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A justification for pedestrian countdown signals at signalized intersections: The safety impact on senior motorists

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ABSTRACT

Introduction: Pedestrian countdown signals (PCSs) are specifically designed to improve pedestrian safety at intersections. However, the cost of retrofitting an existing intersection with a PCS, or the cost of including a PCS in a new intersection, may discourage PCS use at locations with a low pedestrian demand. Surprisingly, however, these devices appear to have positive safety benefits for a demographic group that is poised to increase by 20 percent nationally over the next two decades (2020–2040): older population age 65 years and above. Between 2012 and 2016, the number of licensed older drivers (65 + years) increased by 16 percent (NHTSA, 2013). Using the state of Michigan as a case study, this paper reports on the safety impacts of PCSs for motorists age 65 + years.
Methods: The study used ten years of crash data (five years before and 5 years after PCSs installation) from 93 intersections with PCS (treated sites) and a comparison group of 97 intersections without countdown timers (but with pedestrian signals). A before-after with comparison group methodology, crash proportions and cost benefit analysis were used to conduct the PCS evaluation on senior motorists.
Results: The study indicated that the inclusion of PCSs significantly reduced total (all severity) and injury only crashes for drivers aged 65 and above by 18 and 29 percent ($p < 0.05$) respectively. Monetization of crash impacts also suggests that inclusion of PCSs when installing a pedestrian signal yields a benefit-cost ratio ranging from 181 to 604 depending on the service life of the device. The focus on motorists aged 65 + is noteworthy, as PCSs did not necessarily have a statistically significant impact when motorists of all age groups are considered.
Conclusion: Localities may wish to consider PCSs when there are concerns about senior motorist crashes at intersections since they also benefit from PCSs. Because PCSs may be installed at locations with other safety treatments, a synthesis of other locations' experiences with PCSs would complement the results of this study.

1. Introduction

Pedestrian Countdown Signals (PCSs) are designed to improve safety for pedestrians by displaying the number of remaining

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Fig. 1. A pedestrian countdown signal indicating two seconds remain to complete the crossing maneuver.

seconds left to cross a street prior to conflicting vehicular traffic being permitted to enter the intersection (FHWA, 2009). An example of a PCS is shown Fig. 1, where 2 s remain to complete the crossing maneuver. By contrast, traditional pedestrian signal, which was used in the comparison group, does not display the number that is shown in Fig. 1. Before the introduction of the 2009 Manual on Uniform Traffic Control Devices (FHWA, 2009) which requires states to include PCSs whenever there is a new signal installation, Michigan required that pedestrian countdown signals be placed at signalized intersections in central business districts, established school roads, and other high-volume intersections. PCSs were also installed at intersections that were undergoing modernization and at intersections that had safety and operational concerns.

Because these timers are also visible to motorists, they can sometimes be used as advance information regarding the termination of the green phase and hence help motorists make better decisions regarding whether they should stop or continue to traverse the intersection (Ma et al., 2010). In this manner, it is possible, but not proven that drivers may benefit from a PCS just as they benefit from a green countdown signal, which has frequently been shown to yield safety benefits for motorists in several USA studies (Schattler et al., 2007 in Peoria, Illinois; Pulugurtha et al., 2004 in Charlotte, North Carolina; Reddy et al., 2008 in Florida; Schrock et al., 2008 in Kansas; and Elekwachi, 2010 in Washington DC). This study used Michigan as a testbed to examine the impacts of PCS on older drivers for two reasons. First, as of 2017, Michigan had a sizeable proportion of persons age 65+ (16.7%) that is nonetheless relatively close to the U.S. average (15.6%) (Henry J. Kaiser Family Foundation, 2019). Second, Michigan had a sizeable number of locations where PCSs had been installed, allowing a study to select only those locations where treated and untreated groups were comparable in terms of individual characteristics (e.g., education and poverty status) and roadway characteristics (e.g., traffic volumes and intersection geometry).

1.1. PCSs influence on pedestrian behavior

Several studies have examined the impacts of PCSs on pedestrian behavior. Huang and Zegeer (2000) suggest nuanced impacts based on installations in Florida: while the PCS reduced the occurrence of pedestrians running once the flashing don't walk indication appeared (a benefit), the PCS discouraged pedestrian compliance because some pedestrians initiated their crossing during the same "don't walk" indication. Findings from these studies (Stollof et al., 2007; Kwigizile et al., 2015, Atta Boateng et al., 2018; both in USA) indicate that these devices improved safety for both pedestrians and motorists. Other USA studies (Schattler et al., 2007 in Illinois; Markowitz et al., 2006 in California; and Singer and Lerner, 2005 in Alexandria, Virginia) also showed that PCSs encourage pedestrian compliance, reduce pedestrian injuries, and are preferred by pedestrians. However, findings from USA studies by Pulugurtha et al. (2004, 2010a,b) (in Charlotte, North Carolina) and Arhin et al. (2011) (in Washington, D.C.) did not find significant differences in the pedestrian crossing behaviors or improvement in vehicle-pedestrian crashes.

1.2. PCSs likely influence motorist behavior

To be clear, most, but not all studies indicate that PCSs do appear to influence driver behavior. Yulong (2009) in Beijing, China and Köll et al. (2004) in Switzerland, Austria, and Germany showed that such devices influence driver behavior. Elekwachi (2010) in Washington, D.C. found that 83 percent of survey participants agreed that PCS information affects braking or stopping maneuvers at signalized intersections. In Las Vegas, Nevada (USA), Nambisan and Karkee (2010) found that vehicle speeds were greater as one gets closer to the timer, especially when either the number of seconds left for pedestrians or the flashing "Don't Walk" is displayed (as opposed to when the pedestrian "Walk" signal is displayed). In Berkeley, California (USA), Huey and Ragland (2007) also found that drivers behave differently depending on whether a pedestrian countdown timer is used. Perhaps the only study that has found PCSs do not appear to influence motorist behavior was conducted in Maryland, USA by Eccles et al. (2004); that study concluded that, at least during the clearance interval (i.e., during the flashing “Don't Walk” indication) no change in vehicle approach speed could be detected. Thus, given that most studies suggest a behavioral change by motorists, a related research question is whether this driver response to the PCS reduces or increases crash risk.

1.3. *The impact of PCS on motorist behavior may be positive-or not*

The literature certainly suggests there is a plausible benefit of timers in general for motorists. In Singapore, Lum and Halim (2006) found that green signal countdown signal installation led to a 65 percent reduction in red-light running violations. Based on respective analyses in Shanghai and Singapore, Ma et al. (2010) and Liu et al. (2007) concluded that green countdown signals can improve safety at signalized intersections because the timer allows drivers to envision the phase transition and thus effectively eliminates the intersection dilemma zone. Unlike green countdown signals, however, empirical studies of the effect of PCSs on motorist safety are mixed. In Taoyuan City (Taiwan), Chen et al. (2015) found that pedestrian green signal countdowns were associated with an increase in red-light running violations (compared to intersections without these timers) and that violating motorcyclists had higher speeds at intersections with these timers. Su and Tang (2008), in Hsinchu (Taiwan), concluded that motorcyclists appeared to accelerate more aggressively at intersections with these timers, and Chiou and Chang (2010) in Jhubei City (Taiwan) concluded that red signal countdowns did not improve intersection safety after installation. By contrast, Lum and Halim (2006) and Chiou and Chang (2010) indicated the opposite finding: red light violations decreased after installing green signal countdown signals in Singapore and Taiwan respectively, and Kwigizile et al. (2015), Boateng (2016), and Atta Boateng et al. (2018) found these devices improved safety for both pedestrians and motorists in Michigan, USA.

1.4. *The impact of PCSs may not be uniform across all age groups*

Part of the challenge of detecting how PCSs affect motorists may be two distinct sources of variability: (1) motorist response to the countdown timer and (2) behavioral impact by age group. As an example of the former, Ma et al. (2010) reported that green signal countdown devices could encourage multiple behaviors, two of which one would expect to have divergent impacts on crash risk: timers could encourage drivers to traverse the intersection with higher speeds or timers could enable drivers to respond appropriately to the phase transition. As an example of the latter, although not focused on motorists per se, Stollof et al. (2007) found that older pedestrians are more likely to move out of the crosswalk at the onset of the steady DON'T WALK at crossings with PCS. Certainly crash risk varies by age group: Alam and Spainhour (2008) in Florida and Rakotonirainy et al. (2012) in Queensland, Australia showed that older drivers are mostly at fault in intersection crashes, McGwin and Brown (1999) and Preusser et al. (1998) (both studies conducted in the USA) revealed higher intersection-related crash frequency among older drivers, and Sifrit et al. (2010) and Pollatsek et al. (2012) both in the USA attributed part of the higher crash risk for older drivers because of difficulty in identifying potential hazards at intersections (while asserting that age may not be the sole reason for this higher crash risk).

1.5. *A focus on motorists age 65+*

A critical implication of the previous work (e.g., Stollof et al., 2007) is that the impacts of PCS on driver behaviors are not consistent with age. An age group that is of particular interest to safety professionals is motorists age 65+, a group whose net travel and numbers have been increasing. From 2020 to 2040, the number of persons age 65 + is forecast to grow up to about 20 percent (National Highway Traffic Safety Administration (NHTSA), 2013).

Accordingly, this paper evaluates the impact of PCS on motorists age 65 + years using data from Michigan, which was interested in the impact of PCSs on drivers. A key subtopic is the impact on older drivers, as motorists age 65 + in the U.S. have higher crash risk than the general population. For example, Michigan crash records for 2007–2016 showed that the number of drivers of all age groups involved in all crashes increased by 0.2 percent and the number of drivers involved in fatal crashes increased by 0.8 percent. During the same 10-year period, the number of drivers age 65 years and above in all crashes increased by 32.0 percent, while fatal crashes for this age group increased by 16.8 percent (Michigan, 2013).

1.5.1. *Purpose and scope*

This paper evaluates the safety impacts of PCSs on drivers who are 65 years or older—also known as drivers age 65+. The primary objectives are (1) to determine if PCSs have an impact on crashes involving older drivers 65 years and above and (2) if, PCSs do have a positive safety impact, what is the relative benefit of PCSs given that they have an associated capital cost? A secondary objective is to determine if PCSs affect the proportion of crashes that are rear-end, angle, and sideswipe involving older drivers at these intersections. The scope of this study is limited to data from one U.S. state—Michigan—which allows one to garner a relatively consistent yet large longitudinal set of ten year crash data. These data are based on 93 sites with PCSs and 97 comparison sites which had pedestrian signals but without a countdown timer. In this study, intersection related crashes are crashes that occurred within 250 feet of the center of an intersection.

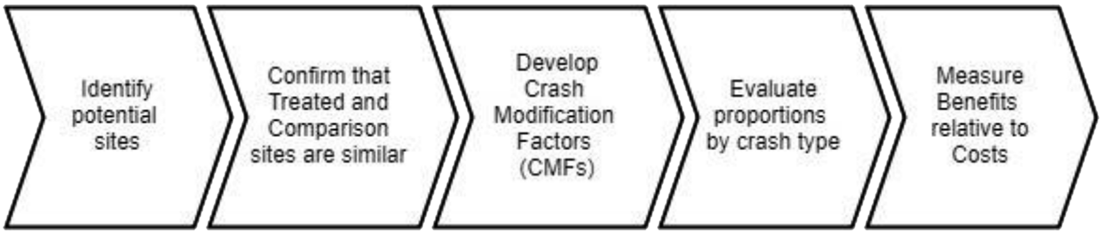

Fig. 2. Summary of the methodology.

2. Methodology

A case-study before-after approach with comparison groups was used to determine the safety impacts of PCSs through five main steps:

- Identify potential sites.
- Confirm that treated and comparison sites are similar.
- Develop crash modification factors (CMFs).
- Evaluate proportions by crash type.
- Measure benefits relative to costs.

2.1. Summary of the study approach

Fig. 2 summarizes the five main steps that comprised the methodology. Steps 2, 3, and 4 can help minimize the risk of confounding factors such as weather, traffic flow and changes in the demographic characteristics but not eliminate this risk entirely. For example, when one divides the number of crashes by the number of intersections to obtain the intersection crash rate over a five year period, a greater nominal reduction in these rates is obtained if one compares crashes involving drivers age 65 and above than if one compares crashes involving drivers age less than 65. Thus, the study design can address this impact of age. However, other changes not reflected herein, such as changes in vehicle technology, are not fully reflected in the study, although the use of the CMFs should minimize the impacts of crash randomness.

2.2. Identifying potential analysis sites

A total of 370 of these locations had PCSs installed mostly on state roads, between 2006 and 2012. The City of Detroit also provided 449 PCS locations (mostly on city roads). Each of these intersections had traffic signals in addition to the PCSs, hence all were signalized intersections. Using the Google Pro search engine, 2010 Census data (U.S. Census Bureau, 2010), geometric data, and traffic volumes, 93 treated sites and 97 comparison sites were selected, where each site included five years of data prior to PCS installation and five years after installation. (Because the installation date varied by location, the earliest year of analysis was 2004 and the latest year of analysis was 2016). Because regression to the mean bias can result if sites are selected solely on the basis of crash frequency (Fayish and Gross, 2010, Pennsylvania, USA), the 93 treated sites were chosen, from the potential 819 locations, on the basis of population, education level and poverty status, traffic volume, geometric characteristics, and land use characteristics.

Based on the Highway Safety Manual (HSM), crashes that occur in zone A as shown in Fig. 3 or within 250 feet from the center of an intersection are usually referred to as intersection related crashes. Hence, a 250 foot buffer size was adopted for crash selection at each intersection using Geographic Information Systems (GIS) software (ESRI ArcGIS 10.3.1). All crashes that fell within this buffer

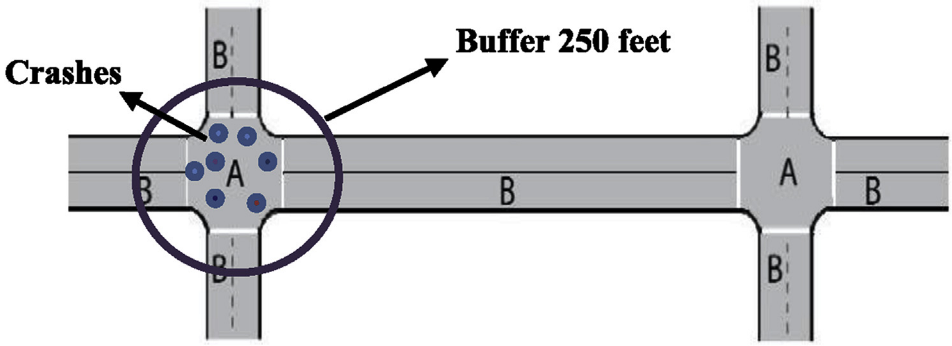

Fig. 3. Definition of intersection related crashes.

zone were considered as an intersection related crashes. Sites were carefully selected to ensure that no sites overlapped (a concern on city roads) so that double counts of crashes were avoided. Using the same GIS package, roadway and demographic data from Michigan shapefiles were superimposed on the intersections to facilitate the selection of the comparison sites based on the characteristics of the treated sites.

2.3. Confirming that treated and comparison sites are similar

The study used a comparison group methodology (Fayish and Gross, 2010; Hauer, 1991) to estimate crashes that would have occurred at the treated sites if no PCSs were installed on these sites using crash data from the comparison sites. In Florida, Shen and Gan (2003) described this method's strength as dependent on the similarities between the comparison and the treated sites where two conditions must be met.

First, there must be similar factors affecting safety at the treated and comparison sites. To ascertain that these factors were indeed similar, a paired t-test was conducted for 15 variables reflecting land use, traffic volume, and geometry at the treated and comparison sites.

Second, treatment group crashes and comparison group crashes must be similar during the before period. While a plot of these crashes can provide an initial screening, a more robust assessment is to use the sample odd ratios (Gross et al., 2010; Hauer, 1991). The sample odd ratios for each before and after pair were computed using total crashes before the installation of the PCSs (Equation (1))

$$\textit{Sample Odds Ratio} = \frac{T_b \times \frac{C_a}{T_a} \times C_b}{\left(1 + \frac{1}{T_a} + \frac{1}{C_b}\right)} \tag{1}$$

where: T_b = total treatment site crashes in the before period in year a, T_a = total treatment site crashes in the after period in year b, C_b = total comparison site crashes in the before period in year a, and C_a = total comparison site crashes in the after period in year b. At a confidence interval of 95 percent for this ratio, the calculated means of *sample odds ratio* ($\pm$ 1.96* *Std. Deviation)* should include 1.0 to confirm that the comparison sites are deemed as similar to the treated sites.

2.4. Developing crash modification factors

The effectiveness of PCSs was evaluated using the comparison group methodology (Gross et al., 2010) where four crash frequencies are determined:

N_{TB} = treatment sites crashes in the before period,
N_{TA} = treatment sites crashes in the after period,
N_{CB} = comparison sites crashes in the before period,
N_{CA} = comparison sites crashes in the before period.

The comparison ratio (Equation (2)) describes how the number of crashes in the absence of the treatment is expected to change:

$$\text{Comparison ratio} = \frac{N_{CA}}{N_{CB}} \tag{2}$$

While Equation (3) is used to compute the number of expected crashes for the treatment group that would have occurred in the after period without the installation of countdown signals ($Nexp_{TA}$), Equation (4) is used to calculate the variance of the expected number of crashes in the after period without the treatment, $Var(Nexp_{TA})$:

$$Nexp_{TA} = (N_{TB})\left(\frac{N_{CA}}{N_{CB}}\right) \tag{3}$$

$$Var(Nexp_{TA}) = (Nexp_{TA})^2\left(\frac{1}{N_{TB}} + \frac{1}{N_{CB}} + \frac{1}{N_{CA}}\right) \tag{4}$$

To calculate the number of expected crashes after the installation of the PCSs, a multiplier called Crash Modification Factor (CMF) as well as its variance [var. (CMF)] were estimated using Equations (5) and (6):

$$CMF = \frac{\frac{N_{TA}}{Nexp_{TA}}}{\left[1 + \left(\frac{var(Nexp_{TA})}{Nexp_{TA}^2}\right)\right]} \tag{5}$$

$$\mathrm{Var(CMF)} = \mathrm{CMF}^2 \left\{ \frac{\left(\frac{1}{\mathrm{N_{TA}}}\right) + \left(\frac{\mathrm{var(Nexp_{TA})}}{\mathrm{Nexp_{TA}^2}}\right)}{\left[1 + \left(\frac{\mathrm{var(Nexp_{TA})}}{\mathrm{Nexp_{TA}^2}}\right)\right]^2} \right\} \tag{6}$$

Finally, the standard error and confidence intervals were calculated to measure the certainty or uncertainty in the crash modification factor using Equations (7) and (8), where typically a value of 1.96 is used for cumulative probability term (which corresponds to a p-value of 0.05) in Equation (8):

$$\text{standard error} = \sqrt{\mathrm{var(CMF)}} \tag{7}$$

$$\text{confidence interval} = \mathrm{CMF} \pm \text{cumulative probability term} * \text{standard error} \tag{8}$$

The crash reductions (in percent) can be computed using Equation (9):

$$100*(1\text{-CMF}). \tag{9}$$

2.5. Evaluating proportions by crash type

The comparison group methodology presumes that the treatment of interest affects safety in the same way at comparison and treatment sites (Shen and Gan, 2003). However, the effect of a countermeasure on a particular group may differ. For example, drivers age 65 and above were more involved in angle crashes than younger drivers (Michigan, 2013).

Accordingly, the study sought to identify significant differences in the proportion of four crash types following PCS installation: single vehicle, angle, rear end, and sideswipe (in the same direction), categorizing these by severity (e.g., all crashes versus injury, no injury versus injury) and age (e.g., all ages and drivers age 65+). (Throughout this paper, “injury” crashes include fatal crashes). The number of crashes for each crash type was converted into proportions because the number of years in the before and after periods of installation of PCSs (2006–2012) in Michigan were not consistent for all of the study sites (Equation (10)).

$$\text{Crash Proportions} = \frac{\substack{\textit{Number of Crashes} \\ \textit{for Each Crash Type}}}{\text{Total Crashes}} \tag{10}$$

The proportions for each crash type in the before and after period were compared to determine the effect of PCSs on these crash types. The crash proportions were further tested for their statistical significance using the two-proportions Z-test with a null hypothesis that the two proportions (before and after periods) were equal (Equation (11)).

$$Z = \frac{X_1 - X_2}{\sqrt{\left(T'(1-T')\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right)}} \tag{11}$$

where X_1 and X_2 denote crash type proportions during the before and after installation of PCSs, n_1 and n_2 denote the total number of crashes during both periods, and T' denotes the proportion of successes or the common proportions in both populations. Since the true value of T' is unknown, Equation (12) is used to estimate T' which follows a standard normal distribution and where Y_1 and Y_2 denote the number of crashes during the before and after periods, respectively.

$$\mathrm{T'} = \frac{\mathrm{Y_1 + Y_2}}{\mathrm{n_1 + n_2}} \tag{12}$$

2.6. Measuring benefits relative to costs

A cost benefit analysis monetized the benefits associated with PCSs (expressed in dollar units) to the installation and maintenance cost of the signals. Benefits were computed as the expected crash reductions of PCSs based on CMFs for crashes involving drivers age 65 years and above, where only CMFs that were statistically significant were included in the analysis. Crashes were monetized following the figures reported for Michigan by Kostyniuk et al. (2017) which were $226,531 (injury crashes) and $4347 (property damage only crashes). These estimates are based on (1) monetary costs and (2) nonmonetary quality-of-life costs. The monetary cost results from the cost associated with crimes and traffic crashes. Such costs include medical care, emergency response, impacts on future earnings, public service (refers to cost on the initial police report, follow-up investigations, emergency and fire services), adjudication and sanctioning, and property damage and loss as reported by Kostyniuk et al. (2017). Nonmonetary cost consists of cost associated with pain, suffering and other losses. Based on in-office data from MDOT, the cost for one countdown signal head is estimated as $291.90 compared to $185.63 for the pedestrian signal head without countdown timer. Thus costs for PCSs were based on the difference between expenses for installing a pedestrian signal head with countdown timers and installing one without the countdown timer, reported to be $850.16 by MDOT for a typical four-leg intersection with a total of 8 signal heads and $637.62 for a three leg intersection with six signal heads. Communication with Michigan DOT staff further showed that the cost for maintaining PCSs and standard pedestrian signals are the same, thus, the maintenance cost is not included in the calculations of the benefit cost ratio. The average cost for the 93 sites used for this study is estimated to be \$822.74. Equation (13) was used to compute the average annual saving per intersection based on these costs.

$$AAS = (RI \times IC)[SI] + (RP \times CP)[SP] \tag{13}$$

where.

AAS = average annual saving per intersection,
RI = reduction in injury crashes,
CI = injury crash cost
SI = 1 if the CMF for injury crashes is significant, 0 otherwise
RP = reduction in PDO crashes,
CP = PDO crash cost
SP = 1 if the CMF for PDO crashes is significant, 0 otherwise

While Thompson and Ford (2012) point out that a life expectancy for pedestrian signals is 15 years, the authors also point out that traffic signal life is affected by environmental factors (temperature and wind speed), the signal design itself (e.g., how it is mounted and the type of actuation), and the functional class of the roadway. While Fayish and Gross (2010) used a service life of 10 years in the computation of cost-benefit analysis of PCSs, Harkey et al. (2007) reported that some "pedhead-mounted" units had lasted "5–10 years or more without problems." The research team therefore computed the benefit-cost ratio by varying the service life and discount rate with design life to a lower bound value of 5 years and a higher bound value of 20 years. The appropriate discount rates for 2018 associated with 5, 10, and 20 years of service life were used for PCS installation (Office of Management and Budget, 2018), and the 15 year discount rate was interpolated from the 10 year and 20 year rates by the researchers. The discounted present value of benefits (crash saving) was determined from the estimated annual crash saving using Equation (14), and the benefit-cost ratio (BCR) was estimated using Equation (15):

$$PV_{benefits} = (AAS) \times \left(\frac{(1+R)^N - 1}{R^*(1+R)^N} \right) \tag{14}$$

where:

PV = present value of savings,
R = discount rate (in decimals),
N = service life (years).

$$BCR = \frac{PV_{benefits}}{PV_{costs}} \tag{15}$$

3. Results

After confirming the suitability of comparison sites, CMFs were developed for total crashes (all severities), injury crashes, crashes involving drivers less than 65 and those involving drivers age 65 and older (all severities and injury). The impact of PCSs on different crash types, primarily rear-end and angle, was determined. Then, based on the instances where a significant difference was found, a benefit-cost ratio was determined. As shown in Table 1, the median age for drivers at treated sites was similar to that of drivers at untreated sites (with ages of 37 and 36 respectively). The means were also similar: for drivers age 65 or older, the mean ages at treated and untreated sites were 74.20 and 74.35 years, respectively.

3.1. Suitability of comparison sites

Two tests—examination of the independent variables thought to affect crash risk and estimation of the crash risk prior to PCS installation—appear to suggest that the treated and comparison sites were sufficiently similar to support the before-after comparison

Table 1
Summary statistics of drivers at the treated and non treated sites.

Variable	Treated Sites			Non-Treated Sites		
	All Drivers	Drivers < 65 Years	Drivers > 65 Years	All Drivers	Drivers < 65 Years	Drivers > 65 Years
Mean	39.37	35.80	74.20	39.15	35.53	74.35
Standard Error	0.16	0.13	0.23	0.15	0.12	0.20
Median	37	34	72	36	33	73
Mode	19	19	65	19	19	66
Standard Deviation	17.30	13.67	7.59	17.42	13.74	7.33

Table 2
Independent variables that influence crash risk.

No	Variables	93-Treated Sites				97-Non-Treated				T-Statistics Tests	
		Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	t	p-value Ho: mean (diff) = 0
1	AADT Maj Average	14072	11459	1637	70100	16500	12055	2322	60752	−1.631	0.106
2	AADT Min Average	7348	6600	730	35214	7797	5602	518	30382	−0.645	0.521
3	Median div raised (Min)	0.02	0.15	0	1	0.1	0.31	0	1	1.683	0.096
4	Median div not raised (Min)	0.72	0.45	0	1	0.7	0.46	0	1	0.684	0.496
5	Median not div not raised (Min)	0.26	0.44	0	1	0.21	0.41	0	1	1.097	0.276
6	Median div raised (Maj)	0.22	0.44	0	2	0.2	0.4	0	1	0.376	0.708
7	Median div, not raised (Maj)	0.71	0.46	0	1	0.75	0.43	0	1	−0.168	0.867
8	Median not div not raised (Maj)	0.09	0.28	0	1	0.04	0.2	0	1	1.157	0.250
9	Commercial	0.53	0.5	0	1	0.61	0.49	0	1	−1.182	0.240
10	Residential	0.08	0.27	0	1	0.04	0.2	0	1	1.000	0.320
11	Mixed	0.4	0.49	0	1	0.35	0.48	0	1	0.779	0.438
12	Number of lanes (Maj)	5.68	2	1	10	6.19	1.98	2	12	−1.913	0.059
13	Number of lanes (Min)	3.85	1.77	1	10	4.08	1.77	1	9	−1.082	0.282
14	#_of exclusive left turns (Maj)	0.63	0.53	0	2	0.67	0.53	0	2	−0.761	0.449
15	# of exclusive left turns (Min)	0.51	0.52	0	2	0.63	0.53	0	2	−1.264	0.209

group methodology. For the former test, Table 2 shows that none of the 15 variables showed significant differences during the before period between the treated and comparison sites ($p > 0.05$). This suggests that traffic volume (e.g., the average annual daily traffic on the mainline as well as the AADT on the minor approach), the geometry (e.g., the presence of a median), and the land use (e.g., whether commercial, residential or mixture of commercial and residential development was near the intersection) were similar between the treated and comparison sites. For the latter test, the 95 percent confidence interval for the sample odds ratio was found to be 0.847–1.119, based on a mean sample odd ratio of 0.98 and a standard error of 0.069. Because the confidence interval includes 1, the comparison sites are similar to the treated sites. Fig. 4 suggests that for each year prior to the installation of the PCSs, the treatment group and comparison groups have a similar crash frequency).

3.2. Development of crash modification factors

Examination of crash frequency (e.g., Table 3) does not indicate whether PCSs themselves had an impact on crash risk, given the

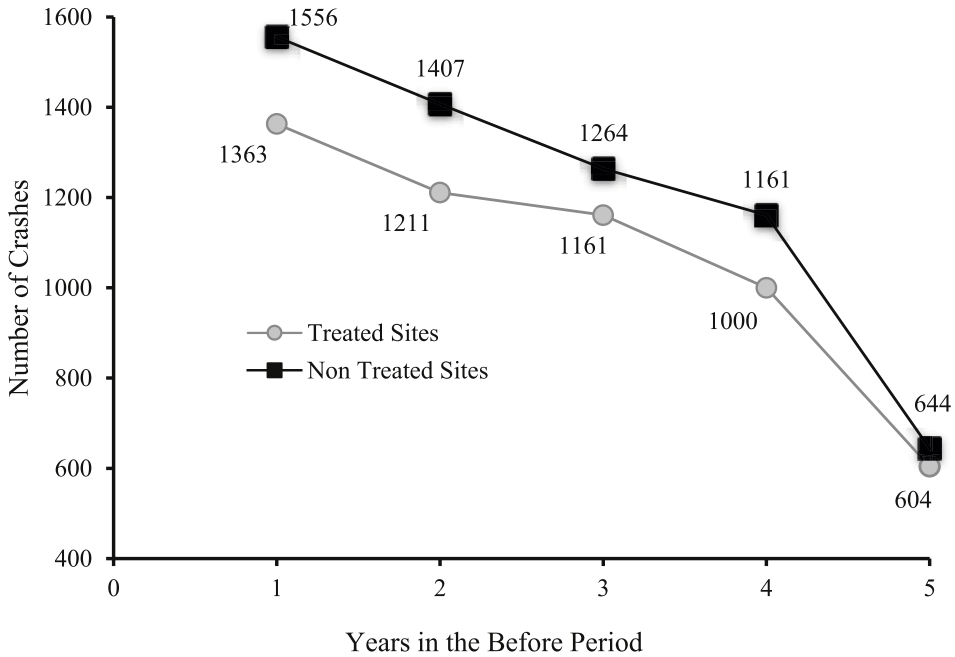

Fig. 4. Graphical comparison of treated and non-treated sites in the before years.

Table 3
Statistics of crashes at treated and comparison sites.

Crash Types [a]	Period	Treated Sites Statistics				Non Treated Sites Statistics			
		Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Driver Crashes- Injury and PDO	Before	57.41	44.82	5	230	62.19	50.02	2	215
	After	50.06	57.28	2	333	54.56	49.11	3	214
Driver Crashes- Injury only	Before	12.55	10.46	0	51	12.92	10.34	0	46
	After	11.09	14.75	0	95	12.02	11.21	0	51
Divers < 65 years- Injury and PDO	Before	50	38.53	5	197	54.34	43.85	2	176
	After	42.11	47.34	2	261	45.64	41.3	2	180
Drivers < 65 years-Injury only	Before	11.16	9.16	0	46	11.26	9.07	0	41
	After	9.68	12.51	0	74	9.97	9.32	0	45
Driver 65 years and above- Injury and PDO	Before	7.49	7.78	0	37	7.85	7.46	0	39
	After	7.18	11.6	0	73	8.92	9.52	0	44
Driver 65 years and above - Injury only	Before	1.68	1.94	0	1	1.66	1.83	0	7
	After	1.75	3.02	0	21	2.06	2.52	0	11

[a] Injury category includes fatal crashes. PDO category are property damage only crashes.

potential impact of confounding factors. Accordingly, total driver crashes prior to and following installation of PCSs were used in the computation of expected crashes at the treatment locations in the after period. CMFs were developed for six crash types: all crashes (all severities), injury driver crashes, crashes (all severity) involving a driver less than 65 years, injury crashes involving a driver less than 65 years, crashes involving a driver 65-years-and-older, injury crashes involving a driver 65-years-and-older. Table 4 presents CMFs estimated for PCSs for crashes involving a driver.

While PCSs significantly reduced crashes (all severities) involving drivers 65 years and older by 18 percent (see Table 4), injury only and PDO only crashes reduced by 29 percent and 16 percent respectively. Reductions in crashes (all severities, injury only and PDO only) involving drivers 65 years and older are statistically significant ($p < 0.05$). Other categories of crashes investigated recorded marginal reductions in crashes with PCSs but did not show any significant change in crash rates.

3.3. Development of proportions by crash type

Table 4 showed that installation of PCSs significantly reduced crash risk for older drivers. A separate question is whether PCS installation influences the types of crashes that result following PCS installation. Table 5 shows the proportion of crash types recorded for the study in the before and after PCS installation and indicates that PCS installation has reduced the proportion of angle crashes by approximately 3.2 percent when all motorists are considered. However, when considering drivers by age, the proportion of angle crashes was reduced by a lesser amount for younger drivers (e.g., 2.5% for injury and PDO crashes and 1.4% for injury only crashes for motorists age 64 and under) and a much greater amount for older drivers (e.g., 8.1% for injury and PDO crashes and 16.9% for injury only crashes for motorists age 65 and above). These changes in angle crashes is significant whether all drivers are combined or whether age groups are considered. While reduction in injury crashes involving motorist 65 years and under were not found to be

Table 4
Summary of results obtained from before-after with comparison group.

Type of Crash [a]	Period	Treated Sites Crashes	Comp. Group Crashes	NExp. Treat After	CMF	Safety Effect %	Std. Error	Confidence Interval	*P-Value* at 95% C.L
Drivers - Injury and PDO	Before	5339	6032	4684	0.99	0.65	0.03	0.94–1.05	0.81
	After	4656	5292						
Drivers - Injury only	Before	1167	1253	1086	0.95	5.3	0.06	0.84–1.06	0.34
	After	1031	1166						
Drivers - PDO Only	Before	4172	4779	3602	1.00	−0.57	0.03	0.94–1.07	0.86
	After	3625	4126						
Drivers < 65 years - Injury and PDO	Before	4629	5271	3888	1.03	−2.69	0.03	0.96–1.08	0.38
	After	3995	4427						
Drivers < 65 years -Injury only	Before	1031	1092	913	0.99	0.73	0.06	0.86–1.10	0.91
	After	909	967						
Drivers < 65 years -PDO only	Before	3598	4179	2979	1.04	−3.51	0.04	0.97–1.10	0.31
	After	3086	3460						
Driver 65 years and above - Injury and PDO	Before	710	761	807	0.81	18.41	0.06	0.70–0.93	0.00
	After	661	865						
Driver 65 years and above - Injury only	Before	136	161	169	0.71	29.1	0.11	0.49–0.93	0.01
	After	122	200						
Driver 65 years and above - PDO only	Before	574	600	636	0.84	15.7	0.07	0.71–0.98	0.02
	After	539	665						

[a] Injury category includes fatal crashes. PDO category are property damage only crashes.

Table 5
Crash type proportions [a].

Crash Type	Total Crashes (Injury and PDO)		Injury Only		No-Injury Only	
	Before	After	Before	After	Before	After
Single Motor Vehicle	400(7.5%)	308(6.6%)	180(15.4%)	145(14.1%)	220(5.3%)	163(4.5%)
Angle	1440(27.0%)	1108(23.8%)	388(33.2%)	310(30.1%)	1052(25.2%)	798(22.0%)
Rear End	1733(32.5%)	1654(35.5%)	334(28.6%)	318(30.8%)	1399(33.5%)	1336(36.9%)
Sideswipe [b]	759(14.2%)	680(14.6%)	48(4.1%)	40(3.9%)	711(17.0%)	640(17.7%)
Others	1007(18.9%)	908(19.5%)	217(18.6%	218(21.1%)	790(18.9%)	688(18.98%)
Totals	5339(100%)	4656(100%)	1167(100%)	1031(100%)	4172(100%)	3625(100%)
Crash Type	Involving Drivers > 65 Years Injury and PDO (before–after)		Involving Drivers > 65 Years Injury only: (before–after)		Involving Drivers > 65 Years No-Injury Only: (before–after)	
	Before	After	Before	After	Before	After
Single Motor Vehicle	358(7.7%)	283(7.1%)	172(16.6%)	132(14.5%)	186(5.2%)	152(4.9%)
Angle	1203(25.9%)	934(23.4%)	326(31.6%	275(30.3%)	877(24.4%)	659(21.4%)
Rear End	1523(32.8%)	1422(35.6%)	318(30.8%)	296(32.6%)	1205(33.5%)	1126(36.5%)
Sideswipe [b]	647(13.9%)	569(14.2%)	42(4.1%)	38(4.2%)	605(16.8%)	531(17.2%)
Others	898(19.4%)	787(19.7%)	173(16.8%)	168(18.5%)	739(20.2%)	619(20.1%)
Total	4629(100%)	3995(100%)	1031(100%)	909(100%)	3598(100%)	3086(100%)
Crash Type	Involving Drivers < 65 Years Injury and PDO (before–after)		Involving Drivers < 65 Years Injury only: (before–after)		Involving Drivers < 65 Years No-Injury Only: (before–after)	
	Before	After	Before	After	Before	After
Single Motor Vehicle	42(6.1%)	25(3.8%)	8(5.9%)	13(10.7%)	34(5.9%)	12(2.2%)
Angle	237(34.4%)	174(26.3%)	62(45.6%)	35(28.7%)	175(30.5%)	139(25.8%)
Rear End	210(30.5%)	232(35.1%)	16(11.8%)	22(18.0%)	194(33.8%)	210(39.0%)
Sideswipe [b]	112(16.3%)	111(16.8%)	6(4.4%)	2(1.6%)	106(18.5%)	109(20.2%)
Others	109(15.8%)	119(18.0%)	44(32.4%)	50(41.0%)	65(11.3%)	69(12.8%)
Total	710(100%)	661(100%)	136(100%)	122(100%)	574(100%)	539(100%)

[a] Injury category includes fatal crashes. PDO category are property damage only crashes.
[b] Sideswipe crashes denote vehicles traveling in the same direction.

significant, injury crashes involving motorists age 65 and above were significant ($p \leq 0.05$ based on the Z statistical test as shown in Table 6). Similarly, a comparison of proportion of injury and no-injury crashes after the installation of PCSs generally showed improvements in safety for all drivers (young and old) involved in angle related crashes.

Because the proportion of angle crashes decreases significantly, it is not surprising that other crash types increase. Notably, rear end crashes, which are the largest portion (34%) of all crashes, affect the overall impact of PCSs. One potential explanation is that because Michigan experiences long periods of snow during the winter season, one might expect an increase in rear end crashes. Another potential explanation is that some of the angle crashes (which occurred prior to PCS installation) are becoming rear-end crashes (following PCS installation). Also, because angle crashes tend to be more severe than rear-end crashes, one might have expected the significant shift from rear-end to angle crashes, coupled with the nominal (but not significant) reduction in total crashes based on the CMF in Table 4, to result in a reduction in injury crashes overall. However, as shown in Table 4, there was not a significant change in injury crashes.

That said, other crash types such as the single motor vehicle, sideswipe in the same direction, and other crash types did not show any significant improvement or deterioration in safety after PCSs installations. Further, PCSs did not seem to be affecting injury crashes when such crashes are stratified by crash type. In short, the proportion analysis suggests that PCSs do have different impacts in terms of angle crashes and rear-end crashes, especially when age groups are considered, but these differences have not yet been shown to impact injury level.

3.4. Cost benefit analysis of PCSs

Based on equation (13), the annual average savings (AAS) in dollar units was computed as $30,957.46 while the present value of the safety benefit of PCSs was estimated as $622,771.75 per intersection. With the present value cost per intersection as $822.74, the resulting benefit to cost ratio varies from 181:1 for service life of five years and 604:1 for a service life of 20 years; more common values in the 10–15 year range (based on Fayish and Gross (2010) and Thompson and Ford, (2012)) would be 342 to 483. Thus for locations with a substantial number of motorists age 65 + , there is a clear savings in crash cost compared to the cost of installing PCSs without the countdown signals as shown in Table 7.

Table 6
Two-proportion Z-test for crash types [a].

Crash Type	Change in Total Crash Proportions Injury and PDO: (before–after)	p- Value	Change in Total Crash Proportions Injury: (before–after)	p- Value	Change in Total Crash Proportions No-Injury: (before–after)	p- Value
Single Motor Vehicle	0.9%	0.09	1.4%	0.37	0.8%	0.11
Angle	3.2%	0.00	3.2%	0.11	3.2%	0.00
Rear End	−3.1%	0.00	−2.2%	0.25	−3.3%	0.00
Sideswipe [b]	−0.4%	0.58	0.2%	0.78	−0.6%	0.48
Others	−0.6%	0.45	−2.5%	0.13	0.0%	0.96
Crash Type	**Involving Drivers < 65 Years Injury and PDO (before–after)**	**p- Value**	**Involving Drivers < 65 Years Injury only: (before–after)**	**p-Value**	**Involving Drivers < 65 Years No-Injury Only: (before–after)**	**p-Value**
Single Motor Vehicle	0.6%	0.25	2.2%	0.19	0.3%	0.61
Angle	2.5%	0.01	1.4%	0.52	3.0%	0.00
Rear End	−2.8%	0.01	−1.7%	0.42	−3.0%	0.01
Sideswipe [b]	−0.3%	0.72	−0.1%	0.91	−0.4%	0.67
Others	0.1%	0.73	−1.7%	0.33	0.1%	0.93
Crash Type	**Involving Drivers > 65 Years Injury and PDO (before–after)**	**p- Value**	**Involving Drivers > 65 Years Injury only: (before–after)**	**p-Value**	**Involving Drivers > 65 Years No-Injury Only: (before–after)**	**p-Value**
Single Motor Vehicle	2.3%	0.05	−4.8%	0.16	3.7%	0.00
Angle	8.1%	0.00	16.9%	0.00	4.7%	0.08
Rear End	−4.6%	0.07	−6.3%	0.16	−5.2%	0.07
Sideswipe [b]	−0.5%	0.79	2.8%	0.20	−1.8%	0.46
Others	−5.2%	0.28	−8.6%	0.15	−1.5%	0.45

[a] Injury category includes fatal crashes. PDO category are property damage only crashes.
[b] Sideswipe crashes denote vehicles traveling in the same direction.

Table 7
Sensitivity analysis of benefit-cost ratio for PCSs[a].

Service Life	Discount Rate (%)	PV Benefits ($)	BCR
5.00	1.30	$148,929.05	181.02
10.00	1.80	$281,010.49	341.55
15.00	2.00	$397,780.54	483.48
20.00	2.20	$496,563.38	603.55

[a] All analyses are based on year 2018 dollars, an average annual savings of $30,957.46, and present value of costs of $822.74.

4. Conclusions and recommendation

This study sought to evaluate the effectiveness of pedestrian countdown signals (PCSs) on driver crash risk particularly older drivers (drivers age 65 years and above), where, at intersections where a PCS had been installed, crashes were compared prior to and following installation. The intersections were randomly selected; some had PCSs (treatment sites) and others had pedestrian signals without countdown timers (comparison group). A benefit-cost analysis was performed, focusing on one particular group for which PCSs were not necessarily designed: crash reductions for motorists age 65 + and the differential costs for installing PCSs versus pedestrian signals without countdown timers.

Based on crash modification factors, the only significant change in crash frequency associated with PCSs was a reduction of 18% in total crashes and 29% in injury crashes for drivers age 65+ ($p < 0.05$). By contrast, no significant changes occurred when one examined total crashes for drivers of all ages, total crashes for drivers' age under 65, or injury crashes for drivers' age under 65 group ($p > 0.05$). An analysis of the proportions of crashes that are occurring suggested that for the motorists age 65+, the installation of PCSs may be associated with a shift from angle to rear-end crashes: the 8% reduction in the proportion of angle crashes for these older motorists is significant ($p < 0.01$) compared to an almost 5% increase in the proportion of rear-end crashes for these older motorists ($p = 0.07$). A caution is that this shift from angle to rear-end crashes seems to yield benefits in terms of reduction in severity: total injury crashes for motorists age 65 + showed a significant change. This caution also applies when all drivers are considered: there is a significant reduction in the proportion of crashes that are angle and a significant increase in the proportion of crashes that are rear-end ($p < 0.01$ in both cases), total injury crashes for all motorists does not change significantly. That said, a conservative benefit-cost ratio based solely on the statistically significant impacts in this study—reduction in crashes for motorists age 65 + as noted in Table 4—yields BCR values ranging from 181 to 604, depending on the service life of the PCS.

The BCR provided by this paper is meaningful in practice because it suggests that PCSs may have benefits for one other group besides pedestrians: motorists age 65+. Thus, for locations where PDO crashes attributable to this population are a concern, the results suggest a strong safety benefit to these PCSs. This benefit is in addition to any benefit to pedestrians of these devices. Apart from the discussion of other safety treatments in section 5.1, the results provide some clues regarding potential transferability to other locations, although there are two elements of uncertainty regarding potential safety impacts in other locations. The first element pertains to how the PCS affects driver behavior. If the PCS is reducing crash risk for persons age 65 + because the additional information is helping eliminate the dilemma zone, then one would expect these benefits to be transferable to other locations that similarly have related crashes. Such an inference would align with a finding by Dissanayake and Perera (2009) who found that crashes related to left turns were higher for Kansas drivers age 65 + than for other age groups in that state. However, locations with very few such crashes (e.g., no red light running) might not see such benefits. The second element of uncertainty pertains to motorist age: for locations with few motorists age 65+, or for locations where vehicle safety features might reduce the greater risk of harm that is faced by older drivers involved in a crash, the impacts of PCS on such drivers might differ from those observed in this study."

4.1. Limitations of the study

These results do not definitively indicate why PCSs reduced older driver risk but the paper suggests two related factors: driver behavior and occupant robustness. It is possible that the PCS is having a similar effect to green countdown signals in that the extra information allows motorists to avoid the dilemma zone, as suggested by Ma et al. (2010), Liu et al. (2007), and Lum and Halim (2006). As for why injury-only crashes are reduced for seniors but not for other age groups, Cicchino (2015) suggests that drivers age 70 + are more fragile than younger drivers when involved in a crash, and Dissanayake and Perera (2009) cite previous work suggesting that "fragility" begins to increase at age 60. Table 6 showed that when considering solely injury crashes, there was a significant reduction in the proportion of crashes that are angle—but only for this age group. Thus the reduction in the proportion of crashes that are angle, which tend to be more severe than rear-end crashes, may have benefitted seniors in terms of injury reduction but may not have had the same marked effect on other age groups. However, these data can only show relationships but cannot prove causality: an alternative explanation is that there was some type of additional improvement made at the intersections when the PCS was installed which reduced injury crashes for seniors only but somehow did not have an effect on injury crashes for other age groups, as discussed next.

The authors further note that it is impossible to guarantee that these safety impacts are solely attributed to the presence of the PCS, given that Michigan's criteria included the installation of PCS at intersections that were undergoing modernization. (Michigan DOT had provided the dates at which PCS was installed, which were used for the before-after data. A re-analysis of the 93 sites showed that at 47 sites, one other change had been made at some point (although not necessarily the same date as the date of PCS installation): the signal type was changed from diagonal wire to box span wire.) Thus it is possible that this change in signal configuration was a contributing factor at some sites. (Schattler et al., (2008), in Illinois as well as Michigan, compared diagonal wire to mast arms (not box spring wire) and found that mast arms reduced red light running but not yellow light running; this work was not specific to older drivers. Kwigizile et al. (2015) found that box span wire nominally, but not significantly, reduced injury crashes for persons age 65 + and for persons of all ages—yet when injury and PDO were combined, there was an increase in crashes for persons age 65+, which differs from the results presented in Table 5. Further, even if such box span wire installations have no effect, when one divides the number of crashes in Table 4 by the number of intersections to obtain the intersection crash rate over a five year period, a greater nominal reduction in these rates is obtained if one compares crashes involving drivers age 65 and above than if one compares crashes involving drivers age less than 65. Thus, it is possible that other factors in addition to drivers' age, such as road and vehicle design, traffic data (especially on city roads as such data were not available), and other countermeasures may have additional impacts not fully examined herein.

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Conflict of interest

The authors report that they have no conflicts of interest.

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References

McGwin Jr., Gerald, Brown, David B., 1999. Characteristics of traffic crashes among young, middle-aged, and older drivers. Accid. Anal. Prev. 31 (3), 181–198.

Pulugurtha, S.S., Desai, A., Pulugurtha, N.M., 2010a. Are pedestrian countdown signals effective in reducing crashes? Traffic Inj. Prev. 11 (6), 632–641.

Alam, B.M., Spainhour, L.K., 2008. Contribution of behavioral aspects of older drivers to fatal traffic crashes in Florida. Transp. Res. Rec. 2078 (1), 49–56.

Arhin, S.A., Noel, E.C., Lakew, M., 2011. June. Evaluation of the impact of two pedestrian countdown signal displays on pedestrian behavior in an urban area. In: 3rd International Conference on Road Safety and Simulation, pp. 14–16. http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/2/Arhin,S.pdf, Accessed date: 20 June 2015.

Atta Boateng, R., Kwigizile, V., Oh, J.S., 2018. A comparison of safety benefits of pedestrian countdown signals with and without pushbuttons in Michigan. Traffic Inj. Prev. 19 (6), 588–593.

Boateng, R.A., 2016. Comprehensive Evaluation of the Effectiveness of Pedestrian Countdown Signals on Road Users in Michigan.

Chen, P.L., Pai, C.W., Jou, R.C., Saleh, W., Kuo, M.S., 2015. Exploring motorcycle red-light violation in response to pedestrian green signal countdown device. Accid. Anal. Prev. 75, 128–136.

Chiou, Y.C., Chang, C.H., 2010. Driver responses to green and red vehicular signal countdown displays: safety and efficiency aspects. Accid. Anal. Prev. 42 (4), 1057–1065.

Cicchino, J.B., 2015. Why have fatality rates among older drivers declined? The relative contributions of changes in survivability and crash involvement. Accid. Anal. Prev. 83 (October), 67–73.

Dissanayake, S., Perera, L., 2009. Highway Safety Issues of Older Drivers in Kansas. Kansas State University, Manhattan.

Eccles, K.A., Tao, R., Mangum, B.C., 2004. Evaluation of pedestrian countdown signals in Montgomery County, Maryland. Transp. Res. Rec. 1878 (1), 36–41.

Elekwachi, O.L., 2010. Empirical Investigation of the Effect of Countdown Pedestrian Signals on Driver Behavior and Capacity at Urban Signalized Intersections. Ph.D. Dissertation. Morgan State University, Baltimore.

Fayish, A.C., Gross, F., 2010. Safety effectiveness of leading pedestrian intervals evaluated by a before–after study with comparison groups. Transp. Res. Rec. 2198 (1), 15–22.

FHWA, 2009. In: Manual on Uniform Traffic Control Devices for Streets and Highways 2009 Edition, Washington, D.C.. http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf, Accessed date: 24 June 2015.

Gross, F., Persaud, B., Lyon, C., 2010. A Guide to Developing Quality Crash Modification Factors (No. FHWA-SA-10-032).

Harkey, D.L., Carter, D.L., Barlow, J.M., Bentzen, B.L., 2007. Accessible pedestrian signals: a guide to best practices. In: National Cooperative Highway Research Program, Contractor's Guide for NCHRP Project, . http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w117a.pdf, Accessed date: 2 May 2019.

Hauer, E., 1991. Comparison groups in road safety studies: an analysis. Accid. Anal. Prev. 23 (6), 609–622.

Huang, H., Zegeer, C., 2000. In: The Effects of Pedestrian Countdown Signals in Lake Buena Vista. Florida Department of Transportation, Tallahassee, Florida. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.638, Accessed date: 13 June 2019.

Huey, S.B., Ragland, D., 2007. Changes in Driver Behavior Resulting from Pedestrian Countdown Signals.

Kaiser Family Foundation, Henry J., 2019. In: Population Distribution by Age, San Francisco. https://www.kff.org/other/state-indicator/distribution-by-age/?dataView=1&currentTimeframe=0&sortModel=%7B%22colId%22:%2265%2B%22,%22sort%22:%22desc%22%7D, Accessed date: 14 June 2019.

Köll, H., Bader, M., Axhausen, K.W., 2004. Driver behaviour during flashing green before amber: a comparative study. Accid. Anal. Prev. 36 (2), 273–280.

Kostyniuk, L.P., Molnar, L.J., St, Louis, R.M., Zanier, N., Eby, D.W., 2017. 2017 update. In: Societal Costs of Traffic Crashes and Crime in Michigan, . https://www.michigan.gov/documents/msp/FinalReport_FINAL_edits_9.14.2017_605583_7.pdf, Accessed date: 28 May 2015.

Kwigizile, V., Oh, J.S., Van Houten, R., Prieto, D., Boateng, R., Rodriguez, L., Ceifetz, A., Yassin, J., Bagdade, J., Andridge, P., 2015. In: Evaluation of Michigan's Engineering Improvements for Older Drivers (No. RC 1636). Dept. of Transportation. Office of Research Administration, Michigan. https://www.michigan.gov/documents/mdot/RC1636_501939_7.pdf.

Liu, Y., Chang, G.L., Tao, R., Hicks, T., Tabacek, E., 2007. Empirical observations of dynamic dilemma zones at signalized intersections. Transp. Res. Rec. 2035 (1), 122–133.

Lum, K.M., Halim, H., 2006. A before-and-after study on green signal countdown device installation. Transp. Res. F Traffic Psychol. Behav. 9 (1), 29–41.

Ma, W., Liu, Y., Yang, X., 2010. Investigating the impacts of green signal countdown devices: empirical approach and case study in China. J. Transport. Eng. 136 (11), 1049–1055.

Markowitz, F., Sciortino, S., Fleck, J.L., Yee, B.M., 2006. Pedestrian countdown signals: experience with an extensive pilot installation. ITE J.-Institute Transp. Eng. 76 (1), 43.

Michigan Department of State Police Criminal Justice Information Center-Traffic Crash Statistics, Michigan Office of Highway Safety Planning-OHSP, 2013. http://publications.michigantrafficcrashfacts.org/2013/2013MTCF_vol1.pdf, Accessed date: 22 June 2015.

Nambisan, S.S., Karkee, G.J., 2010. Do pedestrian countdown signals influence vehicle speeds? Transp. Res. Rec. 2149 (1), 70–76.

National Highway Traffic Safety Administration (NHTSA), 2013. Traffic safety for older people—5-year plan. report no. DOT HS. 811, 837.

Office of Management and Budget, 2018. 2015. Discount Rates for OMB Circular No. A-94. August. https://www.whitehouse.gov/wp-content/uploads/2017/11/DISCHIST-2018-1.pdf.

Pollatsek, A., Romoser, M.R., Fisher, D.L., 2012. Identifying and remediating failures of selective attention in older drivers. Curr. Dir. Psychol. Sci. 21 (1), 3–7.

Preusser, D.F., Williams, A.F., Ferguson, S.A., Ulmer, R.G., Weinstein, H.B., 1998. Fatal crash risk for older drivers at intersections. Accid. Anal. Prev. 30 (2), 151–159.

Pulugurtha, S.S., Nambisan, S.S., 2004. An evaluation of the effectiveness of pedestrian countdown signals. In: ITE 2004 Annual Meeting and Exhibit, Institute of Transportation Engineers (ITE).

Rakotonirainy, A., Steinhardt, D., Delhomme, P., Darvell, M., Schramm, A., 2012. Older drivers' crashes in Queensland, Australia. Accid. Anal. Prev. 48, 423–429.

Reddy, V., Abdel-Aty, M.A., Pinapaka, S., 2008. In: Evaluation of Innovative Safety Treatments: A Study of the Effectiveness of White Enforcement Lights. Florida Department of Transportation. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SF/BD500/BD500_rpt.pdf, Accessed date: 25 June 2015.

Schattler, K.L., Wakim, J.G., Datta, T.K., McAvoy, D., 2007. Evaluation of pedestrian and driver behaviors at countdown pedestrian signals in Peoria, Illinois. Transp. Res. Rec. (1), 98–106 2002.

Schattler, K.L., Christ, M.T., McAvoy, D., Glauber, C.M., 2008. Evaluation of signal mounting configurations at urban signalized intersections in Michigan and Illinois. Transp. Res. Board 87th Annu. Meet paper no. 08-0045.

Schrock, S.D., Bundy, B., 2008. Pedestrian Countdown Timers: Do Drivers Use Them to Increase Safety or to Increase Risk Taking? (No. 08-2203).

Shen, J., Gan, A., 2003. Development of crash reduction factors: methods, problems, and research needs. Transp. Res. Rec. 1840 (1), 50–56.

Sifrit, K.J., Stutts, J., Staplin, L., Martell, C., 2010. September. Intersection crashes among drivers in their 60s, 70s and 80s. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. vol. 54. SAGE Publications, Los Angeles, CA, pp. 2057–2061 Sage CA.

Singer, J.P., Lerner, N., 2005. Countdown Pedestrian Signals: a comparison of alternative pedestrian change interval displays. Westat. http://www.atssa.com/galleries/default-file/Ped_Countdown_Report.pdf, Accessed date: 25 June 2015.

Stollof, E., McGee, H., Eccles, K.A., 2007. Pedestrian signal safety for older persons. https://www.aaafoundation.org/sites/default/files/PEDsigtiming.pdf, Accessed date: 27 June 2015.

Su, J., Tang, W., 2008. Evaluation of the driver starting behaviours at countdown pedestrian signals in Hsinchu, Taiwan. Urban Traffic 23 (2), 1–12 (in Chinese).

Thompson, P.D., Ford, K.M., 2012. Estimating Life Expectancies of Highway Assets: Guidebook, vol. 1 Transportation Research Board.

Yulong, H., 2009. Investigating Road Users' Preference on Signal Countdown Devices at Intersections in Beijing, Transportation Research Board 88th Annual Meeting. paper no. 09-3430.

Pulugurtha, S.S., Desai, A., Pulugurtha, N.M., 2010b. Are pedestrian countdown signals effective in reducing crashes? Traffic injury prevention 11 (6), 632–641.