Infrastructure redesign to improve vulnerable road users' safety

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Abstract

The research reported the case of a footbridge in the Turin province (Italy) that surveyed increasing accidents involving vulnerable road users who chose not to use it when crossing the main road. The reasons behind this choice were investigated and, embracing an ergonomic and systems approach, possible redesign solutions were suggested. The results showed how the different components of the footbridge system (environment, physical design, users, etc.) interact to determine the vulnerable road users' behaviour. Requirements for infrastructure redesign were defined and discussed with the local institutional stakeholders to be implemented in the on-going local Plan of Urban Regeneration and Environmental Improvement.

Introduction

When addressing issues concerning road safety, recommendations usually mention to enforce and improve national and international legislation, especially in matters related to speed, drink–driving and use of helmets (for riders of motorized two-wheelers), seat-belts and child car restraints, and severity and promptness of punishment for violations (WHO, 2013). At the same time, other remedies to contrast the phenomenon are mentioned, like information, education, and police surveillance. Despite these measures, according to the World Health Organization (WHO) in 2012 the world vulnerable road users accounted for the 43% of road deaths (WHO, 2013). In 2011 in Italy over 21,000 injured and 589 deaths - out of which 368 were people over 65 years - were registered among the vulnerable road users (ISTAT, 2011). The phenomenon is of such international noteworthy relevance that the United Nations dedicated the 6th to the 12th May 2013 as "Road Safety Week" to highlight pedestrian safety across 70 different countries. In addition, the European Road Safety Programme 2011-2020 (European Commission, 2010) has envisaged halving the number of road deaths by 2020 and strengthening the actions in safety of vehicles, infrastructure, and users.

At a scientific level different approaches to road safety have been developed. These approaches move from an individual perspective - where accidents are attributed to human errors - to a systems theory - where all the stakeholders and components to a

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road safety programme are taken into account to suggest countermeasures and realist solutions to be implemented (Larsson, Dekker, & Tingvall, 2010). To this extent, the proposed research took place in Italy, in a Turin province area assessed at high risk of road accidents. Despite there being a usable footbridge, the area has witnessed increasing accidents involving vulnerable road users who chose not to use it when crossing the main road. *Why do pedestrians and cyclists decide not to use the footbridge?* The answer to the question may be addressed under different perspectives. An individual and road-user approach would state that if the vulnerable road users had made proper use of the footbridge and the car drivers had driven respecting the speed limits, road accidents would not have happened. On the other hand, systems approach researchers would state that if the different components of the target road system had been properly designed, these would have limited the chance of human errors.

The present study intends to demonstrate how user-centred and systems design approaches can be used to illustrate the designers how road system components interact with the final users and suggest verified (re)design solutions. In the aim to design and implement "*good patterns of interchange between artificial and human systems*" (Re, 2012, pag. 54), the Human Factors and Ergonomics (HF/E) discipline has displayed a strong interest in safety issues. This approach is useful to address road safety issues because it is focused on adapting the system to human being needs, and highlighting interactions and users' centrality in design. The main objective is to improve the interactions between the road users, the environment, the designers and the management with the final aim to enhance road safety.

Therefore, the present research had the following specific objectives:

(1) To illustrate evidence-based design representations of the footbridge and road system, and point out the current flawed infrastructural aspects under discussion;
(2) To describe the vulnerable road users' behaviors, particularly in relation to the decision to use (or not) the footbridge of SP363 road Villastellone;
(3) To inform designers of future infrastructure system with possible redesign solutions.

Road safety approaches

All the countermeasures aimed at changing the behaviour of the road user are certainly adequate to produce some positive effects. Nevertheless these recommendations betray a direct connection to a traditional approach to road safety that proved not to be more effective in preventing road accidents and injuries (Wegman, 2002). Such an approach is often called the road-user approach (Larsson et al., 2010), and it states, at its basis, that road users are responsible for the safety of the road transport system. This view influences the road safety issues' interpretation in terms of human error, which is considered the cause of most road crashes (WHO, 2013; Brookhuis et al., 2011). In such a view accidents are to be prevented through behavioral changes and coping skills: in this approach it is the user that has to adapt herself to the road transport system. At the end of the nineties, a more system-oriented view gained visibility, in terms of the road system that has to be adapted to the human being and her limitations and imperfections. It became evident that accidents are rarely due to a single factor, but they are rather a resultant of the variability of different components. For this reason improvements in road safety can be achieved only if all the elements are addressed (Larsson et al., 2010; Elvik et al. 2009; Ghazwan, 2007). This led to the introduction of the Road Transport System (RTS) concept, outlining a road system composed of three main elements in interaction: the user, the vehicle and the infrastructure (the environment). This different focus highlighted factors that could be beyond road's users control, such as poor design or failure in the performance of road infrastructures: errors in road design can now be considered as one of the main elements that could cause accidents. Human errors are considered as part of the system, something that designers and managers have to take into account delivering a system that should accommodate potential mistakes (Brookhuis et al., 2011; IRF, 2003). The prevention of human errors is made through information and education, but also providing road users with surroundings in which the chance of human errors is limited (WHO, 2013; Racioppi et al., 2004). Humans make errors because the system is not adequately designed to meet their capabilities and needs. To provide an example, Vision Zero represents the Swedish holistic and systemic approach to road safety grounded on these premises. It states that the system must be adapted to the mental and physical conditions and limitations of the human being, placing a great responsibility on road builders and managers (WHO, 2009). Therefore the countermeasures adopted by policies have been integrated with different elements: development of road infrastructure design to mitigate the consequences of road crashes, measures to reduce the transfer of energy on impact, changes to the road network (motorways, bypasses, etc,), improved levels of road maintenance, installing safety barriers and obstacle protection, etc.

Nevertheless, these approaches could fail in preventing and addressing accidents causes and consequences. The main difficulty is to integrate all the different RTS components in the same intervention. First of all, the various elements of a RTS could have evolved in separate ways, due to historical reasons. For example, in the past, roads were designed primarily to meet social and economic needs; even now we sometimes have to face road networks neither designed nor adapted to vehicles, because two elements (the road and the vehicles) developed independently of each other. Furthermore, in the past the road user was hardly ever considered; when considered, they were above all drivers. Another common issue is the fact that, even though a systemic approach is taken in account, improvements put in place were not integrated in a whole. Safety measures regarding all the RTS components can easily become useless, if they are developed in isolation from each other. In the last few years, road authorities have tried to solve these issues and improve the quality and the performance of the road network, by allocating more and more responsibility to road designers, encouraging involvement of experts in human sciences and aiming to adopt multidisciplinary approaches.

The research setting: the SP393 road Villastellone

In 2012 the Piedmont Region published the ten-year balance of road accidents report (Regione Piemonte - Centro monitoraggio regionale della sicurezza stradale, 2012), in which it is shown that in 2011 the number of victims among the vulnerable road users has not significantly changed with respect to 2001. In particular, the data referred to in the two recent years of 2010-2011 (see Table 1) deaths among the vulnerable road users show only a slight increment of 5%. The pedestrians involved in mortal accidents were from 54 in 2010 to 61 in 2011 with an increment of 19%, while the motorcycles' deaths registered an increment of 23%. Only the cyclists show a reduction in mortal accidents, but they register an increment of 8% of injured cyclists. A concerning aspect is registered among the youths in-between 22-29 years old, whose deaths in road accidents increased by 44%.

Table 1. Accidents in Piedmont between 2001 and 2011 - injuries and deaths of vulnerable road users (Regione Piemonte - Centro monitoraggio regionale della sicurezza stradale, 2012)

	Deaths				Injured			
Vulnerable users	**Mean 2001-2010**	**2010**	**2011**	**Variation**	**Mean 2001-2010**	**2010**	**2011**	**Variation**
Pedestrians	63	54	61	**13%**	1.562	1.663	1.629	**-2%**
Cyclists	27	27	15	**-44%**	844	947	1.027	**8%**
Motorcyclists	68	52	64	**23%**	1.863	1.789	1.849	**3%**
TOTAL	**158**	**133**	**140**	**5%**	**4.269**	**4.399**	**4.505**	**2%**
Users by age	**Mean 2001-2010**	**2010**	**2011**	**Variation**	**Mean 2001-2010**	**2010**	**2011**	**Variation**
Kids (11-13 yrs old)	3	1	0	-	246	249	249	**0%**
Teens (14-17 yrs old)	14	9	5	**-44%**	1.060	947	867	**-8%**
New-licenced (18-21 yrs old)	30	26	17	**-35%**	2.388	2.106	1.951	**-7%**
Youths (22-29 yrs old)	79	32	46	**44%**	4.647	3.610	3.380	**-6%**
Adults (30-69 yrs old)	213	166	159	**-4%**	11.212	10.889	10.460	**-4%**
Older people (over 70 yrs old)	85	89	89	**0%**	1.348	1.494	1.594	**7%**

In the list of the Turin province roads declared, SP393 road Villastellone presents a high degree of accidents. This is a road with high traffic level that goes through the southern area of Turin connecting the towns of Moncalieri and Carmagnola, through Villastellone, Cambiano and Carignano. A road safety assessment with regard to SP393 road Villastellone was presented in a Safety Analysis Document, edited by the Province of Turin (Provincia di Torino, 2012) in line with the National Plan of Road Safety which suggests the Road Safety Audit (a preliminary safety analysis applied in the design phase) and Road safety Review procedures (applied to the operative infrastructures). The SP393 road Villastellone has been ranked at the 20th place out of 679 Piedmont Region roads regarding Risk Index[9]. When comparing these data with those at national level, the SP393 road Villastellone reports a high risk assessment, as it presents an average of 14.5 deaths × 100 km / year, despite the National Plan of Road Safety for this kind of roads has fixed the target at 0.9 deaths / year. The Severity Index is equal to 152.8 (number of deaths on the sum of deaths and injuries × thousand) compared to the regional 47.7 and provincial 67.1.

In the present study, the problem space refered to the roads intersection at km 10+800 of the SP393 road Villastellone, where cars and trucks intersect with pedestrians and cyclists who come from the nearby village of Villastellone, to reach

[9] The Risk Index RI is calculated by dividing the specific rate of road accidents equal to 1.53 (considering the regional RI equal to 1.0 and the provincial RI equal to 0.74) and the Mortality Risk MR equal to 2.30 (considering the regional MR equal to 1.0 and the provincial MR equal to 1.46).

an area called Villasport, which includes many sport centres, leisure and business activities (see Figure 1). The number of accidents involving road vulnerable road users and vehicles is considered.

Figure 1. View to the footbridge and the road system in Villastellone

Method

The research design consisted of different souces of evidence able to account for the different system components of the SP363 road Vittastellone area under analysis, and support data triangulation to achieve data saturation and convergence. The data collection took over a 7-month period. The main stakeholders and final users of the road and footbridge system area were involved. All the participants gave informed consent.

Archival data of the traffic road area were collected. They consisted of statistics regarding the road traffic incidents involving road means and vulnerable road users (ISTAT, 2013); infrastructure maps; newspapers and journal articles of the province target-area. These data tracked over a three-year period (Jan. 2010- Dec. 2012). In addition, primary sources were collected and included original documents, observation data, interviews, questionnaires and focus groups.

Firstly, direct observations and pictures were taken to gather first data on the environmental and infractural conditions of the 500 m road area under analysis, with an aim to register the state-of-the art of the signs and markings present in compliance with the Italian regulatory standards; the intersections with other roads and with private passages, the sidewalks, and parking areas, the lighting system (number and position of the street lights).

To understand the vulnerable road users' behaviours in their choice in using the footbridge to reach Villasport area, a multiple-choice-answers questionnaire was designed. The items regarded the frequency they attend the services of Villasport area per week, the time of the day they travelled, the means of transportation (motorbike, byke, by foot) used, and comments to possible alternatives to the use of the footbridge. The participants were N= 60 vulnerable road users (N= 30 male users, N= 30 female users; mean age= 32 yrs). In returning the questionnaires, the respondees were asked the availability to participate in group-interviews to expand on the reasons behind the choice (or not) to use the footbridge. Consequently, two groups-interviews were organised involving N= 9 adults (users of Villasport area, parents, random passer-by) and N= 4 teenagers (whose informed consent was signed by their parents). They were inquired about their behaviours in different situations and the Critical Incident Technique (Butterfield, 2005; Flanagan, 1954) was used to investigate *negative* past events related to the choice of not using the footbridge. The interviews lasted approx. 60 minutes; they were recorded and completely transcribed.

The empirical data were analysed considering the specific road system components involved (environment, infrastructure, etc) in interaction with the vulnerable road user. The content analysis (Krippendorff, 2004) was performed through the use of the NVivo software (Tom and Lyn Richards, 1981, cit. in Bazeley, 2007), with a good degree of inter-judge agreement (k-Cohen= .74).

Results

The data collected from the first exploratory observational phase resulted in an *infographic* map (see Figure 2) of the SP363 Villastellone road system. The *infographic* map highlighted the current critical and/or missing environmental and infrastructural elements to bring under attention. It highlighted that there was a lack of signs and markings in the critical intersections with roads and private passages (flaws N. 2, 5), the lighting system was insufficient, in particular in the parking areas and along the footbridge (flaws N. 1, 3, 4) and the pedestrian path of the footbridge resulted compromised in not-paved sections (flaws N. 6) that could affect the vulnerable road users' safety in particular in adverse climate conditions, like rain or snow.

The results from the questionnaires and two groups-interviews produced user-centred rich material to illustrate to the designers the behaviours of the users, their motivations and the specific context of use. These were related to the users' characteristics (socio-demographic data); the means of transportation used (bike, motorbike, car, or none); the specific needs to reach Villasport area; the external environment conditions. In particular, some elements were crucial for a more complete understanding of the interactions occurring between the vulnerable road users and the road system components. Users declared that the pedestrian path of the footbridge is not completely paved, causing slippery spots under adverse climate conditions and too long to use when travelling to Villasport area – in fact the footbridge path is 352.81 m. long and 12.80 m. wide. In addition, one side of the footbridge ends near a grove of trees that is perceived by vulnerable users as particularly unsafe in dark lighting conditions. In fact, this area and along the footbridge street lacks sufficient lighting spots. The intersections of the main road with secondary roads and the footbridge connect poorly with main infrastructural safety elements: lack of marks and signals for the drivers informing the presence of vulnerable road users; absence of speed limiters; etc.

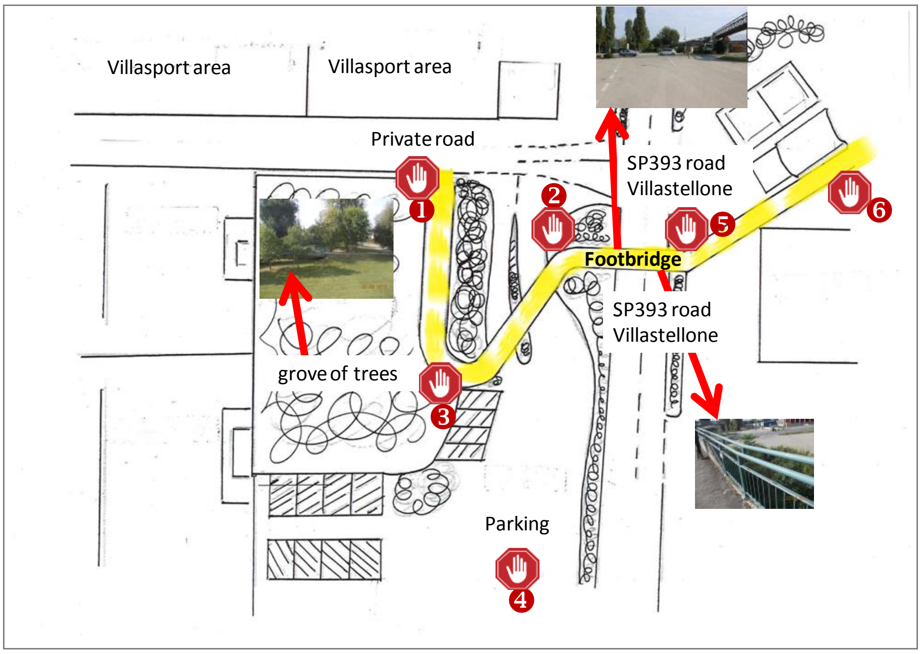

Figure 2. Infographic map of the SP363 road Villastellone of the area under analysis, with flawed infrastructural aspects marked.

In order to better illustrate to the designers how road system components interact with the final users and to share a sufficiently wide view on complex systems, the scenario-based design technique was used (Carroll, 2000; Rosson & Carroll, 2002). Scenarios are "*stories about people and their activities. [...] Scenarios highlight goals suggested by the appearance and behaviour of the system; what people try to do with the system;and what interpratations people make of what happens to them*" (Carrol, 2000, p. 46). Scenarios are a powerful instrument when addressing the complexity of systems and analysis, and deemed to be an effective mechanism to discover requirements for the scope of the present study. Scenarios may vary from brief stories to richly structured analysis, but are always based on the idea to present sequences of actions carried out by agents detecting possible omissions, threats and inconsistencies during their interaction with the system under analysis.

Five scenarios were designed highlighting the *setting* (the footbridge and the SP363 Villastellone area), *agents* who might be *involved* (the different range of vulnerable road users) with contextualised *needs* and *goals* (aiming to Villasport area, and deciding to use, or not, the footbridge). For example, in Scenario N. 1 the *agent* is an aged vulnerable user using the footbridge but due to lack of adequate infrastructure (path poorly paved) is at risk of falling and getting injured.

Scenario N. 1 - It is a cold rainy day of end November. Maria is 72 yrs old and needs to keep in shape. She has atrophy in her left foot therefore three days a week she has her morning gym practice. She has time, so safely decides to use the footbridge to reach Villasport area; she has her bag in one hand and in the other her gym bag. The pedestrian path is not completely paved, with barely avoidable puddles. Suddenly she loses control, and slides down.
Outcome: Loose of balance and fall with consequent injury/ies.

Scenarios help designers by providing (re)design requirements and solutions of future infrastructure system. To ensure the grounding of the shared requirements in vulnerable users' needs, the requirements were acquired *with the vulnerable users and stakeholder*, to be able to uproot tacit knowledge elicitation and modelling of users' needs. This implied a focus on requirements based on linguistic expressions rather than formal specification and validation (Sutcliffe & Maiden, 1993).

Scenario N. 2 - It is 2 p.m. and Marco, Giulio and Paolo –a group of teenage-friends needs to reach the Villasport area for swimming practice. They usually meet after lunch. To make it faster they decide to take the shortcut by the bowling green. It is daylight, they know the street, they are in a group and feel confident. At that time of the day, the traffic is consistent. The group is having fun and is distracted and thus does not perceive a vehicle arriving over the speed limit.
Outcome: Possible collision due to fast speed driving.

		Component
Requirement	Drivers shall be able to be informed of the presence of vulnerable road users.	Infrastructure
Requirement	Drivers shall be able to be informed of the obligation to reduce speed when approaching the footbridge area.	Infrastructure
Requirement	Vulnerable users and drivers shall be able to be surrounded by adequate lighting spots when approaching the footbridge area.	Infrastructure Environment
Requirement	Vulnerable users shall be able to feel a social safety perception when using the footbridge.	Infrastructure Users

A focus group with the local institutional stakeholders was then organised to present the study results. The possible redesign solutions of future infrastructure system were analysed and first suggestions were decided to be implemented in the on-going local Plan of Urban Regeneration and Environmental Improvement.

Discussion and conclusions

The study intended to address the road safety issue in a province assessed at high risk of accidents by user-centred and systems design approaches to illustrate the designers how road system components interact with the final users and suggest verified (re)design solutions. The data collection involved the main local institutional stakeholders and vulnerable road users and made use of different souces of evidence able to account for the different system components of the SP363 road Vittastellone area under analysis.

The results showed evidence-based design representations of Villastellone road system and provided possible redesign solutions which were discussed in a focus group organised with the local institutional stakeholders. In particular, the main infractructural flaws were immediately addressed. The lighting system was improved in the areas along the footbridge and car parking lot. New traffic circles and guard rails to separate the two driving lanes are under construction with the aim to slow the vehicles speed. To protect pedestrians and cyclists from the traffic road and promote the use of bikes instead of cars, new bicycle and pedestrian mobility paths separated by the main road are under construction.

These are concrete answers to address the infrastructural problems arisen from the research results. Still, the specific technical solutions have to be accompanied by an understanding of the different situations and factors occurring in a specific complex system, to be able to respond to the final users, in particular the vulnerable road users. Pedestrians still result among the most vulnerable road users. This is mostly because for years their needs have been neglected in favor of motorized transportation. To reduce injuries among vulnerable road users, an important role can be played by road infrastructure. The recent engineering innovations favours an understanding of needs and variability of all road users, adapting the system design to the capabilities and limitations of the human being for each user category and different use of the road.

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