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Implications of Adaptive Traffic Light Operations on Pedestrian Safety

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Abstract: *Within the category of vulnerable road users pedestrian are recognised as those with the highest probability in road accidents to be affected by serious or fatal casualties. However, due to the randomness of their behaviour and sometimes the limited attention of traffic light operation settings devote to this road user category, in particular in isolated signalised junctions, there is a huge potential in the capability of new and intelligent systems to play a fundamental role in the improvements of pedestrian safety. In this paper an in-depth analysis of a 4 arms isolated signalised urbanjunction located in a small town in Sicily (Italy) has been carried out.In-depth analysis, differentiating by time of the day, gender, age and junction arms has been carried out and impact in terms of variation in safety levels have been assessed. From the lesson learnt potential impact of the implementation of new and intelligent systems such as puffinand pelican crossing modifying the signal settings and/or the junction layout have been assessed.The paper then concludes with a comparison of the safety levels of the current settings against those related to the week when variable traffic light settings have been implemented.*
Keywords: *pedestrian behaviour, road safety, signalised intersection, Time to Collision*

I. Introduction

In Italy compared to 2011 data charted by ISTAT [1], the overall accidents fell by 9.2%, the injured by 9.3% and the dead by 5.4%. During the period of time between 2001 and 2012, the reduction of road deaths was 48.5%, a decrease in the number of deaths from 7,096 to 3,653. In seven cases out of ten the victims of road accidents are drivers of vehicles (70.0%), 14.6% in passengers and 15.4% pedestrians. Lastly it was an increase in deaths of pedestrians male, compared to 2011 (from 333 to 357, equal to 6.7%), despite the overall decline in pedestrian road fatalities (- 4.4% compared to 2011). This increase, for men, far above all the age groups 75-79 and 80-84age. Always among the pedestrians, it also decreases the number of injuries (-1.7% compared to 2011).

Pedestrian road safety remains a key point of the transport road safety policy in urban areas. Pedestrians are vulnerable road users and despite their limited representation in traffic events, pedestrian involved injuries and fatalities are overrepresented in traffic collisions. Crosswalks are, as it well known, sites where pedestrians face lower levels of road safety, because they have to cross the street and must be aware of the incoming traffic. Intersections with high vehicle flows should be signalized in order to prevent accidents and raise the level of road safety for both pedestrians and vehicle drivers.

The pedestrian illegal crossing behaviour is one of the major fact in the road safety issue. Behaviours observations can be useful for pedestrian safety analysis in order to:

- Provide more data about specific sites than only reported crashes;
- Account for rate of occurrence more easily than reported crashes considering that nowadays crashes analyses require good estimates of pedestrian volumes before and after treatments are installed;
- Enable data collection at wider range of sample of sites, not just sites with high numbers of reported crashes.

Garder[2]has described on 15 Sweden cities that pedestrians crossed against red light more often in larger cities, at intersections with less cross traffic and turning traffic. In fact shorter crossing distances and median islands were also positively associated with disobeying red signals. Garder[2] defines that males were more likely to jaywalk than females. According to Tiwari et al.[3] it is possible to consider that the longer traffic signal is the more pedestrians would violate the signal.

Nevertheless, the provision of signalised pedestrian crossing facility may not promise the pedestrian safety due to some reasons such as traffic violation and unsafe signal phasing. Signalised crossing facility located at high speed intersection with turning vehicles may become a hazard to the pedestrian safety as referred by Faria et al. [4].

There is an evidence saying that the crash risk level will increased eight times when pedestrian adopted an illegal crossing behaviours at signalised intersection (King et al., [5]). Pedestrian-vehicle conflict at signalised intersection happened due to several factors relate to the pedestrian, driver, traffic and environment conditions (Rosenbloom, [6]).The probability of pedestrian involved with an accident is high while they cross the road particularly with high number of speeding traffic. Driver attempt to clear the intersection may collide with the pedestrian who has departed from a sidewalk area. A study done by Rosenbloomet al. [7] have shown that the demographic factors of a driver is related with the frequency and severity of pedestrian crashes. Male middle age driver involved in vehicle-pedestrian crashes more frequently than other road driver groups. Prevention of crash at signalised intersection might be accomplished by changing time and phase setting for traffic signal indications. The minimum time required for a pedestrian to completely cross a road should be the basis for time setting at each phase of the signal cycle on Tiwari at al. [3] research.

Crossing two directions of a signalised intersection practically need a very long clearance times by any pedestrian compared to cross only one traffic direction. In addition, longer waiting time perceived by pedestrian at signalised intersection will risk the pedestrian who cross a road with unsafe behaviour. The influenced of environmental factors to the risk of crossing pedestrian has been studied by many researcher. Among of them concern on the effect of weather (Rosenbloom, [6]), the darkness of crossing location due to poor lighting or night time (Sullman et al., [8]; Yang et al., [9]), type of area (Lassarre et al., [10]), and the population (Cooper et al., [11]). Pedestrian crash risk has been related to several categories of factors including roadway characteristics;surrounding land use,time interval (hours,day,week, etc.) and pedestrian and driver behaviours.

This paper is focused on pedestrian behaviour;especially, it is intended to provide an exploratory analysis of the percentage of violator pedestrians during road crossing when is active an adaptive traffic signal.

II. Methods

The majority of pedestrian casualties in road crashes occurs along trips in urban areas, and particularly while road crossing, where pedestrians interact with motorized traffic. The analysis of pedestrians risk exposure while road crossing under different conditions along urban trips may contribute towards more efficient and pedestrian-oriented planning and implementation of road design, traffic control and crossing facilities, the more accurate estimation of pedestrians road crash risk in urban areas, and thus to the improvement of pedestrians safety.

The road crash risk of pedestrians is mainly estimated on the basis of macroscopic indicators, such as:

- the number of road crashes or casualties to the population of pedestrians;
- the walking distance travelled;
- the walking time spent;
- the number of trips or the number of road crossings.

Microscopic analysis of pedestrians' exposure have been proposed in only a few studies. For example, it has been suggested to use the number of pedestrians crossing a given road section at given time intervalsor the product of the number of vehicles and the number of pedestrians crossing a given road section at given time intervals.Another study (Lee & Abdel-Aty, [12]) proposed a composite indicator of pedestrians' exposure, taking into account pedestrian characteristics, road and traffic conditions, as well as pedestrian compliance with traffic rules. The traffic conflicts technique has also been used for measuring the exposure of pedestrians at specific crossing locations. Earlier research (Gårder, [2]) proposed a microscopic indicator of pedestrians exposure in relation to vehicle speed, pedestrian walking speed and crossing width. This indicator reflects the proportion of space unavailable to pedestrians for unobstructed and safe crossing, i.e. the proportion of space which is occupied by vehicles. The existing approaches for estimating pedestrians road crash risk exposure are summarized in TABLE 1 below.

Table 1*Existing approach to estimate pedestrian road crash exposure*

source	year	scope			field survey data	macroscopic indicators					microscopic indicators				variables			
		risk	exposure	behaviour		population	number of trips	walking distance	walking time	number of crossing	ped*veh	ped character * behaviour	traffic conflicts	veh*crossing time	age/gender	road type	traffic control	day/night
Routledge et al.	1974																	
Van der Molen	1981																	
Howarth	1982																	
Cameron																		
Johan&Engel	1983																	
Garder	1989																	
Keall	1995																	
Baltes	1998																	
Lee & Abdel-Aty	2005																	
Lassarre et al.	2007																	

Sueur et al. [13] studied how culture influences an individual's perception of risks when crossing a street, using survival analysis. Their study is the first to use this analysis to assess cognitive mechanisms and optimality of decisions underlying road crossing behaviour. The observations were made at a safe site consisting of a crosswalk and a street light and at an unsafe site (i.e. no crosswalk or street light). At the unsafe site, it has been measured the time needed by a pedestrian to take a decision (T_{dec}). During T_{dec}, a pedestrian estimates whether he can (T_{safe}) or cannot (T_{risk}) cross the road. Collotta et al. [14] have examined the pedestrian crossing behaviour analysingthe effect of adaptive traffic signal which use wireless sensor. When considering sex of pedestrians, it appears that males seem to take more risks when crossing than females (Holland & Hill, 2007 [15]; Rosenbloom et al., [7]; Faria et al., [4]). Young and old individuals seem to commit also more road crossing violations than middle age people (Holland & Hill, [15]; Sullman et al., [8]).

A benefit cost analysis of the different types of traffic signal controlled crossing shows a positive benefit-cost-ratio for a complete signal regulation of an X-crossing, while the ratio is negative for a single signal-controlled pedestrian crossing (Elvik&Amundsen, [16]). Finally, traffic signal controlled pedestrian crossings on the other hand might reduce the accidents for all parties, but the effects are only of significant importance when pedestrian crossings with separate phases for pedestrians at traffic signal controlled intersections are used.

As for example, the difference between Zebra, Pelican and Puffin crossings is related to different light time (phase) in fact: a) a Zebra crossing uses flashing yellow beacon lights and black and white road markings to warn drivers to stop and allow pedestrians to cross the road. Pedestrians wait on the pavement for traffic to stop and then cross to the other side of the road. b) Pelican crossings do not have detectors. This means the length of time the traffic is stopped on a red light cannot be altered, even if the crossing is clear or no one is waiting to cross. It also means that if someone is crossing the road slowly the lights can change to green for traffic, before the pedestrian has safely reached the pavement on the other side. c) a Puffin crossing is a type of traffic signal controlled pedestrian crossing which aims to improve safety and reduce delays. To cross the road, pedestrians press the button at the Puffin crossing to change the traffic lights and then wait for a green man to be displayed. When a green man is shown traffic is stopped on a red light. Unlike Pelican crossings there is no flashing amber light for drivers, traffic is held on red all the time which helps to stop aggressive drivers intimidating pedestrians on the crossing.

Table 2 Geometrical parameters related to zebra crossing on different State

State	Crossingsectionwidth	Thickness of each single strip/ crosswalk	Distancebetweenstrips/ crosswalk	Colour
Italy	A =2,50 m (MIN) (local road, highway) A =4,00 m (MIN) (other road types)	S = 0,50 m	D =0,50 m	white
Swiss	A =3,00 -5,00 m	S = chancing value (min. 3 strips/crosswalk per lane)	D = 0,65 m	yellow
France	A =2,50 m (MIN) (4,00-6,00 m in small towns)	S = 0,50 m	D= 0,50-0,80 m	white
UK	A=2,40-10,00m (only on zebra crossing without traffic light, with "globe")	S = 0,50 -0,71 m	D =0,50 -0,71 m	white
USA	A =3,00-5,00 m (Angle orthogonal to crossing lanes)	S = 0,30- 0,61 m	D =0,30- 0,61 m	white
India	A=3,00-5,00 m	/	/	/
New Zeland	A=2,00 m (MIN) (rather than 3,00 -5,00 m)	S= 0,30 m	D= 0,60 m	white

Referring to the above TABLE 2, it has been verified that the road intersection considering for that study reflects the previous characteristics, for the Italian parameters, in all 4 arms that arrive to the road intersection. Considering the changes in duration and regulation of the traffic light cycle of road intersections, it is good to evaluate the correlation between the phases of green, the width of the crossing and the number of pedestrians who crossing section.

In particular the Minimun Green Time is the summa of two different components related to the "walk" interval (generally 7 s) and the ratio of cross walk length (m) to walking speed (m/s). The HCM[17] recommended formulation for calculating minimum green time as the follows equations (1) and (2):

$$\min G_{ped} = 0{,}27 * n_{ped} + 3.2 \qquad \text{for } W_{cw} \leq 3 \text{ m} \qquad (1)$$

$$\min G_{ped} = 0{,}81 * n_{ped}/W_{cw} + 3.2 \qquad \text{for } W_{cw} > 3 \text{ m} \qquad (2)$$

where:

a. min G_{ped} is the minimum pedestrian green time,
b. n_{ped} is the number of pedestrians waiting to cross during the red light,
c. W_{cw} is the width of the crosswalk.

The data collection is referring to an urban road intersection located in Enna, Italy (see Fig.1);VialeA. Diaz street is the main direction of the 4 arms intersection under investigation.

The peculiarity of this study lies in having shown the same intersection, the traffic light and varying (as the adaptive equipment done) the traffic cycle observing the pedestrian behaviour to vary it. The analysis carried out on 14 days of monitoring has considered the change in the traffic-light cycle along the two directions, main and secondary. The analysed area is particularly suited to the study of youngest as weak and elderly are to be present because many schools and offices in the perimeter areas.

The analysis is focused on the total number of pedestrians and specific values related to the gender, the age and the behavioural aspect during green and red phase.

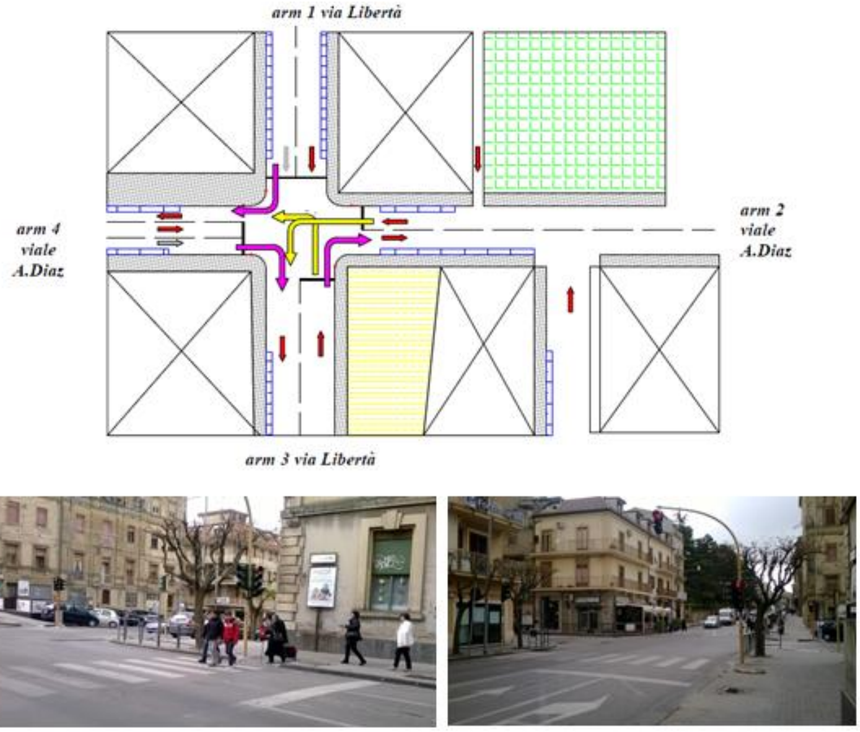

Figure 1 Signalised intersection case study (Enna, Italy)

III. Results and Discussion

This research proposes pelican crossing with independent and coordination time signal operation. Later on, the performances resulted of the implementation of pelican crossing are compared to obtain the best alternative. In addition, this research assesses the relationship between Time to Collision and the pedestrian safety.

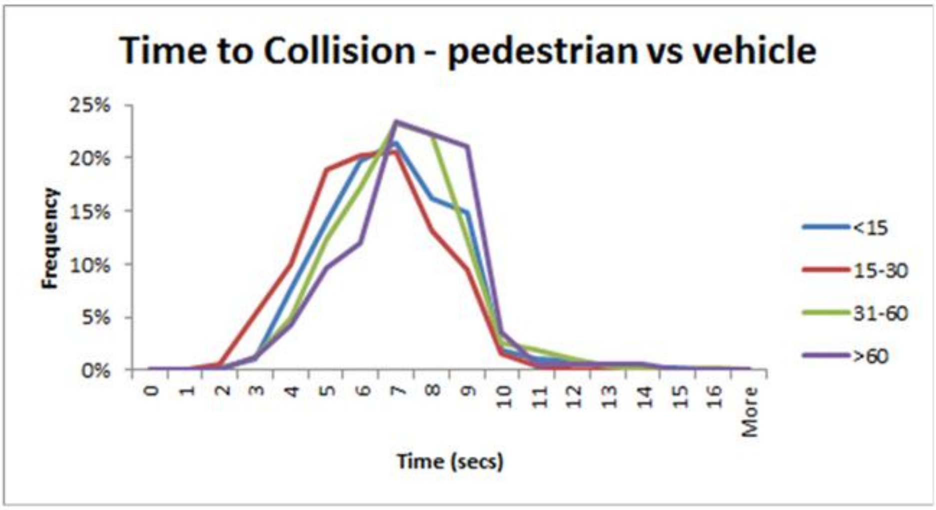

Figure 2 Time to collision (s) between pedestrian and incoming vehicle

Interestingly Fig.2 shows how pedestrian of age group <15 years and between 31 and 60 behave similarly, while age group 15-30 are taking much risk and as expected age group above 60 are more cautious. Average TTC vary from 6.3 seconds associated withage group 15-30 to 7.4 seconds for elderly (above 60).

Analysing the TTC between the first and second week of survey, there is a reduction of about 6% with peaks of 12% in the average time between pedestrian crossing and incoming vehicle, this indicates that the daily variation in traffic light setting contribute to increase the risk of pedestrian crossing during red and then the probability of accident. Interestingly, only the age group between15-30 behave slightly different with an increment of TTC of about 3%.

Fig.3 shows the variability of the TTC within the day, with lowest level associated with higher traffic volumes in the morning and afternoon, while the TTC increases of up to 12% towards the evening mainly due to reduced visibility.

When comparing first and second week of the field observations, the TTC decrease considerably during the first week when traffic light settings change daily with peaks at 10:30-11:30 and 21:30-22:30 of 20% and 8% reduction respectively.

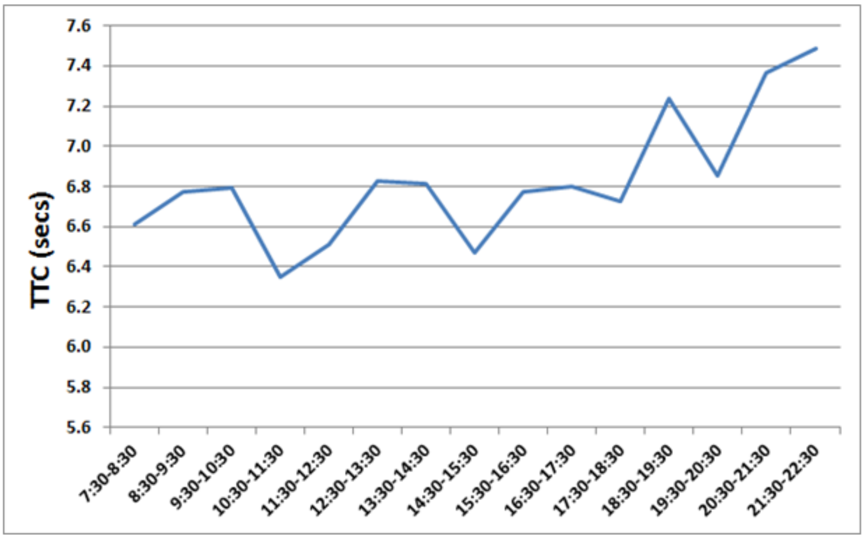

Figure 3 Time to collision (TTC) in seconds for different time of the day

When comparing female and male behaviour at crossing during red light for pedestrian, surprisingly female on average take more risk when crossing with a TTC 8% lower than male. Moreover, when comparing the first and second week, during the first week female are on average even more aggressive with a TTC 12% lower than male with a peak of 18% for the age group <15 years.

Finally, assuming an average speed of incoming vehicles of 40km/h and deceleration of $3m/s^2$, based on the time laps between pedestrian crossing and incoming vehicle measured,there will be 2.4% of pedestrian that could be hit by the incoming vehicle.

IV. Conclusions

From the survey performed during 2 weeks interesting results and behaviour of pedestrian crossing during red light for pedestrian have emerged. Variability of traffic light settings has produced an increased risk for pedestrians which are crossing on average with a reduced time to collision. The age groups that shows the higher risk is the 15-30 and female resulted to behave more aggressively than male.

From this preliminary study, when compared to previous findings described by the literature on implication of adaptive traffic light operations on Red Light Running proneness, it appears that while daily variability of traffic light settings improve the safety of vehicles, it has a detrimental effect on pedestrian safety.

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