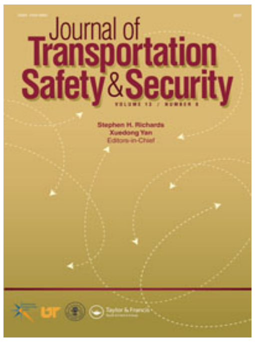

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Effects of fixed speed cameras on spatio-temporal pattern of traffic crashes: Ankara case

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ABSTRACT

Considering that speeding is the predominant factor in severe crashes, this study aims to investigate the effectiveness of fixed speed camera enforcement on spatio-temporal pattern of traffic crashes in Ankara, Turkey. We investigated 1448 crashes involving fatality and/or injury on the sections with and without fixed speed camera in Ankara for the years of 2009 and 2011. Network-based Kernel Density Estimation Method was used to examine the spatial distribution of crash density pattern for pre and post camera instillation years. Comparison of crash statistics between 2009 and 2011 revealed that the fixed speed cameras installed in 2010 resulted in 23% decrease in the number of crashes involving fatalities and/or injuries, 50% in fatalities, and 27% injuries in the examined regions. Moreover, the fixed speed cameras were found to be significantly effective in their catchment area bands in 7 out of 18 indicators including total crashes, injuries, single vehicle crashes, weekdays crashes, noon crashes, evening crashes, and summer crashes. Consistent with the previous studies, findings showed that the fixed speed cameras were effective, especially in reducing traffic injuries and crashes with fatalities or injuries.

KEYWORDS
fixed speed cameras; spatio-temporal analysis; traffic crashes; enforcement; Ankara

1. Introduction

About 1.24 million people die annually on the world's roads and 20 to 50 million people have serious injuries leaving devastating traumas on the life of significant others as well as on the communities (World Health Organization [WHO], 2013). The recent report of World Health Organization confirmed that traffic crashes are one of the major epidemics, especially in the developing countries. Projections suggest that traffic crashes will become the fifth leading cause of death unless new commitment to prevention is taken. Middle-income countries, including Turkey have the highest annual traffic fatality rate with 20.1 per 100 000 population, whereas the rate in high-income countries is 8.7 per 100 000 (WHO, 2013).

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Speeding is one of the most significant contributing factors, especially to the severe crashes. It was shown that 40–50% of the drivers on average in the world drive faster than the posted speed limit and one third of all fatal crashes are directly related with excessive speed (Organization for Economic Co-Operation & Development [OECD], 2006). The European Commission Report (European Commission, 2004) indicated that 11.000 of 40.000 fatalities are related with speeding in Europe annually. Speeding is also a leading cause of collisions in Turkey, which is responsible from 34% of all reported crashes with fatalities or injuries (Turkish Statistical Institute, 2013).

Automatic speed enforcement system (also called speed camera) is one of major enforcement tools to prevent speed limit violations. The most commonly applied automatic speed enforcement system is the fixed speed cameras (FSC), mounted in boxes at fixed locations. These cameras are mostly developed to sense speed violations and automatically identify the vehicle based on photographs of the vehicle and license plate (Elvik, Vaa, Hoye, & Sorensen, 2009; OECD, 2006; Thomas, Srinivasan, Decina, & Staplin, 2008; WHO, 2008).

The FSC system has been used increasingly in Turkey. Ankara, the capital city of Turkey, is also one of the provinces where the system has been extensively installed in the recent years. The FSC system functions as one of the components of Automated Enforcement System (AES) in Ankara. There were 372 cameras in the AES activated in December 2010. Of these cameras, 72 were the FSC located at 9 points to detect only speed violations, while 300 were installed to detect red light violations. An evaluation of the AES 17 months following the installations indicated that monthly monetary violation penalties averaging about 4 million TL (about 1,5 million USD) by the AES. Moreover, after the installation of the system, there was a sharp decrease in speed (68%), red-light (45%) and total (48%) violations (Bastug & Felek, 2012). However, the effectiveness of the FSCs in preventing the road crashes has not been examined in Turkey

The AES was established in 2010 in Ankara and comparison of the year before (2009) and after (2011) the installation indicated a clear improvement in traffic safety. Although the number of vehicles per 1000 persons increased from 265 in 2009 to 280 in 2011 (Sümer, Kaygısız, Söylemez, & Vursavaş, 2014), traffic fatalities per 100,000 people decreased about 26% in Ankara; whereas it decreased 14% in Turkey for the given period (Turkish Statistical Institute, 2010, 2012, 2015). Moreover, recent statistics indicated that vehicle km value increased by 12,3% during the given period in Ankara (General Directorate of Highways, 2010, 2012).

In this study, we aimed to examine the effects of the FSCs on spatio-temporal pattern of traffic crashes in Ankara City in detail using both spatial and non-spatial analyses. We specifically investigated the effects of FSCs (in a total of 28 catchment area bands) located on the sections throughout Ankara in which 70 km/h speed limit roads by comparing the safety conditions before and after camera installation years, 2009 and 2011. The routes in this study were totally 83 km long major dual carriageways roads with four lanes for each way located in both residential and nonresidential (light industry, commercial or services) regions.

2. Background

Driving violations are the main cause of crashes, and thus, effective and systematic traffic police enforcement is the main strategy for transportation safety (Elvik et al., 2009; Kaygisiz & Sümer, 2017; Stanojević, Jovanović, & Lajunen, 2013). Past studies have shown that when road users show full compliance to the traffic rules in the developed countries, road crashes would decrease about 50% (Elvik et al., 2009; European Transport Safety Council, 1999). Compared to Western countries, risky driving is relatively common in Turkey (Sümer & Kaygisiz, 2015). Therefore, systematic traffic enforcement via the FSC would be expected to have much larger effect in Turkey.

A number of recent studies have shown the effectiveness of the traffic enforcement cameras in changing driving behavior (e.g., Al Jaman, Alam, & Hamdi, 2018; Cunningham & Hummer, 2010; Polders et al., 2015; Vanlaar, Robertson, & Marcoux, 2014). Similarly, most studies on the effects of enforcement suggest that automated enforcement, especially fixed speed cameras, are effective and should be a part of main enforcement strategy (e.g., Cameron & Delaney, 2006; Carnis, 2011; Choi, Kim, Kho, & Park, 2019; De Pauw, Daniels, Brijs, Hermans, & Wets, 2014; Dreyfuss & Sher, 2019; Elvik et al., 2009; Høye, 2015; Li, Graham, & Majumdar, 2013; Martínez-Ruíz et al., 2019; Tay & De Barros, 2009). The credibility and consistency of enforcement are critical for a sustained effect, and preventive warning system should always precede the penalty or fines (tickets). In an earlier study, Elvik (1997) observed 64 road sections having installed photo-radar systems in Norway and found that the system reduced crashes with injuries approximately 20%. In another study, Elvik et al. (2009) conducted a comprehensive meta-analysis and demonstrated that FSCs reduce the crashes of all severities 24% and crashes with fatalities 39%.

In their recent study, Martínez-Ruíz et al. (2019) investigated the impact of camera enforcement on traffic violations, including driving over the speed limits. They observed 38 intervention areas and 50 comparison areas (250 m radius), during 42 months before and 34 months after the installation of cameras in Cali, Colombia and analyzed the effect of cameras by using mixed negative binomial regression models. After adjusted comparisons, they found that the intervention sites outperformed the comparison sites with an additional yearly reduction of 5.3% ($p = 0.045$) for all crashes and also stated that the use of cameras for detecting traffic violations seems to have a positive effect on the reduction of crashes in the intervention areas.

Mountain, Hirst, and Maher (2004) investigated the effect of the distance of FSCs by separating the distance bands. The study was conducted on 62 speed cameras in which 30 miles/h (48 km/h) speed limit roads in the United Kingdom. They used empirical Bayes method and found that the number of injury crashes was significantly decreased by 25% up to 250 m from the camera. The reduction rate dropped to 15% between 250 and 500 m, and 12% between 500 and 1000 m though these decrements were not statistically significant.

Similarly, Hess (2004) examined the effects of 49 speed cameras by using cumulative distances of 250 m, 500 m, 1000 m and 2000 m in Cambridge, the UK. The author considered regression to the mean effect and found that the effects of the cameras were significant and the effect decreases with distance from the cameras. The highest effects were found up to 250 m from the camera with decrease of 46% in the number of injury crashes. This ratio was 41% for 500 m distance, 32% for 1000 m, and 21% for 2000 m.

Chen, Meckle, and Wilson (2002) evaluated the effect of the photo radar program on a highway corridor in British Columbia, Canada. The observed corridor was divided into two sections under the direct surveillance of photo radar locations and not having the photo radar locations. Other highways and main roads in the same districts were chosen as the comparison groups. Two years of before-and-after traffic crash data and spillover effects were analyzed by using the empirical Bayes method. This study estimated that the reduction in the number of expected crashes was about 14% (± 11%) at the speed camera (photo radar) locations and 19% (± 10%) at non-speed cameras locations.

In a recent study (De Pauw et al., 2014) carried out on the highways in Flanders-Belgium, a before-after study with controlling for the trend on 65 fixed speed cameras installed between 2002 and 2007s indicated that the FSCs had a significant decrease with 29% reduction in the number of severe crashes involving fatalities, but not a significant effect on injury crashes with 8% decrease. Besides, it was also reported that a favorable effect was found for all road user categories (car occupants, cyclists, moped riders, motorcyclists and pedestrians), with a higher decrease in the number of injured road users at the treated locations compared to the general trend.

Fixed speed cameras are generally located on the sections having excessive traffic speed, hotspot, and the hazardous locations where the crash risk is heightened (Cameron & Delaney, 2006; Wilson, Willis, Hendrikz, Le Brocque, & Bellamy, 2010). In addition, determining the hotspots via spatio-temporal crash analysis is important in to assess the effect of fixed speed cameras. There are several methods developed for determining the crash hotspots on the roads. Wang, Zhao, Ivan, Ahmed, and Jackson (2018), Bham, Manepalli, and Samaranayke (2017), Szénási and Jankó (2017), Geurts, Wets, Brijs, and Vanhoof (2004), Anderson (2007) and Anderson (2009) review the existing methods for the road crash hotspot detection. Recently, the use of kernel density estimation (KDE) methods for assessing crash hot spots has become the most popular approach because of its advantages over the other hot spot detection methods. Recent studies have documented the advantages of using the KDE method (e.g., Anderson, 2009; Blazquez & Celis, 2013; Bíl, Andrášik, & Janoška, 2013; Kaygisiz, Düzgün, Yildiz, & Senbil, 2015; Kaygisiz, Yildiz, & Düzgün, 2015; Kaygisiz & Hauger, 2017). The main advantage of KDE is the possibility of determining the dense crash locations, unlike the traditional methods such as clustering algorithms, where the crash data is grouped based on either supervised or unsupervised manner. Hence, the dense locations from KDE highlight the spatial distribution of high-risk locations on a road segment or in a road network (Anderson, 2009).

Okabe, Okunuki, and Shiode (2006) reviewed the standard (also called planar) KDE on network space and improved the network-based KDE analysis by designing SANET (Spatial Analysis on a Network) tool to analyze spatial phenomena that occur on networks. The main difference between the planar and network-based method is the way of calculating distance. Distance is calculated by measuring Euclidian interval (as the bird flight distance) in planar KDE while it is calculated by measuring network interval in the network-based KDE. Considering its advantages, we employed the network-based KDE in the current study.

3. Objectives

The main objective of this study is to examine the effectiveness of all FSCs on road safety with a total of seven installed cameras at the mid-section between the main intersections on the major arteries of the metropolitan area of Ankara. Because these FSCs, which detect only excessive speed, were installed in 2010, the data used in this study were taken from the previous and following years, 2009 and 2011. We analyzed the crash data using both spatial and non-spatial analyses to evaluate the effects of the FSCs in detail. Specifically, we tested the effects on the locations of FSCs by considering spatial crash pattern as well as the effects considering certain distance from the FSCs by separating distance bands. We also investigated the effect of the FSCs on different crash types and conditions.

4. The methodology

4.1. Research design

The present study examines the effectiveness of fixed speed camera enforcement on the spatio-temporal pattern of traffic crashes in Ankara, Turkey by comparing two time periods before (year of 2009) and after (year of 2011) the installment of cameras. Therefore, our research design was a cross-sectional method with before and after comparison between the pre- and post-intervention periods. Comparison of injury and crash characteristics between the pre- and post-intervention periods is one of the most widely used study designs to evaluate the effectiveness of a traffic safety measure (see, Shinar, 2017; Staton et al., 2016).

We used the official data provided by the Turkish Traffic Police Agencies and analyzed it using spatial analysis based on spatial crash pattern and non-spatial analysis by comparing the mean values of the crash characteristics of the two-time period at the different catchment bands.

4.2. Data

All statistics about traffic crashes with fatalities or injuries have been stored in a traffic crash database under Traffic Information System (TIS) in the Turkish Traffic Police Agencies since 2003. The data is geo-coded and contains information about date, time, kilometer of the road segment where the traffic crash took place, type of the traffic crash, number of vehicles involved in the traffic crash, code of the highway, coordinates of the traffic crash, age, sex and intoxication state of the driver, weather conditions, lighting conditions, vehicle type, and number of persons injured/killed. Approximately 120.000 crash cases annually are collected by the safety officials using crash report forms both manually and digitally and uploaded in TIS.

In this study, all crashes with at least a fatality or an injury on the major arteries passing through Ankara City in the years of 2009 and 2011 were analyzed to estimate the effectiveness of all FSCs installed on the stated sections in 2010. Firstly, data for all crashes with a total of 1448 were taken from the TIS database and then screened and verified using the crash forms in order to eliminate erroneous information. It was found that 6% of the obtained data contained some errors indicated by the inconsistencies between the manual crash reports and stored information in the TIS database. These errors were corrected by re-encoding data via relevant crash forms, resulting in 100% accurate crash data for the analysis. Additionally, the case network was digitized and both locations and catchment area bands of the fixed speed cameras were marked in Geographic Information Systems (GIS). Finally, crash data were classified according to the analyze type. While all crash data were used for spatial analyze, only the crash data that belong to catchment area bands of the FSCs were used for non-spatial analysis.

4.3. Data analysis

In this study, both spatial and non-spatial analysis techniques were utilized to evaluate the effectiveness of the FSCs in detail. Firstly, the accuracy of the site selection and the effectiveness of the camera in the installed locations were evaluated by using the network-based KDE method in the spatial analysis. Then, in the non-spatial analyses, only the crash data from the catchment area bands of the FSCs was analyzed.

4.3.1. Spatial analysis

In spatial analysis, the pattern of crash density was analyzed with their geocode data and dense crash locations (referred to as hotspots), which were determined using the network-based KDE method for both 2009 and 2011 via SANET toolset in ArcGIS 9.3/ArcMap. The density at a specific location is estimated by adapting of Equation 1 (Bailey & Gatrell, 1995):

$$\widehat{\lambda_\tau}(s) = \sum_{i=1}^{n} \frac{1}{\tau^2} k\left(\frac{s-s_i}{\tau}\right) \tag{1}$$

Where s is a location in the study area, i.e., road network, and $s_1 \ldots s_n$ are the locations of n events (i.e., accidents), τ is the bandwidth (i.e., radius of the circle), and k is the kernel which is a function of the distance and the bandwidth. The formula of kernel is stated below in Equation 2:

$$k = \frac{3}{\pi}\left(1 - \frac{d_i^2}{\tau^2}\right) \tag{2}$$

Where, d_i is the distance from the center of the kernel and any accident in the radius circle. The schematic representation of the KDE parameters is presented in Figure 1.

In the KDE method, the bandwidth and cell size are two important variables and they must be determined according to size of the case study area and the number of events to detect dense segments properly. After testing several bandwidth and cell size alternatives for the KDE maps, it was found that 700 meters of bandwidth and 40 meters of cell size were the most

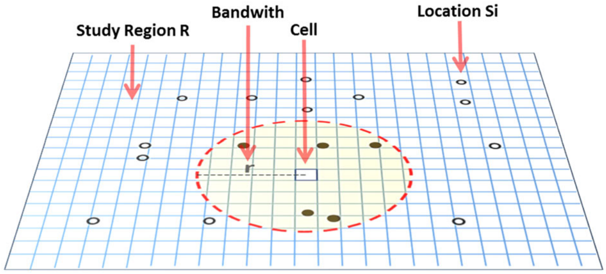

Figure 1. Schematic representation of KDE parameters (Kaygisiz & Hauger, 2017).

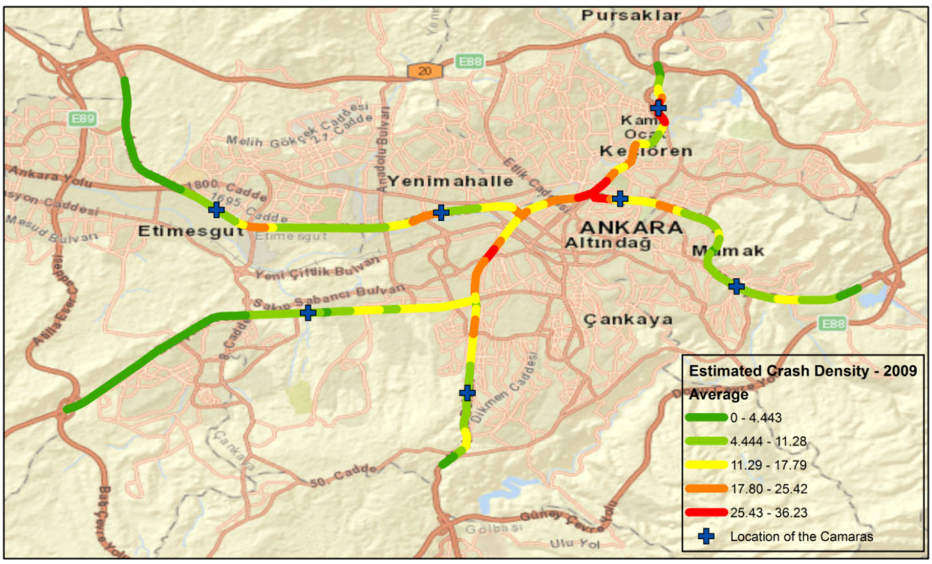

Figure 2. Location of the cameras and 2-dimensional representation of hot spots in 2009.

appropriate parameters for KDE. Moreover, KDE maps were illustrated in 3-D surface views by using Google Earth in order to enhance visual perception of the hot spots. This spatial analysis technique was carried out for each of two periods: before and after year of camera installation, 2009 and 2011 respectively. Thus, the accuracy of the site selection and the effectiveness of the camera to crashes could be evaluated (see Figures 2 and 3).

4.3.2. Non-spatial analysis (ANOVA)

In non-spatial analyses, the indicators of crash characteristic assessed on seven bands where FSC was installed were compared with 21 catchment area bands located around the bands with FSC. Considering that FSCs were installed in 2010, the data on crash characteristics were collected in the two-year period, beginning from 2009, when there were no FSCs, and 2011 following the instillment. Analyses were conducted separately on each crash characteristic in 18 groups via crash point map for both before

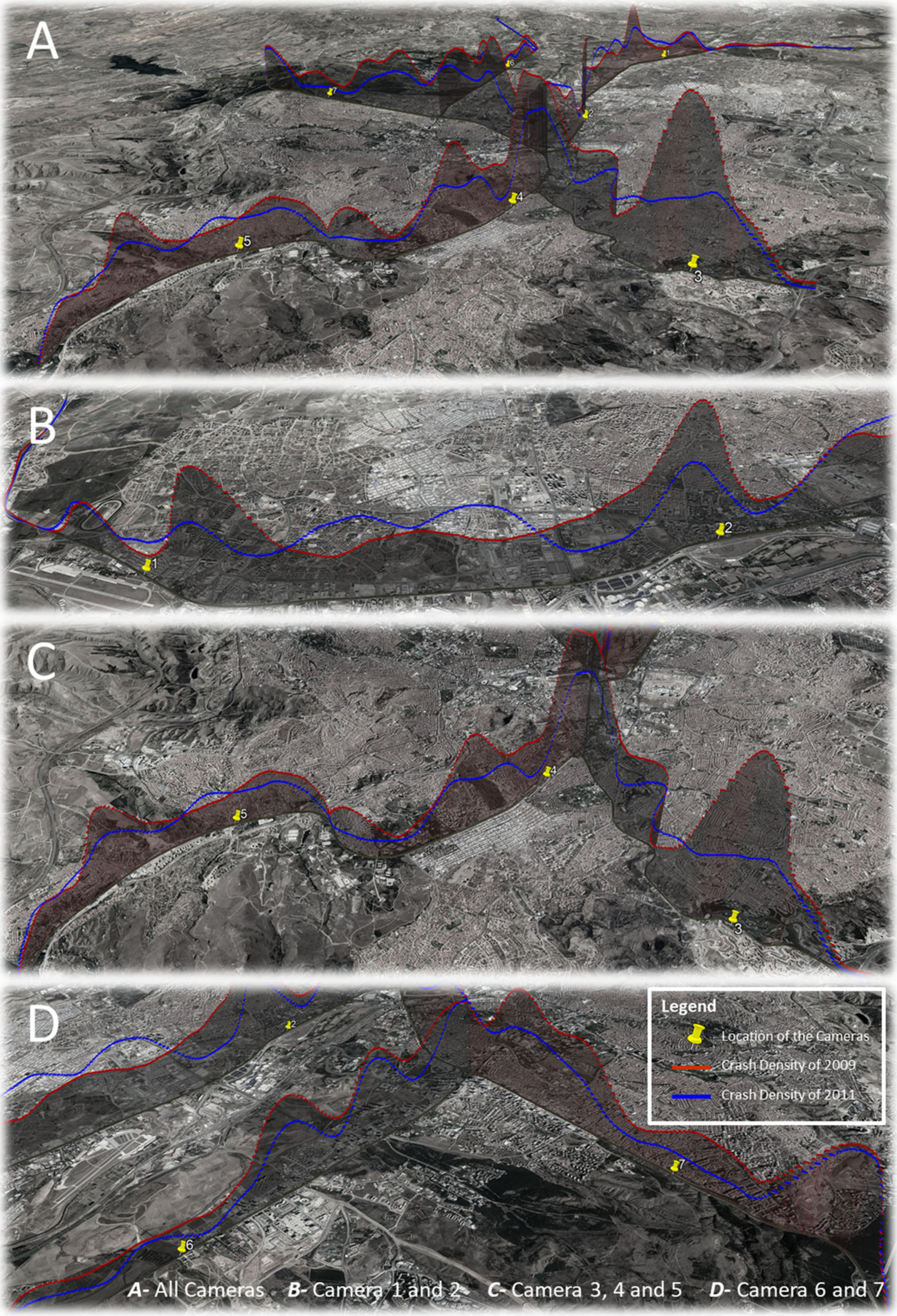

Figure 3. Location of the cameras and 3-dimensional representation of hot spots in 2009 and 2011.

(2009) and after year (2011) of camera installation. Schematic representation of a fixed speed camera and its catchment area divided bands can be seen in Figure 4.

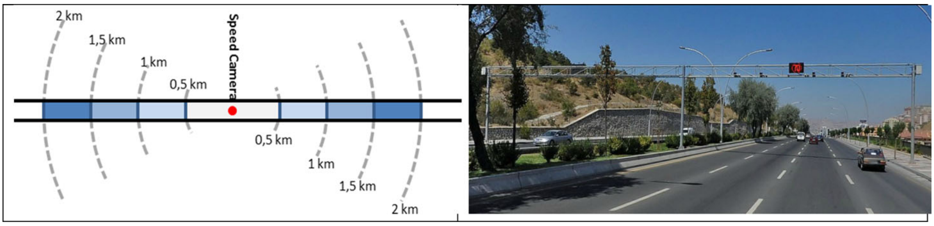

Figure 4. Fixed speed camera and its catchment area bands.

Specifically, we analyzed the data in the three steps. First, the catchment area and band distance were determined by assessing both 2 and 3-dimensional spatial analyses outputs for the year of 2009 (before period). It was found that 500 meters of band distance and 2000 meters of catchment area were the most appropriate parameters for non-spatial analysis. Then, 2000 meters of catchment area was divided into four bands; (1) up to 500 m, (2) 500–1000 m, (3) 1000–1500 m, and (4) 1500–2000 m from the camera. Eventually, the study was carried out with 7 bands where FSC was installed and also 21 bands without FSC as a comparison group, located around the bands with FSC. Thus, it was ensured that all main intersection crashes were completely excluded on non-spatial analyses in order to focus on speed related crashes.

Second, crashes in the band distances were identified and classified according to the crash characteristics in 18 groups via crash point map for both before (2009) and after year (2011) of camera installation. Thus, the data used in these analyses included crash characteristics in the catchment area bands for the years of 2009 and 2011. The crash characteristics examined in this study are as follows:

- Total number of crashes,
- Total number of injuries,
- Distribution of crashes by type (pedestrian crash, non-pedestrian crash),
- Distribution of crashes by number of vehicles involved (single vehicle, two vehicle, more than two vehicle),
- Distribution of crashes on weekdays and weekend,
- Distribution of crashes by the time of a day (morning, noon, evening, night, midnight),
- Distribution of crashes by season (winter, spring, summer, fall).

Lastly, to better understand the effectiveness of FSCs, a series of one-way ANOVAs was run on the crash characteristics using SPSS 20.0 software program, considering catchment area bands and before/after years, 2 (bands with and without FSC) X 2 (year; 2009, 2011). Standardized effect sizes were calculated by using Cohen's d statistics.

Table 1. Before- and after comparison of crashes and casualties.

	2009	2010	2011	2009 > 2011 percentage changes
Crashes (fatal or injured)	820	741	628	−23.41
- Fatal crashes	18	17	12	−33.33
- Injured crashes	818	724	616	−24.69
✓ Pedestrian crashes	179	133	128	−28.49
✓ Non-Pedestrian crashes	641	608	500	−22.00
Fatalities	24	23	12	−50.00
Injuries	1435	1372	1045	−27.18

5. Findings

Overall, when comparing main safety parameters of the year before (2009) the FSCs were installed with the year after (2011) on investigated area; as seen in Table 1, the FSCs had resulted in a 23% reduction in the number of fatal or injured crashes, a 50% reduction in traffic fatalities, and 27% reduction in injuries. The FSCs had also effects in decreasing pedestrian crashes.

The main findings of this study were presented separately regarding the spatial and non-spatial analyses.

5.1. Findings of spatial analysis

The effectiveness of speed cameras was tested via spatial analysis. First, the accuracy of the position of the camera was examined with respect to whether they were located on or close to the hotspots or not. As seen in Figure 2, prepared by using Network-based KDE analysis in 2009, only one camera (3rd) was located on the most (first degree) intense crash parts. Besides, two cameras (2nd and 4th) were located on the second degree and four cameras (1st, 5th, 6th and 7th) were fourth degree intense crash parts (Figure 3) indicated with the density of the color in the map.

Secondly, it was evaluated that whether those cameras that were installed in relatively accurate locations were more effective. As seen in Table 2, cameras (3rd, 4th and 2nd) located on the more intense crash locations (hotspots) can be expected to result in more reduction in crash density than the less intense crash ones.

Finally, the effect of the FSCs on the pattern of crash density was examined by comparing pre and post year distribution via the network-based KDE method in 3-dimensional space. As seen in Figure 3, after the FSCs were installed in 2010, crash density on almost all of the examined routes were decreased from 2009 to 2011. Besides, for the year 2009, there were eight evident hotspots (peaks) on the considered routes. These hotspots were reduced or completely disappeared in 2011 (Figure 3).

Table 2. Before- and after comparison of estimated crash density at camera points.

Camera ID	2009	2011	2009 > 2011 crash density changes	2009 > 2011 percentage changes
1	6.8	4.5	−2.3	−33.2
2	15.3	8.3	−7.0	−45.7
3	35.7	15.7	−20.0	−56.0
4	12.6	4.1	−8.5	−67.1
5	7.3	8.3	+1.0	+13.5
6	5.0	4.0	−1.0	−20.4
7	8.1	4.1	−4.0	−48.7

5.2. Findings of non-spatial analysis

In addition to the analyses of the spatial pattern, the effects of the FSCs on the crash characteristics were examined in detail by considering catchment bands with and without camera as well as before/after conditions.

As seen in Table 3, standard deviations were high, close to mean values, suggesting that there was an excessive heterogeneity in the distributions across the sections for corresponding variables. The detailed analyses revealed that certain locations (i.e., 5th camera stated in Figures 2 and 3) were not appropriately selected for the FSC. Moreover, sections (i.e., 3rd camera stated in Figures 2 and 3) with above average crash increased the variance. For example, on the bands without a camera in 2009, average number of pedestrian crash is 2.29 whereas standard deviation of this value is 3.51. However, in order to avoid the loss of data, roads and sections having excessive heterogeneous distribution were not removed from the analyses (Table 3).

As presented in Table 3, the results of the ANOVAs on catchment bands of cameras indicated that the FSCs had significant effects on 7 out of 18 types of crash characteristics (Table 3). The most important findings were that FSCs were effective in reducing both injuries (F (1, 27) = 4,91, $p < .05$) and the number of crashes (F (1, 27) = 4,44, $p < .05$) involving fatality and/or injury. Moreover, four other significant effects were found signifying the effectiveness of FSCs. First, whereas the FSCs were effective during the weekdays (F (1, 27) = 5,35, $p < .05$), they were not effective on the weekends. Second, crashes significantly decreased on both the noon (F (1, 27) = 5,10, $p < .05$) and evening times (F (1, 27) = 4,64, $p < .05$). Although the morning, night and midnight crashes also decreased, the differences were not statistically significant. Third, single vehicle crashes (F (1, 27) = 4,04, $p < .05$) decreased significantly. Although two vehicle crashes and more than two vehicle crashes decreased, both of them were not statistically significant. Finally, there was a significant decrease for the summer crashes (F (1, 27) = 4,91, $p < .05$). However, the reduction in the number of crashes occurred in the other seasons was not significant.

Results of the *Cohen d* calculations demonstrated that FSC had relatively large effects on crashes, especially during weekdays and summer times.

Table 3. Effects of fixed speed cameras on crashes in the catchment bands.

	2009 – Before year				2011 – After year						
	Camera band[a]		Out of camera band		Band with camera		Band without camera			Cohen's *d*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	F	Yes[b]	No[c]
Total crashes	12.43	10.80	12.71	7.91	7.43	3.55	8.62	5.55	4.44*	.62	.60
Injuries	22.00	23.76	23.00	12.76	12.43	6.66	14.95	9.26	4.91*	.55	.72
- *Distribution of crashes by type*											
Pedestrian Crash	2.00	2.88	2.29	3.51	1.29	1.25	1.38	1.69	.99		
Non-Pedestrian Crash	10.43	11.22	10.43	6.38	6.14	4.14	7.24	4.43	3.69		
- *Distribution of crashes by number of vehicles involved*											
Single Vehicle	8.71	9.93	5.43	4.66	4.29	3.64	3.67	3.07	4.04*	.59	.45
Two vehicle	2.71	2.36	5.43	4.65	2.57	1.51	3.48	2.40	1.01		
More than two vehicle	1.00	1.29	1.86	1.93	.57	.79	1.48	1.40	.70		
- *Distribution of crashes on weekdays and weekend*											
Weekdays	11.29	9.71	10.52	6.68	6.00	2.45	7.19	4.48	5.35*	.75	.59
Weekend	1.14	1.35	2.19	1.97	1.43	1.27	1.43	1.60	.21		
- *Distribution of crashes by the time of a day*											
Morning	2.14	1.57	2.05	2.01	1.57	1.27	2.00	1.64	.33		
Noon	4.29	6.24	3.52	2.62	2.14	.69	1.71	1.49	5.10*	.48	.85
Evening	4.29	4.19	3.52	2.29	2.00	1.41	2.52	2.18	4.64*	.73	.45
Night	1.29	.95	2.43	2.32	1.57	2.37	1.71	1.59	.13		
Midnight	.43	.79	1.19	1.21	.14	.38	.67	1.16	1.48		
- *Distribution of crashes by season*											
Winter	2.43	1.99	2.81	1.97	2.00	1.83	1.90	1.95	1.23		
Spring	2.00	2.24	3.76	2.77	1.71	1.50	2.24	1.95	1.64		
Summer	5.14	5.01	3.62	3.22	2.14	1.77	2.57	1.99	4.91*	.80	.39
Fall	2.86	2.97	2.52	2.04	1.57	1.51	1.90	1.51	2.53		

[a]Because there is no camera in 2009 on all bands, bands with camera in 2011 is stated as a camera band in 2009. There is no camera both two type bands in 2009.
[b]This value means the effect size (Cohen's *d*) between parameters for camera band in 2009 and for band with camera in 2011.
[c]This value means the effect size (Cohen's *d*) between parameters for out of camera band in 2009 and for band without camera in 2011.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

6. Discussion and conclusion

6.1. Results

In this study, both spatial and non-spatial methods of data analyses were utilized to better understand the effectiveness of FSC enforcement on traffic safety. It should also be noted that modeling of 2-D spatial analyses in 3-D has enhanced the visual depiction of the sites as well as clarity of the hot-spots. Thus, it provided an opportunity to examine the patterns of the potential effects in detail via spatial analyses.

Moreover, we obtained critical results regarding the effectiveness of the FSCs on the majority of the examined variables of via non-spatial analyses. Basically, it has been observed that analyzing the mid-section accidents around the FSCs via catchment bands by keeping the intersection accidents out is necessary to better understand the effects of the FSCs on speed related accidents. First, whereas the FSCs were effective during the week-days, they were not effective for the weekends. Similarly, although the night and midnight crashes decreased after the FSCs, these decrements were not statistically significant (Table 3). These two findings should be interpreted by considering the rate of non-routine trips, which are common at the weekend and also night and midnight times. Therefore, those drivers who do not know the location of FSC are expected to be higher in these specific time periods. Moreover, it is observed during the site inspection that the FSCs are not visible enough both at day (as seen Figure 4) and night time, and there are no horizontal and vertical signs before the FSCs which increase the impact of FSCs by striking and raising awareness of drivers as indicated in the previous studies (Elvik et al., 2009; Thomas et al., 2008). Taking all these into account, the location of the FSCs should be notified to the driver via horizontal and vertical caution signs with reflective materials.

Furthermore, it was found that the FSCs were significantly effective in their catchment area bands for the summer crashes while the reduction in the number of crashes occurred in the other seasons was not significant. Moreover, results showed that only single vehicle crashes decreased significantly. Although both two vehicle crashes and more than two vehicle crashes decreased, this was not statistically significant. Recent studies have shown that single vehicle crashes are mostly resulted from the excessive speed (Kim, Ulfarsson, Kim, & Shankar, 2013), and also in the periods of non-precipitation (i.e., mostly during the summer season), the speed of traffic increases significantly (Faria et al., 2018; Jägerbrand and Sjöbergh, 2016).

In summary, consistent with the previous studies (e.g., Chen et al., 2002; De Pauw et al., 2014; Elvik et al., 2009; Hess, 2004; Mountain et al., 2004), our results of both spatial and non-spatial analyses have showed that the fixed speed cameras were effective measure to improve traffic safety.

6.2. Limitations

The city of Ankara has a road transport system with a priority in vehicle mobility. In the recent years, grade intersections were converted to the grade-separated intersections, vehicle roads were expanded, and speed limits in the main arterial roads were increased to 82 km per hours from 70 km (Kaygisiz & Sümer, 2017). In addition, although there is no data regarding the traffic exposure rates, such as the volume, flow rate or density of traffic for the road network examined in our study, the number of vehicles per 1000 persons and vehicle km value in state roads have increased in Ankara recently (General Directorate of Highways, 2010, 2012; Sümer et al., 2014). It is possible that all these factors may affect the number of accidents in the study network.

Therefore, data from a shorter period of time, one year before and one year after the FSCs instillation, were used to minimize potential confounding effects of the aforementioned exposure factors in this study. However, it should also be considered that using data from a shorter period of time might be prone to bias as a result of regression to the mean effect. The effects of FSCs should be investigated by controlling for the other potential intervening factors such as, exposure rates, road network interventions and differentiations in land use with a longitudinal design via time series analysis (e.g., Vanlaar et al., 2014), empirical Bayes analysis (e.g., Mountain et al., 2004) in the future studies. These limitations should be considered in interpreting the findings of this study.

Finally, the crash data involving fatality and injury were used in this study. Thus, only the severe crashes were analyzed. Future studies should examine the effectiveness of FSCs on the other crash types.

6.3. Conclusion

In this study, the spatial and non-spatial data analyses indicated that the fixed speed cameras were effective on the investigated region in Ankara. Employing both spatial and non-spatial analyses methods helped us better understand the effectiveness of FSCs. Spatial analysis, prepared by using Network-based KDE, yielded more explanatory results in determining the accuracy of the cameras' position, while non-spatial analysis using ANOVAs, demonstrated the magnitude and the effect size of FSCs on both injuries and crashes. Both spatial and non-spatial analyses in consensus have indicated that FSCs are an effective countermeasure to improve traffic safety.

Finally, although a number of past studies examined the effects of the FSCs using non-spatial analyses (Cameron & Delaney, 2006; Chen et al., 2002; De Pauw et al., 2014; Elvik, 1997; Hess, 2004; Høye, 2015; Li et al., 2013; Mountain et al., 2004; Wilson et al., 2010), the proposed methodology in our study, which was based on both spatial and non-spatial analysis with 18 types of crash characteristics, contributed to the current literature by providing a systematic framework in analyzing the effectiveness of FSCs.

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