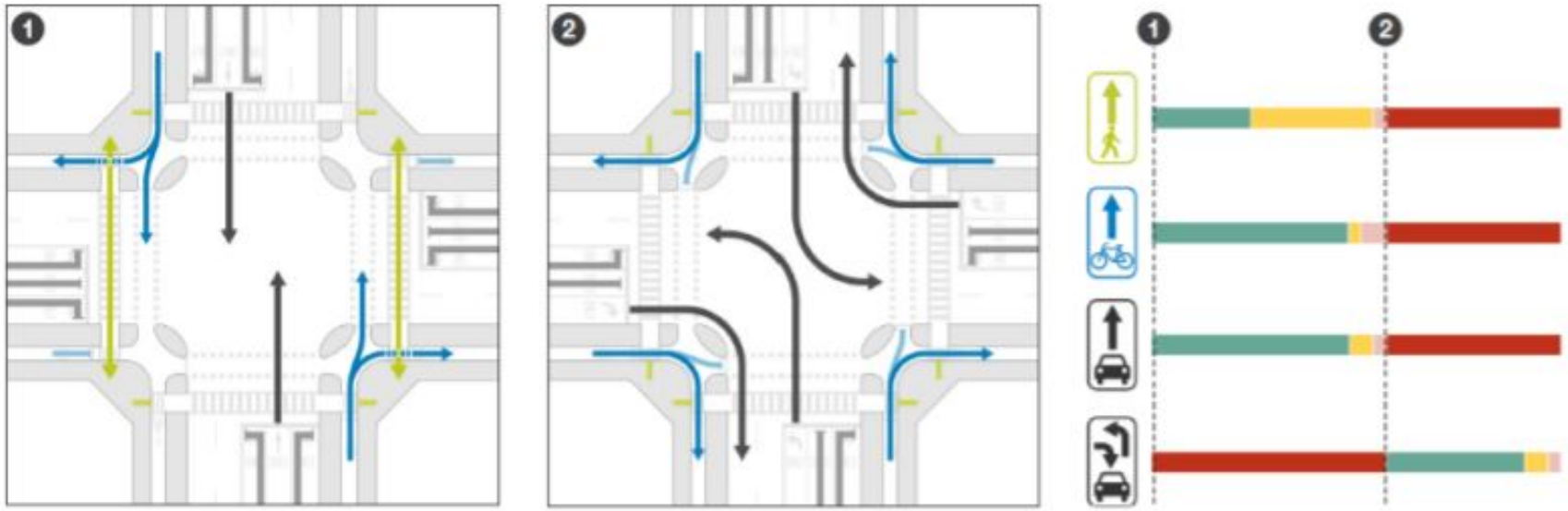
Leading Bike Interval (LBI)



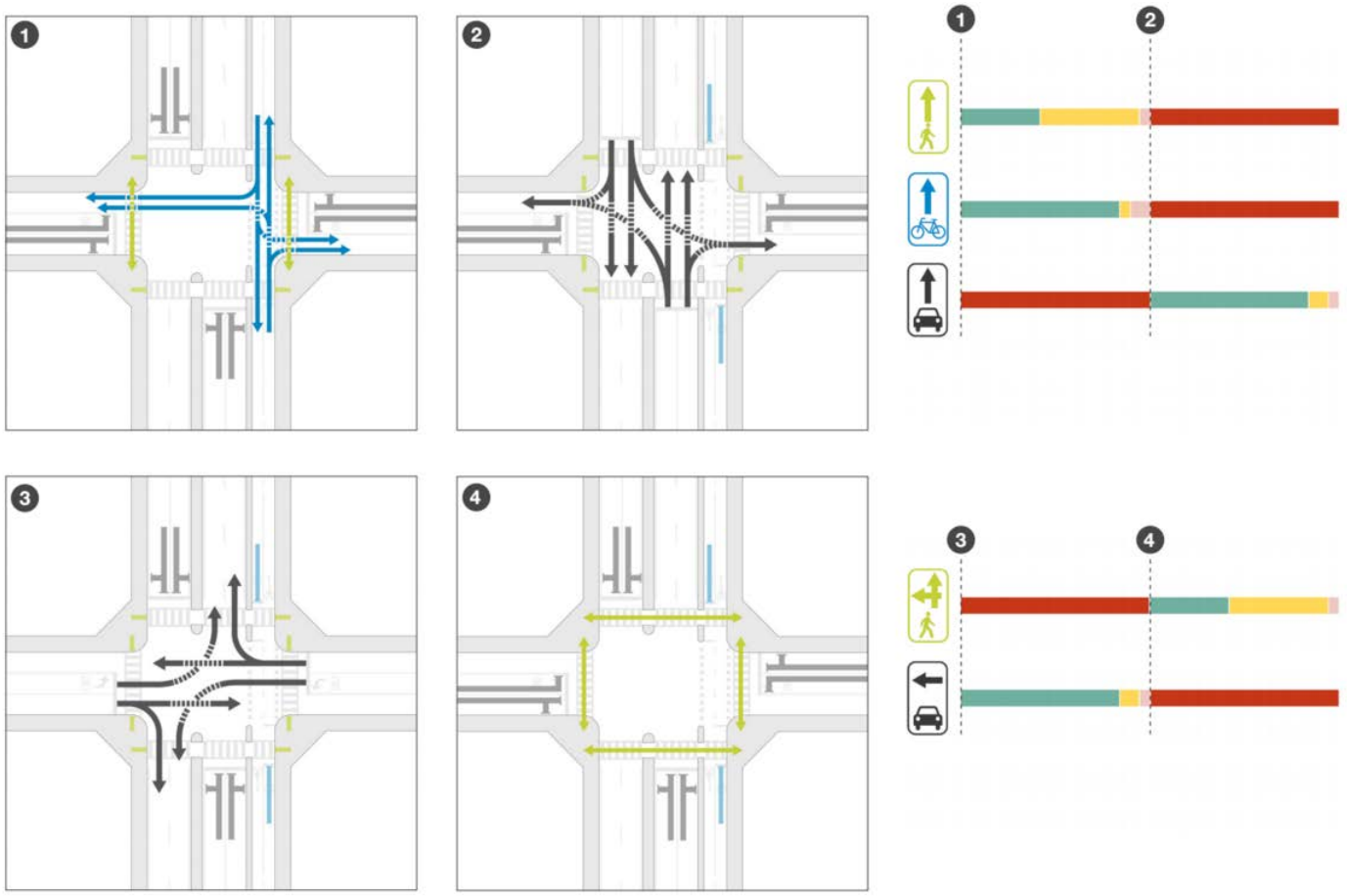
Source:
Mass DOT

Split Leading Bike Interval



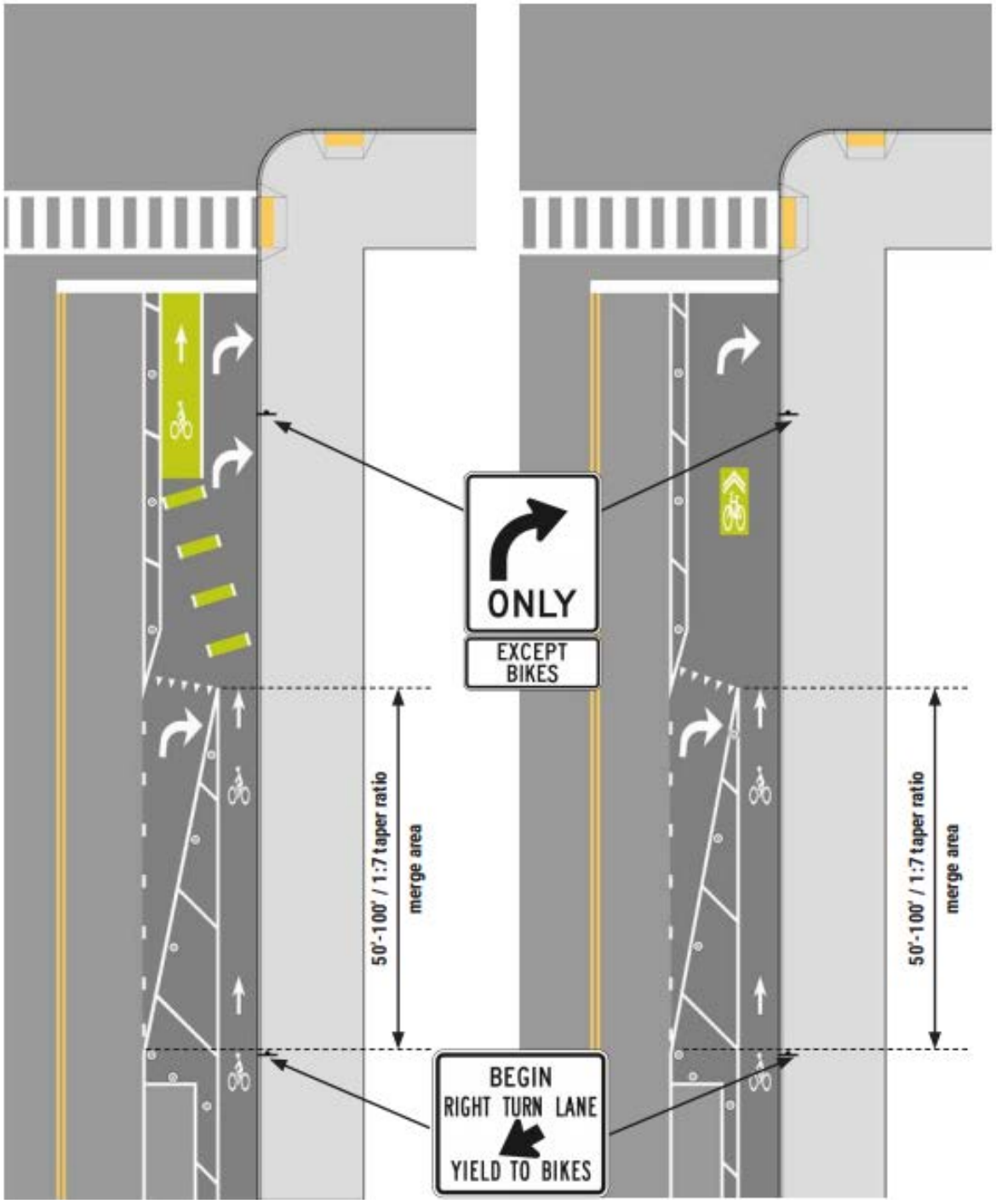
Source:
Mass DOT

Exclusive Bike Phase



Source:
Mass DOT

Mixing Zone



Source:
Mass DOT

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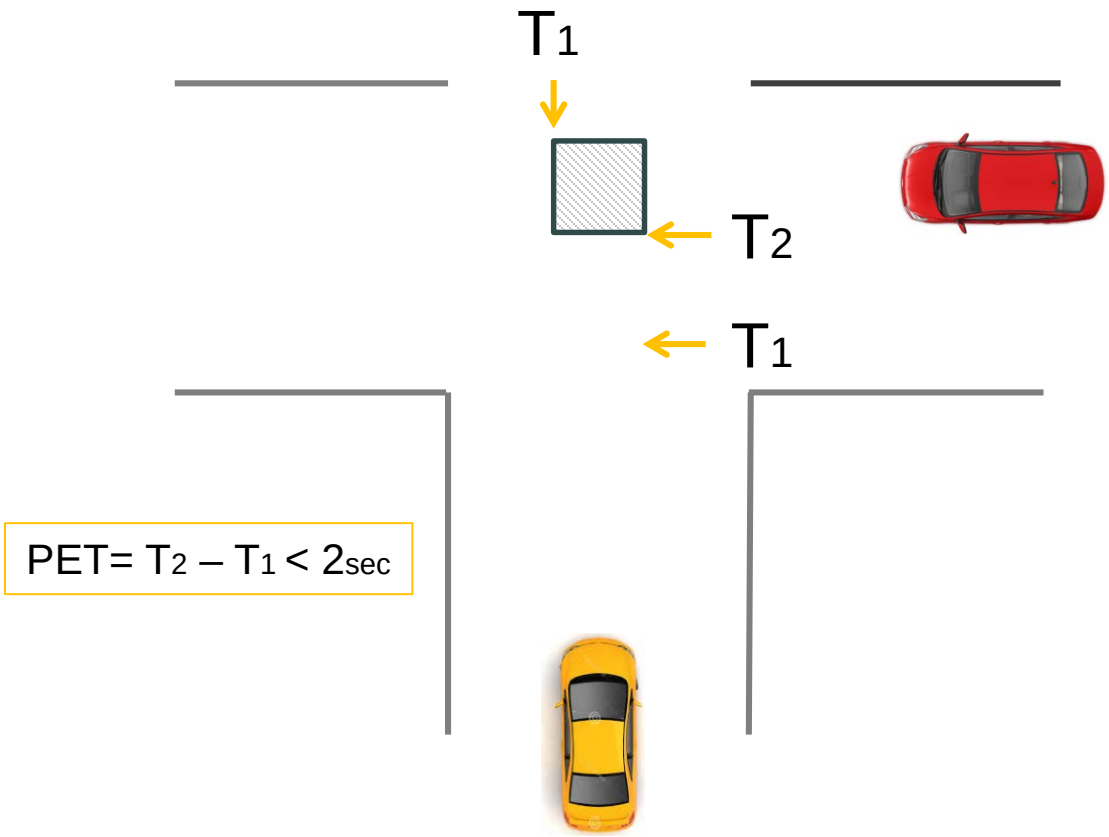
Field Evaluation

- Initial Intent: Observe sites before/after LBI or Split LBI addition to develop quantitative guidance
- What actually happened: We analyzed video of a variety of sites and provided mostly qualitative guidance
- Metrics:
  - "Incident" – Calculated Time Difference (Threshold ≤ 5s)
  - PET Value
  - Time Since Bicycle Green
  - Speed
  - Evasive Action Taken
    - Braking
    - Swerving
    - Changing Lanes
    - etc…

PET

- Post Encroachment Time is "*the time from the end of encroachment to the time that the through vehicle actually arrives at the potential point of collision*"
- A minimum value of PET of 2 seconds would achieve safety benefits, and a PET of less than 2 seconds would result in an interaction and a risk of a collision at signalized intersections (Tang and Kuwahara, 2011; Hurwitz et al. 2015).

How is it calculated?



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Severity Metrics

PET Value	Severity
≤ 1.5 s	Very Dangerous Interaction
1.5 s < x ≤ 3s	Dangerous Interaction
3s < x ≤ 5s	Mild Interaction
x > 5s	No Interaction

Example Video Reduction

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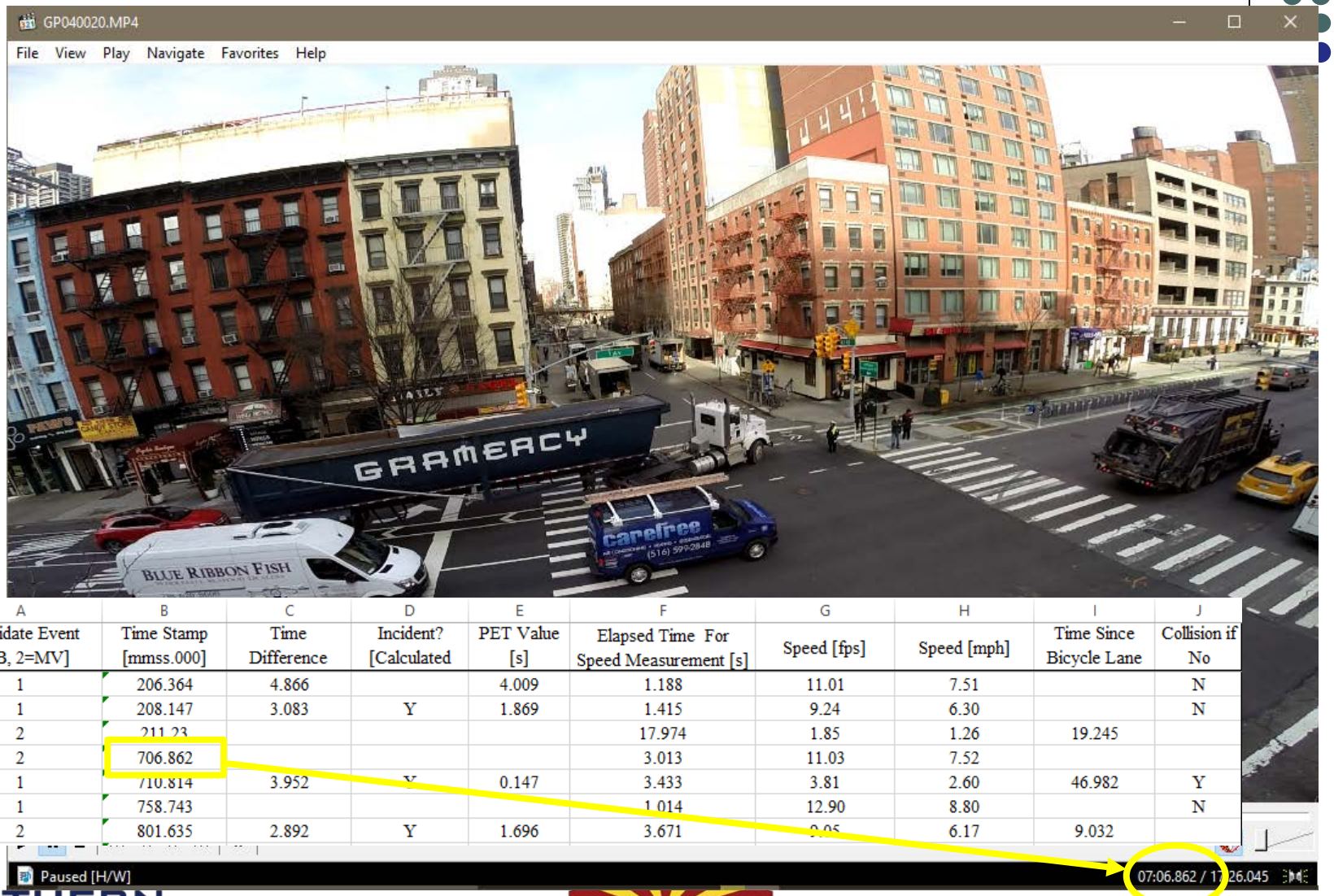
Time stamp



	A	B	C	D	E	F	G	H	I	J
1	Candidate Event [1=B, 2=MV]	Time Stamp [mmss.000]	Time Difference	Incident? [Calculated	PET Value [s]	Elapsed Time For Speed Measurement [s]	Speed [fps]	Speed [mph]	Time Since Bicycle Lane	Collision if No
07	1	206.364	4.866		4.009	1.188	11.01	7.51		N
08	1	208.147	3.083	Y	1.869	1.415	9.24	6.30		N
09	2	211.23				17.974	1.85	1.26	19.245	
10	2	706.862				3.013	11.03	7.52		
11	1	710.814	3.952	Y	0.147	3.433	3.81	2.60	46.982	Y
12	1	758.743				1.014	12.90	8.80		N
13	2	801.635	2.892	Y	1.696	3.671	9.05	6.17	9.032	

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Calculated Time Difference

	A	B	C	D	E	F	G	H	I	J
1	Candidate Event [1=B, 2=MV]	Time Stamp [mmss.000]	Time Difference	Incident? [Calculated	PET Value [s]	Elapsed Time For Speed Measurement [s]	Speed [fps]	Speed [mph]	Time Since Bicycle Lane	Collision if No
07	1	206.364	4.866		4.009	1.188	11.01	7.51		N
08	1	208.147	3.083	Y	1.869	1.415	9.24	6.30		N
09	2	211.23				17.974	1.85	1.26	19.245	
10	2	706.862				3.013	11.03	7.52		
11	1	710.814	3.952	Y	0.147	3.433	3.81	2.60	46.982	Y
12	1	758.743				1.014	12.90	8.80		N
13	2	801.635	2.892	Y	1.696	3.071	9.05	6.17	9.032	

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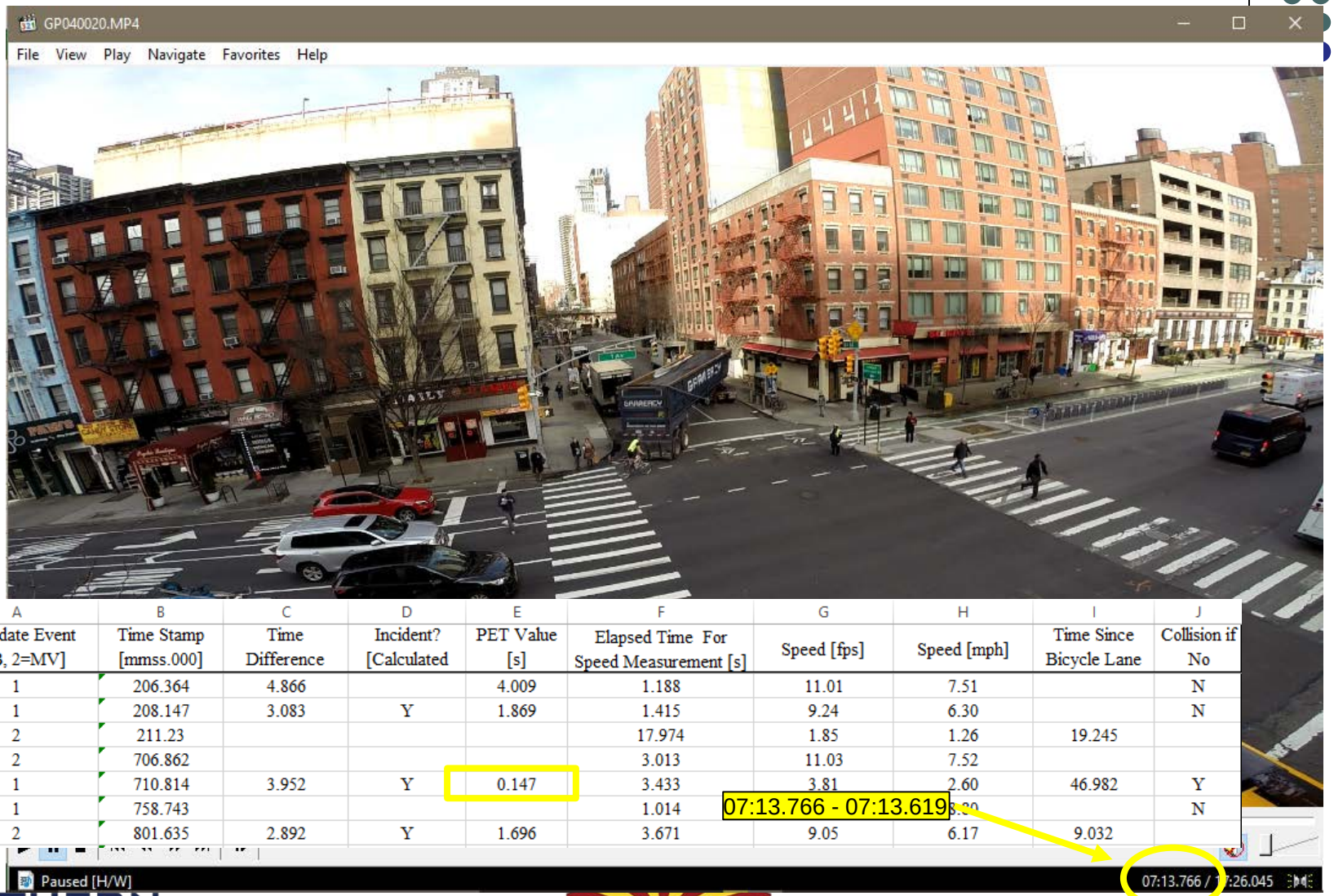
PET Value



	A	B	C	D	E	F	G	H	I	J
1	Candidate Event [1=B, 2=MV]	Time Stamp [mmss.000]	Time Difference	Incident? [Calculated	PET Value [s]	Elapsed Time For Speed Measurement [s]	Speed [fps]	Speed [mph]	Time Since Bicycle Lane	Collision if No
07	1	206.364	4.866		4.009	1.188	11.01	7.51		N
08	1	208.147	3.083	Y	1.869	1.415	9.24	6.30		N
09	2	211.23				17.974	1.85	1.26	19.245	
10	2	706.862				3.013	11.03	7.52		
11	1	710.814	3.952	Y	0.147	3.433	3.81	2.60	46.982	Y
12	1	758.743				1.014				N
13	2	801.635	2.892	Y	1.696	3.671	9.05	6.17	9.032	

Speed

	A	B	C	D	E	F	G	H	I	J
1	Candidate Event [1=B, 2=MV]	Time Stamp [mmss.000]	Time Difference	Incident? [Calculated	PET Value [s]	Elapsed Time For Speed Measurement [s]	Speed [fps]	Speed [mph]	Time Since Bicycle Lane	Collision if No
07	1	206.364	4.866		4.009	1.188	11.01	7.51		N
08	1	208.147	3.083	Y	1.869	1.415	13.08 ft / 3.443 s	6.30		N
09	2	211.23				17.974	1.85	1.26	19.245	
10	2	706.862				3.013	11.03	7.52		
11	1	710.814	3.952	Y	0.147	3.433	3.81	2.60	46.982	Y
12	1	758.743				1.014	12.90	8.80		N
13	2	801.635	2.892	Y	1.696	3.671	9.05	6.17	9.032	

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Time since Bicycle Green

	A	B	C	D	E	F	G	H	I	J
1	Candidate Event [1=B, 2=MV]	Time Stamp [mmss.000]	Time Difference	Incident? [Calculated	PET Value [s]	Elapsed Time For Speed Measurement [s]	Speed [fps]	Speed [mph]	Time Since Bicycle Lane	Collision if No
07	1	206.364	4.866		4.009	1.188	11.01	7.51		N
08	1	208.147	3.083	Y	1.869	1.415	9.24	6.30		N
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12	1	758.743				1.014	12.90	8.80		N
13	2	801.635	2.892	Y	1.696	3.671	9.05	6.17	9.032	

07:13.619 – 06:23.882

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Data Overview

Intersection	Before			After		
	Treatment	Date	Hours	Treatment	Date	**Hours**
1st Ave and 61st St	-	-	-	Split LBI	3/16/2017	10:30 am – 7:30 pm
2nd Ave and 74th St	-	-	-	Mixing Zone	5/18/2017	8 am – 7 pm
6th Ave and 23rd St	Concurrent with LPI	6/7/2017	8 am – 7 pm	Split LBI	2/20/2017	7 am – 6 pm
12th and Campbell	Concurrent	9/12/2017 – 9/16/2017	8 am – 8 pm	LBI	9/19/2017 – 9/25/2017	8 am – 8 pm
Grand and Multnomah	**-**	**-**	**-**	Mixing Zone	7/10/2017	7 am – 7pm

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Summary of Data Analysis

Location	Treatment	Hours	Total # of Bicycles	Total # of Motor Vehicles	Total Incidents	% Total Incidents	Near Misses	# of Collisions without Evasive Action
1st Av and 61st St	Split LBI	8:57	1166	1619	445	38.16	11	197
2nd Av and 74th St	Mixing Zone	11:00	1425	1206	253	17.75	4	57
6th Av and 23rd St	LPI	10:00	1952	1034	433	22.18	8	147
6th Av and 23rd St	Split LBI	11:00	1300	773	221	17.00	0	46
Grand and Multnomah	Mixing Zone	11:00	352	1143	76	21.59	0	4

Split LBI

6th Avenue and 23rd St Geometry (Split LBI)

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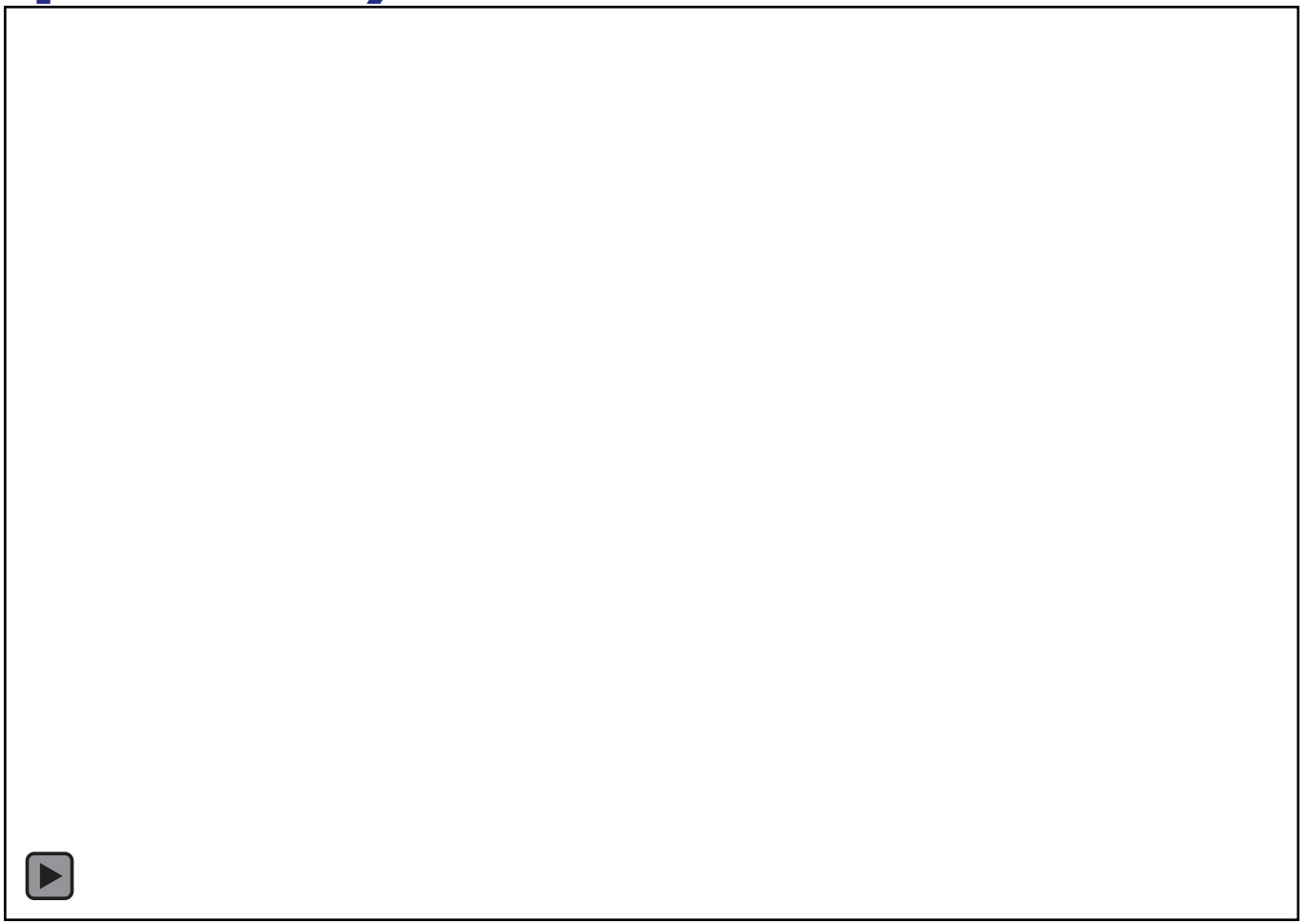
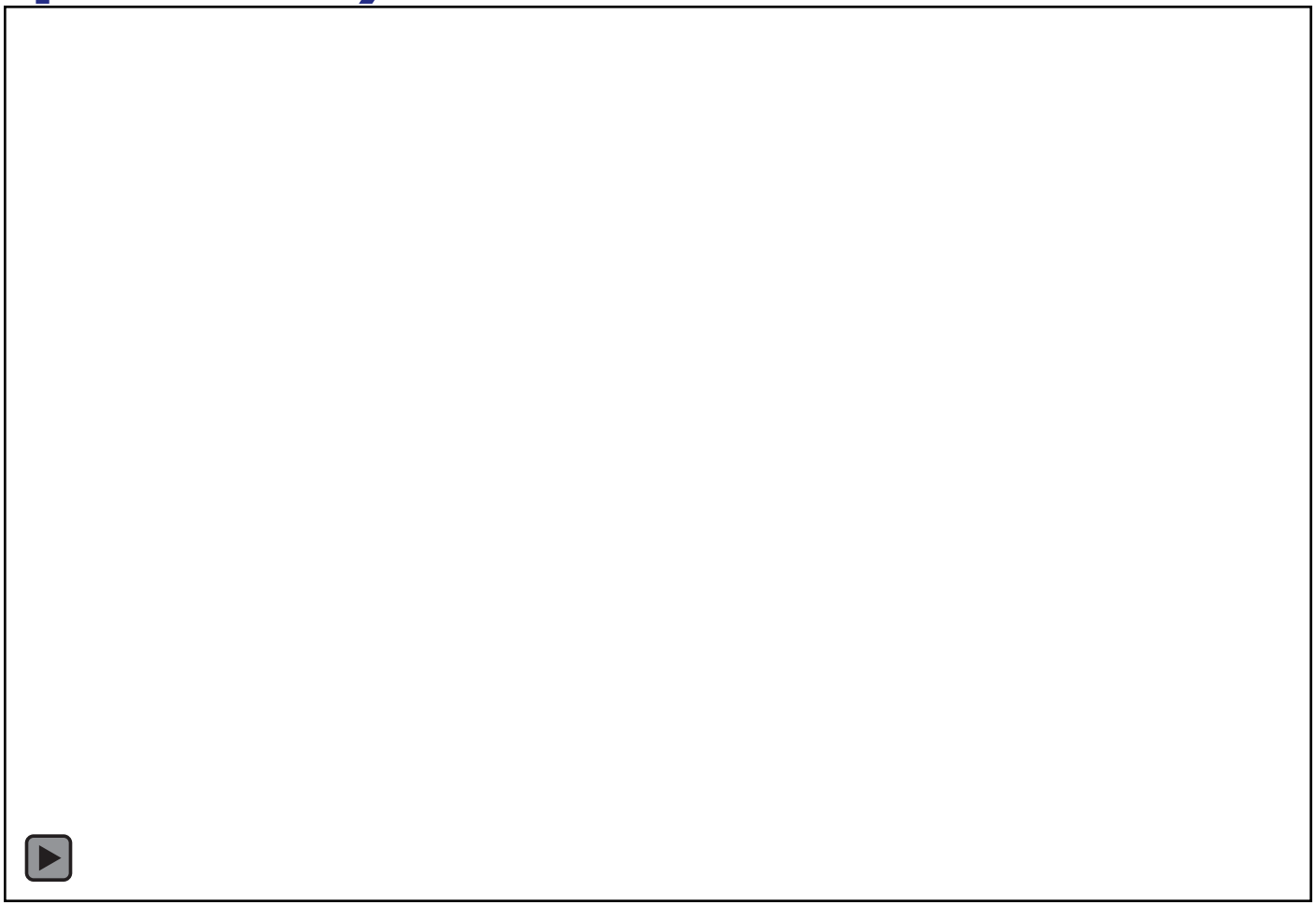
6th Avenue and 23rd St (Split LBI)



Ideal Conditions

6th Avenue and 23rd St (Split LBI)

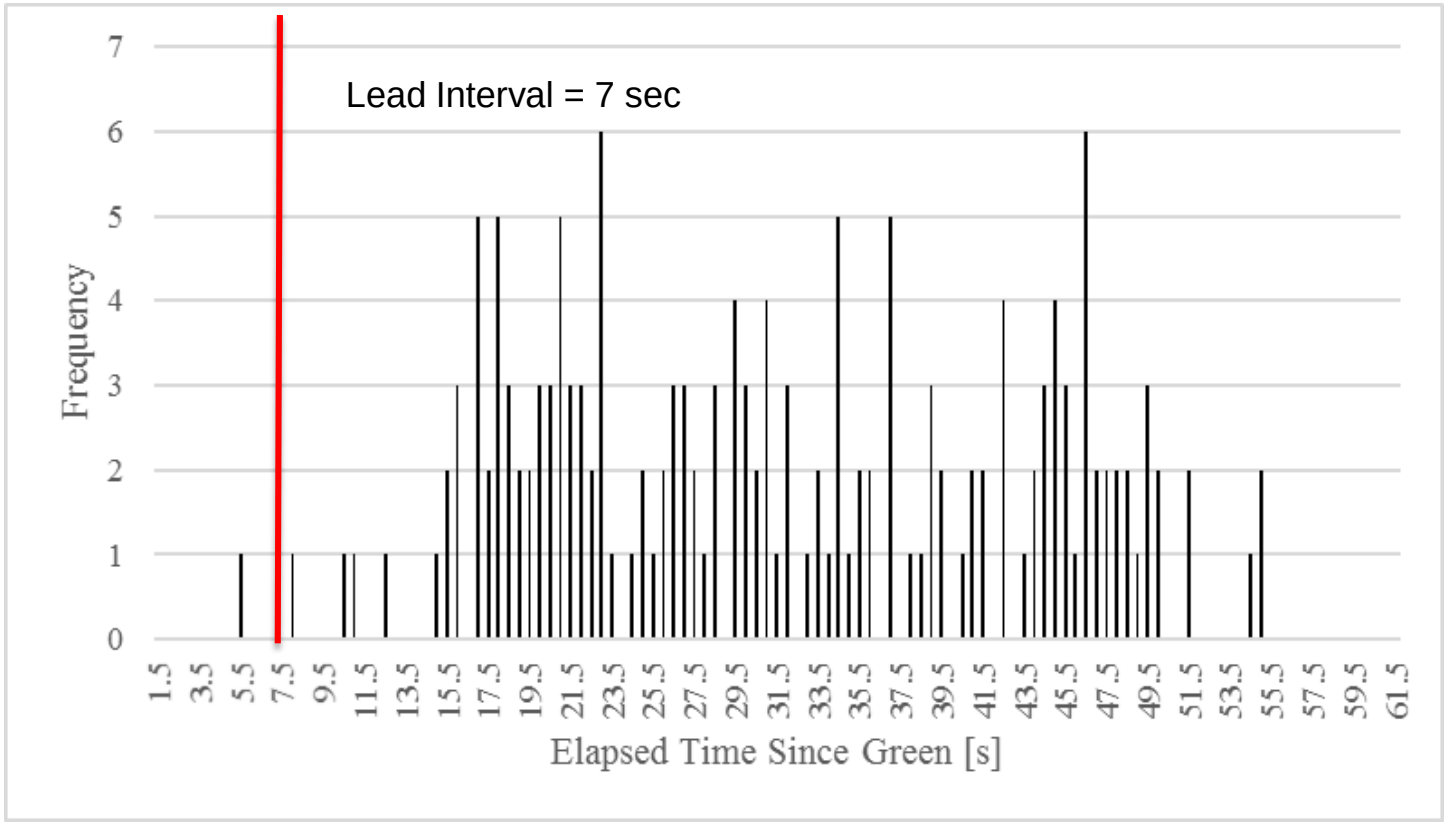


Interactions

6th Avenue and 23rd St (Split LBI) Summary

Number of Bicycles	1300
Number of Motor Vehicles	773
Number of Incidents	221
Percentage of Incidents Based on Number of Bicycles	17.00%
Near Misses	0
Number of Collisions if No Evasive Action Taken	46

6th Avenue and 23rd St Elapsed Time since Green



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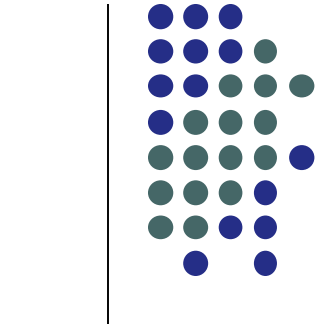
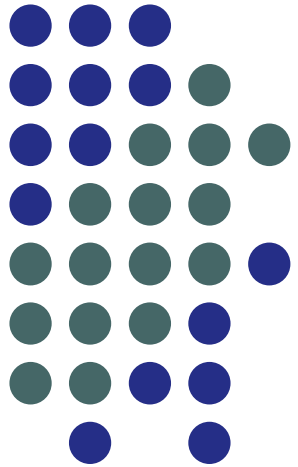
Split LBI – Overall Findings

- With a Split LBI, the risk is shifted to the stale green
- Conflicts are significantly higher at 1st Ave and 61st St compared to 6th Ave and 23rd St.
  - Higher levels of turn volumes
  - Downhill grade
  - Crossing pedestrians impact (?)
- What can we do?
  - Increase the lead interval
  - Coordinate with adjacent signals, so that most bicycles go through the lead interval (bicycle green wave)
  - When turn volumes are high, separate the phases

Concurrent with LPI





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6th Avenue and 23rd Street Geometry

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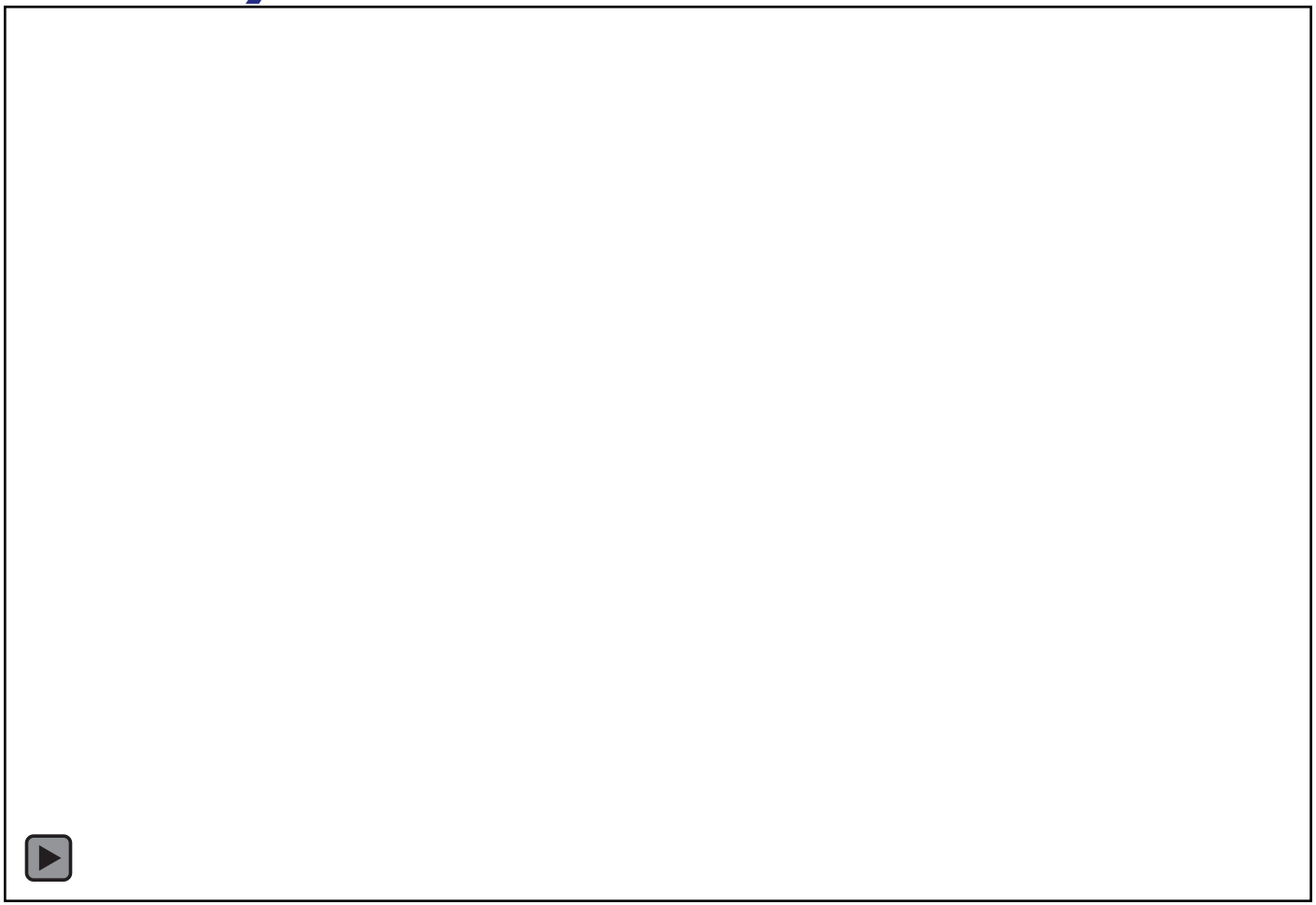
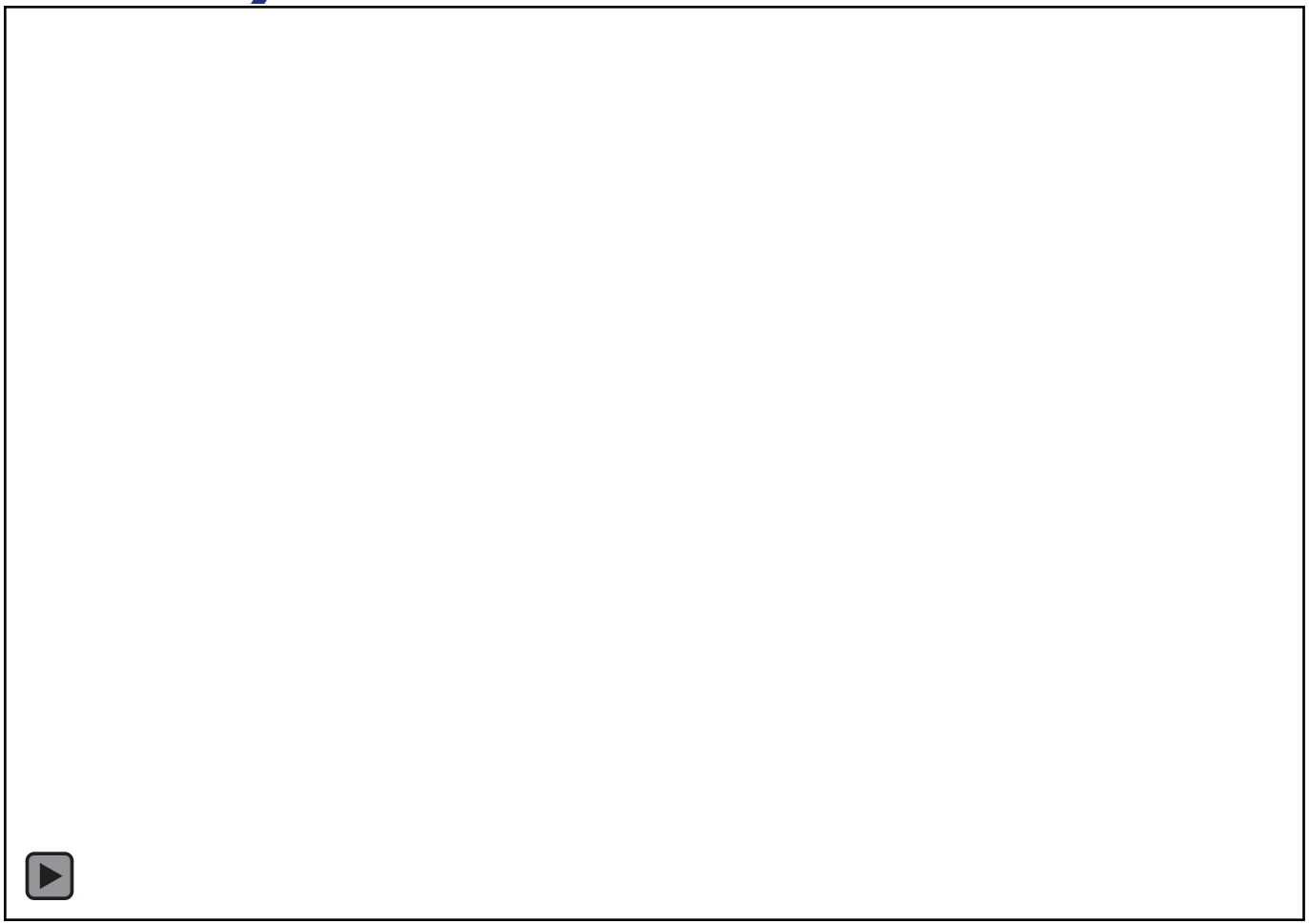
6th Avenue and 23rd Street (w/ LPI)



Start of Cycle

6th Avenue and 23rd Street (w/ LPI)



Multiple Bicycles and Vehicles Interact

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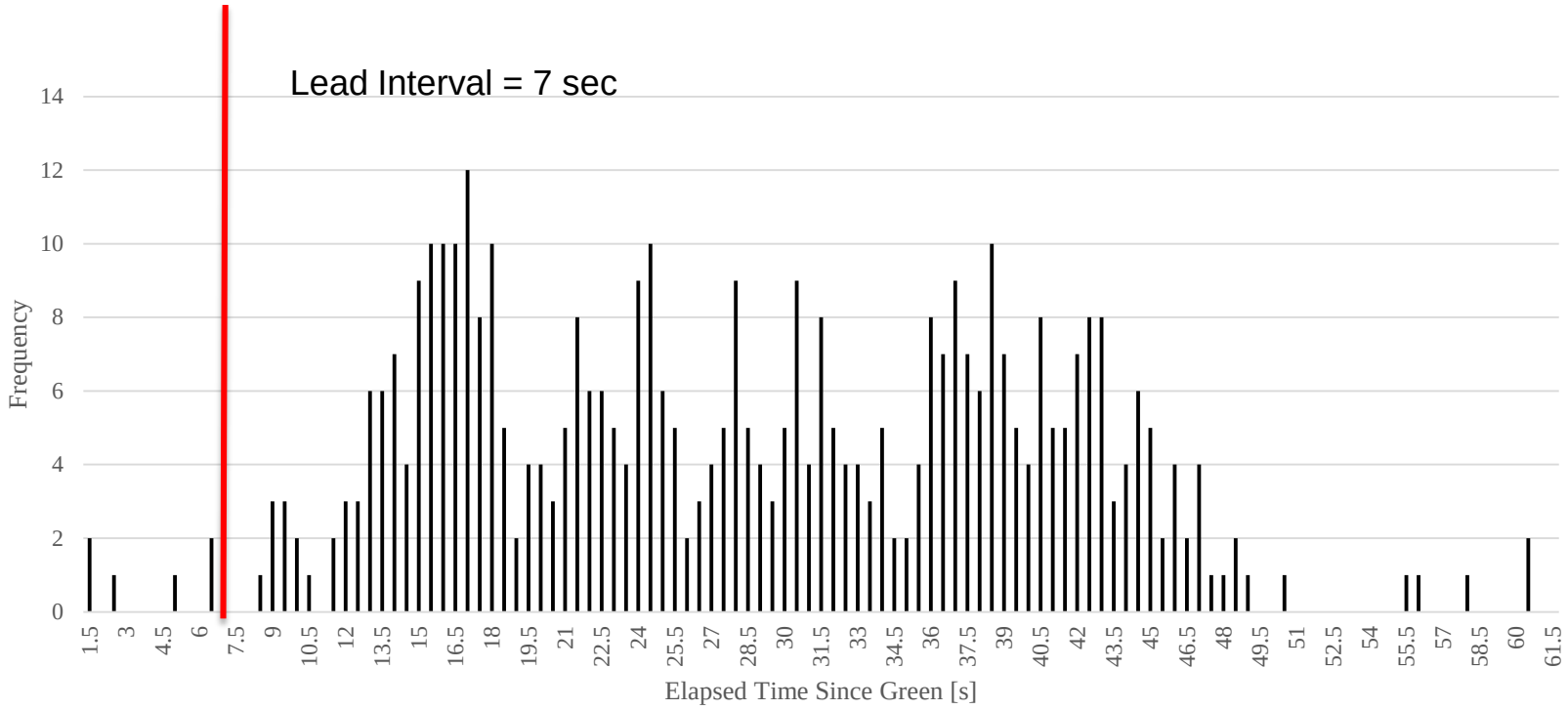
6th Avenue and 23rd Street (w/ LPI) Summary

Number of Bicycles	1952
Number of Motor Vehicles	1034
Number of Incidents	443
Percentage of Incidents Based on Number of Bicycles	22.18%
Near Misses	8
Number of Collisions if No Evasive Action Taken	147

6th Ave and 23rd St (Before)Severity Summary

Severity	Total Incidents of Specified Severity	Percentage of Total Incidents
Very Dangerous Interaction	142	**32.1%**
Dangerous Interaction	129	**29.1%**
Mild Interaction	134	**30.2%**
No Interaction	**28**	**6.3%**

6th Ave and 23rd St (w/ LPI) Elapsed Time Since Green



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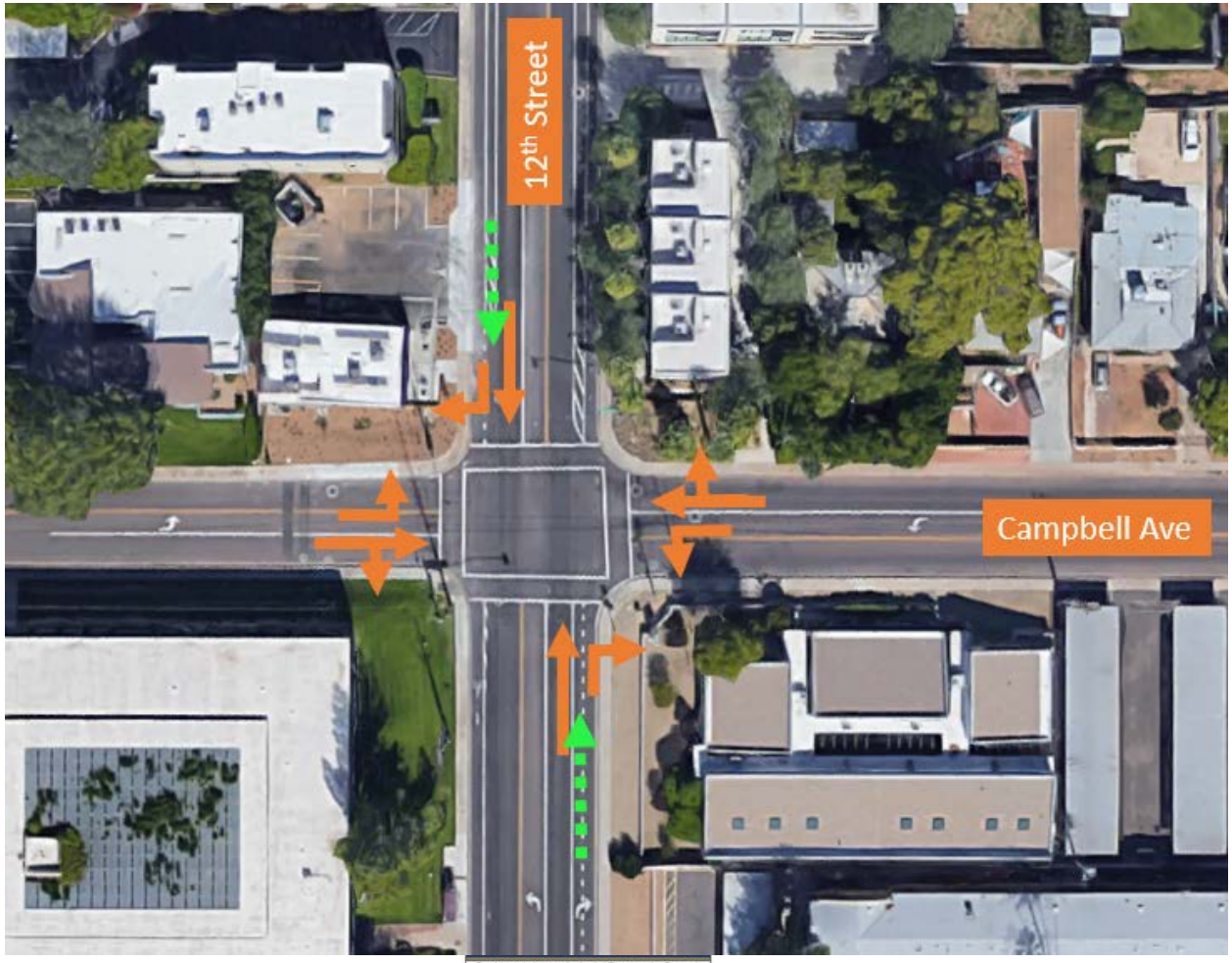
6th Ave and 23rd St (Before) Notes - Concurrent with LPI

- Taxi drivers park on the bicycle lane often to pick up people causing bicycles to go around them
- Massive queue build up in every cycle
- Bicycles start moving during the pedestrian walk phase
- Right turning vehicles back up the queue due to not having an exclusive turning lane, and waiting on pedestrians to cross.

12th St & Campbell (LBI)



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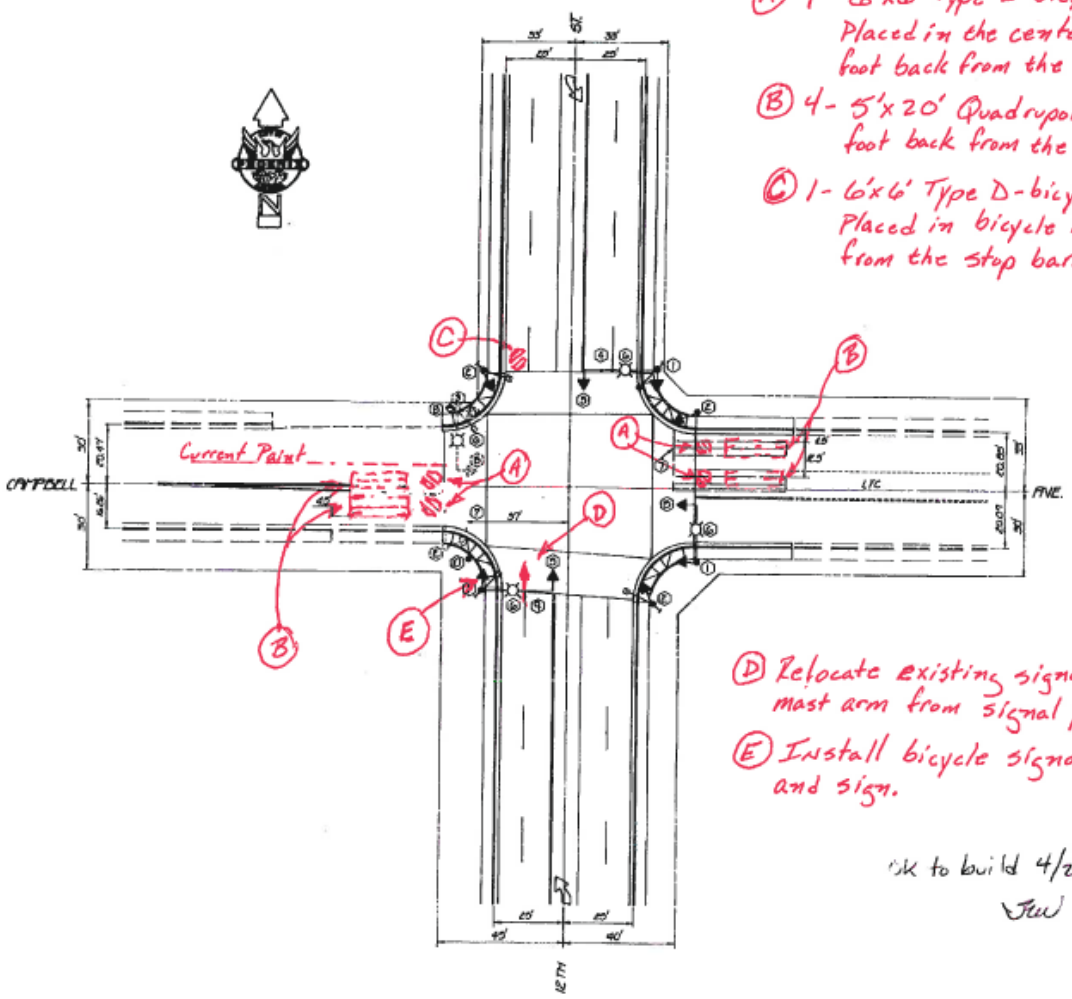

(A) 4 - 6'x6' Type D-bicycle quadrupole loops Placed in the center of the lane one foot back from the stop bar.

(B) 4 - 5'x20' Quadrupole loops placed four foot back from the D-type bicycle loop.

(C) 1 - 6'x6' Type D-bicycle quadrupole loop Placed in bicycle lane one foot back from the stop bar.

Jim Baker
james.a.baker@phoenix.gov
602-495-7451

INSTALL

1. TRAFFIC SIGNAL POLE TYPE M - 3 NEW
2. TRAFFIC SIGNAL POLE TYPE A - 3 NEW 1 EXISTING
3. M/U POLE - 1 EXISTING
4. 55' MAST ARM - 2 NEW
5. 12" SIGNAL HEAD - 3 NEW 1 EXISTING
6. HPS LUMINAIRE - 4 NEW
7. 5'x40' QUADRUPOLE LOOP - 3 NEW
8. CONTROLLER - 1 NEW
9. 55' MAST ARM
10. PED-PUSH BUTTON POLE

(D) Relocate existing signal head to mast arm from signal pole.

(E) Install bicycle signal head (12") and sign.

ok to build 4/27/16
JW

"AS BUILT"
DRY
INSTALLED 12-19-30

REVISIONS	BY	DATE
DESIGNED BY:		
DRAWN BY: C. PAULA		
APPROVED BY:		
DEPUTY STREETS AND TRAFFIC DIRECTOR		
DEPUTY STREETS AND TRAFFIC DIRECTOR		
STREETS AND TRAFFIC DIRECTOR		
WORK ORDER NO.:		
PROJECT NO.: 572979		

CITY OF PHOENIX, ARIZONA
STREETS AND TRAFFIC DEPARTMENT

TRAFFIC SIGNAL EQUIPMENT
12TH STREET
CAMPBELL AVE. TO ORANGEWOOD AVE

SCALE - 1"=20'
DATE - OCTOBER 1930
SHEET 3A OF 3 SHEETS

FILE NO. 4011

Camera View

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12th St & Campbell

- Controller settings
  - Intersection runs coordinated 24/7
  - Campbell St on 8s recall for all data to force interaction
  - Before data:
    - Bike indication comes on with concurrent green, but not leading
    - Collected week of 9.12.16
  - After data:
    - 5s Leading Bike Interval when bike detected
    - Collected week of 9.19.16

12th St & Campbell Results

- No LBI:
  - 86 bikes over 5 days
  - No incidents or conflicts
- LBI
  - 74 bikes over 7 days
  - No incidents or conflicts
- Citizen video
  - https://www.youtube.com/watch?v=YUzL1R0-kCg

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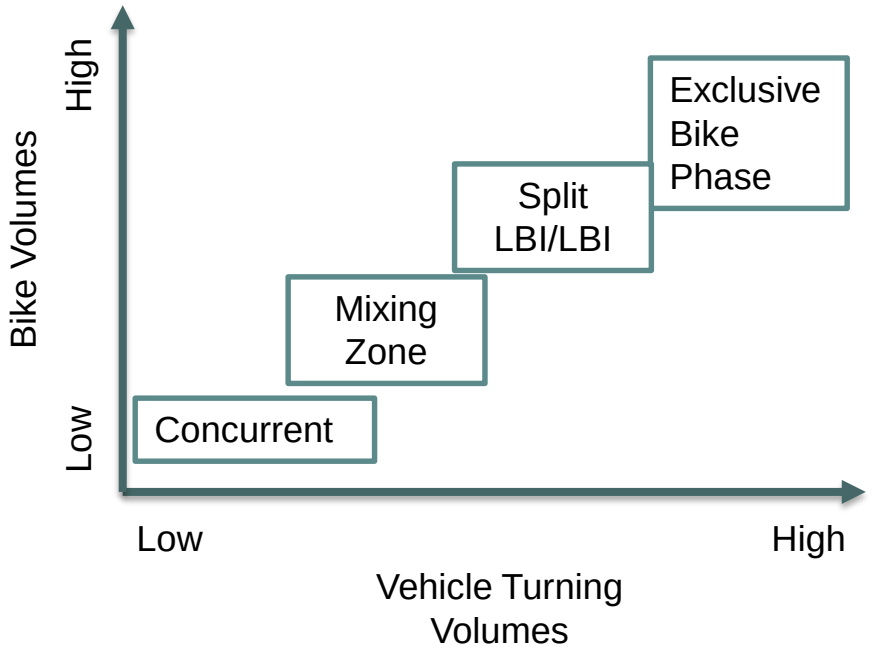
Which Strategy to Choose?



Ranking of Strategies by Vehicular Efficiency

Concurrent Phase

Mixing Zone

Split LBI

LBI

Exclusive Bike Phase

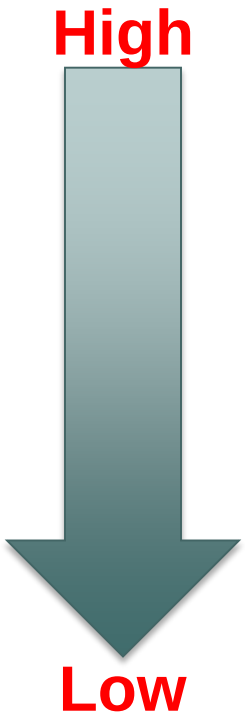
Strategy desirability by Vehicle Turning Volumes

Exclusive Bike Phase

Split LBI/LBI

Mixing Zone

Concurrent Phase



Conclusions / Recommendations

- Concurrent timing is best suited for low bicycle and low turning vehicle volumes
  - Right hook potential exists throughout green
- LBI / Split LBI are suitable when bike / turning vehicle volumes are medium-high
  - Split LBI is more efficient, but requires additional signage without RTOR prohibition
  - Right hook potential moved towards stale green
  - Bike coordination can further reduce this risk

Conclusions / Recommendations

- Exclusive Bike Phase is recommended with high bicycle and high motor vehicle volume
  - Delay is greatest, but conflicts removed
- Mixing Zones
  - Application is unclear from this work
  - Previous work showed come confusion by users
  - May be best suited for medium-low volumes (bike and vehicle)

Future Work

- Supplement surrogate safety data with crash data for further investigation into safety impacts of treatments
- Determine volume thresholds for application of various treatments (currently working on this)
- Examine gap acceptance of cyclists in various cities, and its relation to safety perception
- Quantify impact of pedestrian volumes on strategies

Thank you!
Questions?

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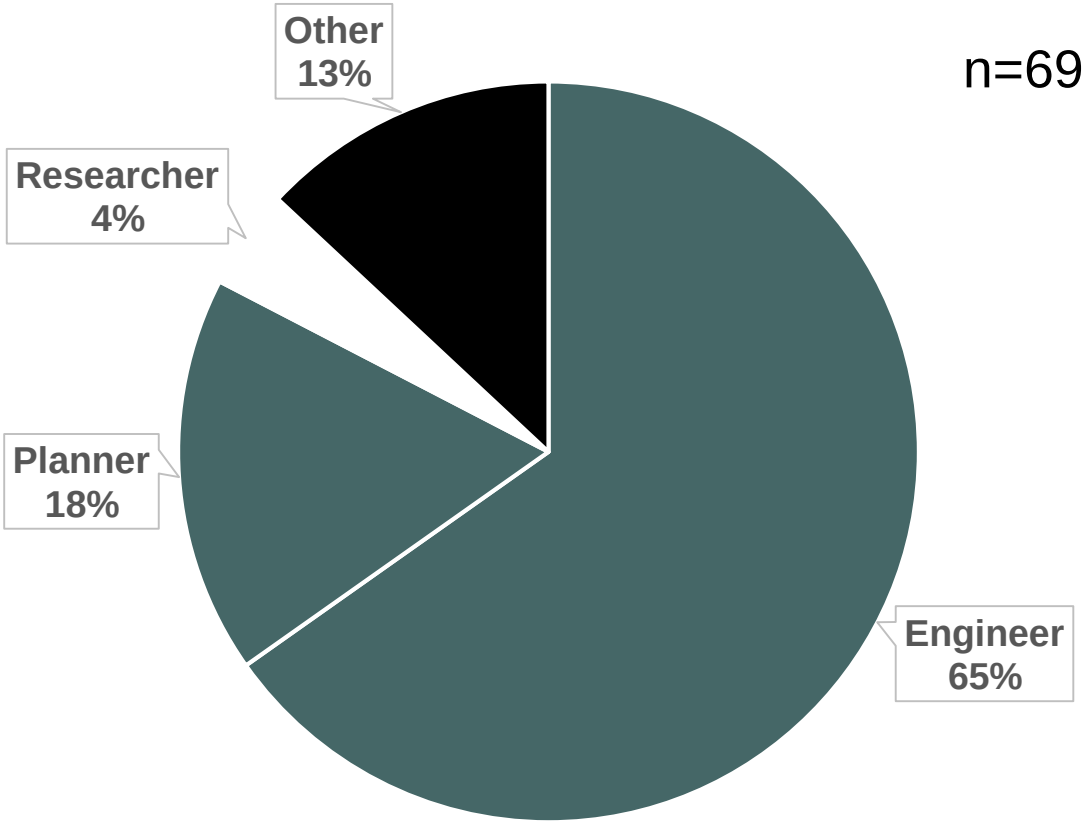
Survey Respondents



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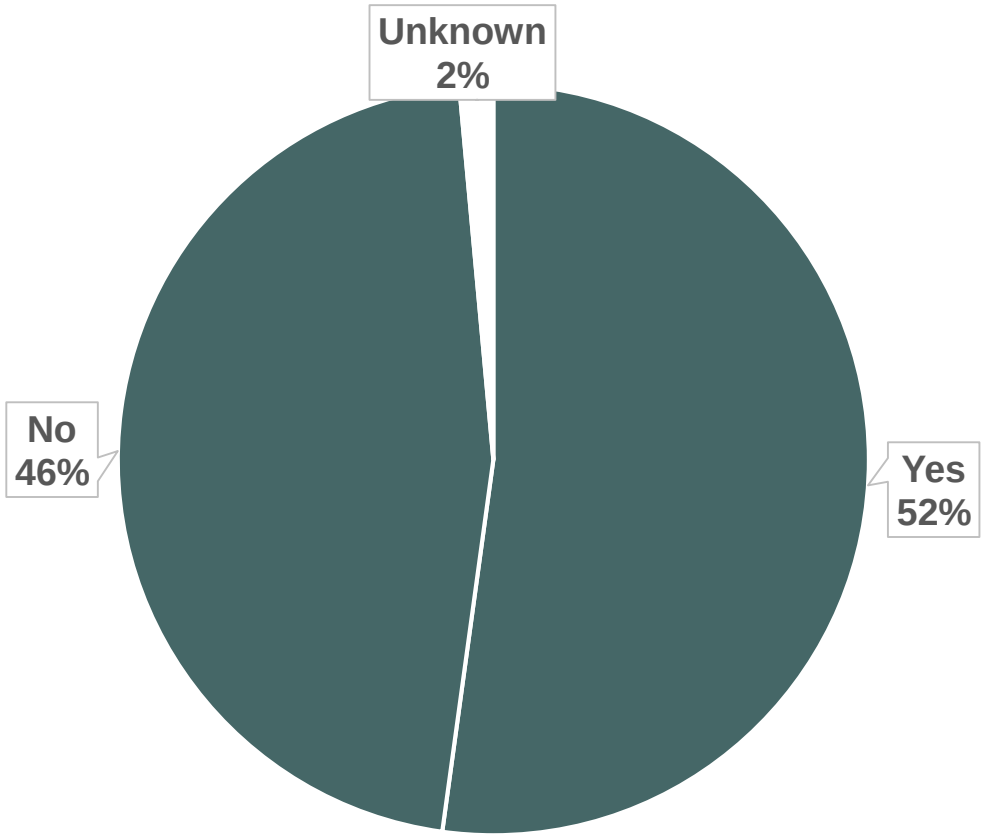
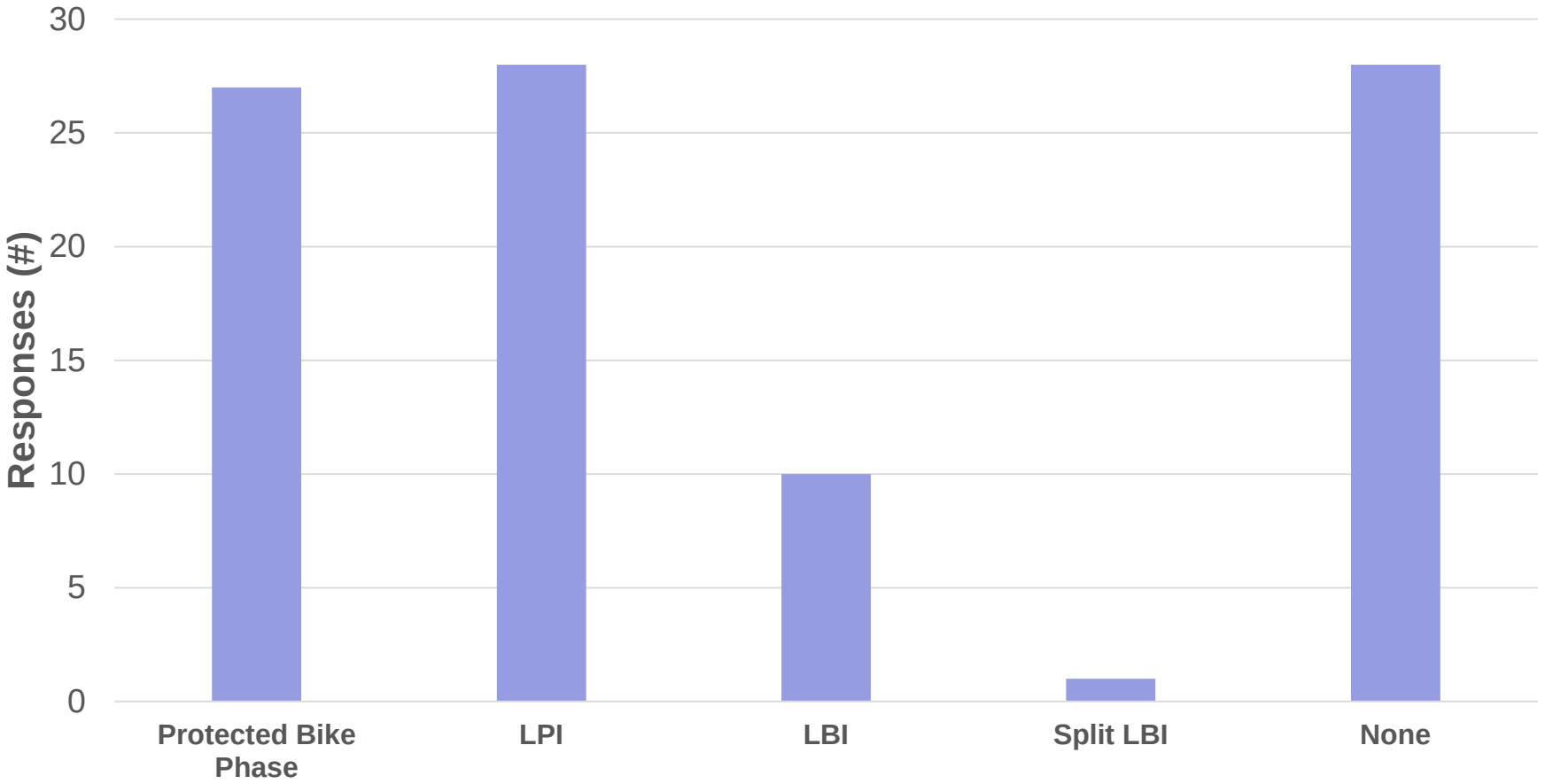
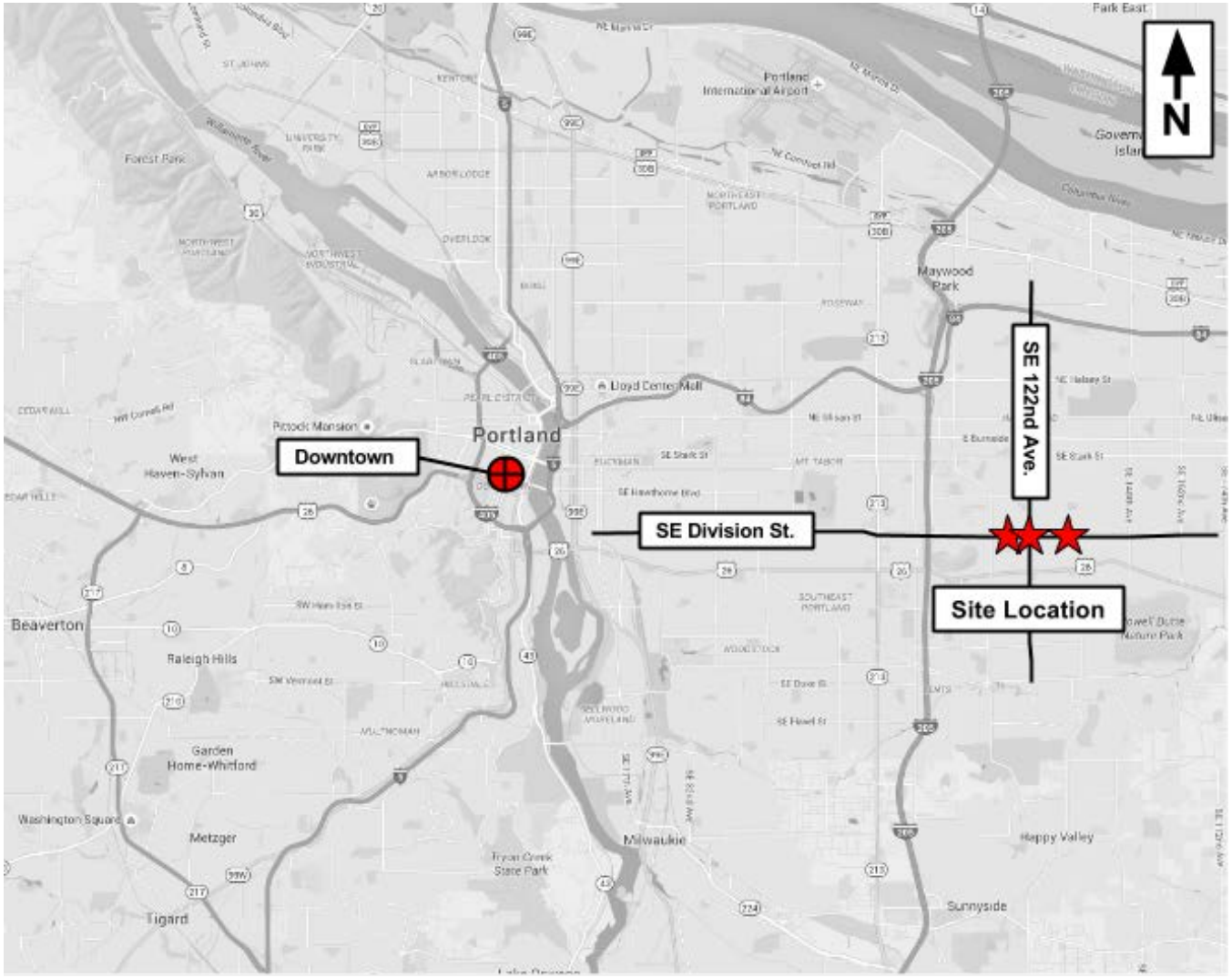
Awareness of Split LBI



Control Strategy Implementation



Simulation



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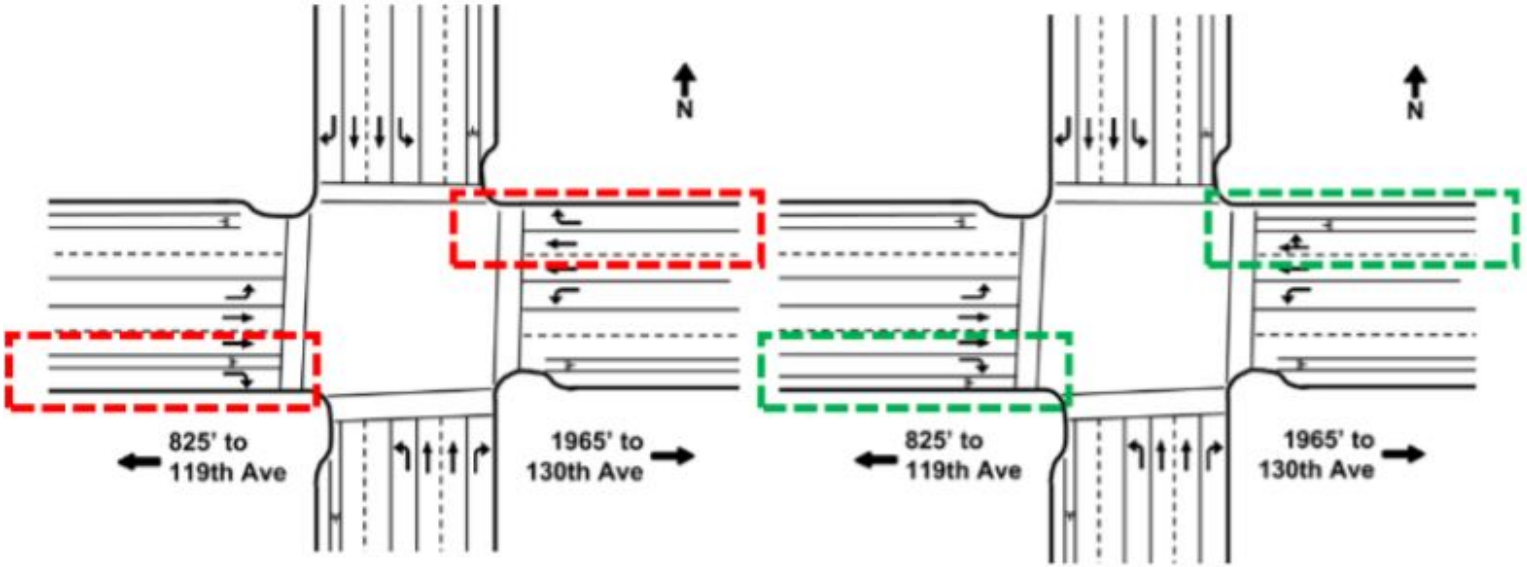
Simulation notes

- Software in the Loop with ASC/3 controller
- Geometry adjustment



A) Real-world Geometry

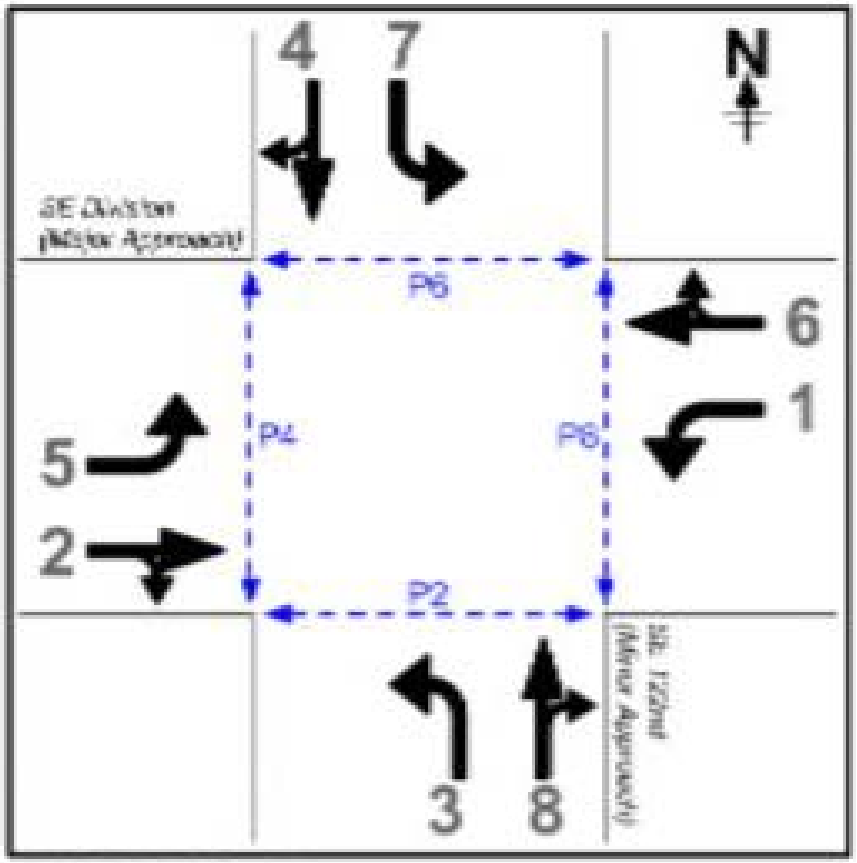
B) Altered Geometry

Simulation notes

- Data was collected by Quality Counts 9.22.15
  - Ped volumes not coded for directions
  - Bike volumes extremely low

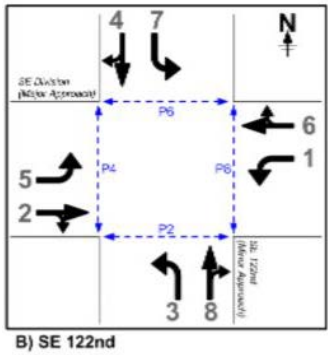
% Bikes	*Number of Bikes*	*In at 119th (EB)*	*In at 130th (WB)*
1%	36	18	18
2%	71	36	36
3%	17	53	53
4%	143	71	71
5%	178	89	89
6%	214	17	17
7%	250	125	125
7%	250	125	125
8%	285	143	143
9%	321	160	160
10%	357	178	178

Study Intersection Phasing



B) SE 122nd

LBI, Vehicle Delay (Phase 6)



B) SE 122nd

Movement and Case		Bicycle Volume as Percent of Mode Share, Delay (secs)									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Through	Base Case Delay	25.3	25.5	25.9	25.8	26.0	26.4	26.6	26.6	26.9	27.5
	LBI Delay	**30.0**	**29.9**	**30.4**	**30.3**	**30.7**	**31.0**	**31.3**	**31.3**	**31.2**	**32.1**
	% Difference	19%	17%	17%	18%	18%	17%	18%	18%	16%	17%
Right Turn	Base Case Delay	22.2	22.6	22.9	23.3	23.4	24.2	24.8	25	25.4	26.5
	LBI Delay	**26.3**	**26.6**	**26.9**	**27.2**	**27.6**	**27.9**	**28.8**	**28.4**	**28.1**	**29.4**
	% Difference	19%	18%	18%	17%	18%	16%	16%	13%	11%	11%

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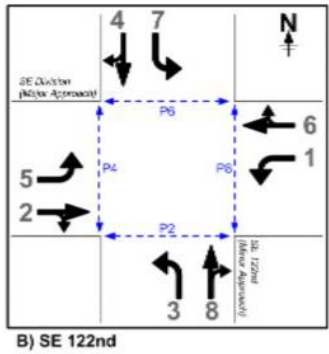
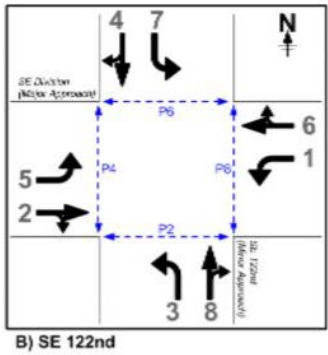
LBI, Bicycle Delay (Phase 6)



Movement and Case		Bicycle Volume as Percent of Mode Share, Delay (secs)									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Through	Base Case Delay	17.8	18.8	17.3	18.1	20.5	20.1	21.1	23.6	25.1	22.5
	LBI Delay	18.1	18.7	16.9	18.7	21.0	20.4	20.9	24.3	25.1	22.6
	% Difference	2%	-1%	-2%	4%	2%	1%	-1%	3%	0%	1%
Right Turn	Base Case Delay	2.2	7.0	5.9	8.6	10.4	10.4	12.1	13.2	16.4	13.1
	LBI Delay	2.2	7.1	6.0	8.2	10.8	9.9	11.7	14.2	16.4	14.3
	% Difference	0%	2%	1%	-5%	4%	-4%	-4%	8%	0%	5%

Split LBI, Vehicle Delay (Phase 2)



B) SE 122nd

Movement and Case		Bicycle Volume as Percent of Mode Share, Delay (secs)									
		1%	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
Through	Base Case Delay	17.2	17.2	17.3	17.4	17.3	17.5	17.5	17.7	17.7	17.8
	LBI Delay	**17.4**	17.4	17.5	**17.7**	17.5	**17.8**	**17.8**	17.8	17.9	17.9
	% Difference	1%	1%	1%	2%	1%	2%	2%	1%	1%	1%
Right Turn	Base Case Delay	5.15	5.18	5.26	5.39	5.43	5.71	5.97	5.99	6.18	6.23
	LBI Delay	**5.55**	**5.66**	**5.71**	**5.99**	**5.84**	**6.7**	**6.22**	**6.49**	**6.49**	**6.7**
	% Difference	8%	915	9%	11%	8%	6%	4%	8%	5%	8%

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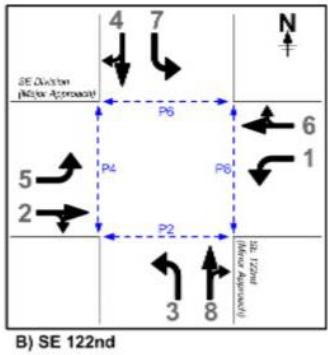
Split LBI, Bicycle Delay (Phase 2)



Movement and Case		Bicycle Volume as Percent of Mode Share, Delay (secs)									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Through	Base Case Delay	22.2	21.5	20.4	21.4	21.2	22.8	24.2	24.9	22.9	24.8
	LBI Delay	23.3	23.3	21.1	22.6	22.4	24.4	**26.0**	26.1	**25.4**	**26.6**
	% Difference	5%	8%	3%	5%	6%	7%	7%	5%	11%	7%
Right Turn	Base Case Delay	8.0	8.0	7.4	11.9	11.1	13.1	12.4	13.9	11.8	13.7
	LBI Delay	2.2	4.8	7.8	10.7	13.2	14.0	14.9	14.7	**15.5**	16.2
	% Difference	-72%	-40%	6%	-10%	-19%	7%	20%	6%	32%	18%

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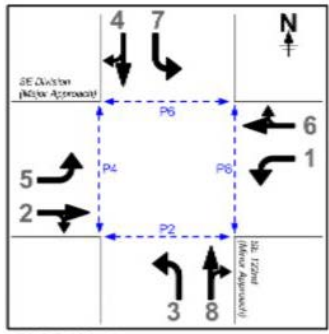
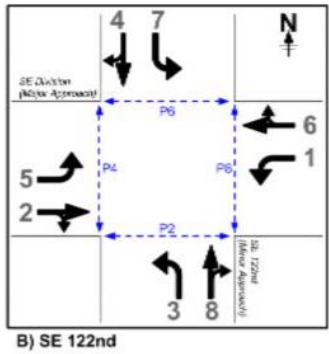
Exclusive Bike Phase Vehicle Delay



B) SE 122nd

Movement	Base Case (sec)	EBP (sec)	% Difference
EB TH	17.2	**21.68**	26%
EB RT	5.15	**5.52**	7%
EB LT	62.5	**74.52**	19%
WB TH	22.28	**21.23**	-16%
WB RT	22.16	**19.26**	-13%
WB LT	52.23	**56.25**	8%
SB TH	34.12	35.15	3%
SB RT	6.12	6.7	-1%
SB LT	54.81	65.81	20%
NB TH	37.1	37.64	1%
NB RT	7.4	7.77	5%
NB LT	53.1	**54.74**	3%

Exclusive Bike Phase Bicycle Delay



Movement	Base Case (sec)	EBP (sec)	% Difference
EB TH	22.17	**45.63**	16%
EB RT	8.2	6.1	-25%
EB LT	42.65	**85.46**	100%
WB TH	17.75	**44.65**	152%
WB RT	2.15	14.29	565%
WB LT	29.29	40.77	39%
SB TH	33.29	**30.62**	-8%
SB RT	0	0	-
SB LT	0	0	-
NB TH	35.36	25.72	-27%
NB RT	3.22	3.26	1%
NB LT	54.62	**50.66**	-7%

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Mixing Zone

2nd Avenue and 74th Street (Mixing Zone)

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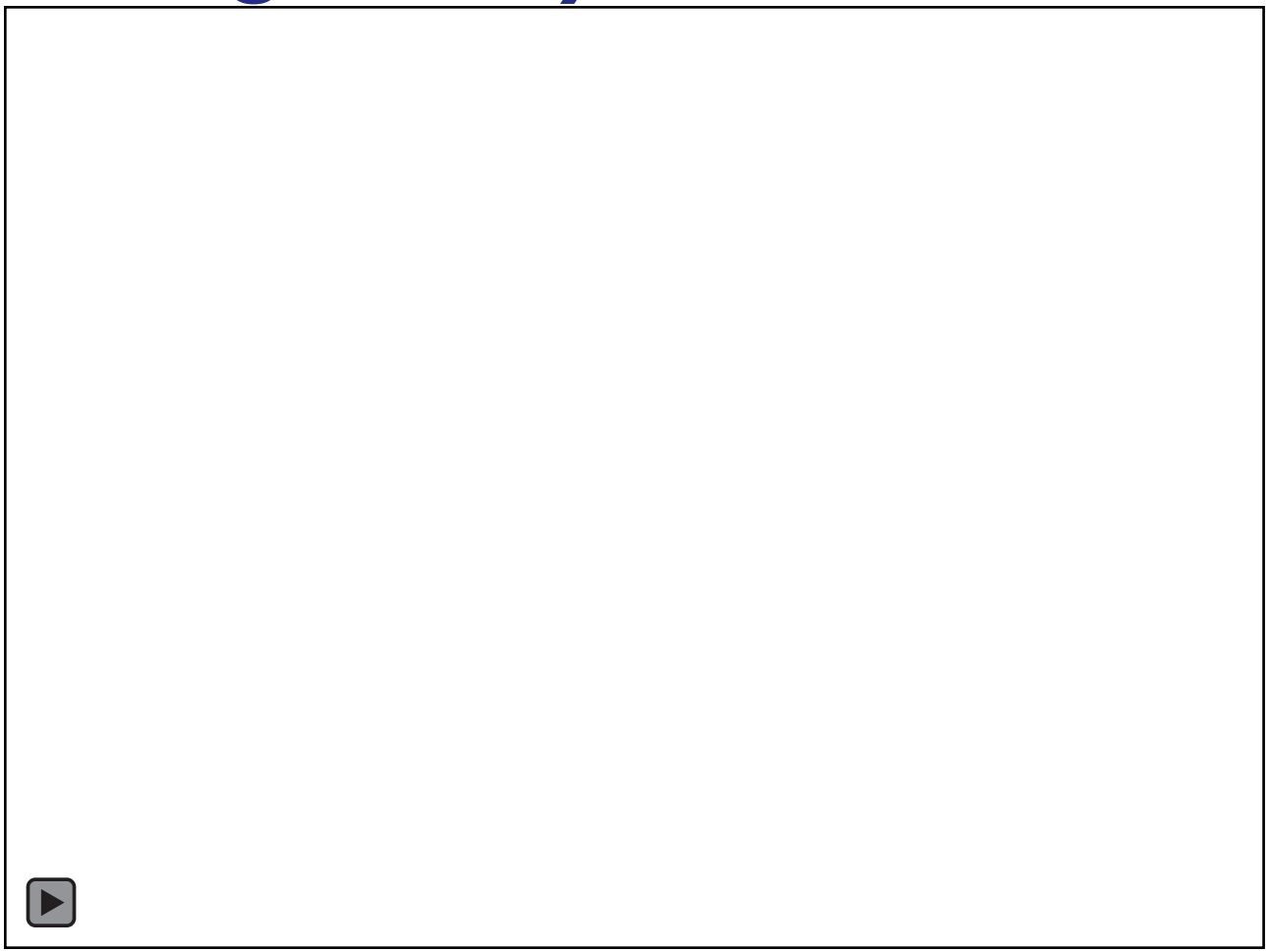
2nd Avenue and 74th Street (Mixing Zone)



Start of Cycle

2nd Avenue and 74th Street Mixing Zone Summary

Number of Bicycles	1425
Number of Motor Vehicles	1206
Number of Incidents	253
Percentage of Incidents Based on Number of Bicycles	17.75%
Near Misses	4
Number of Collisions if No Evasive Action Taken	57

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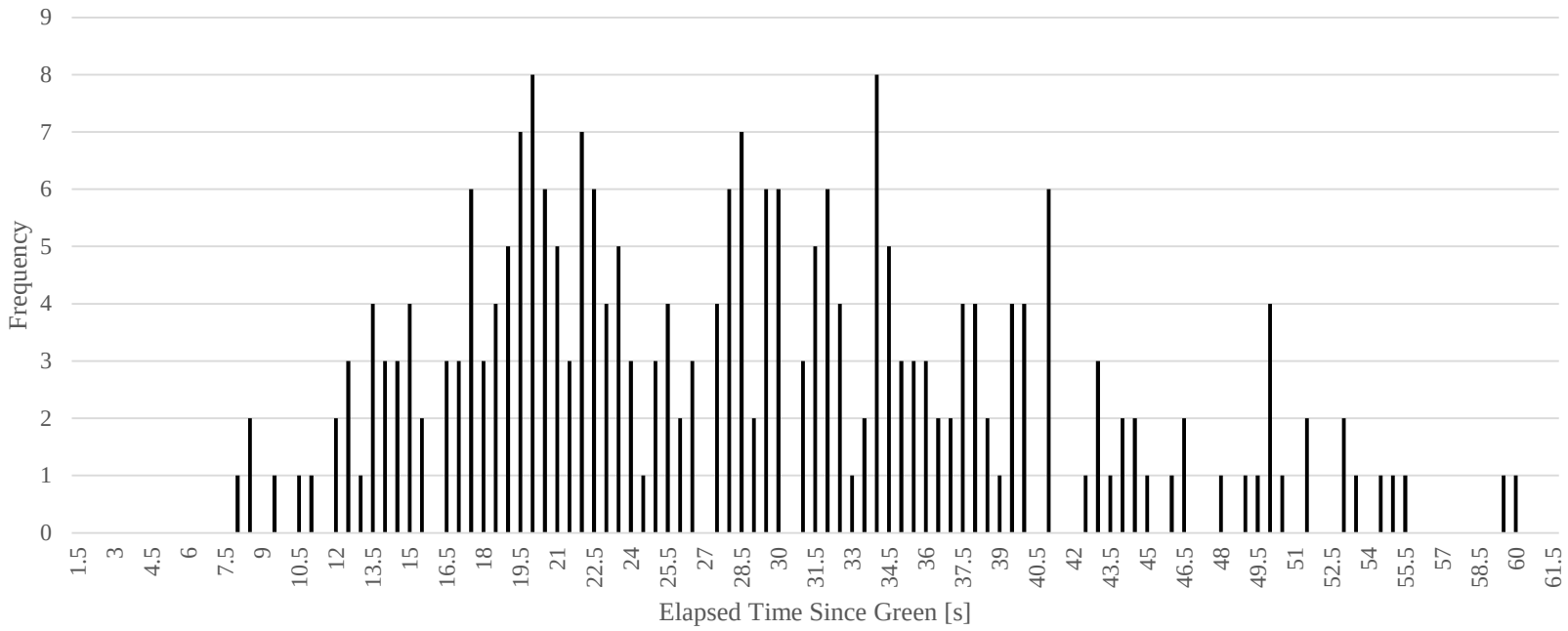
2nd Avenue and 74th Street Severity Summary

Severity	Total Incidents of Specified Severity	Percentage of Total Incidents
Very Dangerous Interaction	95	**37.5%**
Dangerous Interaction	93	**36.8%**
Mild Interaction	54	**21.3%**
No Interaction	**11**	**4.3%**

2nd Ave and 74th St
Elapsed Time Since Green



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2nd Avenue and 74th Street Mixing Zone Notes

- Bicycles and Vehicles were heavily influenced by pedestrian behaviors at this site
  - Pedestrians tend to wait in the crosswalk for a walk phase
  - Pedestrians walked along the bicycle lane and jay walked often
- A good amount of vehicles merged into the mixing zone at the last second

Grand and Multnomah Mixing Zone

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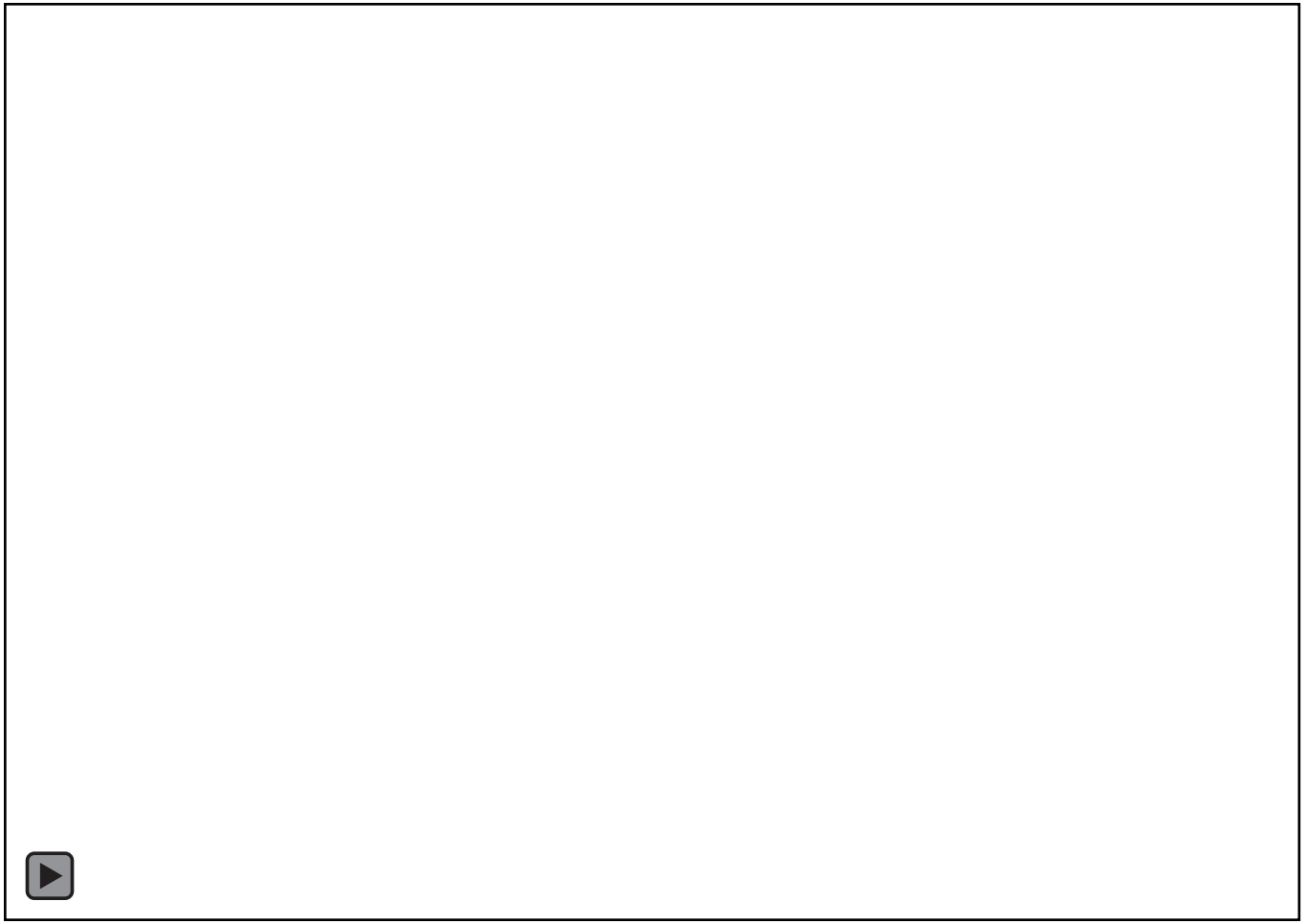
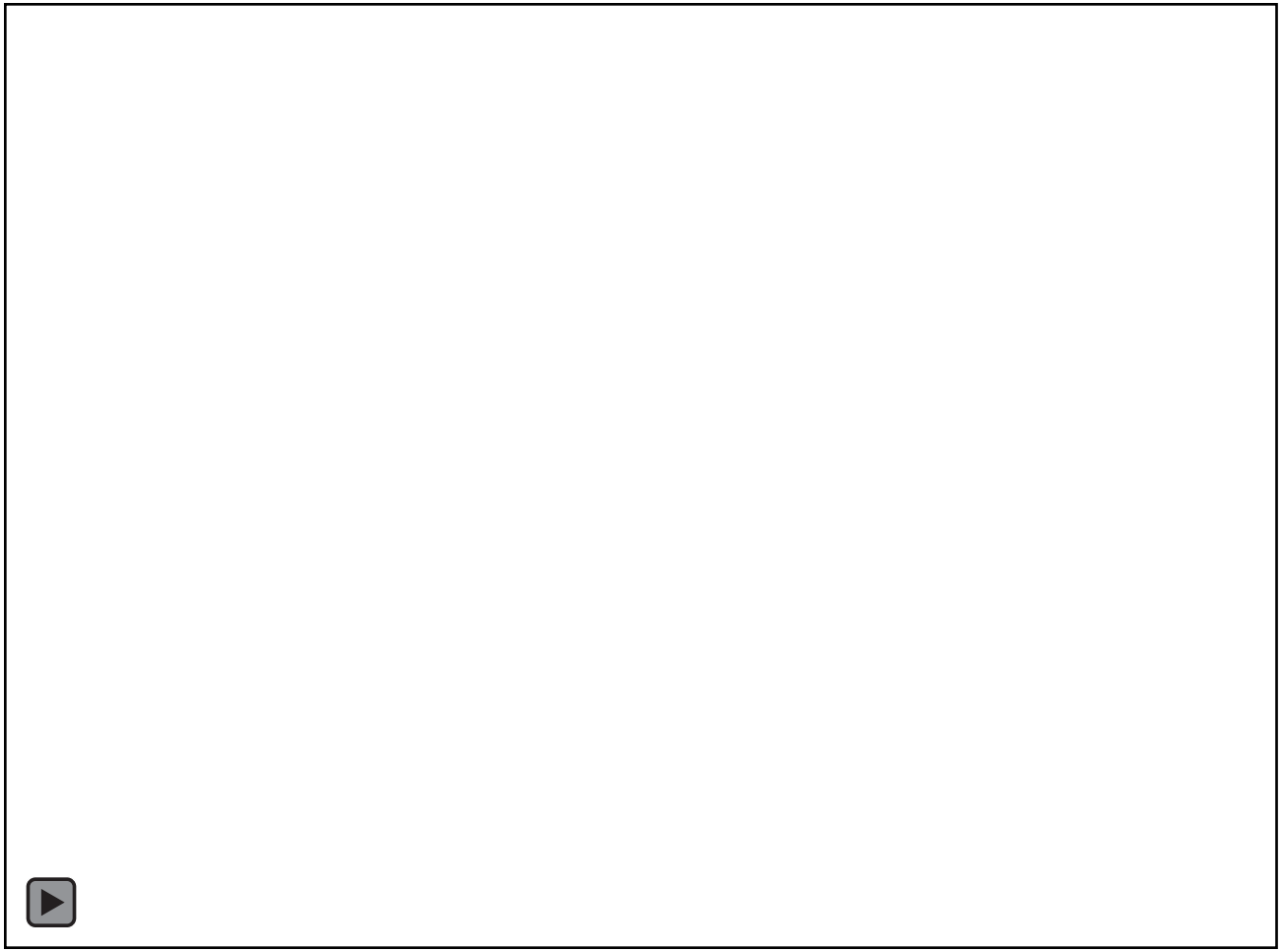
Grand Ave and Multnomah St



Bicycle goes around bus

Grand Ave and Multnomah St



Multiple Vehicles in queue

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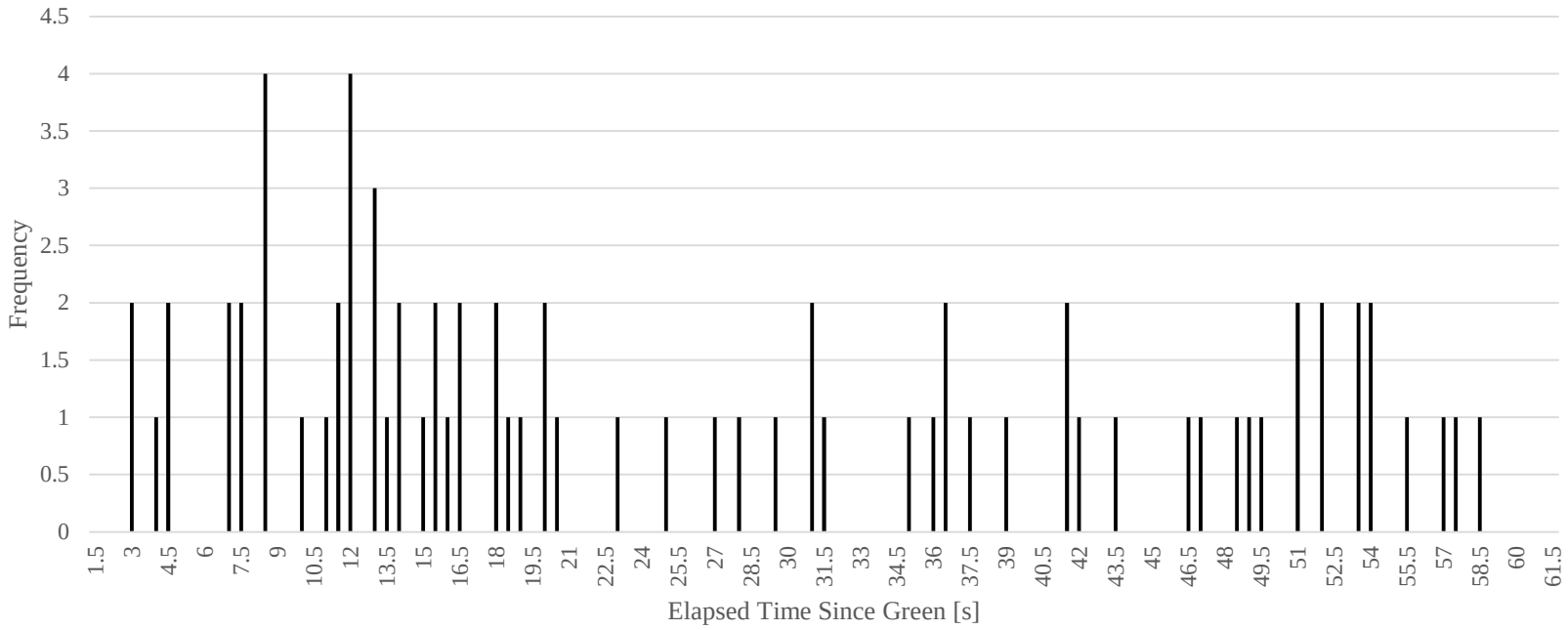
Grand Ave and Multnomah St Mixing Zone Summary

Number of Bicycles	352
Number of Motor Vehicles	1143
Number of Incidents	76
Percentage of Incidents Based on Number of Bicycles	21.59%
Near Misses	0
Number of Collisions if No Evasive Action Taken	4

Grand Ave and Multnomah St Severity Summary

Severity	Total Incidents of Specified Severity	Percentage of Total Incidents
Very Dangerous Interaction	22	**28.9%**
Dangerous Interaction	22	**28.9%**
Mild Interaction	25	**32.9%**
No Interaction	**7**	**9.2%**

Grand and Multnomah Elapsed Time Since Green



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Grand Ave and Multnomah St Mixing Zone Notes

- Bus stop at this location causes bicycles to wait behind the bus until it moves rather than going around it
- Bicycles tend to move towards the middle of the mixing zone rather than staying adjacent to the sidewalk
- A good amount of vehicles tend to merge into the mixing zone at the last second

Mixing Zone - Overall Findings

- % Conflicts at the mixing zone at both locations were comparable.
- Confusion observed in the mixing zone scenario
  - Previous research by Monsere et al. found that only 63% of the bicycles correctly used the mixing zone.