The Relative Effectiveness of Pedestrian Safety Countermeasures at Urban Intersections
— Lessons from a New York City Experience

Li Chen
Corresponding Author
Department of Civil Engineering
City College of New York
160 Convent Avenue
New York, NY 10031
E-mail: lichen.cuny@gmail.com

Cynthia Chen
Department of Civil and Environmental Engineering
University of Washington
Box 352700
Seattle, WA 98195
E-mail: qzchen@u.washington.edu

Reid Ewing
Department of City and Metropolitan Planning
University of Utah
Salt Lake City, UT 84112
E-mail: REwing6269@aol.com

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Abstract

Walking has many benefits for pedestrians and the society. Yet, pedestrians are a vulnerable group and safety concerns are a significant barrier in one's decision to walk. Multiple countermeasures have been proposed to promote pedestrian safety, however, their relative effectiveness is unknown and those effective in reducing pedestrian crashes may be at odds with motorist safety. In this study, we seek to evaluate the relative effectiveness of five countermeasures in New York City—increasing the total cycle length, Barnes Dance, split phase timing, signal installation, and high visibility crosswalk—and examine potential trade-offs in their effectiveness in reducing pedestrian crashes and multiple vehicle crashes. We adopted a rigorous two-stage design that first identifies a comparison group, corresponding to each treatment group, and then estimates a negative binomial model with the Generalized Estimating Equation (GEE) method to further control confounding factors and within-subject correlation. Built environment characteristics are also accounted for. Set in a large urban area, this study suggests that the four signal-related countermeasures are more effective in reducing crashes than high visibility crosswalks. The findings indicate that the types of conflicts and balance the time for different groups of road users at the intersections should be considered so that the improvement of the safety of one group does not compromise that of other groups.

INTRODUCTION

There is a growing need for safe and walkable communities—where people can walk more often, walk to more places, and walk more safely. Walking, whether for utilitarian or recreational purposes, has many benefits, including improved physical health (*1*), reduced traffic congestion, enhanced quality of life and economic vitality (*2*). However, pedestrians are vulnerable road users and safety concerns can discourage the decision to walk. According to National Highway Traffic Safety Administration (NHTSA), there were 59,000 pedestrian injuries and 4,092 deaths resulted from traffic crashes in 2009 in the United States (*3*). Twelve percent of the traffic fatalities involved pedestrians (*3*). In cities with population exceeding 1 million, the percentage is much higher. In New York City (NYC), for example, 52 percent of traffic fatalities from 2005 to 2009 involved pedestrians (*4*). Selecting effective countermeasures to improve pedestrian safety is a critical component in creating pedestrian-friendly communities.

Intersections entail one of the most complex traffic situations, with different crossing and entering movements by vehicle drivers, pedestrians, and bicyclists. Consequently, the risk of crashes and injuries is high at intersections—in 2009, more than 50 percent of the fatal and injurious crashes occur at intersections (*5, 6*). In New York City about 60 percent of the total crashes and 65 percent of the pedestrian crashes occurred at intersections between 1989 and 2008.

Multiple countermeasures may be candidates for improving pedestrian safety at intersections (*7, 8, 9*). The relative effectiveness of one countermeasure as compared to others is one of the most important criteria in deciding what strategy should be deployed (*10*). Many studies have evaluated the effectiveness of individual countermeasures (*8*). Though the relative effectiveness of different countermeasures can be compared across different studies, differences in the study context can make the comparison across studies difficult. For example, all three dimensions of the built environment—density, diversity, and design—have been found to be associated with crashes and injuries (*11, 12*) . Differences in research design, analysis methods, and outcome measurements between studies can further add to the difficulty in comparisons. Most of the existing evaluations used surrogate measures—behavioral or operational measures, such as pedestrian-vehicle conflicts, motorist yielding, pedestrian looking behavior, or pedestrian compliance with traffic signals, instead of actual crash reductions (*8*).

The purpose of this study is to conduct a quantitative evaluation of the relative effectiveness of five countermeasures in improving pedestrian safety at urban intersections. The five treatments are: increasing cycle length for pedestrian crossing, Barnes Dance (also called pedestrian scramble), split phase timing, signal installation, and high visibility crosswalk. Except signal installation, the other four treatments are specifically designed to improve pedestrian safety. We included signal installation in the study since it can be used to improve the safety of all road users.

Countermeasures designed to improve pedestrian safety can compromise the safety of motorists (*12, 13*). For example, increasing cycle length for pedestrian crossing is associated with a longer wait for motorists, which may increase speeding and crash risk. Is it possible for countermeasures to achieve safety for both pedestrians and motorists? Split phase, an invention by the New York City Department of Transportation, may achieve safety for both pedestrians and motorists by separating pedestrians and motorists into two protected phases. The secondary purpose of this study is to understand how countermeasures designed for pedestrian safety affect vehicle-vehicle crashes.

In the rest of the paper, we first describe the five countermeasures evaluated in the study, followed by our study design and methodology. We then present our study results, followed by conclusions and recommendations.

THE FIVE PEDESTRIAN COUNTERMEASURES IN NYC

Conflict is one of the three principal factors (the other two factors are exposure and speed) responsible for crashes (*14*). Even with a signal, conflicts occur. Within a phase, pedestrians and left- and right-turning vehicles, left-turning vehicles and opposing through traffic, or left-turning vehicles and opposing right-turning vehicles have conflicting movements. Between phases, conflicts could arise due to inadequate time allocated to road users (e.g., pedestrians).

Four of the five countermeasures selected in this study attempt to resolve conflicts within a phase or between phases. Two of them—increasing the total cycle length and Barnes Dance attempt to reduce conflicts between phases by lengthening the time to cross the street or releasing pedestrians in all directions at once. The other two —signal installation and split phase—are designed to reduce conflicts by separating conflicts in time and space. The fifth one selected—high visibility crosswalk—is designed to improve safety via raising drivers' awareness of pedestrians when approaching the intersection.

Increasing cycle length for pedestrian crossing

Increasing the total cycle length to lengthen pedestrian crossing time can be particularly useful for older persons whose walking speed is relatively slow. The downside is that vehicles on the main street must wait longer at a red signal due to the longer green phase for the cross street and consequently a longer queue may accumulate during the peak period. In addition, pedestrians waiting to cross the cross street may also become impatient and decide to cross against the signal.

The cycle lengths of many of the intersections on Queens Boulevard (a 12-lane thoroughfare) and Ocean Parkway (has a central 7-lane roadway, two service roads, and two medians with trees) were increased as a traffic safety countermeasure: from 120-second to 150-second on Queens Boulevard (*15*), allowing an additional 20-second walk time for pedestrians crossing the very wide main street, and from 90 to 120 seconds on Ocean Parkway, allowing an increase in pedestrian crossing time from 6 to 17 seconds (*15*).

We find no previous study that examined the impact of increasing total cycle length on crashes. The only relevant study was conducted by Ng et al. (*16*) who examined the relationship between cycle time and crashes using a cross-sectional dataset of intersections with different cycle lengths and found no apparent relationship between the two.

Barnes Dance

Barnes Dance, also called pedestrian scramble, is a special phase added to the regular two-phase permissive signal timing, which stops vehicle traffic in all directions and allows pedestrians to cross in any fashion, including diagonally. Figure 1 shows the three phases of the signal timing and some pictures of intersections in the special phase in different cities (Phase 3).

During this 3rd special phase, any potential conflict between pedestrians and motorists is removed. The downside is that the time for diagonal crossing is very short (only 33 seconds) while the waiting time is long (57 seconds). The lack of sufficient crossing time may prompt pedestrians to cross diagonally against signal. In addition, Barnes Dance creates “lost time” (the time during which no vehicles are able to pass through an intersection), which will result in a loss of roadway capacity.

Bechtel et al. (*17*) studied Barnes Dance at one intersection in Chinatown in Oakland, California and found a 50% reduction in pedestrian-vehicle conflicts. Kattan et al. (*18*) studied Barnes Dance at two intersections in downtown Calgary, Canada. They measured the number of pedestrian-vehicle conflicts and pedestrian violations (crossing against signal) and found that Barnes Dance decreased the number of pedestrian-vehicle conflicts occurring at the intersection but increased the number of violations after the implementation of Barnes Dance.

Split phase

In split phase timing, the regular two phases of a traffic cycle are split into three phases as shown in Figure 2. Under this operation, pedestrians receive a "walking person" display while the parallel movement of traffic that would normally turn left or right through the crosswalk is held with a left or right red arrow signal and the through movement proceeds on a green signal (as shown in Figure 2). After the pedestrian crossing is completed, a red "steady hand" is displayed and the turns are then made on a green arrow signal while the through movement continues to move. Split phase requires dedicated turn lanes since through and turning movements are governed by different signal indications.

Split phase timing allows pedestrian crossings and bicycle movements to be completely free from conflicts with turning vehicles. Assuming pedestrian compliance, left-turn vehicle progression is smoother than the before situation without split phase timing. The downside is that the time available for pedestrian crossings and the time allowed for vehicle turning movements are less than what would be if they were allowed to move concurrently with the through traffic. Consequently, pedestrians with low walking speed may not have sufficient time to complete the crossing; for intersections with a high volume of turning vehicles, this could result in a long queue waiting for their right-of-way. No other studies investigating the safety impacts of this countermeasure were found.

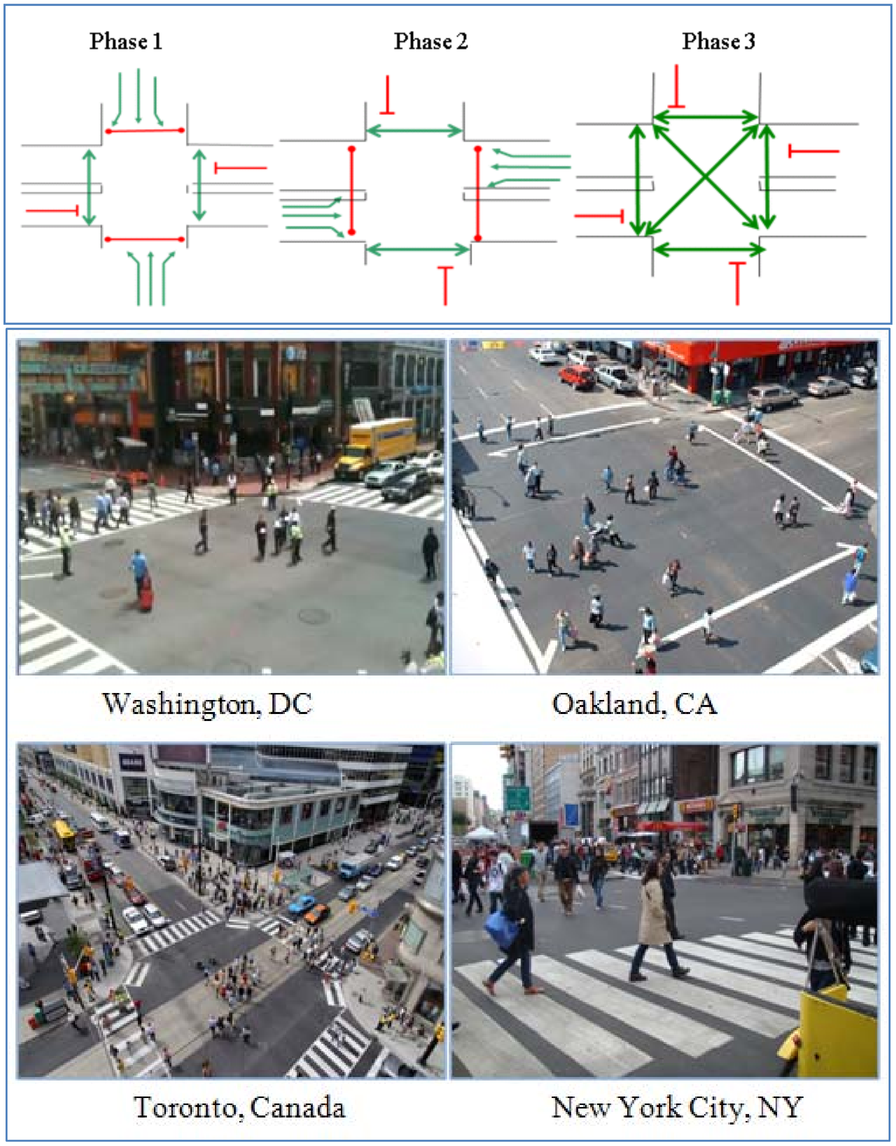

FIGURE 1 Barnes Dance Signal Timing

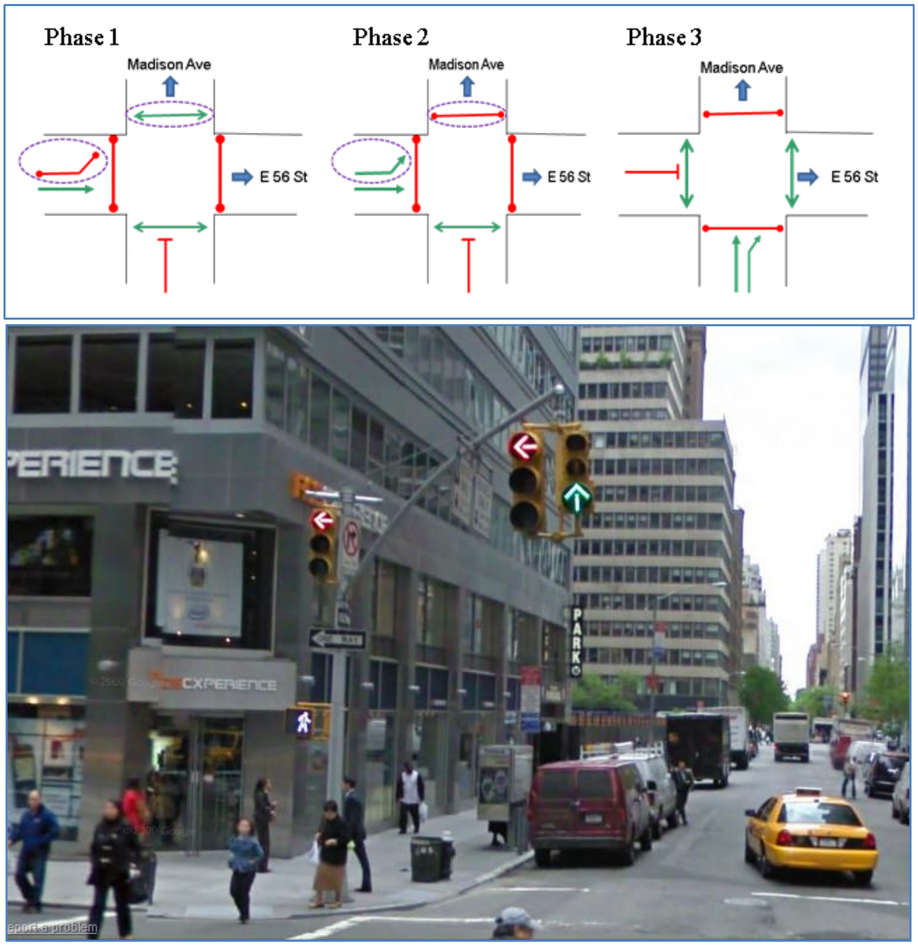

FIGURE 2 Split Phase Signal Timing

Signal installation

New signals were installed at hundreds of non-signalized intersections in NYC based on *Manual on Uniform Traffic Control Devices* (MUTCD 2009 Edition) warrants. Signal installation works on the principle of conflict reduction by separating pedestrians from vehicular traffic and separating different traffic movements through signal phasing. However, compared with stop-controlled intersections, it is possible that motorists may be less likely to reduce their speeds when approaching an intersection during the green phase, and thus could be less ready for a potential hazard (e.g., vehicles or pedestrians crossing against the signal).

McGee et al. (*19*) examined the safety impact of installing traffic signals at locations that were previously controlled by stop signs. Data from 122 intersections in urban areas in California, Florida, Maryland, Virginia, Wisconsin, and Toronto, were used. The results indicated that fatal and injurious crashes at both 3-leg and 4-leg intersections decreased following the installation of traffic signals, though the effect was insignificant due to a small crash count and large standard errors. Crashes involving pedestrians, however, were not studied separately.

High visibility crosswalk

High visibility crosswalks aim to increase awareness of pedestrians at intersections by using highly visible marking patterns. High visibility crosswalks installed in NYC have a series of longitudinal white stripes that are constructed from thermoplastic materials (Figure 3). The possible problems with crosswalks generally is that motorists may be less alert to pedestrians crossing at other locations and pedestrians at crosswalks may less alert to potentially conflicting vehicle traffic.

Findings on the high visibility crosswalk are mixed. Nitzburg and Knoblauch (*20*) studied high visibility ladder style crosswalk markings at two non-signalized intersections in Clearwater, Florida. The study found that the high-visibility crosswalk resulted in significant increases in drivers' daytime yielding behavior—drivers were 30 percent to 40 percent more likely to yield after the treatment and the percentage of pedestrians using the crosswalk increased. Conversely, a comparative evaluation of different crossing treatments found much lower driver compliance rates with high visibility signs and markings than with other measures (*21*). Zegeer et al. (*22*) found that marked crosswalks at uncontrolled intersections on two-lane roads were insignificant in reducing pedestrian crashes, and on wider roads with traffic volume more than 12,000 vehicles per day, they were associated with higher pedestrian crash rates .

FIGURE 3 High Visibility Crosswalk in New York City

METHODS

Police-reported pedestrian crashes (vehicle-pedestrian collisions) and multiple-vehicle crashes (vehicle-vehicle collisions) were studied. Each intersection was associated with two observations: crashes within 5-year period prior to the installation and crashes within 2-year period after the installation. A crash is a relatively rare event, thus, including a longer 5-year before period allows us to capture a more stable trend prior to the treatment. On the other hand, the selection of a shorter after period than the before period allows us to include more treatment sites: Crash data are only available until 2008, thus implementing a 5-year after period would mean that only treatments installed prior to 2003 could be evaluated and yet, most of the treatments were installed after 2003. The difference in the before- and after-period is controlled by an offset variable in our models.

Stage One: Selection of Comparison Groups

Figure 4 shows the distribution of the five countermeasures in NYC. New signals were equipped at intersections throughout the city; Barnes Dance was mostly installed in residential areas where pedestrian volumes are high; split phase timing was concentrated in midtown east Manhattan; lengthening of signal phases for pedestrian crossings was implemented on wide streets (Queens Boulevard and Ocean Parkway); and high visibility crosswalks were installed on long corridors such as Fulton Street and Park Avenue.

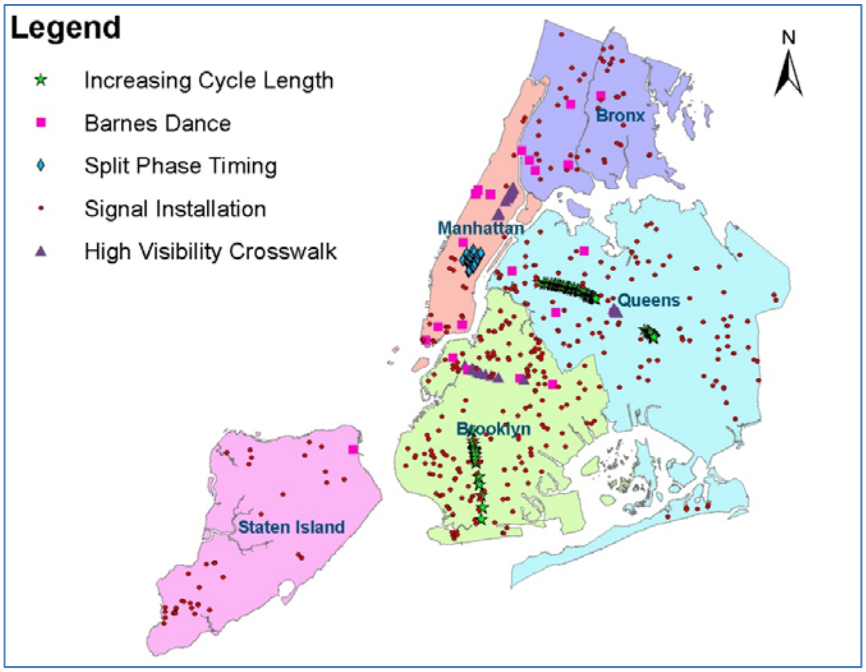

FIGURE 4 Map of the Five Pedestrian Countermeasures

In the first stage, for each treatment group (a group of intersections installed with one of the five countermeasures), we generated a comparison group comprising similar intersections but without the countermeasure. The selection of the comparison group was based on several intersection-level factors that have been found important in affecting crashes: control type (signalized or not) (*23*), the number of intersection legs (*24, 25*), and one-way vs. two-way on the major road at the intersection (*24*). The geographical distribution of the locations in the comparison group was further controlled to resemble the distribution of those in the treatment group. Following lists the variables used for the selection of the comparison groups.

- *Increasing cycle length for pedestrian crossing*
  Geographical distribution in borough, control type (signalized), number of legs, one-way or two-way of the major road
- *Barnes Dance*
  Geographical distribution in borough, control type, number of legs
- *Split phase timing*
  Within the borough of Manhattan, control type (signalized), four-leg, one-way for both major and minor roads
- *Signal installation*
  Within the borough of Manhattan, control type (signalized), four-leg, one-way for both major and minor roads
- *High visibility crosswalk*
  Geographical distribution in borough, control type, number of legs

For the same countermeasure, the before period and the after period are different for intersections treated in different years. For this reason, a treatment group was first divided into multiple subsets defined by the year of installation. Then, for each subset, a set of untreated locations were selected by applying frequency matching techniques to resemble the joint distribution of those selected matching variables as well as the geographical distribution of the treatment group. We then combined the subsets into a single comparison group. This procedure repeated for each countermeasure to generate a single comparison group for each.

Because two countermeasures—increasing cycle length and high visibility crosswalk—were installed on parts of long corridors, we also manually selected those intersections along streets that are parallel to those in the treatment group and added them to the corresponding comparison group. Table 1 shows the distributions of the matching variables in the treatment group and the comparison group for the five pedestrian countermeasures.

Stage Two—Negative Binomial Model with GEE Method

In order to account for other potential confounding factors, such as built environment characteristics that were not controlled in the comparison group selection but are potentially associated with crashes (*14*), we applied negative binomial regression models because the crash count data at those intersections in both the treatment group and comparison group are over-dispersed (variance is greater than the mean).

To control for correlation among observations on the same location at two time points (before and after period), generalized estimating equation (GEE) methodology exchangeable structure was applied because in our study each intersection has only two repeated measures (crash in the before period and crash in the after period) and the exchangeable correlation structure is the simplest one that fits the data well.

TABLE 1 Treatment Group and Comparison Group for the Five Pedestrian Countermeasures

Measure	Increasing cycle length for pedestrian crossing		Barnes Dance		Split phase timing		Signal installation		High visibility crosswalk	
Group*	T	C	T	C	T	C	T	C	T	C
Number of Intersections	244	1173	36	516	30	493	447	442	72	1009
Borough										
Manhattan	0	0	19 (45%)	222 (43%)	30 (100%)	493 (100%)	29 (6%)	25 (6%)	51 (71%)	697 (63%)
Bronx	0	0	10 (24%)	98 (19%)	0	0	41 (9%)	41 (9%)	0	0
Brooklyn	44 (18%)	230 (20%)	4 (10%)	70 (14%)	0	0	187 (42%)	186 (42%)	13 (18%)	240 (22%)
Queens	200 (82%)	943 (80%)	8 (19%)	112 (22%)	0	0	147 (33%)	147 (33%)	8 (11%)	162 (15%)
Staten Island	0	0	1 (2%)	14 (3%)	0	0	43 (10%)	43 (10%)	0	0
Signalization										
non-signalized	0	157 (13%)	0	56 (11%)	0	0	447 (100%)	442 (100%)	22 (31%)	414 (38%)
signalized	244 (100%)	1016 (87%)	42 (100%)	460 (89%)	30 (100%)	493 (100%)	0	0	50 (69%)	685 (62%)
Number of legs										
3-leg	34 (14%)	201 (17%)	10 (24%)	98 (19%)	0	0	111 (24%)	111 (25%)	17 (24%)	314 (29%)
4-leg	198 (81%)	940 (80%)	27 (64%)	376 (73%)	30 (100%)	493 (100%)	330 (74%)	325 (74%)	55 (76%)	785 (71%)
5-leg or more	12 (5%)	32 (3%)	5 (12%)	42 (8%)	0	0	6 (1%)	6 (1%)	0	0
One-way (major road)										
one-way	0	0	2 (5%)	76 (15%)	30 (100%)	493 (100%)	43 (10%)	40 (9%)	0	122 (11%)
two-way	244 (100%)	1173 (100%)	40 (95%)	440 (85%)	0	0	404 (90%)	402 (91%)	72 (100%)	977 (89%)

*Group: T = Treatment Group, C = Comparison Group

The model is specified below:

$$y_{it} = year_t \times \exp\left(\alpha + \mathbf{X}^{(s)}\boldsymbol{\beta} + \mathbf{X}^{(n)}\boldsymbol{\gamma} + \sum_{\boldsymbol{i=1}}^{\mathbf{5}}[a_i(Imp_{i}\_T1) + b_i(Cmp_{i}\_T1) + c_i(if\_Imp_i)]\right)$$

Eq. (1)

Where,
y_{it} is the expected crash count at site *i* during the time *t* (before or after period),
$year_t$ s the number of years during time *t* (5 years for pre-treatment period and 2 years for post-treatment period),
$\mathbf{X}^{(s)}\boldsymbol{\beta}$ are site-level covariates with coefficient $\boldsymbol{\beta}$;
$\mathbf{X}^{(n)}\boldsymbol{\gamma}$ are neighborhood-level covariates with coefficient $\boldsymbol{\gamma}$;
Imp_i_T1 is equal to 1 if the data point comes from the locations with treatment *i* post-treatment and 0 otherwise, and the coefficient for this variable is a_i;
Cmp_i_T1 is equal to 1 if the data point comes from the un-treated locations in the comparison group for treatment *i* post-treatment and 0 otherwise, and the coefficient for this variable is b_i;
If_Imp_i is equal to 1 if the data point comes from locations with treatment *i* and 0 otherwise, and the coefficient for this variable is c_i.

The model includes two sets of independent variables that may potentially affect crash frequencies: neighborhood-level and site-level covariates (Table 2). It is hypothesized that higher exposure and more conflicts are associated with more crashes (*14*). At the neighborhood level, for example, we used daytime population density, retail density, percentage of different age groups (under 21, 21-65, or above 65), motorized or non-motorized mode shares to account for the exposure of vehicular traffic and pedestrians. Daytime population density was calculated as the number of residents plus employment minus the number of people who live and work in the same census tract (to remove double counting) divided by the total area of the census tract; and retail density was calculated as the floor area of retail land use divided by total census tract area. These two variables measure the density of people who live, work, and shop in the neighborhood. Site-level covariates include control type (signalized or non-signalized), the number of legs at the intersections, one-way or two-way and number of lanes on the major roads of the intersections. These variables are mostly to account for the conflicts that pedestrians have with motorized vehicles.

It is possible that there exists a significant difference in before-period crashes between the treatment group and the comparison group, leading to a potential regression-to-mean effect. Therefore, in addition to the explanatory variables included in Table 4, we account for this by including five dummy variables in the model: variables "if_Imp_1"~"if_Imp_5", representing the data point from the five treatment groups, respectively. A positive coefficient of the dummy variable "if_Imp_i" means that for treatment i, the before-period crashes of the treatment group are significantly more than those of the comparison group and a negative coefficient suggests otherwise.

TABLE 2 List and Category of Explanatory Variables

Category	Variables
Roadway Geometry	Control type (1 if signalized; 0 non-signalized) Number of ways (legs) at the intersection One-way or two-way on the major road Number of travel lane on the major road
Socio-demographic	Daytime population density (1,000 per sq mi) Median household income ($1,000) Percent below poverty (%) Percent foreign born population (%) Percent Asian population (%) Percent Black population (%) Percent Hispanic population (%) Percent population age between 21 and 65 (%) Percent population age under 21 (%) Percent population age above 65 (%)
Mode Share	Percent travel by auto (%) Percent travel by public transportation (%) Percent travel by bicycling (%) Percent travel by walking (%)
Land Use	Residential land use density (floor area, sqft/sqft) Commercial land use density (floor area, sqft/sqft) Retail land use density (floor area, sqft/sqft)
Transportation	Percent of one-way roadway (%) Percent of roadway that is truck route (%) Percent of roadway with parking lane (%) Percent of 4-leg intersection (%) Percent of signalized intersection (%) Maximum subway ridership in the census tract (1,000) Subway station density (number per sq mi) Bus stop density (number per sq mi)

The coefficients of variables “Imp_i_T1” and “Cmp_i_T1”, that is, a_i and b_i in the model specification, are of our primary interest. The contrast between the two coefficients represents the difference in change in crash frequencies from the pre-treatment to the post-treatment period for the treatment group versus the comparison group for treatment *i*. In order to test if the difference of the two coefficients is statistically significant at 5% level, the model can be transformed by replacing “Imp_i_T1” and “Cmp_i_T1” with Z_i and P_i:

$$y_{it} = year_t \times \exp\left(\alpha + \mathbf{X}^{(s)}\boldsymbol{\beta} + \mathbf{X}^{(n)}\boldsymbol{\gamma} + \sum_{\boldsymbol{i}=\mathbf{1}}^{\mathbf{5}}[d_i(Z_i) + g_i(P_i) + c_i(if\_Imp_i)]\right)$$

Eq. (2)

Where,

$$Z_i = (Imp_i\_T1 - Cmp_i\_T1)/2\,, P_i = (Imp_i\_T1 + Cmp_i\_T1)/2\,, \forall\, i = 1, 2, \dots, 5$$

The coefficient of Z_i is the difference of the two coefficients associated with "Imp$i$_T1" and "Cmp$i$_T1": $d_i = a_i - b_i$. If d_i is significant and negative, it points to the effectiveness of treatment i in reducing crashes. The differences among the ds suggest the relative effectiveness of the five countermeasures: the more negative a coefficient is, the more effective the corresponding countermeasure is.

DISCUSSION OF RESULTS

Pedestrian and vehicle-vehicle crash counts before and after the treatments are shown in Table 3.

For "increasing total cycle length", the average pedestrian crashes (per intersection per year) decreased at the treated and untreated intersections, but the reduction for the former is much higher than the latter (-50% vs. -4%). The average multiple-vehicle crashes also decreased for both treated and untreated intersections, though the difference between the two is smaller (-45% vs. -37%).

For "Barnes Dance", the average pedestrian crashes were found to decrease in the treatment group and the comparison group, and the former experienced a much higher reduction than the latter (-51% vs. -9%). The average multiple-vehicle crashes increased (10%) post-treatment for the treatment group, but decreased (-12%) for the comparison group.

For "split phase timing", it was found that the average pedestrian crashes and the multiple-vehicle crashes decreased in the treatment group and the comparison group. The reduction in pedestrian crashes at treated locations is much larger than the compared intersections (-39% vs. -8%), while the reductions in multiple-vehicle crashes at treated intersections and at the compared intersection are similar (-56% vs. -44%).

For "signal installation", pedestrian crashes increased at both treated and compared intersections, though the increase in the treated intersections was smaller than the compared intersections (12% vs. 67%). Multiple-vehicle crashes, on the contrary, decreased at the treated and compared intersections, and the reduction for the former was larger than the latter (-49% vs. -14%).

For "high visibility crosswalk", the reduction in pedestrian crashes at treated intersections was higher than that at the compared intersections (-40% vs. -18%), while the reverse is true for multiple-vehicle crashes (-19% vs. -39%), indicating that high visibility crosswalk could potentially reduce pedestrian crashes, but increase multiple-vehicle crashes.

The estimation results of model are shown in Table 4. On the role of the built environment, our results conform to those in the literature (*14*). Variables measuring the exposure of pedestrians, for example, daytime population density, retail density, subway ridership, and percentages of commuters by alternative modes (for example, public transit), and variables measuring the exposure of vehicles, for example, percentage of commuters by auto, are all found to be positively correlated with pedestrian and multiple-vehicle crashes, respectively. Some variables, for example, subway ridership, are found to explain both crashes. Variables such as the percentages of 4-leg intersections, roadways with parking, and truck routes in the census tract were included to measure conflicts at the intersection (*12, 14*). The results suggest that areas with a higher percentage of roadways with parking and more 4-leg intersections are associated with more pedestrian crashes. The percentage of signalized intersections, on the other hand, is associated with fewer multiple-vehicle crashes. Census tracts with a higher percentage of people younger than 21 years old and a higher percentage of black population have more multiple-vehicle crashes, while those with a higher percentage of the population in poverty have more pedestrian crashes.

The estimated coefficients for d_i suggest that the four signal-related countermeasures are effective in reducing pedestrian crashes. Two of them: split phase timing and signal installation, are also effective in reducing vehicle crashes. High visibility crosswalk, on the other hand, is ineffective in reducing either type of crashes. These findings appear to suggest that countermeasures designed to reduce conflicts work better in reducing pedestrian and multiple vehicle crashes than those trying to raise drivers' awareness. That split phase timing and signal installation also reduce multiple vehicle crashes is understandable since these two countermeasures also attempt to reduce conflicts between vehicles. For some, notably, Barnes Dance and high visibility crosswalk, there appears to be a trade-off between reducing pedestrian crashes and multiple vehicle crashes. In both cases, there is a tendency for multiple vehicle crashes to increase, though the effect is insignificant. This increased tendency may be related to the lost time with Barnes Dance, in which vehicles have less time to cross or turn at intersections, and the occurrence of a sudden stop by the first driver approaching an intersection with a high visibility crosswalk, leaving insufficient time for subsequent drivers to stop. The 1998-2008 crash database in NYC indeed shows an increase in rear-end and overtaking crashes at intersections with high visibility crosswalks—these two collision types accounted for 22% of the total collision types in the before period and increased to 31% during the after period.

At the same time, a countermeasure effective in reducing pedestrian crashes is not necessarily equally effective in reducing vehicle crashes. One example is that of increasing total cycle length: this countermeasure is most effective in reducing pedestrian crashes, but its effect on multiple-vehicle crashes is insignificant.

TABLE 3 Pedestrian and Multiple-Vehicle Crash Counts Before and After Treatments

Pedestrian Crashes										
Measure	Group*	Number of Intersections	Before		After		Average Pedestrian Crashes (per intersection per year)			
			Years	Sum	Years	Sum	Before	After	Change	% Change
Increasing cycle length	T	244	5	155	2	31	0.13	0.06	-0.06	-50%
	C	1173	5	1382	2	528	0.24	0.23	-0.01	-4%
Barnes Dance	T	36	5	97	2	19	0.54	0.26	-0.28	-51%
	C	516	5	878	2	275	0.35	0.32	-0.03	-9%
Split phase timing	T	30	5	212	2	52	1.41	0.87	-0.55	-39%
	C	493	5	2005	2	740	0.81	0.75	-0.06	-8%
Signal Installation	T	447	5	382	2	136	0.17	0.19	0.02	12%
	C	442	5	93	2	51	0.04	0.07	0.03	67%
High visibility crosswalk	T	72	5	63	2	15	0.18	0.10	-0.07	-40%
	C	1099	5	1637	2	539	0.30	0.25	-0.05	-18%
Multiple-Vehicle Crashes										
Measure	Group*	Number of Intersections	Before		After		Average Multiple-Vehicle Crashes (per intersection per year)			
			Years	Sum	Years	Sum	Before	After	Change	% Change
Increasing cycle length	T	244	5	1609	2	357	1.32	0.73	-0.59	-45%
	C	1173	5	10604	2	2673	1.81	1.14	-0.67	-37%
Barnes Dance	T	36	5	336	2	150	1.93	2.13	0.19	10%
	C	516	5	3380	2	1147	1.46	1.27	-0.18	-12%
Split phase timing	T	30	5	590	2	103	3.93	1.72	-2.22	-56%
	C	493	5	5662	2	1264	2.30	1.28	-1.02	-44%
Signal Installation	T	447	5	2936	2	509	1.31	0.67	-0.65	-49%
	C	442	5	1022	2	309	0.46	0.40	-0.06	-14%
High visibility crosswalk	T	72	5	262	2	85	0.73	0.59	-0.14	-19%
	C	1099	5	6468	2	1573	1.18	0.72	-0.46	-39%

*Group: T = Treatment Group, C = Comparison Group

TABLE 4 Estimates of Covariates in the Models

Covariates	**Pedestrian Crashes**			**Multiple-Vehicle Crashes**		
	Estimate	**Std. Error**	**p-value**	**Estimate**	**Std. Error**	**p-value**
Intercept	-6.603	0.364	<.0001	-4.867	0.304	<.0001
Site-level Covariates (intersection)						
number of legs	0.471	0.057	<.0001	0.713	0.048	<.0001
signalized intersection	1.367	0.087	<.0001	1.257	0.080	<.0001
number of lanes on major road	0.152	0.023	<.0001	0.176	0.025	<.0001
one-way on major road	-0.370	0.058	<.0001	-0.123	0.055	0.025
Neighborhood-level Covariates (census tract)						
log(daytime population density)	0.318	0.037	<.0001	0.024	0.035	0.497
Percent of population age under 21				0.013	0.003	<.0001
Percent of population below poverty level	0.010	0.002	<.0001			
Percent of black population				0.003	0.001	0.002
Percent of commuter by auto				0.002	0.002	0.350
Percent of commuter by public transit	0.009	0.002	<.0001			
Retail density	0.0003	0.0002	0.172			
Percent of roadway with truck route				0.004	0.002	0.011
Percent of roadway with parking	0.007	0.002	0.0003	0.004	0.002	0.035
Percent of signalized intersections				-0.005	0.002	0.002
percent of 4-leg intersections	0.005	0.002	0.022	0.009	0.002	<.0001
maximum subway ridership	0.004	0.001	0.001	0.004	0.001	0.004
bus stop density	0.001	0.000	0.137			
Effectiveness **($d_i = a_i - b_i$)**						
Increasing cycle length: $a_1 - b_1$	**-0.647**	0.199	**0.001**	-0.110	0.106	0.299
Barnes Dance: $a_2 - b_2$	**-0.547**	0.250	**0.029**	0.140	0.220	0.523
Split phase timing: $a_3 - b_3$	**-0.474**	0.159	**0.003**	**-0.303**	0.122	**0.013**
Signal installation: $a_4 - b_4$	**-0.468**	0.179	**0.009**	**-0.600**	0.118	**<.0001**
High visibility crosswalk: $a_5 - b_5$	-0.245	0.383	0.522	0.158	0.142	0.267

CONCLUSIONS AND RECOMMENDATIONS

We find that signal-related countermeasures are more effective in reducing crashes than high visibility crosswalks. This finding is consistent with others that have largely found that crosswalk markings are ineffective in reducing crashes (*22*). This finding should not be generalized to all measures that rely on drivers' awareness. In fact, many of such countermeasures—for example, increased intensity of roadway lighting (*26, 27*), bus stop relocation from near side to far side of an intersection (*28*), and diagonal parking (vehicles park at an angle, typically about 30 degrees, to the curb in the direction of traffic) were found effective in reducing pedestrian crashes (*29*).

There are trade-offs between improving pedestrian safety and motorist safety. We find that those that indirectly resolve conflicts—increasing total cycle length and Barnes Dance—are more effective in reducing pedestrian crashes and yet less effective in reducing vehicle crashes than those that directly separate conflicts—split phase and signal installation. In the case of Barnes Dance, there is a potential increase in vehicle crashes. This finding suggests that selection of a specific countermeasure at a location highly depends on the characteristics of the location and the problem at hand.

Increasing total cycle length is suitable for certain locations, for example, near senior centers, where there is a higher percentage of elderly pedestrians. Barnes Dance is appropriate in downtown locations where there is a fast accumulation of pedestrians. As this study suggests, Barnes Dance potentially affects vehicle traffic negatively. Therefore, there may be a need to divert traffic away from the location where Barnes Dance is installed. Split phase timing separates pedestrian and turning vehicles completely and thus it is most desirable for locations with some turning movements and narrow streets so that pedestrians can complete the crossing in a relatively short time. For signal installation, our study suggests that this traditional engineering countermeasure remains a very effective approach when the traffic volume meets the MUTCD warrants.

In closing, our study results suggest that at least in contexts similar to the study area—a large, dense urban area—traditional engineering approaches continue to play an important role in improving the safety of pedestrians and motorists and there are trade-offs to be considered between improving pedestrian safety and motorist safety. The transferability of these findings is subject to debate. In general, we argue that the results are likely applicable to other similar urban areas (e.g., San Francisco, Chicago) for two main reasons. First, unlike prior studies that typically involve a few intersections, the sample sizes of the five countermeasures in our study are large. Second, the use of our two-stage methodology not only accounts for differences at the intersection level, but also those at the neighborhood level. Indeed, a recent study in San Francisco on Barnes Dance, modified signal timing, advanced stop lines, and many others (*30*) showed that Barnes Dance "is potentially effective for certain situations (e.g., smaller intersections with heavy volumes of turning vehicles and pedestrians), but can be difficult to use in some situations (e.g., wide intersections with heavy through traffic volumes, including transit service)." The same study also showed that many people felt safer after the signal timing change.

Furthermore, the transferability of the results likely varies with treatments. To a large extent, the question on transferability depends on how the treatment group is selected—random sampling defies threats to transferability (*31*). Among the five countermeasures, the selection of the intersections for some treatments represents more like a random selection than for others. As mentioned earlier (Figure 4), intersections treated with signal installation scattered around in the city, resembling the result of a random sample most, followed by those treated with Barnes Dance, which spread out in residential areas in four boroughs except Staten Island. The other three treatments are much more geographically concentrated—those with split phase timing are all in Midtown East Manhattan; those whose cycle lengths were increased are mostly on Ocean Parkway and Queens Boulevard; and those with high visibility crosswalk are mostly on long corridors. From this perspective, the transferability of the effectiveness found for signal installation and Barnes Dance is likely higher than those found for the other three countermeasures.

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