Pedestrian Crossing Safety Improvements: Before and After Study using Traffic Conflict Techniques

Salvatore Cafiso
Professor, Dpt. of Civil & Environmental Eng., University of Catania, Viale A.Doria n.6 95125 – Catania. Italy. Phone: (39) 095 7382213. Fax: (39) 0957387913. E-mail: dcafiso@dica.unict.it
Alfredo García García
Professor, Dpt. of Transportation, Universidad Politécnica de Valencia, Camino de Vera s/n, 46071 – Valencia. Spain. Phone: (34) 963877374. Fax: (34) 963877379. E-mail: agarciag@tra.upv.es
Rosario Cavarra
PhD Candidate, Dpt. Civil & Environmental Eng., University of Catania, Viale A.Doria n.6 95125 – Catania. Italy. Phone: (39) 3284876102 . Fax: (39) 0957382247. E-mail: rcavarra@dica.unict.it
Mario Alfonso Romero Rojas
PhD Candidate, Dpt. of Transportation, Universidad Politécnica de Valencia, Camino de Vera s/n, 46071 – Valencia. Spain. Phone: (34) 963877374. Fax: (34) 963877379. E-mail:maroro2@doctor.upv.es

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ABSTRACT

Pedestrians' safety improvement is a key objective on mobility planning. For the purpose of improving the pedestrian safety, traditional reactive strategies based on identifying sites with high accident rate and implementation of conventional safety measures are not always effective. Moreover, crash history analysis often cannot be applied to the entire road network, since in many sites the sample size is not enough to have statistical validity, or historical crash data lose its validity due to changes in road system and/or operation.

Traffic Conflict Technique (TCT) represents an efficient approach for a preventive strategy. It was developed as "surrogate measure of road safety" by using near-accident indicators based on measures of spatial and temporal proximity of road users. A conflict is defined as an observed situation in which two or more users are so close in space or time which could lead to a collision if their movements remain unchanged.

The few applications of TCT on the pedestrian-vehicle conflict led the research team to evaluate an adequate measure to resume the risk in different scenarios of interaction between both actors. A new indicator of conflict, called Pedestrian Risk Index (PRI), has been developed. PRI is based on both duration time and severity of the conflict between vehicle and pedestrian.

A before-after study was carried out along the crossing road in Bélgida (Valencia, Spain) in order to evaluate the safety results of new traffic calming devices installed replacing zebra marked crosswalks. To measure the indicators, digital video records were used in order to optimize the analysis.

The application of the Pedestrian Risk Index showed that this indicator is effective to highlight modifications in the driver behavior due to installation of different safety countermeasures at a crosswalk.

INTRODUCTION AND BACKGROUND

Traffic safety is commonly measured in terms of the number of traffic accidents and the consequences of these accidents in terms of severity. While this historical data approach is useful for the identification of safety problems, it is regarded as a 'reactive' approach implying that a significant number of accidents must be recorded before a decision could be taken. A further drawback with this approach concerns the quality and availability of accident data.

In order to perform a different form of safety analysis, the use of Surrogate Measures of safety has been suggested as an alternative to accident data analysis.

To be useful for transportation safety applications, a surrogate measures technique should satisfy two conditions (Tarko et. al., 2009):

1. A measurable or observable non-crash event that is physically related in a predictable and reliable way to crashes, and
2. A practical method for converting or calibrating the non-crash event into a corresponding crash frequency and/or severity.

For the first condition, there are known relationships between surrogate measures and safety, so they can be used to predict relative safety. About the second condition, there is a lack of knowledge for converting the results into either crash frequency or severity.

The Traffic Conflict Technique (TCT) is perhaps the most developed indirect method of safety surrogate measure. The technique itself is grounded in the ability to register the occurrence of near-accidents directly in real-time traffic and therefore offers a faster and, in many aspects, more representative way of estimating expected accident frequency and accident outcomes.

The concept of traffic conflicts was first introduced in 1968 during the ICTCT meeting (International Co-operation on Theories and Concepts in Traffic Safety) in Oslo, as: "*A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is risk of collision if their movements remain unchanged*".

The primary advantage of TCT is that conflicts occurred much more frequently than accidents. The conflict method provided a clearer picture of the initial causes of the accidents, something often lacking from accident reports. Furthermore TCT may provide information on relative risks to diagnose the types of problems at a particular location, and it represents an easy and efficient tool to check location safety issues when there is limited or no crash data.

The predictive validity of the TCT is most often determined by the level of statistical correlation between observed conflicts and accident data. Chin and Quek (Chin and Quek, 1997) suggest that validity problems were at least partially due to the quality and coverage of accident data. Hydén (Hydén, 1987) also pointed out the need for validation in relation to the diagnostic qualities of the Traffic Conflict Technique instead of the more typical "first generation" approach that was mainly directed at establishing predictive ability. Furthermore, Migletz (Migletz et.al., 1985) and Svensson (Svensson, 1992), indicated that conflict studies can produce estimates of accident occurrence that are as good as those based on accident data, but requiring a significantly shorter period for data collection.

If a relationship can be hypothesize between the conflict measure and the probability of collision, then the quantification of this relationship provides a common link between normal traffic environment, near collisions, and actual collisions. The reliability of conflict measures can be improved by the use of objectively defined measures to verify difficult and complex conflict situations, for example, through processes involving video-analysis.

PEDESTRIAN TRAFFIC CONFLICT TECHNIQUE

Although the improvement of conditions for pedestrian movement is a key objective of planning for mobility (Ministry of Public Works, 1998; Harkey and Zegeer, 2004), in the design of transport systems pedestrians are often overlooked (Zegeer et al. , 2004), with serious consequences for safety.

In 2006, more than 3.500 pedestrians died from road traffic accidents in 14 European countries. This corresponds to more than 14% of road traffic fatalities in these countries.

From ERSO (European Road Safety Observatory) statistical data in 2005, in the 19 references countries of the European Union (EU-19: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Luxembourg, Malta, Netherlands, Poland, Portugal, Spain, Sweden, United Kingdom), the average rate of pedestrian fatalities (in and outside pedestrian crossings) per 1 million population amounts at 15,9, with Estonia (47,6) and Poland (46) presenting the highest ratio. The EU-19 average proportion of pedestrian fatalities in the total number of road traffic fatalities is 17,9%. The proportion is lowest in the Netherlands and Luxembourg (below 10%) as well as in Belgium and France (below 12%), while Poland, Estonia and Malta come out with more than 30% .

Although largely developed in the case of conflicts between vehicles, TCT presents some gaps or lacks when vulnerable users, like pedestrian, act a role in the conflict. In literature, existing applications report some attempts to define spatial or temporal index to classify the severity of vehicle-pedestrian conflict.

Among these, it can be mentioned the Time to Collision (TTC), the time, in different phases of conflict, should occur for a vehicle to collide with another road user, if relative speed and remain invariant (Hayward, 1972). When there is a conflict, the value of TTC varies over time, therefore a proper evaluation requires a continuous monitoring with the identification of the critical value (e.g. minimum).

The Time to Zebra (TTZ) was proposed (Varhelyi, 1996) as a variation of the concept of Time to Collision developed in order to estimate frequency and severity of the critical situation between the vehicles that are approaching the pedestrian crossing and the pedestrians who are crossing it. TTZ is determined at the start instant of the conflict that has to be identified by the observer.

The Post Encroachment Time (PET) between two road users, defined by Allen (Allen, 1978), can be adopted to serve the purpose, too. The PET is defined as the period of time from the moment when the first road user is leaving the conflict area until the second road user reaches it. The size of this time gap is proportional to the unsafeness of the observed traffic situation.

Related with PET, Hupfer (Hupfer, 1997) proposed the DST (Deceleration to Safety Time), that is the necessary deceleration to reach the last calculable PET_0 (i.e. when PET =0, there is DST_0). The calculation of DST refers to the position of the first road user, when leaving the conflict area. The second road user may reach this point not earlier than the first road user leaves it.

The above mentioned indices has several applications, but their weakness concerns the point to discriminate the severity among different conflicts and the uncertainty to define the critical instant of the conflict. The Pedestrian Risk Index (PRI) was proposed as new conflict indicator , in order to overcome this poorness and make it appropriate for different traffic situations (Cafiso et al., 2008).

Pedestrian Risk Index (PRI)

PRI is an indicator of the type "if.. then" to evaluate the potential severity of a pedestrian-vehicle conflict, relating it both to time duration and dangerousness of the traffic situation.

If a pedestrian-vehicle conflict is analyzed, it can be identified three different phases:

1. Stopping phase: the vehicle is so far and with a speed that it can stop in safety in the possibility of pedestrian presence on walk side;
2. Conflict phase: the two road users mutual positions and speed can lead to collision if conflict actors don’t take an evasive maneuver (according conflict definition);
3. Passing phase: the vehicle is too close to pedestrian crossing that it can overtake the conflict area before the pedestrian reaches it.

From a safety point of view, the second phase has to be identified and analyzed to determine the physical and behavioral factors causing a potential accident.

With this aim, for each instant of the conflict (Figure 1), three temporal values were defined.

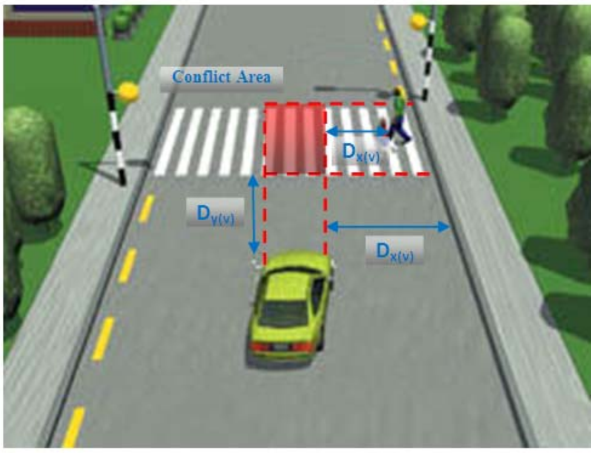

FIGURE 1 Conflict representation.

The first one is the Time to Collision of the vehicle, obtained from following equation:

$$TTC_{i\,(v)} = \frac{D_{yi\,(v)}}{V_{i\,(v)}}$$

where

$TTC_{i(v)}$ [sec] is the time that a vehicle takes to reach the pedestrian crossing or else the time to a potential collision with in crossing pedestrian (TTZ), at the time *i*.

$D_{yi\,(v)}$ [m] is the longitudinal vehicle position or distance between the vehicle and the crossing at the time *i*.

$V_{i(v)}$ [m/sec] is the vehicle speed at the same time *i*.

Time to Collision of pedestrian is carried out in order to establish if a pedestrian can arrive at the conflict area in an appropriate time to collide with vehicle.

$$TTC_{i\,(p)} = \frac{D_{xi\,(v)} - D_{xi(p)}}{V_p}$$

where
$TTC_{i(p)}$ [sec] is the pedestrian time to reach conflict area, at the time *i*.
$D_{xi\,(v)}$ [m] is the transversal vehicle position at the time *i*.
$D_{xi\,(p)}$ [m] is the pedestrian position on crossing at the same time *i*.
V_p [m/sec] is the pedestrian speed.

The third conflict parameter is the vehicle time to stopping (T_s), carried out using the following formula:

$$T_{si} = T_r - \frac{V_{i\,(v)}}{2a_b}$$

Where
T_{si} [sec] is the stopping time at instant i.
T_r [sec]is the reaction time of the driver .
$V_{i(v)}$ is the vehicle speed at the time *i*.
a_b [m/sec^2] is the braking deceleration.

These temporal parameters are utilized to define the time interval of conflict existence, identifying the above mentioned three phases. So, when $TTC_v>T_s$, it means that the vehicle can stop in safety before the conflict area (Stopping phase). At the same way, the pedestrian reaches the conflict area only after the vehicle has passed when $TTC_v<TTC_p$ (Passing phases). The potential conflict time (Conflict phase) is the so called $TTZ_{duration}$ (Time To Zebra duration), i.e. the time during that the vehicle can't stop before to reach the conflict area ($TTC_v<T_s$) and the pedestrian is exposed to conflict with vehicle ($TTC_p > TTC_v$), as illustrated in Figure 2.

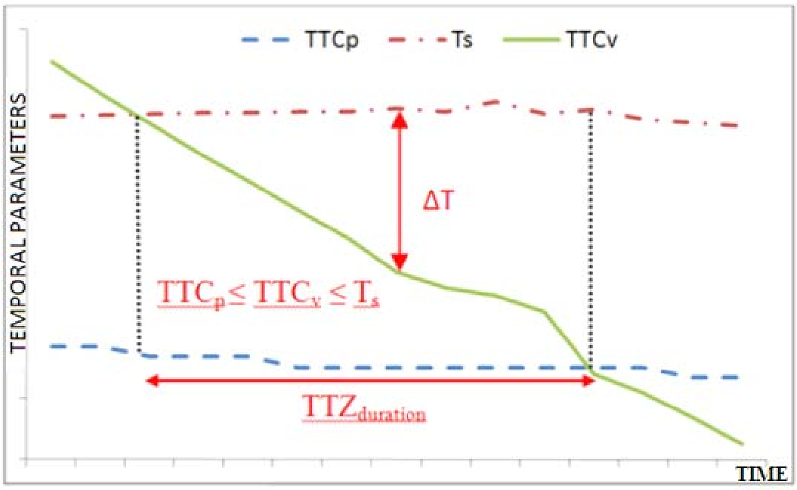

FIGURE 2 Potential conflict time ($TTZ_{duration}$).

The difference ΔT_i, between the Time to Stopping, T_s, and the Time to Collision, TTC at instant i, is taken to evaluate the reduction in the time to make a safe emergency brake.

In order to take into account the severity of collision consequences, an additional parameter used in the formulation of PRI is the potential impact speed (V_{impact}) or the speed at the moment of the collision supposing a braking deceleration.

According previous studies (Hannawald and Kauer, 2004; Rosén and Sander, 2009; Cuerden et al., 2007), the severity of pedestrian fatalities increases with the square of the impact speed, V_{impact}^2 , that can be obtained the formula:

$$V_{impact\ i} = V_{i(v)} - 2a_b \times (D_{yi(v)} - V_{i\ (v)} \times T_r)$$

where

$V_{impacti}$ [m/sec] is the potential collision speed at the instant *i*

$V_{i(v)}$ is the initial vehicle speed at the time *i*,

a_b is breaking deceleration,

$D_{yi\ (v)}$ is the longitudinal vehicle distance from the conflict area,

T_r is the perception and reaction time of the driver.

$V_{i(v)}xT_r$ is the distance travelled during the perception and reaction time.

Pedestrian Risk Index is so defined:

$$PRI = \sum_{TTZ_{duration}} V_{impact\ i}^{\ 2} \times \Delta T_i$$

where

$V_{impacti}$ is the potential collision speed at the instant *i*

ΔT_i [sec] is the difference between the T_{si} and TTC_{vi} (figure 2).

Nevertheless in the former part of the conflict, a relationship of proportionality between V_{impact} and ΔT is detected, both the terms are considered in PRI formula, taking into account the lack of correlation in the latter part of the conflict when TTC is less than the reaction time.

APPLICATION

The selected site for in-field experiment is located along a cross road in the Spanish town of Bélgida (Valencia-Spain,). Two pedestrian crossing are placed in a four legs intersection (Figure 3), combining a main road, where are placed the crossings, and a secondary street serving penetration traffic.

Because the site configuration, the speeds on the main road assume high values, influencing the pedestrian traffic and creating a potential dangerous situation and a sense of no-safety in the vulnerable road users.

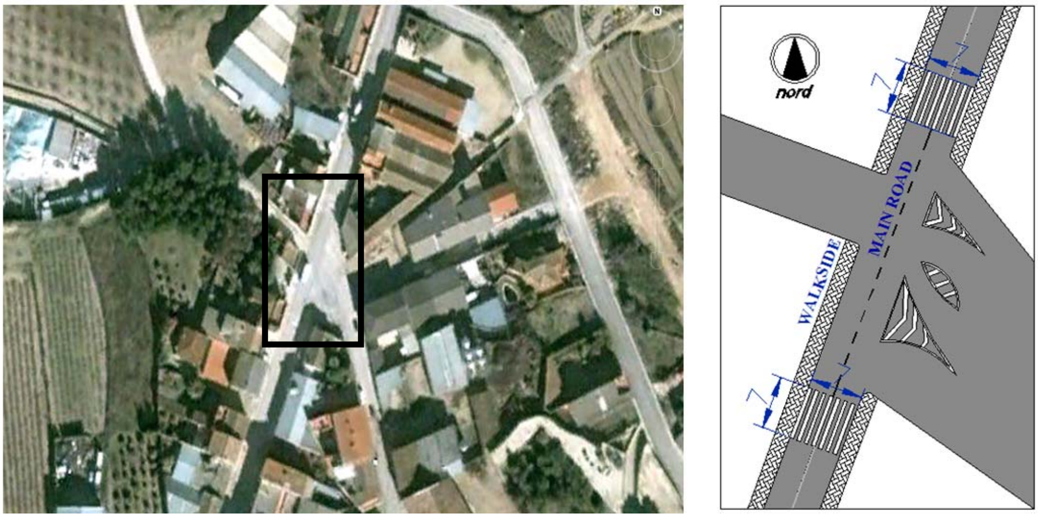

FIGURE 3 Site on study.

Traffic calming improvements have been implemented in different stages on the main road, as a part of the research project called MODETRA "Methodology for the design and implementation of traffic calming devices", led to experiment different traffic calming typologies, in order to evaluate their effectiveness, to provide general recommendation in the choice of interventions and to optimize transportation resources management.

This "composite" before-after study was developed during four phases of the intervention implementation, starting from the original situation (0-configuration) to arrive at more complete configurations with humps and raised crosswalks.

Scenarios

First scenario (North 1 & South 1)

The initial configuration includes two zebra crossing with a bad maintenance state with poorly visible painting. This first video capture was on April 3th 2009, between 9:00 and 13:00 (Figure 4).

FIGURE 4 Southern (A) and Northern (B) Crosswalk in the first scenario.

Second scenario (North 2 & South 2)
The first intervention regards the painting, bringing back it at original contrast and making crossing visibility at optimal condition. In this case the crossings are easily detected but without any speed calming improvement. The crosswalk painting was operated on April 9th 2009 and the videos were taken between 9:00 and 13:00 on April 28th 2009 (Figure 5).

FIGURE 5 Southern (A) and Northern (B) Crosswalk in the second scenario.

Third scenario (North 3 & South 3)
In third phase the two crossings are implemented with different traffic calming interventions.

Northern crosswalk is left in the same condition of the second step but a hump is set 60 meters before for the vehicle from north (maximum height of about 6 cm), while in other direction a raised crosswalk is placed in correspondence of the other zebra crossing (south), in order to calm the speed (Figure 6). The raised crossing was built with a maximum height of about 10 cm and ramps inclination of 1:20, for a plane dimension of 7 m in width and 9 m in length.

The intervention was made on July 2nd 2009 in order to permit video capture on July 15th 2009, in the same temporal interval of previous ones.

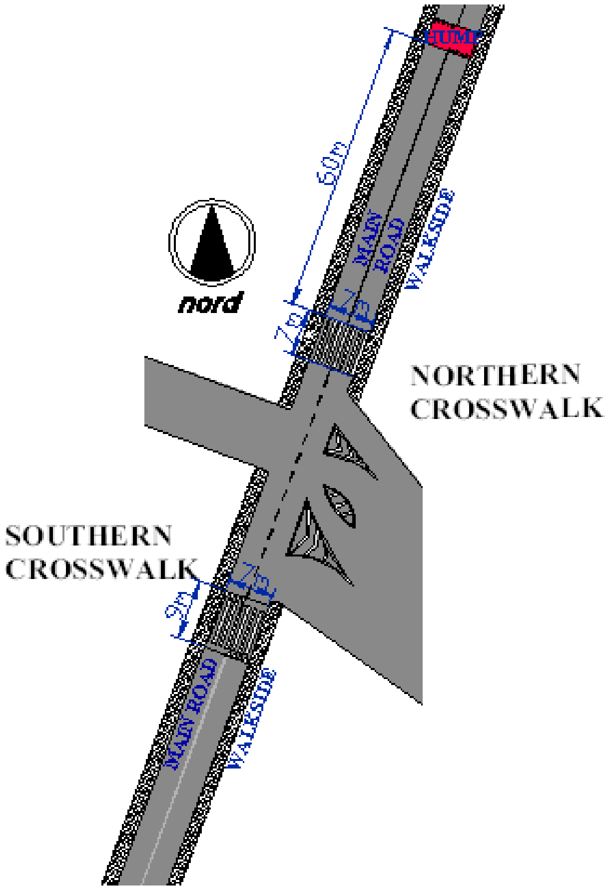

FIGURE 6 Southern and Northern Crosswalk in the third scenario.

Fourth scenario (North 4 & South 4)

The last improvement concerns the setting of a prefabricated raised crosswalk on the northern zebra crossing that is combined with the hump realized in the previous step (Figure 7). The maximum height of this table is of 7.5 cm for a length of 7 meters and width of 5.5 m. The ramps inclination is 1:10.

The southern one remains raised like the third phase with the addition of a prefabricated speed hump at 200 m before it. The designed date of this last video capture was on September 3th 2009, more than 30 days after the intervention, above described, that is on July 30th 2009. Analysis period concerns the four hour interval between 9:00 and 13:00 a.m.

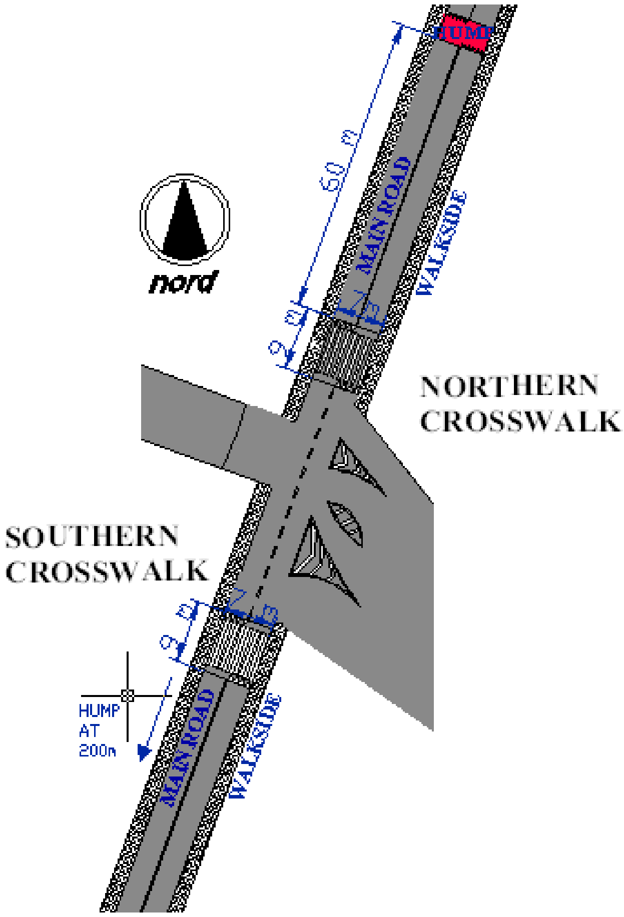

FIGURE 7 Southern and Northern Crosswalk in the fourth scenario

Data survey, collection and treatment

It is possible to use post-processing techniques, such as the video processing in order to extract all the conflict parameters (time and distance) to calculate, for each time step, the factors composing PRI. The utilized technology consisted in six digital cameras set on a raised platform (the mobile laboratory of the Department of Transportation of the University Of Valencia). The location of the cameras permits a sufficiently wide zone of over-position to have a redundancy of elements (visibility of a point at least in two videos). Furthermore an high setting of the cameras is planned, so it is not visible from the drivers in order to not influence their behaviour. The frame rate is 5 per second, that is step of 0.2 sec, according to the need of the analysis that it doesn't require a better accuracy.

To simplify data elaboration, Visual Basic software, called "Vision Artificial", was used. Created by Department of Transportation of the University of Valencia, Vision Artificial permits to extract the position of the vehicle and the pedestrian by frame to frame. In this way it is known the longitudinal and transversal position of the two road users, so that, by using these parameters, speed and position data can be obtained. To evaluate the speed, the research team has adopted a logarithmic interpolation between different frames, in order to refine the measure and make it more realistic.

For the present application it was considerate appropriate to choose a value of a reaction time, T_r, of 2 sec, as well as a deceleration of 0.5 m/sec^2. Moreover, this study adopts a pedestrian crosswalk walking speed value of 1.2 m/s (HCM, 2000). These values can be easily modified if different conditions are evaluated or to carry out a sensitive analysis.

The wheel-powered users are excluded from analysis, because aggressive behavior, in approaching pedestrian crossing, can false safety evaluation (Cafiso, Montella et all., 2008). To uniform the PRI estimate, the only considered vehicles are passenger car and LGV (Light Goods Vehicle).

The extracted data concern the situation of free flow condition for vehicles (isolated vehicle) with and without the presence of a visible pedestrian on sidewalk, waiting to walk on pedestrian crossing (Figura 8).

FIGURE 8 Data analysis with (A) and without (B) pedestrian on sidewalk

Analysis of results

For the different crosswalk configurations, the traffic conflicts were evaluated and the corresponding Pedestrian Risk Indexes were calculated in order to extract information about the effectiveness of the safety improvements and the sensitivity of the new proposed indicator to identify these modifications on site configuration. Tables 1 and 2 show the mean (μ) and standard deviation (σ) of PRI statistics for the different scenarios.

TABLE 1 Means and Standard Deviations of PRI in the Four Configurations in Northern Crosswalk

		1^Scenario [North_1]		2^ Scenario [North_2]		3^ Scenario [North_3]		4^ Scenario [North_4]	
		Sample	PRI	Sample	PRI	Sample	PRI	Sample	PRI
North->South without Pedestrian	μ	60	**1607.29**	32	**1344.91**	40	**424.73**	38	**219.41**
	σ		1370.24		833.57		224.88		209.26
North->South with Pedestrian	μ	38	**2207.21**	37	**1188.63**	35	**462.84**	37	**197.02**
	σ		1636.40		897.29		255.48		118.66

TABLE 2 Means and Standard Deviations of PRI in the Four Configurations in Southern Crosswalk

		1^Scenario [South_1]		2^ Scenario [South_2]		3^ Scenario [South_3]		4^ Scenario [South_4]	
		Sample	PRI	Sample	PRI	Sample	PRI	Sample	PRI
South->North without Pedestrian	μ	60	**903.67**	55	**1124.17**	30	**331.02**	32	**283.20**
	σ		861.48		694.07		371.42		146.00
South->North with Pedestrian	μ	47	**818.28**	35	**784.83**	30	**170.30**	34	**342.30**
	σ		442.99		489.00		143.54		145.23

In order to verify the statistical significance of the differences between the average values of PRI obtained in the different scenarios of pedestrian crossing, a Student t-test was conducted. Considering a level of confidence of 95%, if the P-value is less than 0.05, we can reject the null hypothesis (the case of equal mean) in favor of the alternative and, therefore we can consider the difference in the mean value of PRI as statistically significant (gray cells in Tables 3 and 4). To carry out the t-student test, previously, a F-test was operated to assume or not an equal variance between analyzed samples (Table 3 and Table 4).

TABLE 3 F-test and Student T-test for Means Difference in the Four Configurations in Northern Crosswalk

Scenary	NO PEDESTRIAN					WITH PEDESTRIAN				
	ΔPRI	F-Test		T-Student		ΔPRI	F-Test		T-Student	
		F-ratio	P-value	T-value	P-value		F-ratio	P-value	T-value	P-value
Nord_1 vs Nord_2	262.37	2.702	0.004	1.140	0.258	1018.58	3.326	0.000	3.354	0.001
Nord_1 vs Nord_3	1182.56	37.129	0.000	5.401	0.000	1744.37	41.024	0.000	6.485	0.000
Nord_1 vs Nord_4	1387.88	42.876	0.000	7.705	0.000	2010.19	190.191	0.000	7.552	0.000
Nord_2 vs Nord_3	920.19	13.740	0.000	6.070	0.000	725.78	12.334	0.000	4.721	0.000
Nord_2 vs Nord_4	1125.50	15.868	0.000	7.443	0.000	991.60	57.184	0.000	6.664	0.000
Nord_3 vs Nord_4	205.32	1.1548	0.662	4.168	0.000	265.82	4.635	0.000	5.609	0.000

Tests with different mean at 95% level of significance are highlighted in grey cells

TABLE 4 F-test and T-Student for Means Difference in the Four Configurations in Southern Crosswalk

Scenary	NO PEDESTRIAN					WITH PEDESTRIAN				
	ΔPRI	F-Test		T-Student		ΔPRI	F-Test		T-Student	
		F-ratio	P-value	T-value	P-value		F-ratio	P-value	T-value	P-value
Sud_1 vs Sud_2	-220.50	1.540	0.110	-1.503	0.136	33.45	0.820	0.527	0.323	0.747
Sud_1 vs Sud_3	572.65	5.379	0.000	4.396	0.000	647.98	9.523	0.000	9.293	0.000
Sud_1 vs Sud_4	620.47	34.816	0.000	5.434	0.000	475.98	9.303	0.000	6.873	0.000
Sud_2 vs Sud_3	793.16	3.492	0.001	6.862	0.000	614.53	11.604	0.000	7.087	0.000
Sud_2 vs Sud_4	840.97	22.600	0.000	8.662	0.000	442.53	11.336	0.000	5.126	0.000
Sud_3 vs Sud_4	47.81	6.472	0.000	0.659	0.513	-172.00	0.976	0.955	-4.754	0.000

Tests with different mean at 95% level of significance are highlighted in grey cells

Based on the obtained results and experimental scenarios, the following considerations about the effectiveness of the improvements can be highlighted:

- The repainting of the Zebra has not showed a significant reduction of PRI values.
- The use of traffic calming such as humps and raised tables reveals a considerable improvement in road safety conditions as demonstrate by lowest PRI values. Specifically, the configurations with tables present best effects in calming the behavior of road users compared with the presence of hump set before the pedestrian crossings.
- The sequence of an hump and a table doesn’t imply remarkable benefits in front of solutions with only one equipment.
- The vehicle driver doesn’t seem perceive the presence of a pedestrian waiting to cross on walkside as a limitations of own maneuvering space, as indicated by statistically no significant different in PRIs between with Pedestrian and no Pedestrian cases.

CONCLUSION

Traditionally road accident statistics are used to assess the level of road safety and evaluate road safety programs. In some cases, the lack of good and reliable accident records have hampered proper analysis.

An alternative approach that overcomes this problem is the safety Surrogates Measures, like, Traffic Conflict parameters which relies an observation of critical traffic situation. An advantage of TCT with respect to crash analysis is to permit to analyze a large sample in a short period of observation.

Even a statistical correlation between TCT indices and number of accident is complex to define, the TCT is able to identify and evaluate operational deficiencies and improvements.

A new TCT index was proposed to analyze conflicts between vehicle and pedestrian. PRI is defined to evaluate the potential severity of a pedestrian-vehicle conflict, relating it both to severity and dangerousness of the traffic situation.

The application of the Pedestrian Risk Index method showed that this indicator is effective to highlight modifications in the driver behavior due to safety improvements at a crosswalk.

Specifically in the case of the use of traffic calming such as humps and raised tables, the case study reveals a considerable improvement in road safety conditions. The configurations with tables present best effects in calming the behavior of road users compared with the presence of humps set before the pedestrian crossings. Otherwise, the sequence of a speed hump and a speed table doesn't imply remarkable benefits in front of solutions with only one device.

Use of modern technology such as automated video-analysis techniques is proven to simplify and make faster the Traffic Conflict analysis.

PRI showed its ability to evaluate the potential risk of collision for each pedestrian crossing the road in the presence of a vehicle. Therefore, PRI can be considered a "specific" risk factor, in order to compare different sites, an exposure factor (EXPO) must, also, be used to take into account the vehicle ($AADT_v$) and pedestrian traffic flow ($AADT_{ped}$) at the crossing. The overall risk factor can be evaluated by the combination of PRI and EXPO (e.g. RISK = EXPO x PRI)

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