TRAFFIC CALMING BENEFITS: CASE STUDIES FROM ITALY

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ABSTRACT

Road accidents represent one of the most serious problems faced by the Italian Ministry of Public Health. In 2007, for example, there were almost 330,000 injuries and 5,131 fatalities; 230,871 crashes in all which resulted in an estimated € 30.4 billion financial loss, corresponding to 2% of GDP.

In 1999 the National Road Safety Plan (NRSP), among other things, funded the requalification of several unsafe road infrastructures at higher risk of accidents.

Unlike other infrastructure investment plans, NRSP usually requires: i) specific safety analysis of crash history to identify the critical road; ii) proactive action, e.g. RSAs and RSARs; iii) before-after accident study; iv) ex-post monitoring of road user behaviours, etc. The paper presents some unsafe roads in urban and suburban areas which were renovated through NRSP strategies and whose projects were submitted to Road Safety Audit procedure for blackspot treatment. It examines the effect of physical traffic calming measures (e.g. roundabouts) on accident risk, user behaviours and LOS (Level of Sevice): ante- and post-operam evaluations are compared on the basis of accident data and investigations in situ (particularly traffic flow and operating speed). Finally, a profitability analysis of several parameters (e.g. accident social costs) is performed. In a region like Sicily, the first Road Administration investments on unsafe infrastructures, partially funded by NPRS, have shown very positive results as to safety and financial aspects.

1. GENERAL CONSIDERATIONS

To a greater or lesser extent, geometric and control features of road intersections can influence the operating conditions of the whole road network they belong to, in terms of functionality, efficiency and safety. As for safety, in November 2008 [1] ISTAT (Italian Institute of Statistics) published the data on road accidents occurred in the previous year (2007) from which too alarming a phenomenon still emerged, even though with a slighter reduction than the past. Actually in Italy, on average, 633 road accidents occur every day and cause 14 fatalities and 893 injuries. In 2007 ISTAT recorded 230,871 road crashes in all, causing 5,131 fatalities and 325,850 more or less severe injuries. In 2007 social costs due to road accidents were estimated at about 30.4 billion euros, corresponding to 2% of Italian GDP in the same year.
Istat data also showed the absolute superiority of urban road accidents which were 176,897 (76.6% of the total), causing 238,712 injuries (equal to 73.3%).

In order to stem such a phenomenon in Italy, public funds have been invested for some years to improve safety of road junctions and arms at a significantly higher risk than the average. This paper examines some case studies which have monitored the results, especially in terms of reduction in crash occurrence, achieved in some road sections and intersections after the implementation of *traffic calming measures*, cofinanced by the "*Call for tenders to realise interventions provided for by Annual Implementation Plan 2002 within the National Road Safety Plan – Priority Actions*" [2]. Another case study examines the conversion of a large-sized unconventional roundabout into two linked turbo roundabouts, one next to the other.

1.1. Safety definitions

In general, road safety is directly correlated to the number and severity of accidents. It is however necessary to distinguish *safety*, i.e. the objective safety directly linked to the occurrence of accidents, from *security*, i.e. the subjective perception road users have of safety during their journeys: this is a consequence of the adopted engineering solutions to road infrastructures which can produce different effects on *safety* (objective safety) and on *security* (subjective safety) (*see* Figure 1). Moreover, since modes of road use and traffic flow rate can change in the course of time, the reduction in accidents does not always correspond to an objective improvement of safety and, viceversa, the increasing number of accidents is not always related to the deterioration of objective safety.

It is also worth considering that crash occurrence and fluctuations in the course of time are extremely casual and do not enable to determine if variations in road accident frequency can be due to the effects of engineering solutions to the road sections under examination, or rather are linked to the intrinsic nature of a crash occurrence which, as previously observed, is variable with time [3]. Given this difficulty in interpretating accident data, in the last decades new reliable methods for estimating crash occurrence, known as *Safety Performance Functions* (SPFs), *Accident Prediction Models* (APMs), *Crash Prediction Models* (CPMs) and others, have been developed to "estimate" a parameter representative of an accident element (e.g. frequency) in function of some variables on which it can depend (e.g. road geometry, Annual average daily traffic, etc.). More specifically, in the *empirical Bayesian* methodology the expected value E(Yi) of accidents in a site is considered as a random variable with unknown average E(Y) and variance VAR(Y). Given a certain number of accidents Yi, the best estimation $E(Yi)_{EB}$ of the subset of places with crash occurrence Yi is valued through a weighted average which takes into consideration the two pieces of information available, that is features of the road element and crash history. In analytical terms:

$$E(Yi)_{EB} = \alpha \cdot E(Y) + (1-\alpha) \cdot Yi \qquad (1)$$

E(Yi) is best estimated by defining the weight factor "α" through the relation [4]:

$$\alpha = \frac{1}{1+\frac{Var(Y)}{E(Y)}} \qquad (2)$$

If the distribution of crash occurrence data is considered as negative binomial, one of the characteristic parameters of the model is "the overdispersion parameter" (k = 1/ϕ), which accounts for the real variability of the observations compared to the expected value of crash occurrence. If the predictive model provides the expected number of accidents in entities similar to that under examination in terms of accident density, given a road section with length "L" and during a time period "T", the expected number of accidents wil be equal to ηi = E(Yi) x L x T. Similarly, in the case of a road intersection where the parameter of interest is the number of "accidents/year" ηi = E(Yi) x T. In such conditions, the weight factor "α" results from the following expression:

$$\alpha = \frac{1}{1+\frac{\eta_i}{\varphi \cdot L}} = \frac{1}{1+\frac{E(Y_i)\cdot T}{\varphi}} \tag{3}$$

On the other hand, crash occurrence in a generic road section will be estimated through the following expression:

$$E(Yi)_{EB} = \alpha \cdot [E(Y_i)\cdot L \cdot T] + (1-\alpha)\cdot Yi \tag{4}$$

Finally, variance estimation will be given by the expression:

$$VAR(Y_i)_{EB} = (1-\alpha)\cdot E(Yi)_{EB} \tag{5}$$

1.2. Road Safety Audit

Road safety audit is a formal analysis of a project on a new road, a traffic plan, measures to upgrade a road already into operation or any other project involving road users, and is carried out by a qualified expert team indipendent of project planners and the contractor administration. Its main aim is to guarantee the best safety level for each traffic component allowed to run along the road under study [5]. Specifically, the safety audit report aims, among other things, to:

- identify potential dangers for users;
- ensure appropriate measures to reduce the number and the severity of accidents;
- ensure safety requirements for any user category to be explicitly considered in the planning;
- ensure that design measures, together with an expected localized reduction in crash occurrence, do not increase the number of accidents in other sites of the road network (e.g. owing to a change in traffic demand);
- reduce the total infrastructure running costs, seeing that geometric and functional changes in operating roads with a low safety profile, are highly expensive and sometimes unfeasible.
-

The general criteria for drafting road safety audits (RSAs), or road safety reviews (RSARs) in case of operating roads, concern the theoretical aspects of *mechanics of locomotion*, *geometric features of infrastructures* (plano-altimetric configuration, roadside layout, conditions of visibility, etc.) and the interaction between *user behaviours* and *road space*. From this point of view, the audit report exclusively highlights infrastructure situations which can involve a specific accident risk for each user category and those infrastructures which, in case of accident, would not be suitable to mitigate the severity of the ensuing consequences. Therefore, such an approach does not consider different estimation criteria from those which directly influence road safety. In general, a safety audit is divided into the following two sections:

a) in the former, in light of the current scenario and design measures, there is a description of general problems observed and advice on the solutions and/or planning devices to protect the user categories concerned, which are examined by project planners for any possible integration and implementation;
b) in the latter the specific problems and relevant recommendations are identified.

On 8 June 2001 the Italian Ministry of Public Works issued the circular No. 3699 [6] reporting that:

- benefit-cost analyses carried out in the United Kingdom, Australia and New Zealand have shown consistent reduction in accidents with RSA costs equivalent to about 1% of construction costs and benefit-cost rates equal to approximately 20%;
- in the United Kingdom a study carried out by Transport Research Laboratory on 22 projects under RSA has shown that safety analyses on the preliminary and definitive projects allow to yearly save 11,000 pounds a project, compared to an average cost of the controls corresponding to 2,000 pounds a project;
- in the United Kingdom another study carried out in Surrey County, which compared 10 small projects subject to RSA with 10 similar projects not subject to control, has shown a reduction of about one injured person per year in the projects under RSA.

As illustrated in Fig. 2, implementation costs are lower if RSAs are carried out earlier in a road project lifecycle (e.g. during a preliminary design) rather than later in the process, for instance, during a detailed design or construction [7].

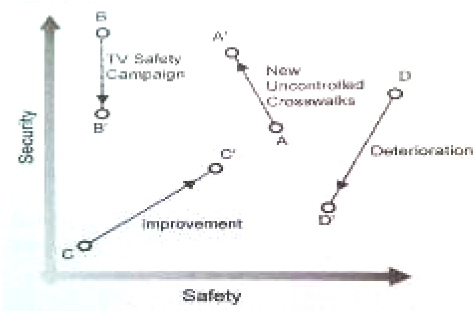

Figure 1 – Relationship between security and safety

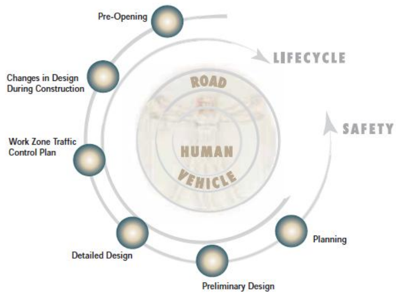

Figure 2 - RASs in a road project lifecycle and implementation costs

2. CASE STUDY 1: SAFETY MEASURES ON A SUBURBAN ROAD

The first case study focuses on a west ring road within the network of the municipal district of Menfi (Sicily), named “via del Serpente”. The infrastructure develops along approximately 2,000 m and stretches from the northern entrance of the town, just next to the existing roundabout “Il Sole”, to the intersection with the road Ex SS 115 (today knowns as “via Garibaldi”). The road surface, with a one-way roadway, is 10-11 metre wide, apart from the lateral bumps. Along its length there are four at grade intersections which originally had a conventional configuration (T-junctions and double-cross junctions). As for transport, the west ring road plays two different roles in the network of the municipal district of Menfi:

- *Transit function*: the infrastructure is useful for the users who come from the main road Menfi – Sambuca or from “fast-flowing” Ex SS 115 and wish to pass through the urban centre of Menfi to reach the seaside resorts of Porto Palo and Fiori;
- *Penetration and access function*: the road allows the penetration and access into the urban centre of Menfi.

Operating speed was very high along the road. Moreover, the analysis of crash occurrence data, provided by the relevant authorities (municipal police and the corps of the Carabinieri), indicated irregular accident concentrations: 9 road accidents with 14 injured people were in fact recorded between 1997 and 2002.Considering all that and the local traffic demand – especially high if contextualized in the remaining road system of the municipal district of Menfi – the municipal government planned some design measures, cofinanced by NRSP, with the aim to achieve the following objectives:

- speed limitation;
- reduction in crash occurrence;
- improvement in the perception of road space.

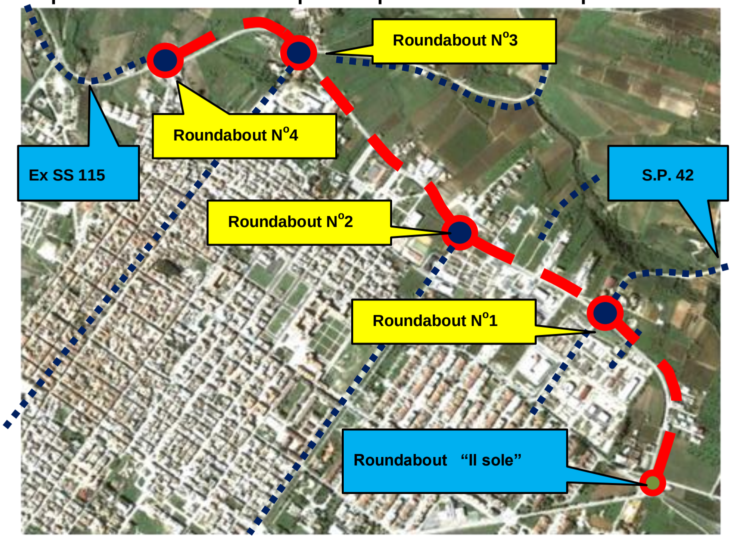

Table 1 – Crash occurrence data

CRASH OCCURRENCE – TOWN OF MENFI			
YEAR	ACCIDENTS	DEATHS	INJURIES
1997	0	0	0
1998	0	0	0
1999	11	3	16
2000	12	2	18
2001	2	1	3
TOTAL	**25**	**6**	**37**

Figure 2- Territorial frame of the west ring road of Menfi,
showing the new roundabouts (roundabouts Nos. 1, 2, 3 and 4)

Road safety measures were aimed at the modification and upgrading of road intersections into conventional roundabouts. The definitive planning was also subject to a road safety audit procedure. The report, drawn up in accordance with the "Guidelines for road safety analysis" [6], was carried up by an expert team, duly selected by the government through a public competition.The main geometric characteristics of the four roundabouts are indicated in the table below:

Table 2 – Geometric characteristics of the four roundabouts

INTERSECTION	**Roundabout No. 1** junction at SP (Provincial Road) 42	**Roundabout No. 2** junction at via Boccaccio	**Roundabout No. 3** junction at road "Menfi – Finocchio"	**Roundabout No. 4** junction at Ex SS (Main Road) 115
Number of arms	4	4	4	3
External diameter [m]	28.00	30.00	28.00	26.00
Ring width [m]	7.00	7.00	7.00	7.50
Central island radius [m]	7.00	8.00	7.00	5.50
Entry radius [m]	12.00	12.00	12.00	12.00
Entry lane width [m]	4.50	4.50	4.50	4.50
Exit radius [m]	14.00	14.00	12.00	14.00
Exit lane width [m]	4.50	4.50	4.50	4.50

Figure 3 - Intersection 1 (before and after)

Figure 4 - Intersection 2 (before and after)

Figure 5 - Intersection 3 (before and after)

Figure 6 - Intersection 4 (after)

2.1. Road safety – *ante operam* situation

In order to deeply understand the risk conditions in the road ring of Menfi (via del Serpente) before implementing safety measures, crash occurrence is here considered by examining the whole road network of Menfi with special regard to the west road ring. Such a research has been based on accident data recorded between 1997 and 2001 and later published by ISTAT, by municipal police and by the corps of the Carabinieri of the municipal district of Menfi. The data on municipal road network surveyed by ISTAT are shown in the table 2. As for the road under study, between 1997 and 2002 there were 9 accidents with 14 injured people. The data pointed out that accidents more frequently occurred at ring road junctions. The relevant accident number in this period are the following:

Average accident number per year:

$$T_i^A = \frac{N_i}{\sum n} = 1{,}8 \quad \text{[accidents/year]} \tag{6}$$

Average injury number per year:

$$T_f^A = \frac{F_i}{\sum n} = 2{,}8 \quad \text{[injuries/year]} \tag{7}$$

Since

T_i^A = Average accident number per year in the configuration before safety measures on the ring road;

T_f^A = Average injury number per year in the configuration before safety measures on the ring road;

N_i = number of accidents occurred in the observed period;

F_i = number of injuries occurred in the observed period;

$\sum n$ = years of observation (equivalent to 5 in the case under study, from 1998 to 2002).

2.2. Road safety – *post operam* situation

Safety measures were aimed at the implementation of four roundabouts (*see* Figs. 3, 4, 5, 6 and Table 1). A positive effect was the reduction of conflicting points between vehicle trajectories. In fact, there are thirty-two conflicting points in a four-arm intersection while the number of conflicting points is equal to 8 in an equivalent roundabout (e.g. in a ring road). Therefore, in the case under study where three of the four intersections implemented are formed by four arms and one by three arms (*see* Table 13), the total number of the conflicting points before the construction of roundabouts was equal to Ni = 3 x 32 + 1 x 9 = 105, while later, after their realization, the total number of the conflicting points is equivalent to Nf = 3 x 8 + 1 x 6 = 30. Thus, there has been a total reduction of 75 conflicting points by simply intervening in the west ring road junctions. Extremely positive are also the effects on the reduction of accident. In fact, in the years 2007, 2008 and 2009, after opening the new roundabouts to traffic, no accidents (and no personal injury) occurred in via del Serpente. Therefore, accident number are as follows:

Average accident number per year:

$$T_i^{F} = \frac{N_i}{\sum n} = 0,0 \qquad \text{[accidents/year]} \tag{8}$$

Average injury number per year:

$$T_f^{F} = \frac{F_i}{\sum n} = 0,0 \qquad \text{[injuries/year]} \tag{9}$$

Since: T_i^{F} = Average accident number per year in the configuration after safety measures on the ring road; T_f^{F} = Average injury number per year in the configuration after safety measures on the ring road.

Given the sample consistency and the moderate variation in Annual average daily traffic (AADT) during the last decade (around 3%), it was thought unnecessary to carry out a more detailed study through a "befor-after" analysis. Basically, changes in intersections did not involve variations in the local mobility demand and therefore the reduction in accident number has to be exclusively correlated to the upgrading measures of road junctions.

Among other things, the reduction in crash occurrence also brings an economic benefit to the community. In fact, an accident is linked to costs which directly or indirectly derive from that accident, among which loss of productive capacity, human costs, health costs, damages, etc. The latest ISTAT data on crash occurrence [1] indicated that the social costs for road accidents in 2007 were 30,386 M€. More specifically, the average social cost per fatality is equal to 1,372,832 euros, taking health costs, lost production and compensation for moral damage into consideration. The average cost per injury (C_i), calculated on the same expenditure categories as those previously mentioned for a fatality, on average corresponds to C_i = 26,316 euros. On the basis of the latter parameter it is possible to estimate the average social cost of accidents per year in the west ring road before implementing the roundabouts ($\overline{C}_S^{Ante}$):

$$\overline{C}_S^{Ante} = T_f^{A} \cdot C_i = 73.689 \qquad \text{[€/year]} \tag{10}$$

It follows that in the years 1997 – 2001, before implementing the four roundabouts, the total social cost of crash occurrence (C_S^{Ante}) was equal to:

$$C_S^{Ante} = \overline{C}_S^{Ante} \cdot \sum n = 368.445 \qquad \text{[€]} \tag{11}$$

Since no accidents occurred in the three-year period 2007 – 2009, the economic benefit is equivalent to 73,368 x 3 = 220,104 euros, much higher than the construction costs of the four roundabouts which amounted to € 175,451; this points out an extremely high profitability from investments in constructing new intersection schemes [8].

2.3. Effects on speed limitation

Being closely related to the previous issue, a comparison between the precise values of design speed was made before and after the implementation of the four roundabouts. Diagrams of design speed were drawn in compliance with the criteria established by Ministerial Decree on 5th November 2001 [9]. More specifically, it follows that:

- on straight roads, in arcs of a circle with a radius not less than $R_{2,5}$ and on clothoids, design speed tends to Vpmax (equal to 100 km/h in the case under study); acceleration spaces when coming out of a circular curve and deceleration spaces when entering the

said curve only affect the elements considered (straight road, wide curves with R > $R_{2,5}$ and clothoids);
- speed is constant along the whole development of curves with a radius lower than $R_{2,5}$ and can be determined by the following equation $V = \sqrt{127 \cdot R \cdot (q + ft)}$;
- acceleration and deceleration values are still determined as 0.8 m/s^2.

By means of an appropriate road design software, a curvature chart was developed and later allowed to draw a diagram of the design speed of the infrastructure *before* and *after* safety measures (*see* Figures 7, 8 and 9) under the aforesaid Ministerial Decree on 5th November 2001. The diagrams of the design speed along the ring road before safety measures and after their implementation are illustrated below.

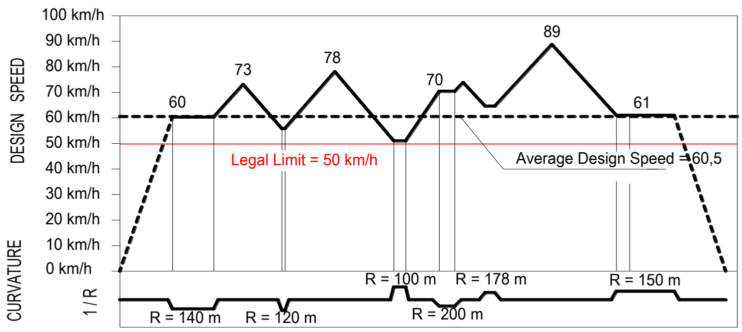

Figure 7 – Diagram of design speed before implementing the roundabouts

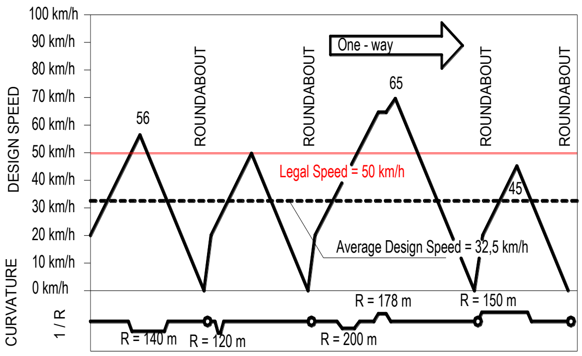

Figure 8 - Diagram of the design speed after implementing the roundabouts.

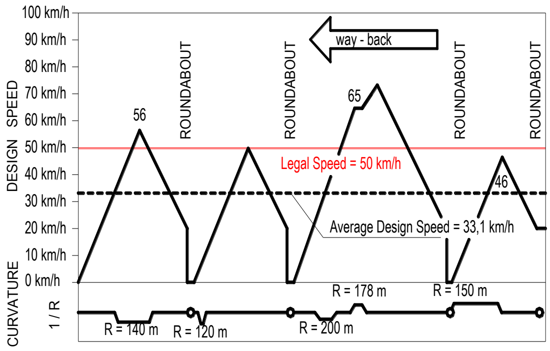

Figure 9 - Diagram of the design speed after implementing the roundabouts.

By comparing the three diagrams a general reduction in design speed can be observed on the whole road section, in peak as well as average speed values. As for the latter, before implementing the safety measures in the ring road, the average speed was 61 km/h while nowadays it is 33 km/h in both directions (*see* Table 3).

Table 3 – Average design speed for the configurations under study

DESIGN SPEED				
Situation under study	**Legal speed** [km/h]	**Average speed** [km/h]	**ΔV** [km/h]	**In compliance with the limits set by the Highway Code**
Ante Operam	50	61	+ 11	**NO**
Post Operam (one-way)	50	33	- 17	**YES**
Post Operam (way back)	50	33	- 17	**YES**

In order to estimate the real speed maintained by users while entering roundabouts and ring roadways, a monitoring campaign was conducted in situ in September 2009. Measurements were carried out in the intersections at the extremities of the ring road, i.e.

at via Garibaldi (intersection No. 4) and at the provincial road SP 42 Menfi – Partanna (intersection No. 1), by two operators through a multifunctional gauge for instantaneous speed with a precision of ± 2 km/h. Speed was measured along the entrances to the roundabout, at an about 15-metre distance to 'give-way' line and along the ring roadway. The data collected at each stop, together with the characteristic speed values (average, maximum, etc.) are synthetically shown in the following tables and graphs. The analyses have indicated the positive effect of these roundabouts on speed limitation; in fact, it follows that:

- average speed values approaching the entrance are lower than 35 km/h in all intersection arms;
- average speed values along the ring roadway of the two roundabouts are lower than 25 km/h.

Table 4 – Descriptive speed statistics at intersection with via Garibaldi

SURVEYED STOPS	Meas. Nos.	Average [km/h]	Max [km/h]	Std.Dev. [km/h]
via del Serpente	21	34.43	49.00	9.69
via Garibaldi	155	28.83	38.00	5.11
Ex S.S. 115	98	33.25	50.00	7.58
Ring	90	24.80	36.00	5.16

Table 5 – Descriptive speed statistics at intersection with SP 42

SURVEYED STOPS	Meas. Nos.	Average [km/h]	Max [km/h]	Std.Dev. [km/h]
via del Serpente	89	28.15	48.00	7.02
via Garibaldi	118	28.16	54.00	6.74
SP 42	78	25.14	36.00	4.97
Ring	58	20.27	31.00	3.98

2.4. Functionality analysis

Road infrastructure safety measures often disregard a careful functionality analysis. This can sometimes bring about potentially risky design choices for operating conditions and consequent deterioration of service levels of arms and junctions subject to technical modifications. Such evidence suggested a study on roundabout functionality. Results are shown in the following table 6.

The surveys were conducted on traffic samples collected on a weekday in February 2009. The total number of light, heavy and motor vehicles was obtained from vehicle counts at a morning hour; then the Origin-Destination (O-D) matrices were generated by homogenizing traffic flow through the following coefficients: 1 heavy vehicle = 2 cars; 1 motorcycle = 0.5 cars.

The efficiency study was also carried out by using the simulation software Kreisel 7.1 [10] and allowed to evaluate capacity, capacity reserves and service levels at each entrance to the four roundabouts. It notably emerged that all the roundabouts had much higher capacity values than the local mobility demand; moreover, all the entrances exhibited a service level A (*see* Table below).

Table 6 - Capacity and service levels at entry arms of roundabouts

	ENTRANCE NAMES	Circulat-ing flow Veh/h	Entrance flow Veh/h	Capacity Veh/h	Degree of Saturation	L.o.S.
ROUNDABOUT No.1	West Ring Road (Arm No. 1)	24	60	1468	0.04	A
	West Ring Road (Arm No. 2)	12	88	1478	0.06	A
	S.P 42	60	36	1444	0.02	A
ROUNDABOUT No.2	West Ring Road (Arm No. 1)	48	57	1920	0.03	A

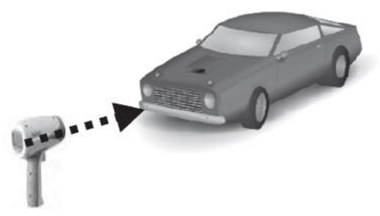

Figure 10 - Scheme of a speed gauge

	West Ring Road (Arm No. 2)	30	68	1937	0.04	A
	Via Brancaccio	65	43	1918	0.02	A
	Arm No. 4	79	36	1906	0.02	A
ROUNDABOUT No.3	West Ring Road (Arm No. 1)	48	57	1920	0.03	A
	West Ring Road (Arm No. 2)	30	68	1937	0.04	A
	Via Vittoria	65	43	1918	0.02	A
	Road "Menfi – Finocchio"	79	36	1906	0.02	A
ROUNDABOUT No.4	Via Garibaldi	28	28	1460	0.02	A
	West Ring Road	12	164	1483	0.11	A
	Ex SS 115	40	88	1444	0.06	A

3. CASE STUDY 2: SAFETY MEASURES ON AN URBAN ROAD

The second case study focuses on Viale Gramsci, a fast-flowing road of the town of Partanna (Sicily) with a reported irregular concentration of accidents in the past. Before the geometric and functional upgrading, the infrastructure had a dual roadway, with each lane 9.5-metre wide and an about 3-metre divider in between. The too great road width led users to drive at extremely high speeds. Also pedestrian flow was very heavy, there being two schools, a church, a first aid centre and a sports facility. Accident data analysis indicated irregular concentrations of accidents: more specifically, 11 accidents (with no fatalities) and 17 injuries from 1997 to 2001. Such data were very alarming seeing that road accidents in viale Gramsci accounted for over 25% of all injuries occurred in the municipal district (*see* Table 7).

Thanks to the funds granted by NRSP, the municipal government planned and implemented safety measures in this road by changing three intersections in as many roundabouts (*see* Figs. 11, 12, 13, 14 and Table 8), with the further aim to limit average operating speeds; the total cost amounted to € 175,451.22. The definitive planning was subject to a road safety audit procedure and revised in light of auditors' recommendations.

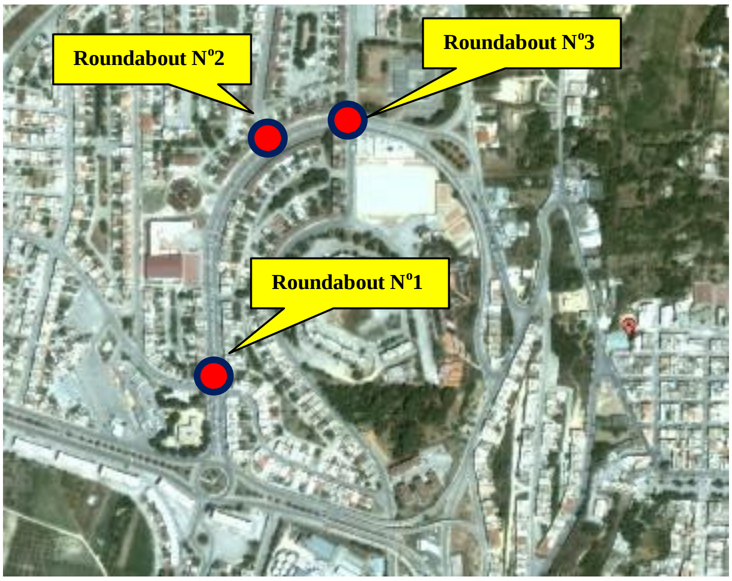

Figure 11 – Layout of the new roundabouts

CRASH OCCURRENCE – TOWN OF PARTANNA			
YEAR	**ACCIDENTS**	**DEATHS**	**INJURIES**
1997	6	0	8
998	8	0	15
1999	6	0	9
2000	11	0	15
2001	19	2	32
TOTAL	**50**	**2**	**79**

Table 7 – Crash occurrence data

Table 8 – Geometric characteristics of the four roundabouts

INTERSECTION	**Roundabout No. 1** junction at via D'Assisi	**Roundabout No. 2** junction at via Leopardi	**Roundabout No. 3** junctions at via Grutta and via Aiello
Number of arms	4	3	4
External diameter [m]	27.00	27.00	32.00
Ring width [m]	7.00	7.00	7.00
Central island radius [m]	6.00	6.00	9.00
Entry radius [m]	12.00	12.00	12.00
Entry lane width [m]	4.50	4.50	5.00
Exit radius [m]	12.00	12.00	14.00
Exit lane width [m]	4.50	4.50	5.00

Figure 12 - Intersection 1 (junction at via D'Assisi), before and after

Figure 13 - Intersection 2 (junction at via Leopardi), before and after

Figure 14 - Intersection 3 (junction at via Grutta and via Aiello), before and after

By performing a similar analysis to that in case study No.1, it follows that:

a) Reduction of conflicting points between the vehicle trajectories, equal to 51 points (*Ante operam*: Ni = 2 x 32 + 1 x 9 = 73; *Post operam*: Nf = 2 x 8 + 1 x 6 = 22).

b) Reduction of accident number: there were 11 accidents and 17 injuries in the five-year observation period before implementing the roundabouts, and only 1 accident and 1 injury in the three-year period (years 2008, 2009 and 2010) after implementing safety measures.

$$T_i^{\,A} = \frac{N_i}{\sum n} = 2{,}2 \qquad \text{[accidents/year]} \qquad (12)$$

$$T_i^{\,F} = \frac{N_i}{\sum n} = 0{,}3 \qquad \text{[accidents/year]} \qquad (13)$$

$$T_f^{\,A} = \frac{F_i}{\sum n} = 3{,}4 \qquad \text{[injuries/year]} \qquad (14)$$

$$T_f^{\,F} = \frac{F_i}{\sum n} = 0{,}3 \qquad \text{[injuries/year]} \qquad (15)$$

Since: $T_i^{\,A}$ = Average accident number per year in the configuration before safety measures on the ring road; $T_i^{\,F}$ = Average accident number per year in the configuration after safety measures on the ring road; $T_f^{\,A}$ = Average injury number per year in the configuration before safety measures on the ring road; $T_f^{\ F}$ = Average injury number per year in the configuration after safety measures on the ring road.

c) Reduction of average accident social costs per year, after implementing the roundabouts ($\overline{C}_S^{\ Post}$):

$$\overline{C}_S^{\ Ante} = T_f^{\ A} \cdot C_i = 89.474 \quad [€/year] \tag{16}$$

$$\overline{C}_S^{\ Post} = T_f^{\ F} \cdot C_i = 7.895 \quad [€/year] \tag{17}$$

Since: $\overline{C}_S^{\ Ante}$= average social cost of accidents per year in the west ring road before implementing the roundabouts.

d) By comparing the diagrams of the design speed before and after implementing the three roundabouts a speed reduction is observed in peak as well as average speed values. As for the latter, before implementing the safety measures in Viale Gramsci, the average speed was 58 km/h in one-way journey (from roundabout 1 towards roundabout 3) and 52 km/h on the way back (from roundabout 3 towards roundabout 1), while nowadays it is 27 km/h in both directions (*see* Table 9). Peak speeds were equal to 70 km/h in the original configuration while the value fell to approximately 40 km/h after implementing the three intersections.

Table 9 – Average design speed for the configurations under study

DESIGN SPEED				
Configuration	**Legal speed** [km/h]	**Average speed** [km/h]	**ΔV** [km/h]	**In compliance with the limits set by the Highway Code**
Ante Operam(one-way)	50	58	+ 8	NO
Ante Operam (way back)	50	52	+2	NO
Post Operam	50	27	- 23	YES

e) As inferred by monitoring campaign conducted in situ in 2010, speeds approaching the roundabouts are moderate. More specifically, when approaching the entrance, at 15-metre distance to 'give-way' sign average speed values are lower than 32 km/h in all intersection arms.

Table 10 – Statistical speed analysis in situ (junction at via d'Assisi and via Belice)

SURVEYED STOPS	Measures Nos.	Average [km/h]	Min [km/h]	Max [km/h]	Std.Dev. [km/h]
via d'Assisi	12	23.41	17	38	5.73
via del Belice	17	30.31	17	60	10.48
via Gramsci (south entrance)	31	28.68	18	49	7.69
via Gramsci (north entrance)	31	28.81	19	47	6.49

Table 11 – Statistical speed analysis in situ (junction at via Leopardi)

SURVEYED STOPS	Measures No.	Average [km/h]	Min [km/h]	Max [km/h]	Std.Dev. [km/h]
via Gramsci (south entrance)	24	26.00	21	31	3.69
via Gramsci (north entrance)	21	21.71	18	25	2.5
via Leopardi	45	31.86	21	41	6.76
via Gramsci (south)	30	26.00	21	31	3.69

Table 12 – Statistical speed analysis in situ (junction at via La Grutta and via Aiello)

SURVEYED STOPS	Measures No.	Average [km/h]	Min [km/h]	Max [km/h]	Std.Dev. [km/h]
via Gramsci (south entrance)	35	26.70	17	36	6.27
via Gramsci (north entrance)	48	30.28	18	43	7.55
via La Grutta	35	27.10	22	31	2.85
via Aiello	49	28.21	22	36	5.01

4. CASE STUDY 3: DESIGN HYPOTHESIS OF TWO LINKED TURBO-ROUNDABOUTS

The last case study focus on the roundabout in "Piazza Simon Bolivar", a four-arm intersection located in the industrial area in the north-west of Palermo (*see* Figure 15).
Owing to the peculiar geometric configuration of the intersection, users do not observe the give-way signs and drive at very high speed, especially at night. The layout has a non-standard geometric design, especially for the following reasons:

- pseudo-elliptical shape of the raised central island;
- variable width of the ring road;
- geometric design which leads to inaccurate perception of the roundabout and, consequently, to high vehicle speeds when entering the roundabout;
- wide space for weaving in and out between vehicles and high driving speed.
- In this case, the wide central island makes it possible to plan two linked turbo roundabouts, one next to the other. Each turbo roundabout has three entrances and two traffic lanes (*see* Figure 18).

Figure 15 – Aerial photography of Piazza Simon Bolivar (Palermo)

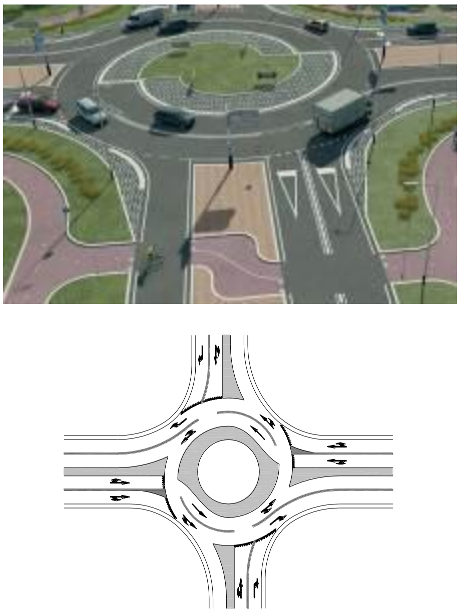

Figure 16 - Rendering and planimetric scheme of a turbo roundabout [13]

4.1. Turbo Roundabouts: Evaluating capacity and efficiency

A turbo roundabout is a particular type of roundabout where traffic signaled lanes are bounded by non-mountable curbs. Its shape allows to easily divert traffic flows which, thanks to lane dividers, are obliged to go along spiral trajectories: therefore, each lane allows only one turning manouvre and makes drivers take the right direction (i.e. the right lane on the approaches) before entering the circulating roadway [11], [12].

If compared with conventional roundabouts, the main benefits of a turbo roundabout are:

- lower number of potentially conflicting points between vehicles; for example, a four-arm turbo roundabout is characterized by ten points of conflict, whereas they are twenty-two in a two-lane roundabout (*see* Table 13);
- slower speed along the ring;
- lower risk of side-by-side accidents.

In light of these considerations, turbo roundabouts could be an alternative to modern roundabouts, especially to guarantee a high safety level, for example in case of quite heavy cyclist/pedestrian traffic (*5*).

Table 13 – Number of conflicting points

Number of arms	Number Of Conflicting Points		
	Unsignalized intersection	Two-lane roundabout	Turbo roundabout
3	9	16	7
4	32	22	10

The entry capacity can be obtained by the following equations [14], [15]:

$$X = \max\left(\frac{Q_i}{C_i}\right) = \max(x_i) \quad i=1,2 \tag{18}$$

$$\rho_i = \frac{x_i}{X} \tag{19}$$

$$C_E = \sum_{i=1}^{n} \rho_i \cdot C_i = \frac{\sum_{i=1}^{n} Q_i}{X} = \frac{(Q_{E,R} + Q_{E,TLT})}{\max[\frac{Q_{E,R}}{C_{E,R}}, \frac{Q_{E,TLT}}{C_{E,TLT}}]} \tag{20}$$

where:
x_i = degree-of-saturation at the lane *i* (demand flow rate/capacity ratio);
X = degree-of-saturation at the critical lane (i.e. with the highest demand/capacity ratio in the examined lanes);
ρ_i = utilization ratio at the lane *i*;
$Q_{E,R}$ = demand flow rate of the right-turn lane at the entry E;
$Q_{E,LTL}$ = demand flow rate of the through and left-turn lane at the entry E.

Figure 17 below illustrates the variation of entry capacities as a function of the utilization degree at lanes under given boundary conditions. The surface has been developed through balanced flows at circulating lanes: $Q_{c,i}$ = $Q_{c,e}$ = 600 veh/h; the right-turn lane capacity is $C_{E,R}$ = 736 veh/h; the through and left-turn lane capacity is $C_{E,TLT}$ = 206 veh/h.
After computing the capacity and degree of saturation of each lane (in case of undersaturation), mean control delay can be determined by means of the following equation [16]:

$$D_i = \frac{3600}{Ci} + 900 \cdot T \cdot \left[\frac{Q_i}{C_i} - 1 + \sqrt{(\frac{Q_i}{C_i} - 1)^2 + \frac{(\frac{3600}{C_i}) \cdot (\frac{Q_i}{C_i})}{450 \cdot T}} \right] + 5 \quad \text{[s/veh]} \tag{21}$$

where for the lane *i*: D_i = mean delay for the single vehicle queuing at entry; Q_i = flow rate (veh/h); C_i = capacity (veh/h); T = reference time (h).

Should general information be necessary, however, mean delays can be determined at each lane; an overall average delay can be obtained by giving different weights to these values according to their respective traffic demands. For instance, the performances at an intersection can be compared with those at a turbo roundabout, but the latter requires a detailed evaluation at each lane. The global mean delay at entry is expressed by the following equation:

$$D_E = \frac{D_{E,R} \cdot Q_{E,R} + D_{E,TLT} \cdot Q_{E,TLT}}{Q_{E,R} + Q_{E,TLT}} \qquad \text{[s/veh]} \qquad (22)$$

where $\mathbf{D_{E,R}}$, $\mathbf{Q_{E,R}}$ and $\mathbf{D_{E,TLT}}$, $\mathbf{Q_{E,TLT}}$ are respectively delays and flow rates at the two lanes of the entry E. Figure 17 shows an example of the global delay variation at entry in relation to the degree of saturation at each lane.

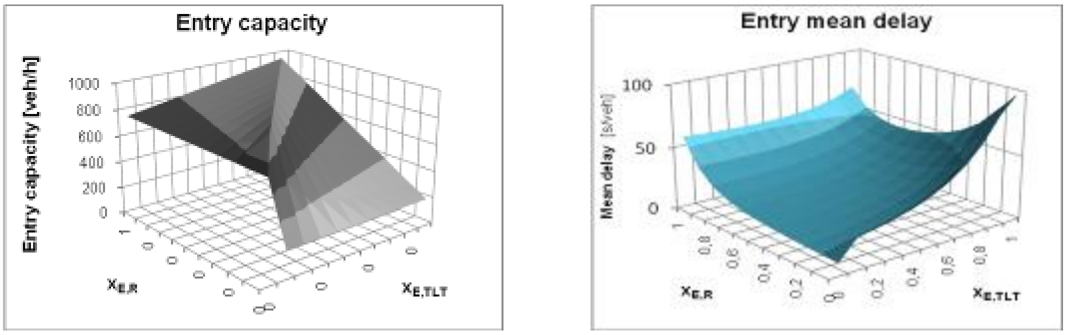

Figure 17 – The two areas have been developed through balanced flows at circulating lanes: Qc,i = Qc and = 600 v/h.

4.2. Design scheme and functional analysis

The design proposal involves the implementation of two turbo roundabouts in order to change user behaviours towards speed limits in urban areas (50 km/h) and reduce accident risk due to side-by-side vehicles. The functionality of such design hypothesis has been verified by using the relations (18), (19) and (20) to estimate the entry capacities, and the relation (21) and (22) to evaluate the mean delays.
In the new intersection configuration (*see* Figure 18), the radius of the central island at each turbo roundabout is equal to 28.00 m; the auxiliary arm introduced to link the two schemes stretches along approximately 55.00 m with two one-way roadways. Also in this case Origin-Destination matrices have been generated by traffic data for the time intervals 18:30÷19:30 and 19:30÷20:30; then simple capacities at each entry have been computed [17]. Results show very good service levels at entries, also during the peak time 18:30 – 19:30 (*see* Table 14).

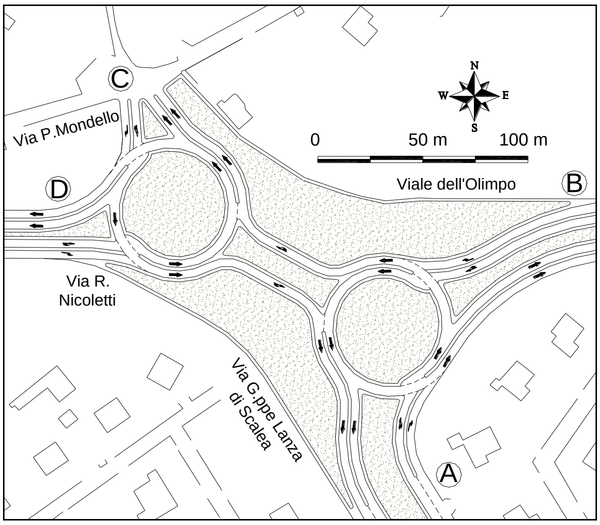

Figure 18 - Design scheme of a double turbo roundabout

Table 14 - Entry capacity and Level-of-Service (18:30 ÷ 19:30)

arm	$Q_{E,R}$ [veh/h]	$Q_{E,TLT}$ [veh/h]	Q_E [veh/h]	$Q_{c,e}$ [veh/h]	$Q_{c,i}$ [veh/h]	Q_c [veh/h]	$C_{E,R}$ [veh/h]	$C_{E,TLT}$ [veh/h]	$x_{E,R}$	$x_{E,TLT}$	C_r [veh/h]	L.O.S.
A	35	154	189	120	0	120	1153	1168	0.03	0.13	1433	A
B	69	27	96	120	0	120	1153	1168	0.06	0.02	1604	A
C	9	60	69	163	0	163	1121	1141	0.01	0.05	1312	A
D	214	60	274	52	0	52	1203	1210	0.18	0.05	1540	A

5. CONCLUSIONS

As a rule, the improvement in safety conditions of road infrastructures is directly correlated to the reduction in road accident number and severity. Considering that statistically higher risk conditions can be found in urban and suburban areas and that road intersections are extremely critical spots for user safety, *traffic calming* measures (including the implementation of roundabouts and turbo roundabouts) can be introduced to put arterial routes, and especially intersections, into safety. Therefore, these case studies highlight how geometric and functional upgrading of conventional T-junctions into standard roundabouts give excellent results, both in urban and suburban roads, in terms of accident rate reduction and limitation of average operating speeds; at the same time, the financial investments required for their implementation turn out to be highly cost-effective seeing that economic benefits (linked to social cost reduction) exceed construction costs in a few years. Moreover, if the projects are subject to *road safety audit* procedure (as here described) public investments in road safety (like those provided for by the Italian National Road Safety Plan) not only have a great social value but also allow to cut down the costs which are directly or indirectly linked to accident effects (health costs, lost production, prospective damages, etc.).

Finally, a case study on a functional modification of a wide roundabout has been described, in which users do not observe the give-way road signs and drive along the intersection at very high speeds. In order to make user behaviour more respectful of speed limits (50 km/h) and consequently reduce accident risk, an innovative scheme has been proposed, characterized by two linked turbo roundabouts, one next to the other. Therefore, capacity and levels of service (LOS) have been estimated through appropriate state-of-the-art methodologies and both have provided excellent results.

REFERENCES

1. ISTAT (2008). Istituto Nazionale di Statistica, Incidenti Stradali anno 2007 (www.istat.it)
2. Piano Nazionale Sicurezza Stradale 2002 - Azioni Prioritarie. Ministero delle infrastrutture e dei trasporti, Ispettorato generale per la circolazione e la sicurezza stradale.
3. Giuffrè, O. (2009). Ruolo dell'infrastruttura nella sicurezza stradale. 2° Convegno Nazionale ACI, "Homo Movens".(pp. 135-150) ISBN 978-88-899449-00-9, La Medusa Editrice, Marsala (TP).
4. Hauer, E. (1997). Observational befor-after studies in road Safety. Pergamon, Oxford, U.K., 1st edition
5. Road Safety Audit, NCHRP SYNTHESIS 336. Transportation Research Board, Washington, D.C., 2004
6. Linee guida per le analisi di sicurezza delle strade (2001). Circolare del Ministero dei Lavori Pubblici (italiano), 8 Giugno 2001, n.3699.
7. Road Safety Audit Guidelines (2006). Federal Highway Administration, Publication No. FHWA-SA-06-06
8. Guerrieri, M. (2010). Il monitoraggio degli interventi di messa in sicurezza cofinanziati dal PNSS. Esame di un caso studio. XXVI Convegno nazionale stradale AIPCR. Vol 1, paper CT C.1, pp 886-889
9. Norme funzionali e geometriche per la costruzione delle strade (2001). Decreto del Ministero delle Infrastrutture e dei Trasporti Italiano, del 5/11/2001
10. www.bps-verker.de
11. Fortuijn, L.G.H.. (2009).Turbo Roundabouts: Design Principles and Safety Performance, CD-ROM. 88th TRB Annual Meeting. Washington D.C. (United States),
12. Mauro R. and F. Branco (2009). Comparative analysis between turbo roundabouts and roundabouts, CD-ROM. 88th TRB Annual Meeting. Washington D.C. (United States)
13. Turborotondes (2008), CROW publicatie 257, April 2008
14. Giuffrè O., Guerrieri M. and Granà A. (2009). Evaluating capacity and efficiency of turbo-roundabouts, CD-ROM. In 88th TRB Annual Meeting. Washington D.C. (United States)
15. Guerrieri, M. (2009). Soluzioni innovative per le intersezioni stradali: un caso di turbo-rotatoria". 2° Convegno Nazionale ACI, "Homo Movens". (pp. 167-182) ISBN 978-88-899449-00-9, La Medusa Editrice, Marsala (TP)
16. HCM 2000, Highway Capacity Manual. Transportation Research Board, special Report 209, Edition 2000
17. Giuffrè O., Guerrieri M. and Granà A. (2010). Turbo-roundabout general design criteria and functional principles: case studies from the real world. IV International Symposium on Highway Geometric Design TRB (Transportation Research Board), Valencia, Spain 2-5 June 2010