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How to redesign urbanized arterial roads? The case of Italian small cities

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Abstract

This paper poses the question of the redesign of urbanized arterial roads following a multi-objective approach. These infrastructures usually have wide lanes that allow high speeds and low safety conditions, resulting in the roads with the highest accident rates in suburban areas. However, since they experienced a rapid urbanization, they need to be redesigned. The aim of this paper is to focus on different technical alternatives aimed at redesigning such roads by increasing their safety performance without downgrading their functionality. The suggested approach moves from the global analysis of the local context and consists of the identification of different objectives and consequent interventions that can be used to reach them. The case of some Sicilian urbanized roads has been analyzed to test the approach and highlight further research steps.

Keywords: road safety; level of service; livability; arterial roads

1. Introduction

Urban transport systems are responsible of important negative impacts especially on safety, quality of life, environmental and social sustainability. On the other hand, cities are continuously growing in population and new dynamics of urbanization in an evolving landscape of change are emerging (Gonzalez-Urango et al., 2020). Therefore,

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urban transport systems need to be adapted to satisfy the needs of citizens and provide benefits for both people and the environment (Santos et al. 2010).

This approach implies the reduction of the negative externalities caused by road transport, among which accidents, road and environmental damage and the promotion of accessibility, pedestrian and cycling mobility. A human-oriented approach is needed, with a specific focus on pedestrians, cyclists and vulnerable users. Different interventions may be proposed starting from traffic calming techniques, sustainable street design focused on pedestrian orientation, walkable areas and bicycle infrastructures (Sarte, 2010; Kahn, 2016).

According to this formulation, this paper focuses on the specific problem of the redesign of "urbanized arterial roads". There are different types of roads built before the development of current urbanization that denote insufficient levels of safety performance because of the surrounding presence of urban areas with high density of driveways or absence of separation between different flows, such as the "crossing roads" of many small urban settlements developed along the major extra-urban itineraries. Moreover, in Italy, during the 60s/70s, many roads have been designed as a by-pass to relieve traffic from small historic town centers. In the past decades, the increased accessibility of nearby spaces generated by these roads and the simultaneous lack of strict urban planning regulations have produced a significant urbanization of the surrounding areas, with the presence of commercial activities and urban settlements. These infrastructures are usually characterized by geometric features that allow high speeds and low safety conditions, and are characterized by the highest accident rates. This results in heterogeneous traffic flows and unregulated parking demand with a decrease in safety conditions. These aspects point to the need to partially "rethink" the expected performance of these roads, with the double intent to increase their safety performances without downgrading their functionality.

1.1. Research approach

The paper analyses the open issue of the redesign of urbanized arterial roads by adopting a multi-objective approach, focusing on a series of parameters related to the road, urban space and traffic characteristics. Since these types of roads are not clearly addressed by the legislation, nor by any international guides, we propose a series of interventions by underlining the need to test their suitability, including road space redesign (e.g. reducing the number of lanes and including bike lanes) and traffic calming interventions, typical of local streets. Regarding the specific case of Italy, the Italian regulatory framework is reported. Then, relevant objectives and criteria in the redesign of such roads are considered. Some proposed interventions (localized or coordinated) are categorized according to their expected impacts on different objectives. The case of some Sicilian roads is presented to test the approach and highlight further research steps.

2. Materials and methods

2.1. Italian regulatory framework

According to functional features, Italian road Design standards (DM 6792/2001) classify urban roads in four different types: urban motorways, main urban roads, neighborhood streets, urban local streets.

While for primary roads at urban scale (urban motorways) the intended functionality is to connect the entire urban area, *main urban roads* should serve as distribution channel interconnecting separate neighborhoods. The range of connection of these roads is defined as "medium" and the traffic components are essentially limited to motor vehicles. These main roads are not exactly equivalent to urban "thoroughfares". The urban roads hierarchy is only partially applicable to the case of small and medium urban areas, where different functions are often attributed to arterial roads. In fact, due to the established function, along these roads (which are typically classified as D category, according to the Italian standards) parking should be forbidden and only emergency stops are allowed, while diversion and entering maneuvers should be limited and localized. The hierarchical approach upon which the Italian design regulations are based attributes to the secondary network (neighborhood streets and urban local streets) the function of accessibility to housing, commercial, and other institutional activities.

The logic of the Italian framework for main urban roads is clearly aimed at separating the main traffic flows (motor vehicles) from secondary flows, including all categories of vulnerable users.

The geometric parameters of this category of roads should be applicable to the design and construction of new urban arterial roads and, but the clear majority of cases, are inapplicable to existing arterials due to the initial design, mostly based on two lanes cross sections, with reduced lane width or without free bordering areas and service roads. Besides, the progressive urbanization has gradually reduced the availability of marginal spaces, progressively modified the original road function, and multiplied the traffic components.

It should be noted that this type of roads is not adequately considered by the current legislation. In this respect, their functions have been sometimes overlapped during the years due to urbanization of the surrounding areas. These urbanized arterial roads that originally could be classified as “D” roads, are somewhat more similar to roads of type “E” according to the Italian standards, even if it is important that they do not lose their original function of bypass. If one wants to increase their livability and ensure adequate safety levels for different traffic components, they should be downgraded. This would allow to intervene with *ad-hoc* strategies that are typical of secondary roads. In this respect, in absence of a clear correspondence between design rules and contexts of intervention, the current Italian standards do not specify how to apply defined treatments to existing roads, but ascribe to designers the demonstration of the effectiveness of the design choices (DM 22/04/2004). In other words, the Italian legislation suggests that in order to define the optimal interventions in terms of safety and functionality per each segment of a road network, road designers must evaluate the impact of a treatment - among the many possible treatments - in comparison to the “alternative zero” and/or to other (possible) safety measures.

2.2. Methods to assess safety improvements of urban main roads

According to Colonna et. al. (2019), for each segment of the urban network, the specific target of road safety improvement should be pursued by applying quantitative methods. When safety-oriented treatments and recommendations are not available as in case of existing roads, these methods allow road designers to predict the effects of specific measures. Among the most widely acknowledged quantitative methods, the Empirical Bayesian (EB) method allows the assessment of the effects of safety treatments – in terms of predicted Crash frequency – by defining Crash Modifications Factors (CMF) which modify the base Safety Performance Function (SPF) of the examined road section (Bahar et al., 2009).

Some results of the application of statistical methods are rather significant in view of possible safety treatments: according to Hauer et al. (2004) the frequency of non-intersection accidents for four-lane undivided urban roads mostly depends on three elements: annual average daily traffic (AADT), number of commercial driveways, speed limits.

However, to best compare the different measures, the alternatives of intervention should be analyzed not only in the light of accidental risk reduction, but also considering the functional aspects related to the use of the road platform by multiple users’ categories (e.g., pedestrians, cyclists) in presence of specific constraints that are difficult to remove (Dumbaugh & Rae, 2009). Consequently, the selection of the set of possible measures should be based on preventive analytical diagnoses, aimed at understanding how the hypothesized safety measures can contribute to re-define the functionality standards and the distribution of traffic flows along the main road network and along secondary roads.

As a matter of fact, in urban areas, each set of treatments is strictly connected to the review or to the development of an “area transportation plan” where the different solutions need to be evaluated in the community vision, not only in terms of road network capacity, but also in terms of re-allocation of some activities, in order to integrate the initial distribution functions of the main network with accessibility solutions (ITE, 2006).

2.3. Criteria of evaluations for the redesign of urban main roads

The growing attention to sustainable development has underlined the importance of environmental, economic and social sustainability, considering it as a key concept in transport planning (Banister, 2008). Based on this premise and drawing inspiration from on Ohkeun et al. (2011) and Andreoni et al. (2021), different criteria of evaluations and related indicators for the design/re-design of urban main roads are presented in Table 1. These range from efficiency to safety and recognizability, comfort and convenience, to broader criteria like collective benefits (environmental, social and economic). A comprehensive approach is therefore needed. However, it is not always possible to intervene on all the above-mentioned aspects (e.g. due to the physical and infrastructural characteristics of the roads or other external factors), and it is necessary to prioritize targeted interventions focused on some main objectives.

Table 1. Criteria of evaluations for the design/redesign of urbanized arterial roads (authors' elaboration)

Criterion	Indicator(s)
Efficiency	Traffic volume and capacity ratio (V/C); Average traffic speed (km/h)
Safety and recognizability	Number of traffic conflicts (cars vs. pedestrians and bicycles); Number of accidents; Lighting facilities and signs
Comfort (with respect to Road-cycleway-walkway)	Design; Landscapes; Obstacles; Materials
Convenience (with respect to Road-cycleway-walkway)	Accessibility; Continuity
Environmental quality	Environmental and acoustic emissions and surface water drain off
Life quality	Outdoor activity; Landscape design and amenity
Economic benefit	Energy saving

In many existing arterial roads that witnessed over the years a significant urbanization of the surrounding areas, and where the geometric design induces high speeds (and low safety conditions), the pivotal aspect is the analysis of the urban location context, the knowledge of the level of service (LOS) and of the traffic composition. In a following step of the analysis, each section of the road network (approximately 80-100 m long) should be analyzed to improve the level of safety and accessibility to different functions, while not sacrificing their original function, i.e. without downgrading too much the global LOS of the network.

In this respect, at least the following targets related to safety and functionality should be pursued: 1. Reduction in vehicle speed; 2. Reduction of accident rate; 3. Protection of vulnerable users; 4. Safe access to activities; 5. Parking and vehicle maneuvers under safe conditions; 6. Maintaining a good level of service of the street; 7. Encouraging activities such as bicycling and jogging by making the roadway pleasant and attractive.

To give an idea of how these different objectives could be reached, a set of interventions are proposed.

2.4. Proposed interventions

Physical/infrastructural interventions that are generally recognized as useful to achieve road safety and functionality objectives include traffic calming measures.

Traffic calming measures can be divided into two groups according to their intended main effect. Volume control measures are used primarily to address problems with through traffic by blocking certain movements, thereby diverting traffic to streets that can better handle it. Speed control measures are used primarily to address speed problems by changing vertical and horizontal alignment, or by narrowing lanes. The distinction between the two types of measures is not as clear-cut as their names suggest, as speed-regulating measures often divert traffic to alternative routes and volume-regulating measures also slow traffic flow. In the case of urbanized arterial roads, speed control measures should be preferred instead of volume control measures to avoid the risk of losing they bypass functions.

It should be emphasized that not all traffic calming measures are appropriate for different types of streets. Measures such as speed humps, chicanes, and road narrowing are used primarily in residential areas. Roundabouts as a means of speed control are widely used in many European countries in both urban and suburban areas. Urban local roads are often treated with combinations of the above and other measures such as pavement treatments or markings, chokers, raised pedestrian crossings or junctions and re-routing of traffic. In rural areas, rumble strips at approaches to intersections are perhaps the most common physical speed control tool. Many physical speed reduction measures are rarely used on rural roads due to the higher speeds involved and the risk of them causing accidents.

Even along urbanized arterial roads, opportunities for traffic reduction are more limited than on local streets in predominantly residential areas, because the efficient movement of motorized traffic is one of the primary functions of these types of roads. This would require higher speeds at road sections and therefore spatially separated pedestrian and cycle facilities. However, speed reduction would need to be implemented at intersections and median pedestrian and bicycle crossings, as cars and unprotected road users must mix at these locations.

For crossing roads of small towns, speed control measures are rather significant in approaching urbanized areas. Along these road sections, the choice of the correct type and position of speed reduction treatments must take into account the operating speed along the road, the presence of urban settlements and driveways along the transition zone, the consequent presence of vulnerable users that could not be perceived in the visual field.

Table 2 shows the impact of the various traffic calming measures considered acceptable along urbanized arterial roads on the objectives set out in section 2.3.

A scale of evaluation of the above impacts was adopted, based on three levels, denoted by the symbols +++, ++ and +. Specifically: the impact level indicated by the symbol +++ is the one that indicates the maximum positive impact on the achievement of the set objective (e.g., reduction of the accident rate by 50%); the impact level indicated by ++ represents a medium impact on the effective pursuit of the considered objective (e.g., reduction of the accident rate between 20% and 50%); the impact level indicated by + represents the minimum impact on the achievement of the set objective (for example: reduction of the accident rate below 20%).

To construct Table 2, the Authors relied primarily on the “Traffic Calming ePrimer”, an FHWA online resource available to the public (https://safety.fhwa.dot.gov/speedmgt/traffic_calm.cfm), on “The handbook of road safety measures - Second Edition” (Elvik et al., 2009) and other references in the literature (e.g., Distefano and Leonardi, 2019; Vanderschuren and Jobanputra, 2009, NACTO, 2013).

Table 2. Levels of impact of traffic calming measures on the safety and functionality of urban main roads.

TRAFFIC CALMING MEASURE	**SAFETY AND FUNCTIONALITY OBJECTIVES REQUIRED BY URBAN MAIN ROADS***						
	1	2	3	4	5	6	7
Vertical deflection							
Raised crosswalk	+++	+++	+++	++	++	+	+++
Raised intersection**	++	+	+++	+++	+++	++	+++
Textured pavements	+	+	++	+++	++	++	++
Speed cushion**	++	+++	++	+++	++	++	+++
Rumble strips	+	+	++	+++	+++	+++	++
Horizontal deflection							
Roundabout	+++	+++	++	+++	++	+++	++
Realigned intersection	+++	++	+++	++	+	++	+++
Tight radii	++	+	++	++	++	++	+++
Horizontal narrowing							
Neckdowns	++	+	+++	+++	+++	++	+++
Centre island narrowing	++	+	+++	++	++	++	+++
Chokers	++	+	+++	+++	++	+++	+++
Bike lanes	++	++	+++	++	++	++	+++
Sidewalks	+	+	+++	++	++	++	+++
Diagonal diverters	+	+	++	+	++	+	+
Median barriers	+	+	++	+	++	+	+

* 1. Reduction in vehicle speed; 2. Reduction of accident rate; 3. Protection of vulnerable users; 4. Safe access to activities; 5. Parking and vehicle manoeuvres under safe conditions; 6. Maintaining a good level of service of the street; 7. Encouraging activities such as bicycling and jogging ** *To be adopted with caution*

2.5 Suggested approach

In order to identify specific interventions, the first step of the analysis should consists in the identification of the global conditions of use of the existing infrastructure. Moving from the geometric features and, more in detail, from the evaluation of the road platform dimensions, localization of intersections and of minor and major driveways, the basic step of the analysis consists in the evaluation of the urbanization rate with the consequent definition of the traffic demand generated and attracted under different conditions of use, with a specific focus on the presence of vulnerable users. The following step consists in analysing the density of hazardous elements in each sub-section in which the road can be segmented, according to geometric features, operating speed, traffic flows.

The above reported local treatments should be applied with regard to the flaws deducted by the previous analysis in the light of more general or extensive measures such as lane section reduction, shoulders widening, construction of central traffic islands, or other measures with a more considerable impact in terms of speed (and travel time) and AADT. A post-intervention monitoring of data is significant to evaluate the actual impact of the applied treatments.

3. Applications

3.1. Case study

Just to provide some examples of specific real-world cases, we chose some specific cases of urbanized arterial roads. In particular, a small town (about 10.000 inhabitants) named Trecastagni, located in Sicily (Italy) on the slope of the volcano Etna was identified as a good candidate. It is characterized by two arterial roads that have been built with the intent to relieve the city center from traffic and allow its bypass to reach the neighboring towns (roads A and B in Fig 1). However, in more recent years, these roads witnessed a rapid urbanization, thus pointing to the need to rethink and redesign them to improve their safety while maintaining their functionality.

A preliminary analysis using a GIS approach was used to identify the main Points of Interest (POIs) and the traffic congestion levels (Fig. 1). Several available data sources have been used, from OpenStreetMap to TomTom traffic data (free trial) and Google maps data. As visible from Fig.1, roads A and B are characterized in some parts by high speeds (50-100 km/h) that are not compatible with the overall environment characterized by the buildings (and therefore houses or activities) in the surroundings. This is more evident for road B. Besides, they are quite similar in terms of road characteristics, like the number and width of the lanes and the urban functions (mainly residential) and they both serve as town bypass of the traffic from south to north (less than 2 km).

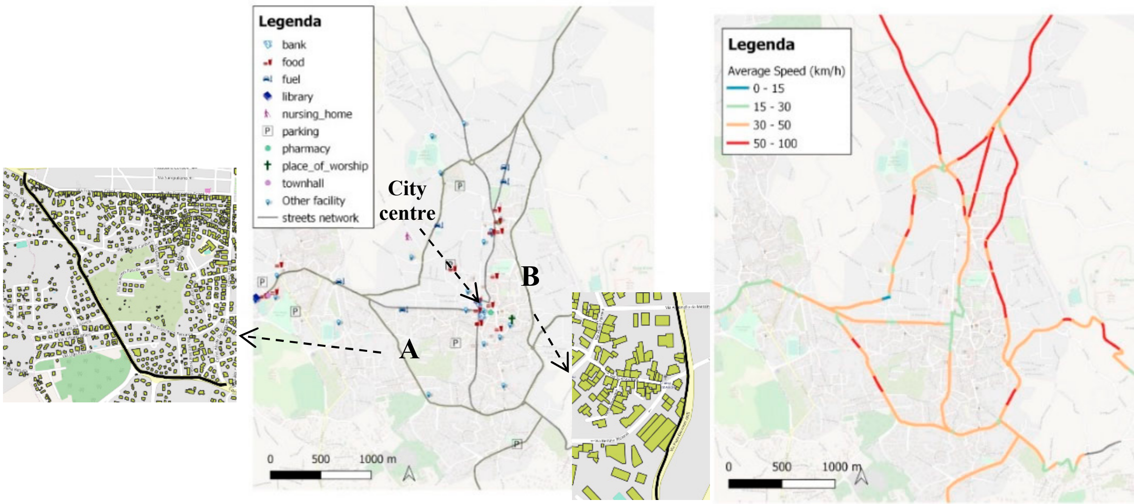

Fig. 1. GIS data of the study area: POIs (on the left) with details of the buildings of two main arterial roads and average traffic speed (right).

3.2. Proposed interventions

Some of the proposed interventions are reported in Fig. 2.

Fig. 2. Proposed interventions for the two roads.

For road A, measures are chosen mainly to encourage pedestrian traffic attracted by the numerous houses in the area. To this end, traffic calming measures are suggested, firstly to make it easier and safer for pedestrians to cross the road, and secondly to reduce speeds. As an example, the section shown in Figure 2.A illustrates the proposal to create a choker by moving the sidewalk forward, with a threefold goal: 1) to reduce the length of the crosswalk; 2) to improve mutual visibility between drivers and pedestrians; 3) to create a narrowing of the roadway that is useful for encouraging drivers to pay more attention to pedestrians and reduce speed. Also, to reduce speed, the installation of speed cushions is foreseen to slow down cars while not penalizing heavy vehicles and possible emergency vehicles.

For road B, on the other hand, some project measures are suggested that are partly similar and partly different from the previous case. Indeed, the area crossed by the road is less affected by the presence of houses and other points of attraction for pedestrians than the road A. Therefore, measures that favor the safety of the street layout should be studied, both by reducing the volume and speed of motorized traffic and by favoring the passage of cyclists. Figure 2.B shows an example of the adaptation of the road section where one can see the creation of one-way bike lanes along both lanes. As well as encouraging cycling, the cycle lanes are an effective way of reducing the width of the roadway and therefore influencing the behavior of drivers, who are encouraged to slow down and drive more carefully (NACTO, 2013). However, this type of intervention should be adequately designed to consider an adequate separation between different traffic components (with or without curbs) and guarantee an almost homogeneous vehicle speed.

It should be stressed that some of the measures presented in the examples in Figure 2 (e.g., the speed cushions and the chockers) are not sufficiently regulated by the road design rules in force in Italy but are nevertheless proposed as design solutions to be adopted in the preparation of the Italian Urban Road Safety Plans (PSSU) under the specific guidelines published in 2001. These interventions are to be intended as examples of possible measures that could improve the livability of these roads. However, deeper analyses should be performed to evaluate the actual conditions and potential impacts on road safety and functionality according to different objectives, as explained in section 2.

4. Conclusions and further research

This paper raised the issue of the redesign of Italian urbanized arterial roads, built with the intent to serve as bypasses of city centers, but that have seen a rapid urbanization of the surroundings, leading to a partial rethinking of their roles. A gap in the Italian legislation related to the regulation of the interventions that are possible in these roads has been highlighted. This points to the need to focus the attention on these roads and to redesign them by pursuing contrasting objectives. In this respect, a multi-objective approach has been proposed together with some *ad-hoc* interventions that could be suitable to reach them. Some examples have been provided with respect to two arterial roads in a small town in Sicily allowing to formulate some implications for further steps of the analysis. In particular, the effectiveness of the proposed interventions should be validated by simulations (both micro and macro) to see the impact on safety and on path choice. In other words, it is important to understand how the reduced speed induced by the proposed interventions affects the travel time and, thus, users' path choice. Even if this paper raised an important and understudied issue, further research is needed to formulate an *ad-hoc* procedure to tackle the redesign of such roads. The final aim should be to define a parametric approach, where one could match different interventions with several parameters related to road, urban space and traffic characteristics, i.e.: number and width of lanes, density of parking spaces, vehicle flows by vehicle types, vehicle speeds, density of commercial activities and residential buildings. A combination of different data sources, multi-criteria evaluation and simulations could be useful to support policy-makers in dealing with the complexity of redesigning livable and functional arterial roads.

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