An Evaluation of the Impact of Leading Pedestrian Interval Signals in NYC

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1. Introduction

Leading Pedestrian Interval Signals (LPIs)

- Pedestrians a few seconds head start
- 2,689 intersections
- Director of Signals Timing Engineering to learn about how the LPIs intersections were selected by the DOT
- Part of NYC's Vision Zero initiative (https://www1.nyc.gov/site/visionzero/index.page)

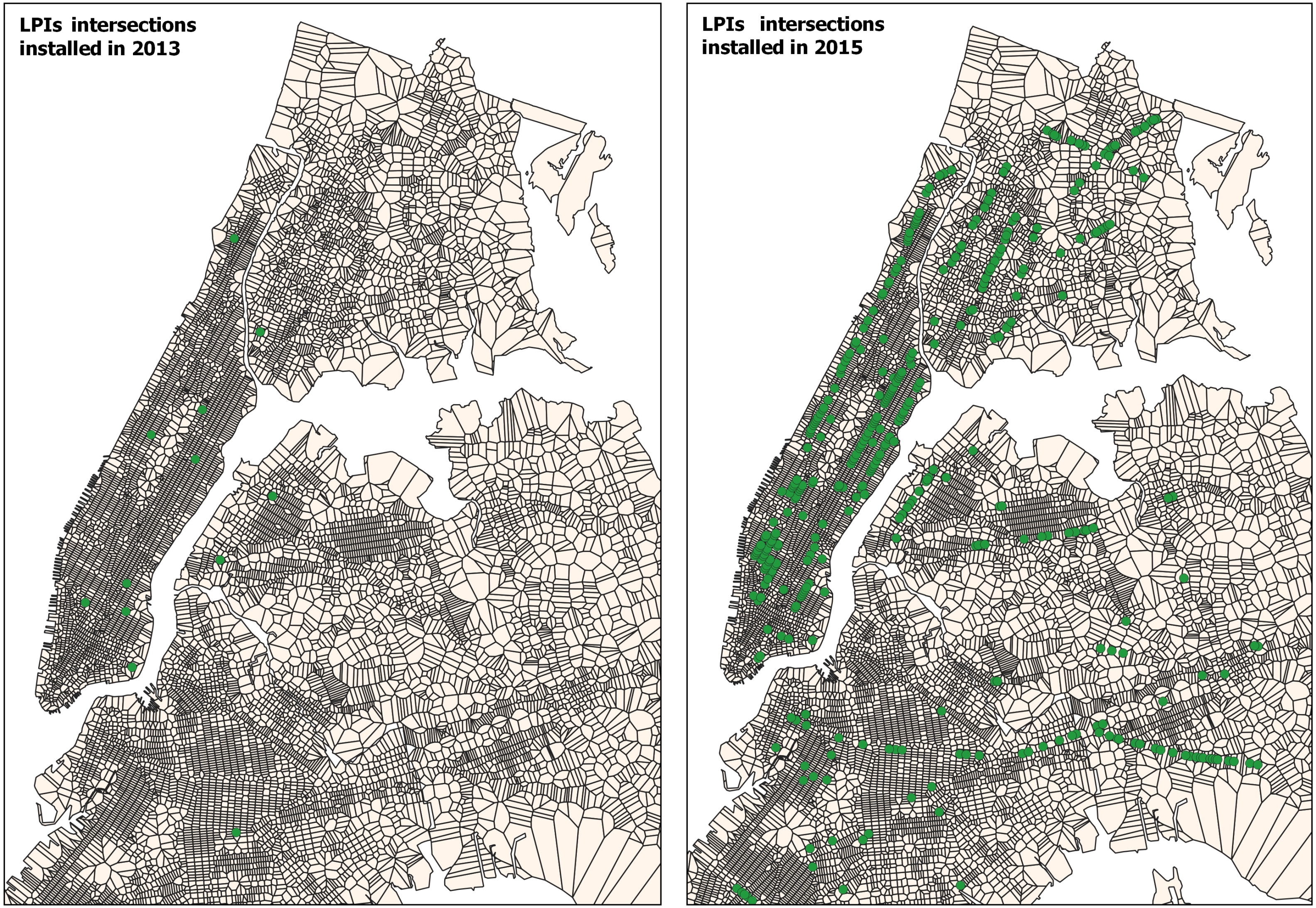
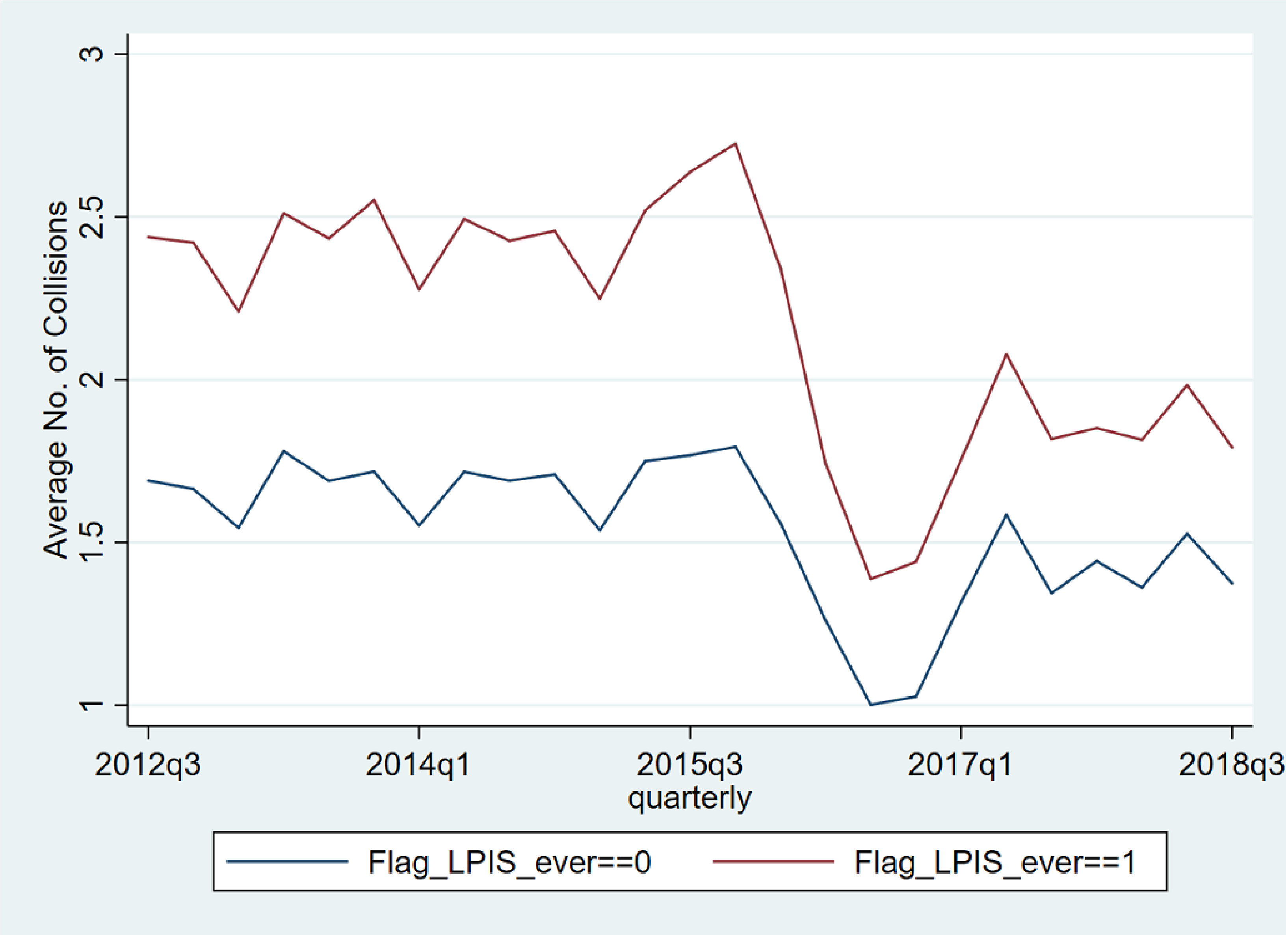

LPIs intersections
installed in 2013
LPIs intersections
installed in 2015

Figure 2: Average collisions by intersection type



NYPD Motor Vehicle Collisions

- From July 2012 to September 2018
- Approximately 1.35 million collisions were recorded

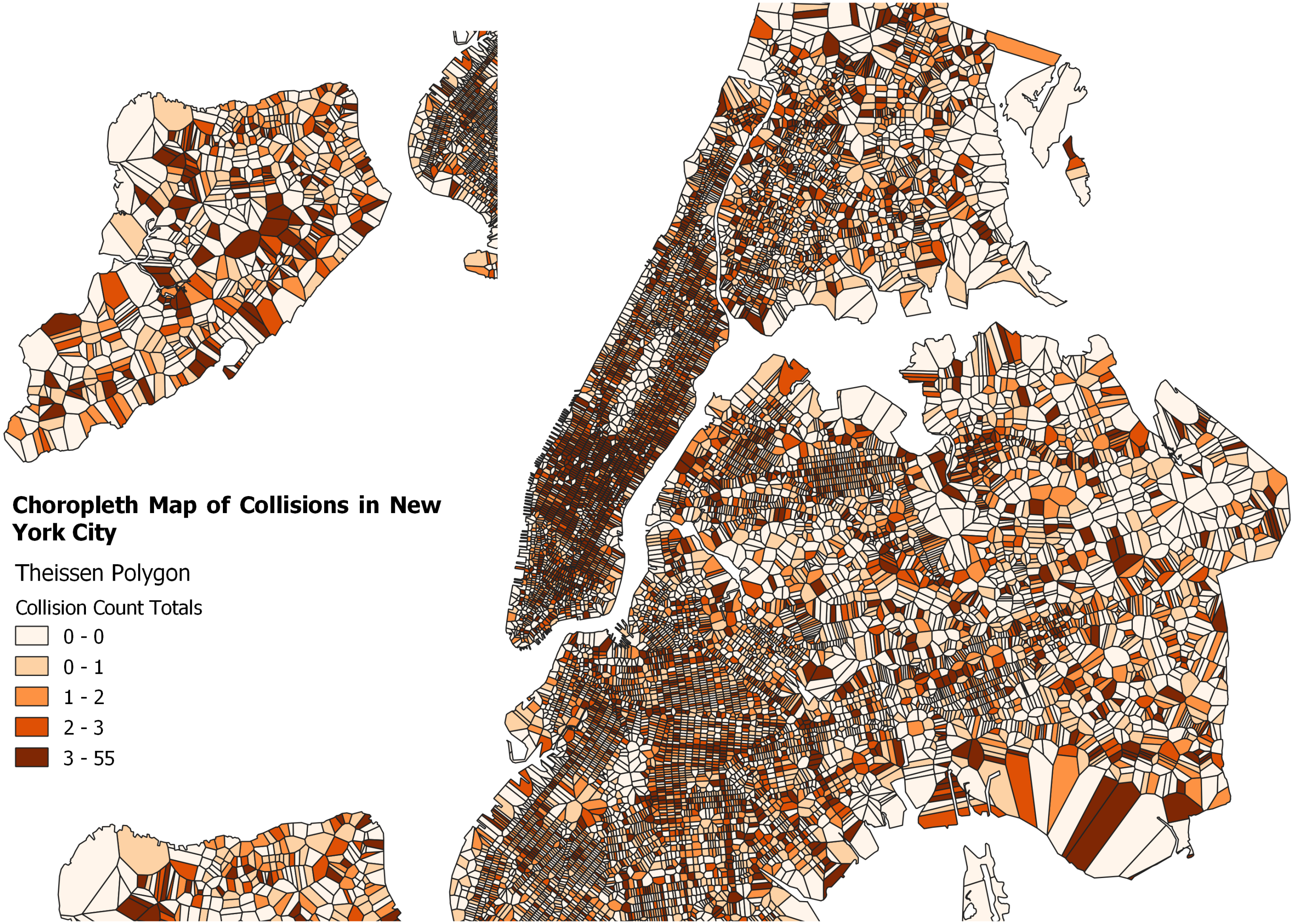
Includes:

- collision outcomes, coordinates, streets, borough, zip code, time, vehicle type, contributing factors

Does not include:

- socio-demographic characteristics, road characteristics, weather, land-use, vehicle motion prior to the accident

Stratified:


Choropleth Map of Collisions in New York City
Theissen Polygon
Collision Count Totals
0 - 0
0 - 1
1 - 2
2 - 3
3 - 55

Hypothesis

The introduction of LPIs reduced collisions and injuries

2. Challenges and Solution

Challenges

- Selectively implemented
- Phased introduction
- Unobserved heterogeneity
    - Characteristics of some intersections that make them “more/less dangerous” to road users
- Spatial autocorrelation
    - Collisions at one intersection could be correlated to collisions at nearby intersections

Identification Strategy

Difference-in-difference (DiD) quasi-experimental research design

$$y_{it} = \alpha_i + \alpha_t + \beta^{DD} D_{it} + e_{it}$$

where dummies for the cross sectional intersections (α_i) and time periods (α_t), and a treatment dummy (D_{it}). The treatment dummy, $D_{it} = 1$ indicates LPIs treatment was implemented at time period (t) and treatment continues for the periods after, otherwise $D_{it} = 0$. e_{it} is the error term that is uncorrelated with D_{it} and α_t.

Goodman-Bacon's general binary treatment difference-in-difference model

- There are 12,987 intersections (i) and 25 periods (t).
- Simplifying from 25 quarters, we can think of it as there being 3 different groups
    - untreated group (U)
    - early treatment group (k) that receives treatment at (t_k^*)
    - late treatment group (l) that receives treatment at (t_l^*)
- Intersections that received the LPIs intervention at a later period after (t_l^*), hence in the periods before that, they act as controls to intersections that had received LPIs intervention at (t_k^*)

A simplfied representation of the model:

$$\hat{\beta}_{jU}^{2x2} \equiv (\bar{y}_j^{POST(j)} - \bar{y}_j^{PRE(j)}) - (\bar{y}_U^{POST(j)} - \bar{y}_U^{PRE(j)}), j = k, \ell.$$

My model is an extension to the simplfied model described above, and it is more complicated as it follows LPIs that were implemented across 25 quarters.

Assumptions

- Unmeasured determinants of the outcomes were time invariant or group invariant
    - α_i is the group fixed effect, which captures the time-invariant characteristics of the intersections (i) such as the design of the intersection, the light conditions of that intersection, and vehicle volumes (busyness of the intersection)
    - α_t is the time fixed effect which captures the time varying characteristics but group-invariant characteristics, like trends in NYC such as seasons and the increase/decrease in population of the neighborhood
- Common trends assumption
    - Trends in the control group should closely parallel the trends in the treatment group
- Timing of the treatment implementation “must be statistically independent of the potential outcomes distributions, conditional on the group-and time-fixed effects
    - Requires that the NYC DOT not change LPIs treatment implementation based on outcomes measured in earlier periods

3. Results

Model Specifications

- Indicator for when intersections received LPIs intervention
- Indicator for when Bike route was built
- Indicator for when Street Improvement was implemented
- Indicator for when Left Turn intervention was implemented
- Interactions of School Zone intersections and time
- Interactions of Senior Zone intersections and time
- Interactions of Priority intersections and time
- Time fixed effects
- Intersection fixed effects

Naive (No fixed effects)

- 29.5% increase in number of collisions

No. of collisions

- 5.30% decrease in number of collisions
- 5.86% decrease during non late night
- no effect during late night

No. of persons injured

- 9.45% decrease in number of persons injured
- 9.8% decrease during non-late nights
- 10.5% decrease during late nights

Breakdown of road users injured

LPIs was effective in reducing:

- Number of pedestrians injured by 13.7%
- Number of motorists injured by 8.2%

Non-late night:

- reduced number of pedestrian injured by 14.2%
- reduced number of motorist injured by 7.5%

But not effective:

- Number of cyclist injured
- During late night hours from 5.00 a.m. to 10.59 p.m.

Decay effect

- 1 year since implementation
- 2 years or more since implementation
    - Number of collisions
    - Number of persons injured
    - Coefficient test for difference
- LPIs effect did not decay over time

Extension Spatial Model (Manhattan)

Total Impact:

- Reduction in number of collisions by 4.2%
- Reduction in number of persons injured by 10.3%
- Reduction in number of pedestrians injured by 17.05%
- Reduction in number of cyclist injured by 16.68%
- Not effective for motorist

Indirect Impact:

- Reduction in number of collisions by 0.71%
- Reduction in number of persons injured by -0.16%.
- Reduction in number of cyclist injured by -0.98%
- Not effective for motorist and pedestrians

4. Discussion

Overview

- Staggered implementation of LPIs in signalized intersections
- Effective in reducing the number of collisions
- Effective in reducing the number of pedestrians injured
- Effective in reducing the numbers of cyclists injured in Manhattan

Late night

With the outcome of number of persons injured in a collision (Table 7)

- LPIs was significant in the overall, late night and non-late night models

In the breakdown of the road users models (Tables 8 - 10)

- None of these models were significant in the late night model at the 5% level

Spatial

- Neighboring intersections with LPIs make drivers slow down at the following intersection
- OR we could hypothesize that drivers might drive more aggressively to reach the next intersection after the LPIs delays the green light for drivers at one intersection
- No evidence for the latter hypothesis as the indirect impact on collisions were negative
- Some evidence of safety effect may be coming vehicles not being able to accelerate to higher speeds

Collisions / Motorist Injured

In the non-spatial model:

- LPIs intervention was significant in reducing number of collisions and motorist injured

In the spatial model Manhattan only:

- LPIs intervention was significant in reducing number of collisions
- LPIs intervention was NOT significant in reducing number of motorist injured

Cyclist

In the non-spatial model

- LPIs have no impact on number of cyclists injured

In the spatial model Manhattan only:

- Direct effect at the intersection with LPIs
- Indirect effect at neighboring intersections

Pedestrians

- No indirect impact for number of pedestrians injured
- But we found that LPIs intervention had an indirect impact on number of collisions

5. Economic Analysis

Cost effectiveness

- Back-of-the-envelope calculations
- Each LPIs cost $1,200 in 2017
- Entire investment for 2,689 intersections was $3.2 million

Federal Highway Administration report of Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries

- Mean human capital cost: $67,342
- Mean comprehensive cost per crash: $129,418

Using the predicted values from the persons injured model:

- 4,609 persons avoided injury at LPIs intersections
- $12 million in human capital cost loss avoided

6. Conclusions

The coefficients from the non-spatial fixed effects DiD analysis of:

- number of collisions, persons and pedestrians injured
- stayed similar in their magnitude across the different models

- suggests that results to be fairly robust

- The LPIs intervention is a very cost effective method of reducing collisions

Future work:

- Replicating the spatial analysis on the entire New York City data
- Investigate if LPIs reduces the numbers of motorists injured outside of Manhattan, since it was effective in reducing number of motorist injured in the overall model.

Questions?

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Tables and Figures

Table 1: Collisions counts and averages

Categories	2012	2013	2014	2015	2016	2017	2018
A. Collision/Injuries outcomes at Intersections							
Collisions	47,611	95,437	94,644	97,792	68,511	78,764	58,942
Injuries of:							
Persons	13,336	26,640	24,466	23,160	18,611	22,666	17,513
Pedestrians	3,725	7,555	6,859	6,095	4,821	5,781	3,942
Cyclist	1,355	2,569	2,598	2,597	1,978	2,339	1,766
Motorist	8,250	16,516	15,008	14,468	11,911	14,967	11,706
B. Collision/Injuries counts at Intersections Stratified by LPIs							
LPIs Ever == 1	13,068	26,101	25,963	27,244	18,588	20,173	15,034
LPIs Ever == 0	34,543	69,336	68,681	70,548	49,923	58,591	43,908
C. Collision/Injuries averages at Intersections Stratified by LPIs							
LPIs Ever == 1	2.43	2.43	2.41	2.53	1.73	1.88	1.86
LPIs Ever == 0	1.68	1.68	1.67	1.71	1.21	1.42	1.42

Table 2: Collisions with longitude and latitude filled

	2012	2013	2014	2015	2016	2017	2018
Coordinates Filled	85,452	171,917	172,730	182,958	162,745	214,935	157,185
(%)	-84.99	-84.39	-83.84	-84.05	-71.44	-93.75	-94.87
Coordinates missing	15,087	31,806	33,296	34,729	65,077	14,327	8,508
(%)	-15.01	-15.61	-16.16	-15.95	-28.56	-6.25	-5.13
Total	0	13	60	408	713	825	670

Table 3: Number of LPIs implemented in Quarters and Years

	2012	2013	2014	2015	2016	2017	2018
Coordinates Filled	85,452	171,917	172,730	182,958	162,745	214,935	157,185
(%)	-84.99	-84.39	-83.84	-84.05	-71.44	-93.75	-94.87
Coordinates missing	15,087	31,806	33,296	34,729	65,077	14,327	8,508
(%)	-15.01	-15.61	-16.16	-15.95	-28.56	-6.25	-5.13
Total	0	13	60	408	713	825	670

Table 4: Characteristics of the intersections

	LPIs intersections	**Control intersections**
No. of intersections in New York City	2,689	10,298
School (intersections within 200 feet of school)	201	475
	-7.47%	-4.61%
Seniors (intersections within safe senior zone)	859	1,717
	-31.94%	-16.67%
Priority Intersection (intersections within 10 ft of signal intersection)	110	109
	-4.09%	-1.06%

Table 5: Naive regression model - Number of collisions per quarter

	1	2	3	4	5	6
VARIABLES	**Poisson**	**OLS**	**Poisson Late night**	**OLS Late night**	**Poisson Non- Late night**	**OLS Non- Late night**
Flag LPIs	0.258***	0.447***	0.309***	0.0568***	0.252***	0.390***
	-0.0253	-0.047	-0.0383	-0.00769	-0.025	-0.0415
Bike route	0.239***	0.421***	0.362***	0.0644***	0.226***	0.357***
	-0.0219	-0.0412	-0.0301	-0.00594	-0.0216	-0.0363
Street Improvement	0.334***	0.707***	0.357***	0.0772***	0.332***	0.630***
	-0.0737	-0.182	-0.089	-0.0224	-0.0738	-0.164
Left Turn	0.519***	1.186***	0.449***	0.106***	0.527***	1.080***
	-0.0608	-0.176	-0.11	-0.0327	-0.0587	-0.152
Observations	324,675	324,675	324,675	324,675	324,675	324,675

Table 6: Fixed effect DiD model - Number of collisions per quarter

	1	2	3	4	5	6
VARIABLES	**Fixed effects poisson**	**Fixed effects regression**	**Fixed effects poisson Late night**	**Fixed effects regression Late night**	**Fixed effects poisson Non-Late night**	**Fixed effects regression Non-Late night**
Flag LPIs	-0.0545***	-0.162***	-0.00245	-0.00039	-0.0604***	-0.161***
	-0.0128	-0.0305	-0.0255	-0.00628	-0.013	-0.0279
Bike route	0.0233	0.0521	0.0421	0.0101	0.0217	0.0434
	-0.0189	-0.0379	-0.04	-0.00865	-0.0189	-0.0345
Street Improvement	-0.0157	-0.209	-0.0133	-0.016	-0.0172	-0.195
	-0.0449	-0.148	-0.0661	-0.0234	-0.0458	-0.135
Left Turn	-0.140***	-0.806***	-0.133*	-0.0683**	-0.139***	-0.742***
	-0.0369	-0.174	-0.0741	-0.0274	-0.0384	-0.162
Observations	283,550	283,550	242,725	242,725	283,200	283,200
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328

Table 7: Fixed effect DiD model - Number of persons injured per quarter

	1	2	3	4	5	6
VARIABLES	**Fixed effects poisson**	**Fixed effects regression**	**Fixed effects poisson Late night**	**Fixed effects regression Late night**	**Fixed effects poisson Non-Late night**	**Fixed effects regression Non-Late night**
Flag LPIs	-0.0993***	-0.0692***	-0.111**	-0.0145**	-0.0980***	-0.0603***
	-0.0213	-0.0134	-0.054	-0.00722	-0.0221	-0.0122
Bike route	0.0169	0.01	-0.00445	-0.000199	0.0193	0.0103
	-0.0307	-0.0166	-0.0789	-0.00986	-0.0316	-0.015
Street Improvement	-0.0272	-0.041	-0.106	-0.0187	-0.0167	-0.0287
	-0.0545	-0.0434	-0.17	-0.028	-0.0557	-0.0388
Left Turn	-0.200***	-0.217***	-0.25	-0.0483*	-0.193***	-0.185***
	-0.066	-0.0623	-0.156	-0.0272	-0.0675	-0.0552
Observations	273,875	273,875	146,725	146,725	272,000	272,000
Number of intersection_id	10,955	10,955	5,869	5,869	10,880	10,880
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328

Table 8: Fixed effect DiD model - Number of pedestrians injured per quarter

	1	2	3	4	5	6
VARIABLES	**Fixed effects poisson**	**Fixed effects regression**	**Fixed effects poisson Late night**	**Fixed effects regression Late night**	**Fixed effects poisson Non-Late night**	**Fixed effects regression Non-Late night**
Flag LPIs	-0.147***	-0.0337***	-0.0895	-0.00493	-0.153***	-0.0329***
	-0.0289	-0.00569	-0.088	-0.00529	-0.0303	-0.00547
Bike route	-0.0789*	-0.0129*	-0.0592	-0.00251	-0.0799*	-0.0123*
	-0.0419	-0.00749	-0.131	-0.00773	-0.0445	-0.00741
Street Improvement	-0.0391	-0.0208	-0.125	-0.00877	-0.0312	-0.0168
	-0.0744	-0.0194	-0.236	-0.0159	-0.0849	-0.02
Left Turn	-0.302***	-0.147***	-0.199	-0.0198	-0.311***	-0.136***
	-0.0718	-0.0264	-0.204	-0.0148	-0.0804	-0.0259
Observations	223,100	223,100	58,475	58,475	218,675	218,675
Number of intersection_id	8,924	8,924	2,339	2,339	8,747	8,747
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328

Table 9: Fixed effect DiD model - Number of cyclists injured per quarter

	1	2	3	4	5	6
VARIABLES	**Fixed effects poisson**	**Fixed effects regression**	**Fixed effects poisson Late night**	**Fixed effects regression Late night**	**Fixed effects poisson Non-Late night**	**Fixed effects regression Non-Late night**
Flag LPIs	-0.0272	-0.00275	0.0632	0.00269	-0.0376	-0.00357
	-0.0418	-0.00431	-0.13	-0.00617	-0.0437	-0.00423
Bike route	0.172***	0.0157***	0.0532	0.00229	0.184***	0.0161***
	-0.0643	-0.00585	-0.204	-0.00951	-0.0677	-0.00584
Street Improvement	0.0935	0.00912	0.252	0.0121	0.0788	0.00728
	-0.116	-0.0125	-0.33	-0.0163	-0.124	-0.0125
Left Turn	-0.206*	-0.0309*	-0.291	-0.0155	-0.199	-0.0272*
	-0.122	-0.0158	-0.339	-0.0186	-0.133	-0.0158
Observations	158,275	158,275	27,575	27,575	152,775	152,775
Number of intersection_id	6,331	6,331	1,103	1,103	6,111	6,111
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328

Table 10: Fixed effect DiD model - Number of motorists injured per quarter

	1	2	3	4	5	6
VARIABLES	**Fixed effects poisson**	**Fixed effects regression**	**Fixed effects poisson Late night**	**Fixed effects regression Late night**	**Fixed effects poisson Non-Late night**	**Fixed effects regression Non-Late night**
Flag LPIs	-0.0856***	-0.0362***	-0.129*	-0.0163*	-0.0778**	-0.0284***
	-0.029	-0.0119	-0.0676	-0.0084	-0.0311	-0.0109
Bike route	0.0359	0.013	0.00446	0.000949	0.0399	0.0127
	-0.0419	-0.0149	-0.0974	-0.0118	-0.044	-0.0136
Street Improvement	-0.0357	-0.0271	-0.12	-0.0172	-0.0216	-0.0171
	-0.0751	-0.0389	-0.219	-0.0322	-0.0758	-0.0337
Left Turn	-0.0792	-0.0408	-0.216	-0.0319	-0.0525	-0.0236
	-0.103	-0.0518	-0.217	-0.03	-0.107	-0.0461
Observations	254,400	254,400	113,775	113,775	248,025	248,025
Number of intersection_id	10,176	10,176	4,551	4,551	9,921	9,921
Number of intersection_id	11,342	11,342	9,709	9,709	11,328	11,328

Table 11: Fixed effects DiD Spatial Lag Model of Manhattan Intersections

	1	2	3	4	5
VARIABLES	**Number of Collisions**	**Number of Person injured**	**Number of Pedestrians injured**	**Number of Cyclists injured**	**Number of Motorist Injured**
Flag LPIs	-0.106***	-0.0643***	-0.0389***	-0.0166***	-0.00897
	-0.0377	-0.0176	-0.00894	-0.00569	-0.0137
W.outcome	0.188***	0.0171**	0.00064	0.0320***	0.0134*
	-0.00628	-0.00709	-0.00714	-0.00705	-0.00713
			Impact		
Direct	-0.106***	-0.064***	-0.039***	-0.017***	-0.009
	0.038	0.018	0.009	0.006	0.014
Indirect	-0.022***	-0.001**	0	-0.001**	0
	0.008	0.001	0	0	0
Total	-0.128***	-0.065***	-0.039***	-0.017***	-0.009
	0.046	0.018	0.009	0.006	0.014
Observations	68,400	68,400	68,400	68,400	68,400
Number of intersection_id	2,736	2,736	2,736	2,736	2,736

Table 12: Fixed effects DiD Spatial Error Model of Manhattan Intersections

	1	2	3	4	5
VARIABLES	**Number of Collisions**	**Number of Person injured**	**Number of Pedestrians injured**	**Number of Cyclists injured**	**Number of Motorist Injured**
Flag LPIs	-0.129***	-0.0644***	-0.0389***	-0.0168***	-0.00893
	-0.0387	-0.0176	-0.00894	-0.00572	-0.0138
e.outcome	0.188***	0.0150**	-0.00143	0.0319***	0.0129*
	-0.00639	-0.00713	-0.00718	-0.00707	-0.00714
Observations	68,400	68,400	68,400	68,400	68,400
Number of intersection_id	2,736	2,736	2,736	2,736	2,736

References

Ajilore, O. (2015). Identifying peer effects using spatial analysis: the role of peers on risky sexual behavior. Review of Economics of the Household, 13(3), 635–652. https://doi.org/10.1007/s11150-013-9235-4 (https://doi.org/10.1007/s11150-013-9235-4) Anselin, L. (1988). Spatial Econometrics: Methods and Models. In Studies in Operational Regional Science. Retrieved from https://www.springer.com/us/book/9789024737352 (https://www.springer.com/us/book/9789024737352)

Anselin, L., & Griffith, D. A. (1988). Do spatial effects really matter in regression analysis? Papers - Regional Science Association, 65, 11–34.

Appendix A - Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries, October 2005 - FHWA-HRT-05-051. (n.d.). Retrieved March 16, 2019, from https://www.fhwa.dot.gov/publications/research/safety/05051/06.cfm (https://www.fhwa.dot.gov/publications/research/safety/05051/06.cfm)

Fayish, A., & Gross, F. (2010). Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before-After Study with Comparison Groups. Transportation Research Record: Journal of the Transportation Research Board, 2198, 15–22. https://doi.org/10.3141/2198-03 (https://doi.org/10.3141/2198-03)

Goodman-Bacon, A. (2018). Difference-in-Differences with Variation in Treatment Timing (No. w25018). https://doi.org/10.3386/w25018 (https://doi.org/10.3386/w25018)

Goughnour, E., Carter, D., Lyon, C., Persaud, B., Lan, B., Chun, P., … Signor, K. (2018). Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian

Safety (No. FHWA-HRT-18-044). U.S. Department of Transportation.

Goughnour, Elissa, Carter, D., Lyon, C., Persaud, B., Lan, B., Chun, P., … Signor, K. (n.d.). Safety Evaluation of Protected Left-Turn Phasing and Leading Pedestrian Intervals on Pedestrian Safety. Retrieved from https://www.fhwa.dot.gov/publications/research/safety/18044/18044.pdf (https://www.fhwa.dot.gov/publications/research/safety/18044/18044.pdf)

Hauer, E., Harwood, D. W., Council, F. M., & Griffith, M. S. (2002). Estimating Safety by the Empirical Bayes Method: A Tutorial. Transportation Research Record: Journal of the Transportation Research Board, 1784(1), 126–131. https://doi.org/10.3141/1784-16 (https://doi.org/10.3141/1784-16)

Hubbard, S. M. L., Bullock, D. M., & Thai, J. H. (2008). Trial Implementation of a Leading Pedestrian Interval: Lessons Learned. ITE Journal, 78(10). Retrieved from https://trid.trb.org/view/873717 (https://trid.trb.org/view/873717)

King, M. R. (2000). CALMING NEW YORK CITY INTERSECTIONS. Transportation Research Circular. Presented at the Urban Street Symposium Transportation Research Board; American Association of State Highway and Transportation Officials; American Society of Civil Engineers; Federal Highway Administration; Institute of Transportation Engineers; and National Association of County Engineers. Retrieved from https://trid.trb.org/view/686665 (https://trid.trb.org/view/686665)

LeSage, J., Pace, R. K., & Pace, R. K. (2009). Introduction to Spatial Econometrics. https://doi.org/10.1201/9781420064254 (https://doi.org/10.1201/9781420064254)

Matyas, L., & Sevestre, P. (Eds.). (2008). The Econometrics of Panel Data: Fundamentals and Recent Developments in Theory and Practice (3rd ed.). In (3rd ed.). Retrieved from https://www.springer.com/us/book/9783540758891 (https://www.springer.com/us/book/9783540758891)

NYC DOT. (2014). Vision Zero Action Plan 2014. Retrieved from http://www.nyc.gov/html/visionzero/pdf/nyc-vision-zero-action-plan.pdf (http://www.nyc.gov/html/visionzero/pdf/nyc-vision-zero-action-plan.pdf)

NYC DOT. (n.d.). NYC DOT - Data Feeds. Retrieved February 20, 2019, from https://www1.nyc.gov/html/dot/html/about/datafeeds.shtml (https://www1.nyc.gov/html/dot/html/about/datafeeds.shtml)

NYC DOT - Leading Pedestrian Interval Signals. (n.d.). Retrieved December 17, 2018, from http://www.nyc.gov/html/dot/html/infrastructure/leading-ped-intervals.shtml (http://www.nyc.gov/html/dot/html/infrastructure/leading-ped-intervals.shtml)

NYC Open Data, O. (2018, December 2). NYPD Motor Vehicle Collisions | NYC Open Data. Retrieved December 2, 2018, from /Public-Safety/NYPD-Motor-Vehicle-Collisions/h9gi-nx95, /Public-Safety/NYPD-Motor-Vehicle-Collisions/h9gi-nx95

NYS DMV. (n.d.). Motorist accident reports | New York State Department of Motor Vehicles. Retrieved February 20, 2019, from https://dmv.ny.gov/dmv-records/motorist-accident-reports (https://dmv.ny.gov/dmv-records/motorist-accident-reports)

Open Data Law - DoITT. (2019, February 16). Retrieved February 16, 2019, from https://www1.nyc.gov/site/doitt/initiatives/open-data-law.page (https://www1.nyc.gov/site/doitt/initiatives/open-data-law.page)

Pécheux, K., Bauer, J., & McLeod, P. (2009). Pedestrian Safety Engineering and ITS-Based Countermeasures Program for Reducing Pedestrian Fatalities, Injury Conflicts, and Other Surrogate Measures Final System Impact Report. Retrieved from Science Applications International Corporation (SAIC) website: https://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/sys_impact_rpt/sys_impact_rp (https://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/sys_impact_rpt/sys_impact_rp

Rhee, K.-A., Kim, J.-K., Lee, Y., & Ulfarsson, G. F. (2016). Spatial regression analysis of traffic crashes in Seoul. Accident Analysis & Prevention, 91, 190–199. https://doi.org/10.1016/j.aap.2016.02.023 (https://doi.org/10.1016/j.aap.2016.02.023)

Sharma, A., Smaglik, E. J., Kothuri, S., Smith, O., Koonce, P., & Huang, T. (2017). Leading pedestrian intervals treating the decision to implement as a marginal benefit–Cost problem. Traffic Signal Systems, Volume 2, 96–104. https://doi.org/10.3141/2620-09 (https://doi.org/10.3141/2620-09)

Tchoukanski, I. (n.d.). Thiessen Polygons. Retrieved March 4, 2019, from https://www.ian-ko.com/ET_GeoWizards/UserGuide/thiessenPolygons.htm (https://www.ian-ko.com/ET_GeoWizards/UserGuide/thiessenPolygons.htm)

Van Houten, R., Retting, R. A., Farmer, C. M., & Van Houten, J. (2000). FIELD EVALUATION OF A LEADING PEDESTRIAN INTERVAL SIGNAL PHASE AT THREE URBAN