Investigation of the impact of low cost traffic engineering measures on road safety in urban areas

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Abstract

This paper investigates the impact of Low Cost Traffic Engineering Measures (LCTEM) on the improvement of road safety in urban areas. A number of such measures were considered, such as speed humps, woonerfs, raised intersections and other traffic calming measures, which have been implemented on one-way, one-lane roads in the Municipality of Neo Psychiko in the Greater Athens Area. Data were analyzed using the before-and-after safety analysis methodology with large control group. The selected control group comprised of two Municipalities in the Athens Greater Area, which present similar road network and land use characteristics with the area considered. The application of the methodology showed that the total number of crashes presented a statistically significant reduction, which can be possibly attributed to the introduction of LCTEM. This reduction concerns passenger cars and single-vehicle crashes and is possibly due to the behavioral improvement of drivers of 25 years old or more. The results of this research are very useful for the identification of the appropriate low cost traffic engineering countermeasures for road safety problems in urban areas.

Keywords: Low cost traffic engineering measures, traffic calming, urban road safety, before-and-after analysis, large comparison groups, speed humps, woonerfs.

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1. Introduction

Road crashes is a major contemporary societal problem as it is the leading cause of death and injury in developed countries for people under 40 years old (World Health Organization, 2010). It is obvious that road crashes are closely linked with the enhanced human need for transportation. Therefore, road crashes occur in rural as well as in urban areas. However, crashes in urban areas are considered more harmful for the overall welfare of human society, as the likelihood of a crash (with or without the involvement of pedestrians) is typically higher.

In Greece, more than 1.000 fatalities and 16.500 injuries are recorded in more than 13.500 road crashes annually (Hellenic Statistical Authority ELSTAT, 2012). Most of the road crashes that occur in Greece concern crashes in urban areas, which account for the 72% of the total number of road crashes. The most significant factor leading to the high increase of road crashes is speed, which obviously affects also the crash severity (Wegman and Aarts, 2006; Kanellaidis et al., 1995). In Greece, the majority of drivers exceed the speed limit in urban areas, and therefore road crashes are continuously increasing (Kanellaidis, et al., 1999).

There is a wide variety of methods and techniques aiming in reducing road crashes in urban areas, such as law enforcement, intensive information campaigns, specific traffic management techniques etc. However, Low Cost Traffic Engineering Measures (LCTEM) (or traffic calming measures) are deemed to be one of the most efficient measures towards tackling one of the most significant problems that communities face nowadays: urban road crashes (European Transport Safety Council, 2003). Low Cost Traffic Engineering Measures are very cost-efficient corrective measures implemented quickly in roads and require very little maintenance costs. According to international experience, LCTEM are also highly effective in alleviating the negative impacts of black spots, that is, they offer high benefit to cost ratios (Gorell and Tootill, 2001; OECD, 2012).

In Denmark, the implementation of LCTEM in three pilot cities resulted in significant speed reduction and increase in the feeling of safety and security by the citizens (Herrstedt, 1992). In France, a reduction of 60% on the total number of road crashes was observed (Faure and Neuville, 1992) after the implementation of LCTEM, along with a reduction of average speeds and especially excessively high speeds. Recent study in Iowa, US (Hallmark et al., 2007) evaluated the implementation of several LCTEM on major roads that included among others, gateway treatments, chicanes, center islands, transverse lane markings, raised intersections, and roundabouts, and concluded that the operating speed decreased by up to 10 km/h.

In the early 1970s, an experimental scheme was designed in a sparsely-populated urban area at Delft, the Netherlands. This scheme comprised of woonerfs (i.e. roads where pedestrians and cyclists have legal priority over motorists) including speed depression measures such as speed humps or narrowed roads to 3 meters wide (Richards, 1990). The speed limit on woonerfs is typically below 20 km/h. Since then, woonerfs have been adopted in several other European or American cities together with other traffic calming measure: speed humps (or bumps), roundabouts, traffic circles, raised intersections, median barriers or islands, curb extensions and chokers, chicanes or street closures. In the US, woonerfs are also referred to as shared streets.

In Sweden, an evaluation study of 72 modern roundabouts showed that for single-lane roundabouts the observed number of pedestrian crashes was three to four times lower than predicted for comparable signalized intersections (Brude and Larsson, 2000). In the cities of Schoon and Van Minnen in the Netherlands, the number of road casualties was significantly reduced, when 181 intersections were replaced with roundabouts (Ciekot, 2001). In the US, the replacement of 11 intersections with roundabouts resulted in a 29% reduction in crashes (FHWA, 2000). Persaud et al. (2001) analyzed the benefit outcomes from converting several conventional intersections to roundabouts in the US and concluded the presence of large reductions in the number of injury crashes, especially those that are accompanied by incapacitations and fatalities.

A German study evaluated the impact of various measures of construction, design and traffic control on speed reduction by conducting before-and-after studies (Schnuell and Lange, 1992). Their evaluation showed that a distinct speed reduction can be obtained only through selected physical improvements. Measures based on optical effects and traffic signs were found to have very little effect on vehicle speed. In Italy, however, an investigation on the effectiveness of speed bumps on road safety showed an insignificant reduction in the observed speeds (Pau and Angius, 2001).

Several studies have provided the positive effects of speed humps in traffic safety. In particular, speed humps constructed in series in Colorado were found to reduce V_{85} and V_{max} by 21-24 km/h and 23 km/h respectively (Ciekot, 2001). In California, a speed hump test showed a considerable reduction in speeds, practically eliminating all speeds above 55 km/h (Ciekot, 2001). The installation of speed humps and tables across several locations in Salt Lake City, Utah, resulted in a reduction of mean and 85^{th} percentile speed by 5.4 km/h, in flat and rolling terrain locations only (Cottrell et al., 2006). Speed compliance towards the speed limit was also increased. The authors further concluded that injury-related crashes decreased, however, the decrease in the number of motor-vehicle crashes was not statistically significant. Moreover, in Denmark, a reduction in road crashes and road casualties by 24% and 45% respectively was also attributed to the introduction of speed humps (Engel and Thomsen, 1992). The ROSEBUD project (European Commission, 2005) reports on case studies where low cost traffic measures have been implemented in Europe. Based on this report, a safety evaluation of speed humps along an urban street section in Israel showed that the cost-benefit ratio from the implementation of this measure may range from 1:4 to 1:2, depending on the type of the speed hump installed.

In Seattle, Washington over 600 traffic circles were constructed during the last 20 years, resulting in safety benefits (Ciekot, 2001). Traffic circles were also found to decrease average speeds at the midpoint between two circles by 13 km/h in Colorado (Ciekot, 2001).

However, the implementation of traffic calming countermeasures has not been limited to one or two-lane urban streets. The reconstruction of the arterial European Road E12 in Sweden based mostly on pedestrian walkways, traffic islands, chicanes and roundabouts has shown that safety did increased not only along E12 but also along adjacent roads. Yield behavior towards pedestrians changed significantly. The difference was even greater with respect to yielding to child bicyclists from 6% before to 84% after (Leden et al., 2006), thus showing the multi – usability of LCTEM.

Elvik (2001) performed a meta-analysis of 33 studies to evaluate the effects of area-wide traffic calming schemes on road safety. The author concluded that on average, traffic calming reduces the number of injury crashes by about 15%. A comprehensive review performed by Bunn et al. (2009) evaluated the effect of traffic calming measures by synthesizing before-and-after studies at several residential areas in Germany, UK, Australia, the Netherlands, Denmark, Japan, and Spain. The elaborate review concluded that area-wide traffic calming have the potential to decrease the number of deaths and injuries, however, more research was found to be warranted in low or middle income countries.

Table 1 presents a description of representative LCTEM along with the results of their safety assessment throughout the literature.

Table 1. Summary of state-of-the-art LCTEM

LCTEM measure	Description	Case study	Results and Effectiveness	References
Speed humps and tables	Humps: Rounded, raised areas placed across the roadway. Circular, parabolic, or sinusoidal profile. Typically used for speed and noise reduction. Tables: flat-topped speed humps.	Colorado	Speed reduction by 21 to 23 km/h.	Ciekot, 2001
		Denmark	Crash and casualty reduction by 24% and 25% respectively.	Engel and Thomsen, 1992
		Salt Lake City	Speed reduction by 5.4 km/h. Increased speed compliance to posted speed limit. Injury crashes reduction.	Cottrell et al., 2006
Woonerfs (shared streets)	Roads where pedestrians and cyclists have priority over vehicles.	The Netherlands, Germany, Washington	Typically implemented with other traffic calming measures.	Richards, 1990
Traffic circles	Raised islands, placed in intersections, around which traffic circulates. Typically placed at intersections with speed, volume, and safety concerns.	Washington	Average speed decrease by 13%.	Ciekot, 2001
		Oregon	Reduce speeds over 30-35 mi/h. Dramatically reduced reported accidents.	FHWA, 2003
Roundabouts	Similar to traffic circles but accommodate higher volume streets	US	Reduce number of crashes by 29%.	FHWA, 2000
		Sweden	Reduce number of pedestrian crashes.	Brude and Larsson, 2000
		Netherlands	Reduce number of road casualties and injuries.	Ciekot, 2001 Persaud et al. 2001

In contrast to the systematic implementation of traffic calming measures in several developed countries, in Greece such measures were implemented in only few municipalities. In the early 1990s, speed humps were implemented in Larisa city together with a large expansion of pedestrian zones (European Commission - TRIP, 2001). LCTEM were also implemented in few other cities; however, it is noted that in most cities the implementation of those measures was either incomplete and without conducting any research on best practices.

In the capital of Greece, Athens, a limited number of traffic calming measures has been implemented. The Municipality of Neo Psychiko is the only area in the Greater Athens Area, where a variety of traffic calming measures has been introduced, following an integrated traffic study of the area. These measures include speed humps, raised intersections, curb extensions, road closures and woonerfs, which were implemented at one-way one-lane streets between the years 1991 and 1993. The purpose for introducing these measures was to reduce road crashes, especially those that involve pedestrians.

Therefore, the objective of this research is to investigate the impact of Low Cost Traffic Engineering Measures (LCTEM) on improving road safety in urban areas. It should be noted that this study evaluates the combined effect of LCTEM on traffic safety rather than looking into the effect of each individual measure in isolation. More specifically, this research attempts to quantify the safety benefits for the Municipality of Neo Psychiko, allowing for conclusions possibly useful to other cities of similar road network and land use characteristics. Furthermore, the investigation of the impact of traffic calming measures on different road user types, crash types and drivers' age allows for a complete safety impact assessment of the scheme. The identification of the possible safety impact could alleviate local reactions due to the related obstruction of the vehicle traffic, especially in countries such as Greece where no similar safety impact assessment is available.

2. Methodology

There is a wide variety of "before-and-after" methodologies used for the identification of the safety impact of specific road improvements. Methodologies without comparison group consist of older and simpler statistical techniques (Poisson and X^2) and newer and more complex techniques methodologies (Hauer, 1997), whereas methodologies with comparison group allow for the consideration of additional impact factors. For the purposes of this research, the methodology with comparison group was considered as the most suitable to address the evaluation of area-wide road safety measures (Hauer, 1997).

More precisely, the "before-and-after methodology with large comparison group" presenting the highest degree of accuracy was adopted, not only because data for larger areas were available but also because the phenomenon of the regression-to-mean (RTM) – which in most of the studies becomes a principal source of error and whose correction plays a primary role towards ensuring researches' reliability (Hirst et al., 2003) – was minimized by the availability of data for several years before and after the implementation of the measures.

3. Dataset Description

In this research three Municipalities of the Greater Athens Area are considered. The Municipality of Neo Psychiko is perceived as the study area, where many traffic calming measures have been implemented. The adjacent municipalities of Holargos and Agia Paraskevi comprise of the large comparison (control) group, as they both present similar road network, land use and demographic characteristics with the study area. The data obtained towards addressing the needs of such research mainly include: (i) crash data, available through the National Statistical Service of Greece; (ii) road network characteristics and population density data obtained from the technical services of the three Municipalities, (iii) data related to the land use characteristics, income, number of trips and vehicle property (Attiko Metro, 1997; Attiko Metro, 2000).

The Municipality of Neo Psychiko has a population of 15.000 – 16.000, and its area is about 1.200 m^2, divided into 174 blocks of about 6.9 m^2 of surface each. The road network of the area consists of collectors and arterial streets. The highest proportion of the streets (89.3%) is unidirectional, while the remaining 10.7% are two-way streets. Additionally, it is worth noting that the majority of the streets are local streets (i.e., not pass-through traffic streets). A variety of traffic calming measures have been implemented in the area of Neo Psychiko: speed humps, raised intersections, curb extensions, road closures and woonerfs, with the latter experimentally constructed during the late 1980s, leading to a complete and technical specification–based traffic calming program at the early 1990s.

During the period 1991-1993, 40 woonerfs and 49 speed humps were constructed in 21 roadways. In addition, many raised intersections, curb extensions (especially at intersection points) and some street closures were constructed at one-way one-lane roads, accounting for the 74% of the total number of roadways in the study area. In this research, the period before the implementation of the measures was considered to be 1985 – 1990, while the period "after" the implementation was from 1994 – 1999. In addition, crash data were available for the entire period both before and after the implementation of these measures.

An annual increase in traffic volumes in the area examined of about 1.31% was found (Attiko Metro, 1997). Regarding the land use characteristics, the highest proportion is residential and less over-regional business land use. Other land uses, such as education, sports, land for cultural events etc, cover a very small proportion of the study area.

The comparison group includes the Municipalities of Holargos and Agia Paraskevi. These Municipalities are located near the study area and as it is shown in Table 2 they all present similar road network, land use and traffic volumes characteristics, which is a prerequisite for applying the before-and-after methodology with large comparison group. Additionally, it is worth mentioning that the majority of streets in all these areas are unidirectional and the dominating land use is residential. Moreover, the monthly average income, the average residents' vehicle property and mode share of trips data are similar.

Table 2. Road network, land use and other characteristics for the area examined and the control group.

Characteristics	**Municipality**		
	Neo Psychiko	Agia Paraskevi	Holargos
Road network characteristics			
Area's extent	1200 m^2	7000 m^2	2735 m^2
Population	16 000	87 500	39 000
Density	130 res/acre	125 res/acre	142 res/acre
Number of blocks	174	514	250
Average surface of each block	6.90 m^2	13.62 m^2	10.94 m^2
Road network length	19 000 m	120 000 m	42 000 m
Basic road network length	3700 m	25 000 m	7000 m
Secondary road network length	15 300 m	95 000 m	35 000 m
Road surface percentage	12.63%	13.79%	12.03%
Total number of streets	75	288	95
Number of one-way streets	67	260	85
Number of two-way streets	8	28	10
One-way streets percentage	89.33%	90.28%	89.47%
Two-way streets percentage	10.67%	9.72%	10.53%
Number of secondary streets	8	15	11
Secondary streets percentage (according to their length)	19.47%	20.83%	16.67%
Land use and other characteristics			
Over-regional business land use	16.21%	14%	12%
Regional business land use	1.44%	1.02%	1.2%
Land use for cultural events etc.	3.8%	4%	3.3%
Education and sports	4.93%	4.2%	3.5%
Residential	73.62%	76.78%	72%
Monthly family average income	1350 €	1100 €	1100 €
% mode share of trips (to the center of Athens)	49% public transport	45% public transport	55% public transport

	51% private vehicles	55% private vehicles	45% private vehicles
Average residents' vehicle property (vehicles/1.000 residents)	300 – 350	350 – 400	350 – 400

4. Data Analysis and Results

This research implements the before-and-after study with comparison group. By this method, crash data for the comparison group are used to estimate crashes that would have occurred at the treated sites if the treatment had not been implemented. An advantage of this method is that it can potentially produce more accurate estimates than the simple before-and-after method. The method's strength increases with increasing similarity between the treated and the comparison groups (Mountain et al., 1992).

The application of the before-and-after methodology with large comparison group is based on the Chi-square Test, as the number of the crashes occurring in the study area is compared to the corresponding crashes of the comparison group. The parameters B_S and A_S represent the total number of crashes in the study area occurred during the "before" and "after" periods, respectively. Similarly, the parameters B_C and A_C represent the total number of crashes occurred in the area of the comparison group both before and after respectively.

The Chi-square Test gives that:

$$X^2 = \frac{(A_S - B_S * C)^2}{(B_S + A_S) * C} \quad (1)$$

$$C = \frac{A_C}{B_C} \quad (2)$$

Where X^2 value is compared with the X^2_α value (for a given probability α and for $n = k - 1$ degrees of freedom, k observations = 2, i.e., 1 before and 1 after the implementation of the measures). It is apparent that in all cases where the estimated X^2 value is higher than the X^2_α (in this research two probabilities α were considered: 90% and 95%, which is a more conservative consideration), the reduction in the number of crashes is considered statistically significant and it can be assumed to be due to the implementation of the low cost traffic engineering measures (LCTEM).

As far as the total number of crashes is concerned, 36 and 33 crashes have been recorded in one-way, one-lane streets in the study area, before and after the implementation of LCTEM respectively, whereas the corresponding numbers in the comparison group are 101 and 149, that is: B_S = 36, A_S = 33, B_C = 101 and A_C = 149, as indicated in Table 3.

Table 3. Total number of crashes "before" and "after" in one direction – one lane street group.

Time period	Area	
	Study area	**Control group**
Before (1985-1990)	B_S = 36	B_C = 101
After (1994-1999)	A_S = 33	A_C = 149

If the X^2 value exceeds the X^2_α value of 2.71 (for a 90% confidence interval) or 3.84 (for a 95% confidence interval), then a statistically significant reduction in the total number of crashes is observed, which indicates the positive impact of LCTEM on the improvement of road safety in the study area. Moreover, it is very essential that crashes' characteristics linked with vehicle, driver and safety equipment be further and separately investigated. Therefore, the following crash types are further examined:

- Crashes with pedestrian involvement
- Crashes that occur in daylight
- Crashes with persons killed or seriously injured
- Crashes with persons slightly injured
- Crashes with young drivers (up to 24 years old)
- Crashes with drivers 25 – 44 years old
- Crashes with drivers 45 – 64 years old
- Passenger car involvement
- Two-wheel involvement
- Crashes occurred in clear sky weather
- Crashes occurred in rain weather conditions
- Crashes with one car involvement
- Crashes with two or more cars involvement
- At angle collision between moving vehicles
- Rear end collision between moving vehicles

The results of the Chi-square analysis considering these crash types are presented in Table 4.

Table 4. Number of crashes, statistical analysis and results for all different crash types.

	Study Area		Control Group		X^2	Improvement (95%CI)	Improvement (90%CI)
Crash Type	**Before**	**After**	**Before**	**After**			
Total number of crashes	36	33	101	149	3.972	56%	56%
Pedestrian involvement	9	7	26	26	0.250	nsc*	nsc*
Daylight	26	28	78	107	0.793	nsc*	nsc*
Killed or seriously injured	3	1	9	10	1.225	nsc*	nsc*
Slightly injured	41	39	126	177	3.077	nsc*	45%
Young drivers (up to 24 years old)	11	13	34	60	0.971	nsc*	nsc*
Driver's age 25 – 44	31	29	75	114	3.600	nsc*	58%
Driver's age 45 – 64	19	11	49	53	2.811	nsc*	50%
Passenger car involvement	48	31	124	188	14.570	87%	87%
Two-wheel involvement	12	19	28	54	0.287	nsc*	nsc*
Clear sky weather	33	30	93	131	3.062	nsc*	50%
Rain weather condition	2	1	6	14	1.921	nsc*	nsc*
One vehicle involvement	11	9	29	49	2.719	nsc*	87%
Two or more cars involvement	25	24	72	100	1.689	nsc*	nsc*
At angle collision between moving vehicles	21	16	54	54	0.676	nsc*	nsc*
Rear end collision between moving vehicles	1	2	5	9	0.007	nsc*	nsc*

* nsc: *not significant change*

In Table 4 the percent improvement is calculated by considering the algebraic difference of improvements between the control group and the study area group.

According to Table 4, a statistically significant reduction at a less conservative confidence interval of 90% is evident for the following crash types:

- total number of crashes
- slightly injured
- drivers' age 25 – 44 years old
- drivers' age 45 – 64 years old
- passenger car involvement
- clear sky weather
- one vehicle involvement

As expected, the analysis showed that the overall number of crashes was statistically significantly reduced with the introduction of the LCTEM at the study area. These findings are consistent with past literature on the effectiveness of traffic calming measures (for example, Ciekot, 2001). In addition, according to the results of the analysis, crashes with persons slightly injured were statistically significantly reduced (at a 90% confidence interval), whereas crashes with persons killed or seriously injured were not. It is therefore obvious that traffic calming measures are deemed ineffective devices towards reducing high speeds in urban areas, provided that crashes with persons killed or seriously injured are extremely linked with high speeds. In contrast, LCTEM can be effective in reducing low to medium speeds, and therefore, the number of slight injuries associated with these speed ranges.

Furthermore, it is evident that the total number of crashes with pedestrian involvement was not statistically significantly reduced, thus constituting one of the most important ineffectiveness of the implementation of traffic calming measures in this area. LCTEM are primarily implemented in urban areas with extensive pedestrian movement. Protecting pedestrians is usually the predominant goal set when introducing traffic calming measures. However, according to this research and contrary to the international state-of-the-art in developed countries, this goal was not found to be met. This is potentially due to the fact that illegal pedestrian crossing of roadways (jaywalking) is very common in Greece. That is, pedestrians very often do not cross intersections at the marked crosswalks, but rather at midblock locations where no protection for them is offered. As such, traffic calming measures that typically target towards the protection of pedestrians at intersections have little to no effect, since unprotected pedestrian crossing (and therefore, opportunities for crashes and injuries) occurs elsewhere as well.

Another very important outcome of this research concerns the age of the drivers affected by the introduction of traffic calming measures in the examined area. More specifically, young drivers (up to 24 years old) were not positively affected by the implementation of those measures, which suggests that their driving behavior was not improved. On the contrary, drivers older than 25 years were positively affected, since the number of crashes related to these ages was statistically significantly reduced. In fact, this outcome of such an analysis reveals the ineffectiveness of LCTEM in improving the driving behavior of one of the most dangerous drivers' groups, that is young drivers up to 24 years old (Yannis et al. 2007). This finding perhaps indicates that young drivers do not slow down at these LCTEM as much as other drivers do. However, it is shown that at a 95% confidence interval none of the age groups were positively affected by the implementation of the LCTEM.

Particularly significant was the Chi-square test concerning the type of vehicles involved in the crashes. According to the data analysis conducted, the statistically significant reduction in the total number of crashes observed is mainly attributed to the reduction of crashes with passenger car involvement (for both confidence intervals of 90% and 95%). LCTEM do not have a positive effect on two-wheel involvement crashes, probably because LCTEM may create movement difficulties on two-wheel drivers, and cause them to significantly slow down in order to avoid a potential overturning.

Clear sky weather in conjunction with the implementation of LCTEM resulted in statistically significant reduction of crashes (at a 90% confidence interval), probably due to the improved visibility conditions; however, the implementation of LCTEM was not found to reduce the number of crashes during raining conditions.

Lastly, crashes that involved one car were statistically significantly reduced (at a 90% confidence interval), in contrast to crashes with two or more cars involved. Consequently, the analysis of crashes with one car involvement reveals the effectiveness of speed humps and woonerfs, whereas the analysis of two or more car involvement crashes reveals the ineffectiveness of raised intersections, speed bumps and curb extensions constructed just before intersection points (where those types of crashes normally occur).

5. Conclusions

In this research the impact of Low Cost Traffic Engineering Measures (LCTEM) on the improvement of road safety in the Municipality of Neo Psychiko in the Greater Athens Area was examined. For the application of the before-and-after safety analysis with large control group, two Municipalities in the Greater Athens Area were considered (Holargos and Agia Paraskevi), as they both present similar road network, land use and demographic characteristics with the study area.

According to the analysis results, considering a 90% confidence interval, a statistically significant reduction in the total number of crashes in the study area was identified, which can be attributed to the implementation of the traffic calming measures. This finding is consistent with past literature related to traffic calming measures, as this was also discussed earlier Cottrell et al., 2006; FHWA 2003; Persaud et al., 2001). This reduction concerns mainly passenger cars. In addition, the number of slight injuries were also found to be reduced. The reduction of single-vehicle crashes was statistically significant, whereas crashes that involved more than one vehicle (at angle, rear end collision, etc.) or two-wheelers were not found to be significantly reduced. Furthermore, a significant reduction in the total number of crashes in the area examined was also observed for drivers of 25 years old or more.

Contrary to common belief and to the initial objectives of the traffic calming scheme, the implementation of the traffic calming measures did not lead to a statistically significant reduction in crashes with pedestrian involvement. This is also inconsistent with past literature (Brude and Larsson, 2000); however, it could be due to the fact that in Greece, pedestrians usually cross at unmarked midblock locations, apart from crosswalks, therefore, the traffic calming measures do not necessarily address their safety concerns. Moreover, young drivers - the most accident prone group - were not found to have improved driving behavior in streets where traffic calming measures were implemented. This suggests that additional measures are required to improve driver behavior of young drivers.

The adoption of the before-and-after safety analysis with large control group was proved appropriate for the objectives of this research, as sufficient data over time and for both the examined area and the control group were available, eliminating thus the phenomenon of the regression-to-mean. The findings of this research can certainly be generalized as far as the specific characteristics of the area examined are taken into consideration. It should not be neglected that the effectiveness of any traffic calming measures depends not only on the measures themselves (type, size, geometrical characteristics, etc), but also on the traffic and land use characteristics of the study area.

It is noted that the present safety impact research should be coupled with other studies concerning the disadvantages that stem from the implementation of traffic calming measures, as the negative impact on traffic flow, on the vehicle suspension system and the safety of neighboring areas (crash immigration) should also be taken into consideration by the decision makers.

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