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Virtual testing of speed reduction schemes on urban collector roads



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ABSTRACT

Urban collector roads are complex driving environments often encompassing both the mobility and the access road functions. In these conditions motorized traffic and vulnerable road users compete continually. Speed reduction measures may play a relevant role in these contexts, provided that such measures are also designed in compliance with the driver's capabilities and expectations.

The paper describes a test procedure using driving simulation experiments, designed to evaluate the re-configuration project of Via Pistoiese, an urban road collector located in Florence (Italy). The road improvement design consisted of several engineering treatments aimed to reduce and homogenize the driving speed, as well as to manage the co-existence of the different road users and mainly to protect pedestrians. The main focus of the research was to understand if the drivers' behaviour was according to the design hypothesis before the safety treatments are implemented in the real world. Due to the multiple engineering treatments included in the re-configuration project, the evaluation of the overall safety effectiveness of the project rather than the single treatment safety impact was the main concern of the research study. In addition, the study aimed to assess the usefulness of the considered testing method to understand how to integrate road design with drivers' performances, especially in heterogeneous traffic environments where drivers' behaviour plays a decisive role in the success of the proposed design solutions.

Fifty-eight participants drove through two immersive virtual environments, reproducing the existing configuration and the project reconfiguration, while data relating to different driving aspects were collected.

Two analyses were performed. The first was focused on the analysis of the mean speed profiles and revealed that the considered engineering treatments are able to control the speeding behaviour without providing a too high discomfort to the drivers. The second analysis was finalized to evaluate the driver's behaviour approaching zebra crossing, evaluating the impact of countermeasures allowing the drivers to perceive in advance a critical situation (a pedestrian that suddenly crossed the street) and consequently to perform a smoother and safer manoeuvre.

The experiments confirmed the validity of the considered engineering treatments, allowing expecting the improvement of the traffic safety in via Pistoiese, and support the usefulness of virtual reality experimentations to predict of the safety effectiveness of design solutions, taking into account the drivers' behaviour.

1. Introduction

Most road accidents occur in urban areas, as a result of their complex driving environments and of the higher predominance of vulnerable road users, more susceptible to injury and fatality in the event of an accident. In 2014, 9.923 people died on urban roads in the European Union. This corresponds to 38% of the road fatalities. Although the total number of fatalities within urban areas decreased since 2005, the proportion has slightly increased (from 36% to 38%). In urban areas 39% of the fatalities were pedestrian compared to 11% outside urban areas. Moreover, the proportion of fatalities at junctions inside urban

areas is double than outside (Traffic Safety Basic Facts, 2016). In Italy the situation is even more serious. According to Italian provisional 2015 data (ACI-ISTAT, 2015), in the first half of 2015 1495 people died on Italian urban roads, corresponding 43.7% of the total number of victims of road traffic accidents. Inside Italian urban areas the number of people killed in 2014 was 5.4% higher than 2013 and, on the basis of provisional data, during the first half of 2015 the number of fatalities increased by 7.4% compared to the first half of 2014. The majority of these accidents involved vulnerable road users. The number of pedestrians killed in traffic increased by 4.0% in 2015 compared to 2014. This is the second consecutive increase (+4.9% between 2014 and

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2013).

Urban collector roads are an important part of the urban road network. They are usually designed promoting mobility but actually provide access to roadside activities (such as commercial areas, schools, residential neighbourhoods) as well. Consequently, they do not easily fall into either the arterial or local/residential road categories. Austroads (2015) defines urban collector roads as non-arterial roads collecting and distributing traffic in an area as well as serving abutting properties. According to Italian road design standards (Ministry of Infrastructure and Transport, 2001a), the urban collector roads (named district roads) provide access to the local street network, serving mainly the mobility function and secondarily the access to built-up areas; the secondary function sometimes prevailing over the principal one. In these heterogeneous traffic environments different types of road users compete continually, with great differences in speed, masses and degrees of protection. Therefore, the performance of the road in terms of both mobility and safety of vulnerable road users, especially of pedestrians, gets worse. In fact, the accident risk increases as the traffic complexity increases (Taylor et al., 2000).

However, little research is available about urban collector roads' safety as part of the general problem of urban road safety. In particular, the specific impact of vehicle's speed on crash frequency in this type of road is not studied in detail, although the speeding effects on both the frequency and the severity of the injuries resulting from crashes is generally well established (OECD/ECMT, 2006). Research findings indicate that even modest speed reductions can prevent the occurrence of collisions and significantly reduce the outcomes of those crashes that do occur. According to the "Power Model" (Nilsson, 2004), a 5% decrease in mean speed typically reduces of 10% the injury accidents and of 20% the fatal accidents. Furthermore, the probability of a pedestrian being killed in a car accident increases with the impact speed. Results from on-the-scene investigations of collisions involving pedestrians and cars show that 90% of pedestrians survive being hit by a car at speeds of 30 km/h while at 40–45 km/h they only have a 50% chance of surviving (OECD/ECMT, 2006). Therefore, speed management is a must on urban collector roads where mixed traffic functions (mobility and access) co-exist.

Reducing speeding in the urban environments has often been based on a combination of traffic calming measures. Literature data suggesting the success of these safety measures on local/residential roads are abundant (Reid and Brown, 2009), but limited information on how these measures are able to manage speeds on urban collector roads are available.

Fitzpatrick and Parham (2000) proposed some safety countermeasures applicable in the latter traffic environments and an approach to speed management through road engineering treatments on urban arterial and collector roads at intersections and midblock has been proposed by a recent Austroads project (Austroads, 2015). The majority of the identified measures have been adapted from past usage on lower traffic volume local roads but many of these (such as speed bumps) may not be appropriate for urban collector roads, especially when they serve commuters, commercial traffic and emergency vehicles, due to the intense and sudden decelerations and accelerations they impose. Where these traffic calming measures are adopted, a posted speed limit of 30 km/h is usually imposed but this does not fit the urban collector roads mobility function for which, according to the Italian Highway Code, the generalized 50 km/h limit applies (Ministry of Infrastructures and Transport, 1992).

The safety impact of individual traffic calming measures is most often studied by evaluating their effects on crash reduction. This is the approach adopted, for instance, by the Highway Safety Manual – HSM (AASHTO, 2010) that allows to estimating expected crash frequencies as a function of traffic volume and roadway characteristics (e.g., number of lanes, median type, intersection control) for different driving environments. This procedure has been followed to examine the effects of various geometric and non-geometric road elements on the safety of

urban collector roads (Sawalha and Sayed, 2001; Barua et al., 2016; Manuel et al., 2014; Wang et al., 2015). However, the evaluation of the cumulative impact of multiple measures, applied in different combinations, is usually not possible, lacking the information on the relative and combined effects of the different measures considered.

To overcome this difficulty, the evaluation of proxy safety indicators derived from studying the influence of the modified urban traffic environment on the driving performances can be considered. The traffic calming measures interacts with the driver's capabilities and expectations and their ability to produce a positive impact on road safety depends on their capacity to influence the drivers' behaviour. Failing to consider the latter can have serious consequences in social and economic terms, especially if roadway requires revision after they are built (Lee et al., 2011). Shinar (2007) concludes that engineering-based solutions to improve safety will remain relatively ineffective unless they take into account all the potential effects on drivers' behaviour.

The use of an interdisciplinary approach based on driving simulations is a promising method to address this challenge, provided that it is appropriately validated. Driving simulator allow testing and comparing different existing or new road configurations or equipment. Thus, they allow determining how road design solutions are perceived and understood by the drivers and which driving behaviour they generate (Vienne et al., 2014). Through virtual reality experimentations, road engineers can understand how multiple design interventions affect the performance of road users through direct measurements. For this reasons, Rudin-Brown et al. (2009) recommended the use of simulation as a first step in evaluation of novel road safety measures.

The approach using an interactive driving simulator for prototyping and evaluating large motorway projects have been attempted and found successful (Upchurch et al., 2002; Flø and Jenssen, 2007; Jelly Lassacher and Shipstead, 2007; Trentacoste, 2008; Lorentzen et al., 2011). However, they usually focus on single road elements, such as signage and road markings (Dutta et al., 2002; Noyce and Elango, 2004), horizontal and vertical coordination of the road layout (Easa and Ganguly, 2005; Garcia et al., 2011) or cross section design (Rosey et al., 2009; Richter and Zierke, 2010). Few studies have devoted themselves to the analysis of the road projects as whole, including different and combined engineering-based measures, aimed to influence the drivers' behaviour to improve road safety.

The present study deals specifically with the latter topic and aims to evaluate the safety effectiveness of the reconfiguration project of Via Pistoiese, an urban collector road situated in Florence (Italy), by studying in virtual reality the drivers' behaviour in both the existing road environment and the design solution considered during the design phase. The driving simulator of the Road Safety and Accident Reconstruction Laboratory (LaSIS) of the University of Florence (IT) was used to perform the study. It has been previously validated by comparing speeds measured in the real-world and at the driving simulator, assessing both the relative and absolute validity (Branzi et al., 2017). The findings established that the data collected in the virtual environment could be directly transferred to real world, supporting the use of the LaSIS driving simulator as a powerful approach to predict of the safety effectiveness of design solutions in urban areas.

2. The case study of via pistoiese

The Road Safety Strategic Plan of the Firenze Municipality rates Via Pistoiese as the second most unsafe road within the road network in Florence, with 158 serious accidents (only one fatal accident) in three years (2013–2015). The vulnerable road users (VRUs) are the most affected: mopeds, bikers and pedestrian are 74% of the people involved in serious accidents.

2.1. Road characteristics

Via Pistoiese is a two-lane urban road whose main function is to

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