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Traffic crash pattern modification as a result of a 30 km/h zone implementation. A case study in Turin (Italy)

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Abstract

The strategy of 30 km/h zones, referred to in the international context as "traffic calming" measures, serves to safeguard pedestrians, cyclists and motorcyclists, collectively referred to as “vulnerable road users” (VRU). Its main function is to compel drivers to observe a maximum speed limit of 30 km/h. However, urban infrastructure transformations modify traffic collision patterns and the involvement of road users, with a spatial temporal redistribution of events. This work seeks to study the effects on collision distribution resulting from the introduction of a 30 km/h zone to the *Mirafiori Nord* area in the city of Turin in late 2008. Collision frequencies, based on data provided by the Italian National Institute of Statistics (ISTAT), were evaluated over the period 2006-2016. Road traffic collisions involving both VRU and motorized users (“noVRU”) were taken into account. Decreases in collision frequency were found for noVRU related crashes, while the VRU crash rate remained essentially unchanged with only minor fluctuations consistent with the regression to the mean phenomenon. The countermeasures, which sought to protect VRU, were however very effective for noVRU. As the effects of each structural modification spill over into neighboring areas, the analysis of collision frequency was extended to a study area greater than the one in which the 30 km/h zone was realized. In fact, due to the migration of events, the reduction in the collision frequency in the speed restricted zone was accompanied by an increase in the same frequency in the immediate surrounding area.

Keywords: road traffic collision; vulnerable road users; 30 km/h zone; collision frequency; migratory effects.

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1. Introduction

Approximately 2 out of every 3 victims of road crashes in major urban areas (Regione Piemonte, 2005) are pedestrians, cyclists or motorcyclists, collectively referred to as "vulnerable road users" (VRU). The ISTAT (Italian National Statistics Institute, 2017) road crash database confirms the criticality of this particular user category also in the case of the city of Turin during the period 2006-2016 (VRU fatalities were 247 out of a total of 388). In order to improve traffic management on urban road networks, it is necessary to prevent the passage of main urban movements (i.e., distribution and collection) across residential areas, which, in general, should only be used for arrivals and departures. Thus, 30 km/h zones are indicated in the international context as a "traffic calming" measure for residential neighborhoods aimed at making such areas safer (Jones et al., 2005).

This strategy of reducing traffic speed to 30 km/h from the usual 50 km/h is mainly addressed at safeguarding VRU and hopefully leads to a significant drop in crash frequency and severity (Elvik, 2001). In this framework, the risk of collision is reduced since the stopping distances for vehicles traveling at 30 km/h are approximately halved. Regarding severity, Rosén and Sander (2009) observed that 50% of pedestrian fatalities involved contact with a vehicle traveling at a speed between 50 km/h and 80 km/h, and that the fatality risk at 50 km/h is more than twice as high as the risk at 40 km/h, and more than five times higher than the risk at 30 km/h.

The present study is aimed at determining and analyzing the patterns of crash distribution within and outside a residential area that was modified with the introduction of a 30 km/h zone. In the paper, the changes to the hazardous road location (HRL) patterns before and after the introduction of the traffic calming measures in the *Mirafiori Nord* area in Turin were identified. A quantification of the effectiveness of the measures in terms of a reduction in the number of crashes involving VRU ("VRU" events), and the benefits in terms of vehicular crash reduction ("noVRU" events) was carried out for a comprehensive evaluation of this kind of traffic calming measure for the Italian context.

2. Methodology

The first step of this analysis consisted of the identification and localization of crash sites before and after the implementation of the 30 km/h zone (between September 2008 and February 2009). Data from 2006 to 2016 were split into two main periods: 2006-2008 (before), and 2009-2016 (after). The second period was further divided into a number of 2 and 3-year sub-periods in accordance with the procedure presented in Bassani et al. (2019).

In the second step, a spatial analysis to identify significant aggregations of events at specific points (clusters) was performed to identify Hazardous Road Locations (HRL). The identification of these clusters was carried out according to the spatial Kernel Density Estimation (KDE) methodology (Loo and Anderson, 2015). With the KDE methodology, each crash event may be converted into a continuous, symmetrical and decreasing probability density function around the event itself. The combination of the probability densities of all the events occurring in one or more years results in a continuous density surface, which presents some peaks and lows. Peaks indicate locations with a high probability of crash occurrence (i.e., HRL), whereas lows indicate locations with a lower probability. This method requires a priori a definition of the bandwidth (h) associated with the distribution (i.e., the radius of the circular area associated with each event). According to Fotheringham et al. (2000), the density function in the immediate area of a single crash location is given by:

$$\hat{f}(u,v) = \frac{1}{n \cdot h} \cdot \sum_{i=1}^{n} K\left(\frac{d_i}{h}\right) \tag{1}$$

where $f(u, v)$ is the crash density estimate at the location (u, v), n is the number of observations, K is a pre-selected Kernel function (uniform, triangular, quadratic, etc.), and d_i is the distance between the location (u, v) and the location of the i-th observation.

It is worth noting that although the choice of K function influences the shape of the surface, it does not significantly affect the final identification of HRL. According to Loo and Anderson (2015), the identification of HRL is mostly affected by h. Large values of h imply smooth density surface; in other words, it inevitably leads to an equitable spatial distribution with difficulties in the distinction of a specific spatial pattern. On the other hand, small h values lead to a surface with numerous peaks making any interpretation too difficult (Gutierrez-Osuna, 2004). Okabe et al. (2009) and

Porta et al. (2009) suggested a range of values for *h* between 100 and 300 m for urban areas: the best value should be defined on the basis of the average length of arcs in the road network.

In order to develop the HRL identification analysis, it is worth remembering that road crashes are random events that fluctuate in time and space; hence, the number of crashes at a specific location varies from month to month, and year to year. This variation in time for the same place reflects the "regression to the mean" phenomenon. In fact, it is highly probable that a period with a high crash frequency recorded on a certain element (i.e., arc or intersection) is followed by a period with a lower frequency, and vice versa (Highway Safety Manual, 2010). In other words, data continuously regress towards the mean of the longer period. These fluctuations may determine false positive and false negative crash data aggregations. The false positive/negative issue can be addressed by aggregating data to two or three consecutive year time periods (Loo and Anderson, 2015). In view of these considerations, the eleven-year period was divided into three periods of three-years and one of two years. Only the first period is related to the pre-intervention conditions: the available data preceding the establishment of the 30 km/h zone refers to the three-year period 2006-2008 only.

3. Case study

In October 2007, the Municipality of Turin and the 2nd District of the city took part in the first regional call to support the development of new 30 km/h zones (Regione Piemonte, 2007). The project focused on the implementation of safety and traffic control measures in the *Mirafiori Nord* area, specifically in the quarter delimited by *corso Sebastopoli*, *corso Siracusa*, *corso Orbassano*, and *via Guido Reni*. The technical decision for the implementation of traffic calming measures in this specific area was taken following a preliminary analysis of a selected number of candidate quarters (Comune di Torino, 2010). The project was in response to the high number of road crashes (and related number of injuries and fatalities) recorded in Turin over the preceding years. No data regarding traffic distribution and speed trends were available for this analysis.

Table 1 shows the trend in the number of crashes, fatalities and injuries involving VRU and vehicular road users (noVRU) between 2006 and 2016 in Turin (ISTAT, 2017). The different trends exhibited in the table demonstrate the effectiveness of different measures adopted at central and local level. In fact, a continuous negative (decreasing) trend in the total number of crashes had been evident in the eleven years from 2006 to 2016. In particular, there was a 34% reduction in crashes recorded in 2016 (3013 events) with respect to 2006 (4560 events). Regarding fatalities, the high fluctuations in the numbers reflects the regression to the mean phenomenon that affects events of limited magnitude (numerically speaking). Table 1 shows the percentage distribution of VRU and noVRU with respect to the total in that year, with the former accounting for an average of 65% of all fatalities and 31% of all injuries in the eleven-year period.

Table 1. Crash statistics in Turin between 2006 and 2016 (all data express the number of crashes, fatalities and injuries respectively; data in parenthesis indicate the percentage with respect to the total) (ISTAT, 2017)

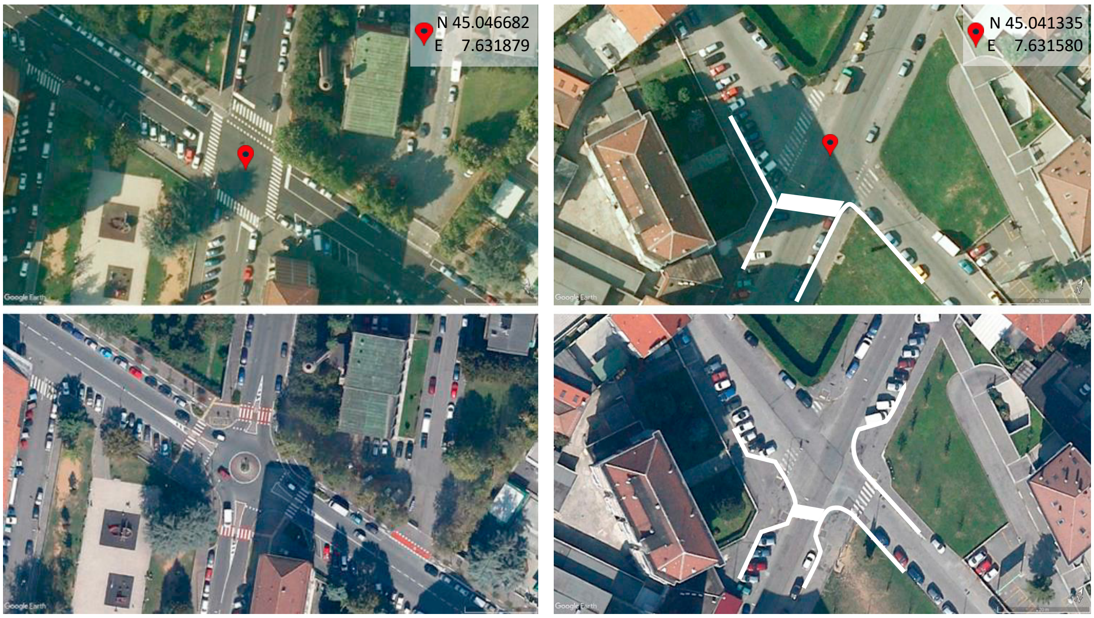
Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2006-'16
Total crashes	4560	4432	3979	3723	3729	3575	3358	3186	3228	3163	3013	39946
Total fatalities	49	47	39	43	29	29	26	43	22	33	28	388
Total injuries	6996	6697	6065	5700	5666	5483	5009	4902	4761	4765	4493	60537
VRU crashes	1835	1817	1624	1575	1539	1473	1421	1358	1439	1429	1344	16854
VRU fatalities	32 (65%)	29 (62%)	15 (38%)	31 (72%)	21 (72%)	21 (72%)	19 (73%)	28 (65%)	16 (73%)	20 (61%)	19 (68%)	251 (65%)
VRU injuries	2049 (29%)	2083 (31%)	1857 (31%)	1800 (32%)	1725 (30%)	1705 (31%)	1581 (32%)	1536 (31%)	1600 (34%)	1621 (34%)	1497 (33%)	19054 (31%)
noVRU crashes	2725	2615	2355	2148	2190	2102	1937	1828	1789	1734	1669	23092
noVRU fatalities	17	18	24	12	8	8	7	15	6	13	9	137
noVRU injuries	4947	4614	4208	3900	3941	3778	3428	3366	3161	3144	2996	41483

In further support of the decision to select the *Mirafiori Nord* area as the candidate for safety improvements was the fact that the actual traffic flows were not consistent with the residential character of the area, due to the presence of travelled ways with very large lanes. It was noted that most drivers used the internal routes to by-pass the surrounding arterials; finally, a high crash density at intersections was also evident before 2007 (Comune di Torino, 2010).

Between September 2008 and February 2009, the following modifications to the infrastructure layout were adopted: (i) the erection of new gates along the perimeter area (equipped with protection island and raised pedestrian crossings), (ii) conversion from a traffic-light controlled junction to a mini-roundabout (intersection between *via Castelgomberto* and *via Filadelfia*, Fig. 1A), (iii) creation of chicanes by alternating the parking lanes with 0° and 60° stall angles on the two sides, (iv) creation of intersections with raised plates and protection islands (Fig. 1B), (v) enhancement of existing bike lanes and introduction of new ones, and (vi) introduction of new one-way systems on minor roads. In Fig. 1B, the horizontal markings of the before and after road configurations have been highlighted with white lines to illustrate these infrastructural modifications.

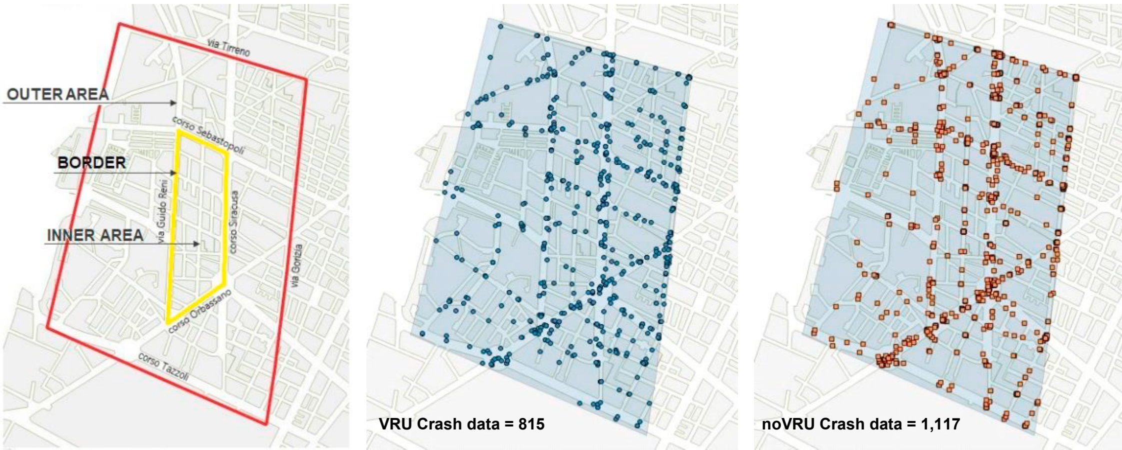
The 30 km/h zone is highlighted with the yellow boundary in Fig. 2A. The study area was extended beyond the 30 km/h zone as indicated with the red line in Fig. 2A, including the neighboring areas with the aim of associating quarters with similar destinations to those of the 30 km/h zone, which is purely residential. These considerations led to the selection of the outer area (with red boundary) shown in Fig. 2A, demarcated by *via Tirreno* (Northside), *corso Tazzoli* (Southside), *via Gorizia* (Eastside), and by the border of the Municipality of Turin (Westside). A separation of crash data was performed for the crashes occurring within the aforementioned area; the data were divided into those involving "VRU" (i.e., where at least one VRU was involved) and vehicular crashes only (called "noVRU"), consisting of 815 and 1,117 events respectively in the period 2006-2016 (Fig. 2B and Fig. 2C).

The HRL identification was carried out by adopting the Quartic Kernel function in eq. (1), while the bandwidth (h) was assumed referring to the average arc length of the study area road network. A value close to half of the average arc length (1/2·135 m = 67.5 m) was assumed to avoid the incorporation of two different intersections within the same cluster. It was decided to adopt a search radius of 75 m slightly greater than half of the average length, so as to allow an evaluation of the individual intersections.



(A) (B)

Fig. 1. Two examples of roadway modifications in the 30 km/h zone of North Mirafiori area (2008-'09). On top, the old road configurations; at the bottom, the conversion of a signalized intersection into a mini-roundabout (A), and the enlargement and rise of sidewalks and the shortening of pedestrian crossings (B).



(A) (B) (C)

Fig. 2. (A) Study area (the red borders indicate the study area, the yellow lines delimit the 30 km/h zone). Crash data available from 2006 to 2016 are reported in (B) for events involving at least one VRU, in (C) for events involving noVRU (total crash events equal to 1,932).

4. Analyses

Fig. 3 includes a series of spatial analysis aimed at evaluating the distribution of HRL in the study area, both in its inner and outer portions. The figures use different colours to depict locations where the Kernel density is higher than the average value (μ) in this study area. In the case of noVRU crashes, yellow areas identify locations with a Kernel density value between $\mu + 2\cdot\sigma$ and $\mu + 4\cdot\sigma$, orange where it is between $\mu + 4\cdot\sigma$ and $\mu + 6\cdot\sigma$, red where the density is above $\mu + 6\cdot\sigma$ (σ indicates the standard deviation). In the case of VRU crashes, the colours are yellow, green and blue for the three intervals respectively. It is worth noting that the number of dangerous locations is independent of both the number of years in the period and the number of crashes counted in the same period, since every analysis is characterized by a different average and standard deviation values. Fig. 4 evidences the locations where the density was found to be higher than $\mu + 6\cdot\sigma$ only. From Fig. 3 and Fig. 4 it can be stated that:

- crash events are concentrated along two main urban corridors that delimit the inner area (*corso Orbassano* and *corso Siracusa*, Fig. 2A);
- some specific locations present event peaks in one period only, thus indicating the presence of false positive HRL;
- other locations present systematic peaks in crash events with the exception of one period only, thus indicating a false negative HRL;
- HRL indicated in Fig. 4 occur exclusively at intersections (this is recurrent in urban areas due to the concentration of conflict points between different road users, which in turn increases the likelihood of crashes);
- the existence of dangerous intersections for vehicular users (i.e., *piazza Pitagora*, intersections *corso Sebastopoli*/*corso Siracusa and via Tirreno*/*corso Trapani*);
- the systematic presence of high concentrations in some specific intersections of collisions involving VRU (i.e., *piazza Omero*, *piazza Pitagora*, intersection between *corso Sebastopoli* and *corso Siracusa*), which require particular attention in the implementation of effective safety countermeasures.

Fig. 4 also illustrates the elimination of HRL in the inner part of the study area. Only in the before period (2006-2008), and only for noVRU users, was there a cluster evident within the inner area, specifically at the intersection between *via Castelgomberto* and *via Boston*. In the after period, HRL are all located close to the perimeter of the study area, and in the surrounding area.

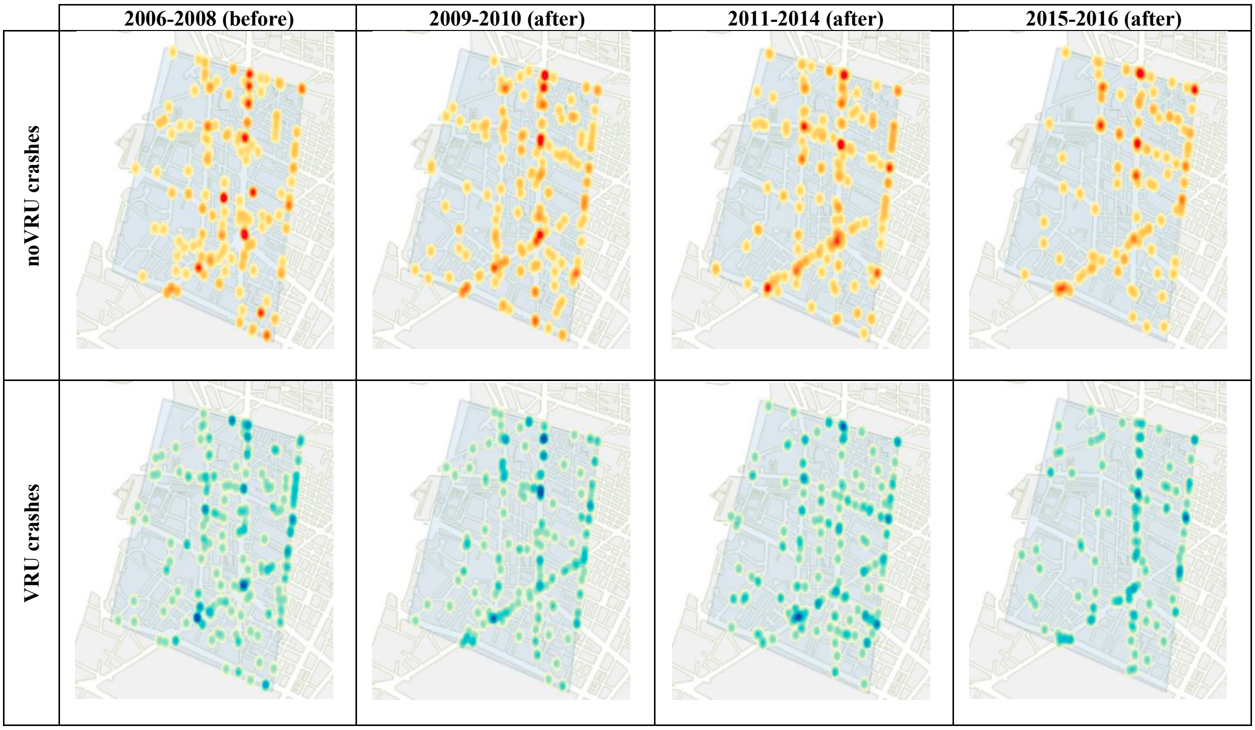


Fig. 3. Heat maps of spatial crash distribution of "noVRU" and "VRU" crashes (only locations with a Kernel density higher than $\mu + 2\cdot\sigma$ are represented). The first column refers to the "before" period (2006-2008), while the other three columns (2009-2016) relate to the "after" period.

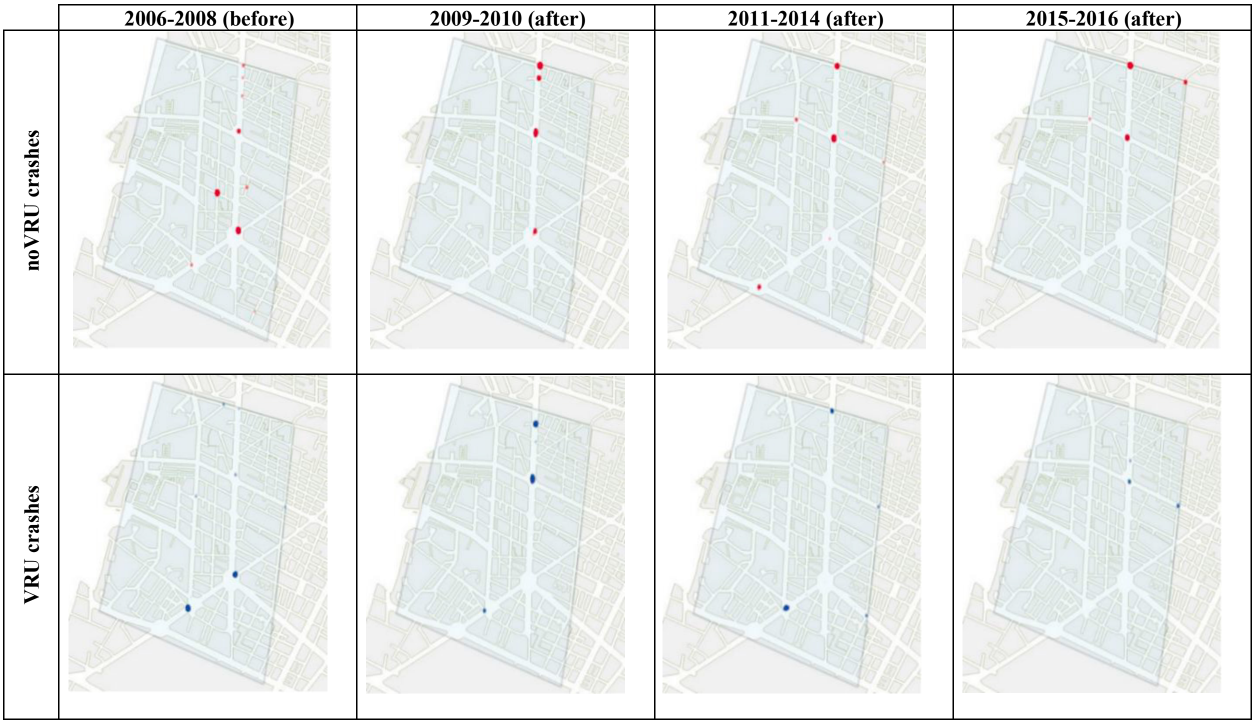


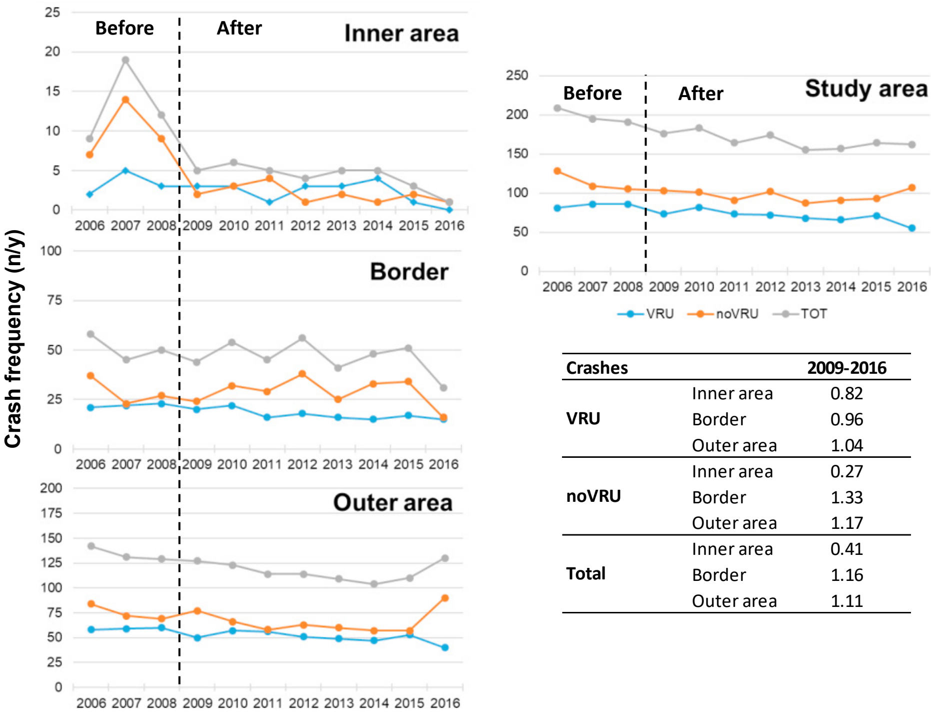
Fig. 4. Heat maps of peaks (HRL with a kernel density higher than $\mu + 6\cdot\sigma$ only) in spatial crash distribution of "noVRU" and "VRU" crashes. The first column refers to the "before" period (2006-2008), while the other three columns (2009-2016) refer to the "after" period.

The crash frequency rates in the three areas of Fig. 2A (30 km/h zone, boundary, and outer areas) were determined for each individual year from 2006 to 2016. The evolution of each frequency was evaluated over the entire period to understand whether any changes occurred in the years following the introduction of the 30 km/h zone. Before- and after-intervention conditions were separated in line with when the traffic calming works were executed in 2008 and 2009. Crash frequency data and odds ratios (OR, estimated with the whole municipality as "comparison group") are summarized in Fig. 5 (Elvik, 2001).

The effects of the 30 km/h zone on the "VRU" crash frequency were found to be limited (OR=0.82) with respect to the safety improvements for noVRU (OR=0.27). For VRU crashes, Fig. 5 shows ordinary fluctuations of data in the inner area from null (2016) to five events (2007). This fluctuation is less marked for data in the external and outer area, which show a slightly decreasing trend consistent with the data reported in Table 1 for the whole Municipality. With respect to noVRU crashes within the 30 km/h zone, it is worth noting the dramatic reduction in 2009. This trend is most certainly a direct consequence of the 30 km/h zone strategy, although it is specifically aimed at safeguarding the VRU component of the road-user community. Data for the inner area revealed pedestrians (50.0%), followed by motorcyclists (41.7%), and cyclists (8.3%) to be the main victims in VRU crashes in the before period, while in the after period pedestrians (52.6%) led, followed by cyclists (31.6%), and motorcyclists (15.8%).

All the data are consistent and demonstrate that the structural changes to the road layout guarantee the safety of vehicle users, since the interventions listed above improved the visibility (larger sight triangles) and led to a reduction in the number of conflict points between all road user categories.

Along the boundary of the 30 km/h zone, total crash frequencies fluctuate with a slightly increasing trend (OR=1.16); this condition could be interpreted as a gradual migration of vehicular crashes from the inner area to the perimeter avenues, as evidenced in Fig. 3 and Fig. 4. On the other hand, in the external area there is a decreasing trend over time, with a peak in 2016 (OR=1.11). This would suggest that a migration did not take place immediately after the adoption of the 30 km/h zone, but rather after a certain time (about 8 years after). Regarding the sum of the frequencies of the three areas, there is a similar trend to that of national trends (ISTAT, 2017).



Crashes		2009-2016
VRU	Inner area	0.82
	Border	0.96
	Outer area	1.04
noVRU	Inner area	0.27
	Border	1.33
	Outer area	1.17
Total	Inner area	0.41
	Border	1.16
	Outer area	1.11

Fig. 5. Summary of crash frequencies in the inner, border, outer and whole study areas. The embedded table reports the before/after odds ratios computed for the 2009-2016 periods (OR < 1 identifies a safety improvement, OR > 1 a safety worsening).

From this analysis there would seem to be a migration of the HRL from the area of intervention to the intersections of the main avenues of the surrounding areas, especially the one between *via Tirreno* and *corso Siracusa*. This hypothesis is corroborated by the trend of crash frequencies and odds ratios previously analyzed.

5. Conclusions

In order to assess the effects of the introduction of a 30 km/h zone on crash patterns, in this work a spatial analysis of road crashes was conducted on the road network of a residential quarter in the *Mirafiori Nord* area in Turin in which several traffic calming measures were introduced at the end of 2008. The analysis included the surroundings zones for two purposes: (i) to compare similar residential areas, and (ii) to assess the extent of any traffic migrations to these areas. Accordingly, the limit of the study area incorporated only neighboring areas with similar characteristics (a mixture of residential zones and small commercial activities, typical of the Italian urban context). Crash event data were gathered from the official road crash database provided by ISTAT (2017).

The results showed how the traffic calming strategy not only results in an improvement in safety for vulnerable road users (VRU), but also produces benefits for vehicular users (noVRU). In fact, a significant reduction in noVRU crashes in the after period (OR=0.27) was found within the area affected by the intervention, due to the reduction in speed (which leads to shorter stopping distances and longer available sight distances) and improved available sight distances (larger sight triangles).

A crash migration phenomenon from the inner part of the area subject to traffic flow modifications to the corridors located along the border of the 30 km/h zone was identified by means of the evaluation of annual crash frequencies, odds ratios, and through the identification of HRL. The study of migratory phenomena allowed the authors to highlight the importance of the extension of the study area to the neighboring ones. In fact, a study conducted on the 30 km/h zone area only could lead to an incomplete assessment of the traffic calming intervention effects, as it would fail to include information on what happens in surrounding areas. In the present work, an analysis limited to the 30 km/h zone would only lead to an exclusively positive evaluation of the intervention. Essentially, any reduction in the crash frequency inside the investigated area needs to be considered in the light of an accompanying increase (with OR>1) in the same rate at the edge and in surrounding areas.

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