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COST-BENEFIT ANALYSIS OF ROAD SAFETY MEASURES

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ABSTRACT

Road accidents represent one of the most serious problems faced by the Ministries of Public Health in the World. In Italy for example, in the year 2007 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 behaviors, 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 black spot treatment. It examines the effect of physical traffic calming measures (e.g. roundabouts) on accident risk and user behaviours: 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.

Keywords: road safety, cost-benefit analysis, roundabouts.

INTRODUCTION

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.

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 independent 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. 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 [3] reporting that:

- benefit-cost analyses carried out in the United Kingdom, Australia and New Zealand have shown consistent reduction in accidents with RSA costs

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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 Figure-1, 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 [4].

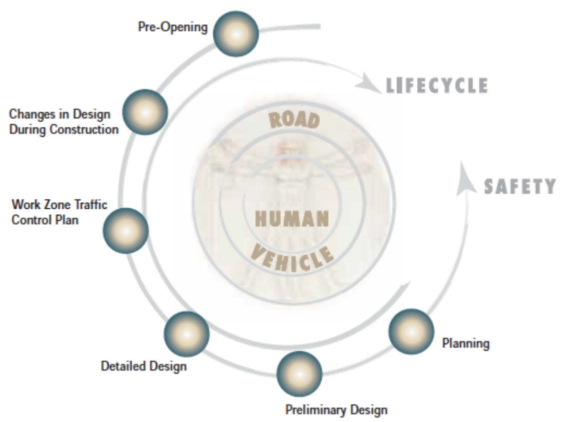

Figure-1. RASs in a road project lifecycle and implementation costs.

SAFETY MEASURES ON A SUBURBAN ROAD (CASE STUDY 1)

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 m 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.

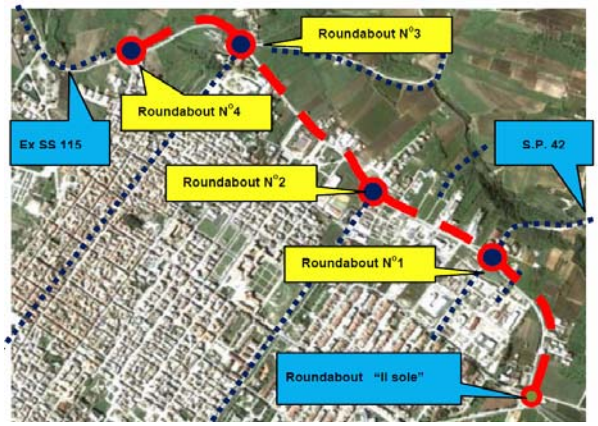

Figure-2. Territorial frame of the west ring road of Menfi, showing the new roundabouts.

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. 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 numbers in this period are the following:

- Average accident number per year:

$$T_i^{\,A} = \frac{N_i}{\Sigma n} = 1{,}8 \text{ (accidents/year)} \quad (1)$$

- Average injury number per year:

$$T_f^{\,A} = \frac{F_i}{\Sigma n} = 2{,}8 \text{ (injuries/year)} \quad (2)$$

Where

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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;
Ni = Number of accidents occurred in the observed period;
F i = Number of injuries occurred in the observed period;
Σn = Years of observation (equivalent to 5 in the case under study, from 1998 to 2002).

Road safety - post operam situation

Safety measures were aimed at the implementation of four conventional roundabouts (see Figure-2). A positive effect was the reduction of conflicting points between vehicle trajectories [5, 6, 7, 8]. 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, 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 is as follows:

- Average accident number per year:

$$T_i^F = \frac{N_i}{\Sigma n} = 0{,}0 \quad \text{(accidents/year)} \tag{3}$$

- Average injury number per year:

$$T_f^F = \frac{F_i}{\Sigma n} = 0{,}0 \quad \text{(injuries/year)} \tag{4}$$

Where

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 (Ci), calculated on the same expenditure categories as those previously mentioned for a fatality, on average corresponds to Ci = 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 ($\overline{C}_S^{Ante}$):

$$\overline{C}_S^{Ante} = T_f^A \cdot C_i = 73.689 \ \text{[€/year]} \tag{5}$$

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:

$$C_S^{Ante} = \overline{C}_S^{Ante} \cdot \Sigma n = 368.445 \ \text{[€]} \tag{6}$$

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.

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. 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 V_{pmax} (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 ;
- acceleration and deceleration values are still determined as 0.8 m/s^2.

By means of 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 under the aforesaid Ministerial Decree on 5th November 2001. By comparing the diagrams shows in Fig. 3 and in Fig. 4, 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.

Table-1. 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

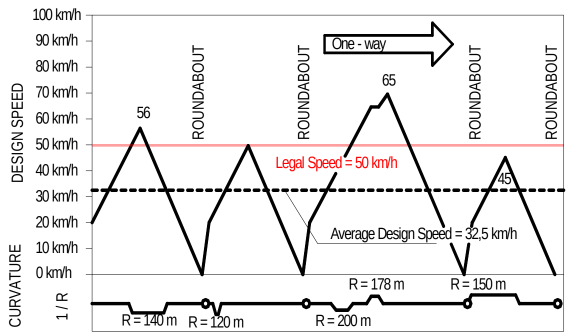

Figure-3. Design speed after implementing the roundabouts.

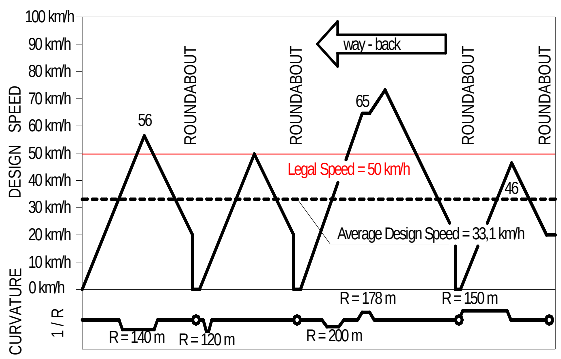

Figure-4. Design speed after implementing the roundabouts.

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, also image processing technique has been used [9, 10, 11, 12, 13]. 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-2. 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-3. 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

SAFETY MEASURES ON AN URBAN ROAD (CASE STUDY 2)

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 m wide and an about 3 m 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.

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 Figure-5), 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.

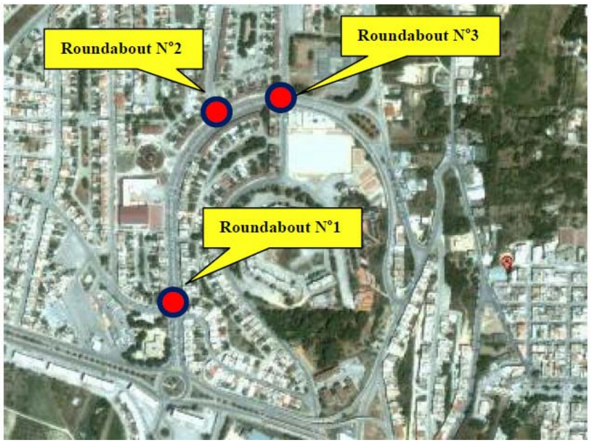

Figure-5. Layout of the new roundabouts.

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.

$$T_i^A = \frac{N_i}{\sum n} = 2{,}2 \ \text{(accidents/year)} \quad (7)$$

$$T_i^F = \frac{N_i}{\sum n} = 0{,}3 \ \text{(accidents/year)} \quad (8)$$

$$T_f^A = \frac{F_i}{\sum n} = 3{,}4 \ \text{(injuries/year)} \quad (9)$$

$$T_f^F = \frac{F_i}{\sum n} = 0{,}3 \ \text{(injuries/year)} \quad (10)$$

Where

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 ($\overline{C}_S{}^{Post}$):

$$\overline{C}_S{}^{Ante} = T_f{}^A \cdot C_i = 89.474 \ [\text{€/year}] \quad (11)$$

$$\overline{C}_S{}^{Post} = T_f{}^F \cdot C_i = 7.895 \ [\text{€/year}] \quad (12)$$

Where

$\overline{C}_S{}^{Ante}$ = 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 [14, 15]. 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. 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-4. Design speed for the configurations under study.

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

Table-5. 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-6. 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-7. 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

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.).

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