INTERSECTIONS DESIGN AND POWERED TWO WHEELERS INTERACTION: EXPERIMENTAL INVESTIGATION OF AN ACCIDENT PREDICTION MODEL

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ABSTRACT

Powered two wheelers (PTW) differ in their use of the road from other vehicles and they have different needs; predictable road geometry, good visibility, high quality road surface, while important for all road users, are essential for PTW.

In order to increase road safety, the European Commission has recently introduced a comprehensive system of infrastructure safety management (Directive Proposal 5 October 2006). Significant improvements in safety, particularly as it relates to the road infrastructure, can only be achieved if vulnerable modes such as PTWs are 'mainstreamed' in safety management and road design, with their benefits of use (particularly in traffic-congested urban environments) included as part of the wider transport policy.

From this statement, the aim of this paper is the validation, for Italian roads, of a previous model in order to address the intersection geometric features on the prediction of the motorcyclist safety, using traffic and accident data collected on site.

Keywords: powered two wheelers, intersection, accident prediction model

1. INTRODUCTION

In these days of increasing congestion in our cities, powered two wheelers (PTW) provide a valuable contribution to mobility. Their relatively small size enables them to blend efficiently into the traffic flow, while needing less space compared to other vehicles. However, PTW form one of the most vulnerable groups of road users and accidents involving injuries to them are a major social concern. The communication of the European Commission of February 2006 "European Road Safety Action Program: Mid-Term Review" points out that "the number of motorcyclists killed as a proportion of total road deaths, which was relatively stable at around 9.5% until 1996, has risen relentlessly to 14% in 2003. In overall terms, the number of motorcyclists killed rose by 5.6% between 2000 and 2003, while the total number of people dead on the roads fell by 12% over the same period. The PTW riders are the only category of users for which the fatality rate is rising in contrast to the overall downward trend" [1] (figure 1). Since the majority of these accidents involves people younger than 35 years old, the design of safe roads for all users' categories, inclosing PTW, becomes a primary requirement.

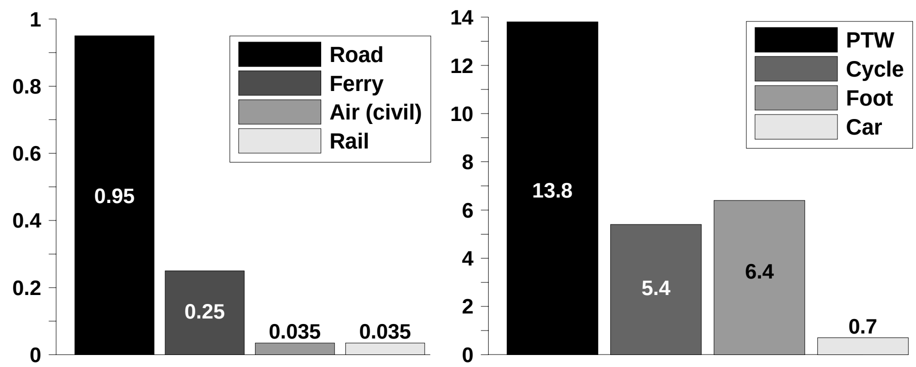

Figure 1: EU15 deaths per 100 million person kilometres by mode of transport and on the road [2]

Numerous studies show that human failure is the primary cause of PTW accidents; nevertheless a large number of them are produced by infrastructure shortcomings and at least half of them occur at an intersection [3]. So the evaluation of what elements of the intersection have an influence on the accidents trend and what opportunities exist to change them obtaining a reduction of crashes number and severity, becomes very important. In this way accident prediction models (APMs) are very useful tools.

After an overview on the main features of an APM, starting from traffic and accident data detected on different urban intersections, the aim of this paper consists in providing useful results for designers, construction and maintenance contractors, in order to address the junction geometric features on the prediction of the PTW safety.

2. ACCIDENT PREDICTION MODELS FOR INTERSECTIONS

2.1 Introduction

Accident prediction models (APMs) have often developed to explain uncertainty in the occurrence of road crashes, otherwise defined as risk. Being very useful tools for estimating the expected number of accidents on entities such as intersections, they are typically used in the identification of sites for possible safety treatments [4]. An APM, also known as Safety Performance Function (SPF), is, in essence, a mathematical equation that expresses the average accident frequency of a site as a function of traffic flow and other its characteristics. There exist many model forms for APM, but one of the most common ones for intersections is the following [4]:

$$E\{k\} = \alpha F_1^{\beta_1} F_2^{\beta_2} \quad (1)$$

where $E\{k\}$ is the expected number of accidents per unit of time, F_1 and F_2 are the entering flows on the major and minor roads respectively, β_1 and β_2 are coefficients to be estimated. The calibration of these coefficients is not straightforward because [4]:

- high quality data is required to obtain a large enough sample of entities and crashes;
- to acquire the accident database, several years of data are used;
- specification of the mathematical form is not a trivial task.

To obtain an APM significant for PTW accidents prediction, is very important to take into consideration heterogeneous traffic flows, because in our cities the same road space is used by cars, buses, scooters, motorcycles, bicycles, pedestrians, etc [5]. All these vehicles, which have varied dynamic and static features, share the same carriageway, causing a traffic characterized by lack of any effective canalization, mode segregation or control of speeds. So having an ideal capacity by lane is a misconception, because lane discipline is very loose. Motorcyclists, for example, judges whether the lateral distance (width) between a scooter and bus is acceptable to progress on the roadway. Another PTW rider in the same situation would have a different critical width acceptance. If it is unacceptable, then an entity is constrained by preceding entities. In homogeneous conditions, traffic entities form one-dimensional queues (figure 2); in heterogeneous ones, mass queues develop and they grow lengthwise as well as laterally.

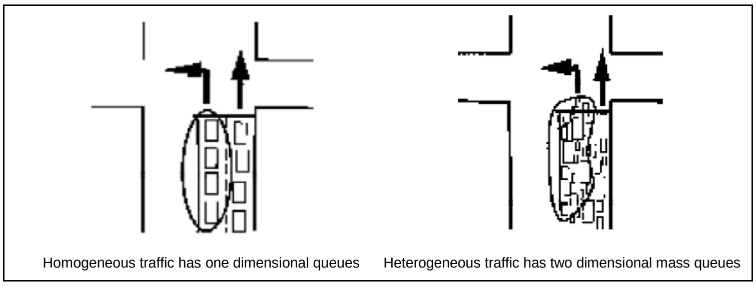

Figure 2: Queuing theory [5]

The "car following" notion used in homogeneous traffic flow models is not applicable in heterogeneous condition (figure 3). Since cars do not comprise most of the traffic mixture, "car following" is an incorrect term. Secondly, since width of entities vary greatly in heterogeneous traffic, figuring out which leading entity/vehicle it is following is difficult. Leading entities may run parallel or staggered.

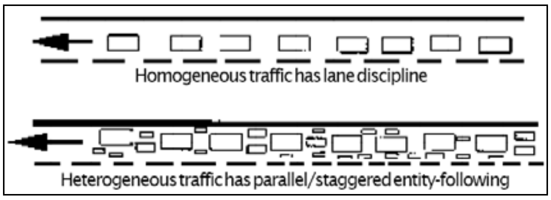

Figure 3: Car following [5]

2.2 Accident prediction models for intersections: literature review

A literature review indicated that mostly of previous studies on APMs for intersections have been concerned with all vehicles-related crashes and flows [6-14]. These models, in particular, evaluate the accident frequency of an intersection as a function of the total flows on major and minor road approaches, without taking into consideration the traffic heterogeneity. Since there is the evidence that PTW crashes at junctions are very significant, the use of traffic flows disaggregated by nonmotorcycles and motorcycles is extremely important.

The complexities of calibrating APMs perhaps explain why there is a relatively small selection of these available for intersections. Of note are the research works of Harner et al., that provided models for predicting motorcycle crashes on urban roads in Malaysia at signalized, non-signalized and three-legged priority junctions [15-17]. Traffic entering the intersection, approach speed, lane width, number of lanes, shoulder width and land use at the crossing approach were found to be significant in describing motorcycle accidents. A generalized linear modelling technique was adopted, with Poisson or negative binomial error structure. This is widely accepted as more appropriate for the characteristics of crashes (i.e. discrete, rare, and independent) than the classical linear model based on normal error structure with a constant variance [9]. Crashes can be characterized by their mean number per unit time and are simply represented by a Poisson random variable. The 51 intersections studied were selected based on the following conditions:

- only marginal or insignificant change in land use;
- no major modifications or upgrading;
- an equal number of lanes on the corresponding major and minor roads;
- only marginal change of signal characteristics, for example, timing and phasing;
- intersections must have had fatalities and/or serious and slight injuries in crashes.

Four-year's worth of motorcycle crash data on the selected intersections, from 1997 to 2000, were collected. Hourly traffic volume (disaggregated by nonmotorcycles and motorcycles) was counted on major and minor road approaches and then converted to the estimated annual average daily traffic (AADT). Intersection geometry, number of legs, approach speed, pedestrian flow and land use (commercial or non-commercial areas) for each selected intersection were also observed on site. In the general model proposed, the response variable was the number of motorcycle crashes and the explanatory variables were traffic flow (disaggregated by nonmotorcycles and motorcycles both for major and minor roads), pedestrian flow, approach speed, lane width, number of lanes and legs, shoulder width and land use. The continuous variables were identified as traffic flow, pedestrian flow, approach speed, lane width and number of lanes, while the categorical variables were number of legs with two-factor levels, shoulder width with three-factor levels, and land-use with two factor levels. In particular, the motorcycle crashes per year (MCA) were been evaluated as follows:

$$MCA = (k_1 \cdot QNMm^{\alpha_1}) \cdot (QNMn^{\alpha_2}) \cdot (QMm^{\alpha_3}) \cdot (QMn^{\alpha_4}) \cdot (QPED^{\alpha_5}) \cdot EXP^{Z} \tag{2}$$

where:

$$\begin{aligned} z = {} & \beta_1 \cdot SPEED + \beta_2 \cdot LWm + \beta_3 \cdot LWn + \beta_4 \cdot LNm + \beta_5 \cdot LNn + \\ & \beta_6 \cdot NL + \beta_7 \cdot SHDW + \beta_8 \cdot LU + e \end{aligned} \tag{3}$$

Descriptions of all the explanatory variables are presented in table 1. The k_1, k_2, α_1, α_2, α_3, α_4, α_5, β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8 are the parameters to be estimated and the term e is the error representing the residual difference between the actual and predicted models.

Table 1: Description of the explanatory variables

Variable	Description	Coding system
QNMm	Nonmotorcycle flow on major road (nmpd)	QNMm
QNMn	Nonmotorcycle flow on minor road (nmpd)	QNMn
QMm	Motorcycle flow on major road (mpd)	QMm
QMn	Motorcycle flow on minor road (mpd)	QMn
QPED	Pedestrian flow (pedestrians/ h)	QPED
SPEED	Approach speed (km/h)	SPEED
LWm	Average lane width on major road (m)	LWm
LWn	Average lane width on minor road (m)	LWn
LNm	Number of lanes on major road (lanes/traffic direction)	LNm
LNn	Number of lanes on minor road (lanes/traffic direction)	LNn
NL	Number of legs	(1) 3-legged (2) 4-legged
SHDW	Average shoulder width on major and minor road [m]	(1) SHDW = 0.00 m (2) 0.00<SHDW<1.00 m (3) SHDW > 1.00 m
LU	Land use category	(1) Non-commercial Area (2) Commercial area

Key: mpd = motorcycles per day; nmpd = nonmotorcycles per day.

Using a logarithmic transformation, the loglinear version of the model is:

$$Ln(MCA) = Ln(k_1) + \alpha_1 \cdot Ln(QNMm) + \alpha_2 \cdot Ln \cdot (QNMn) + \alpha_3 \cdot Ln \cdot (QMm) \\ + \alpha_4 \cdot Ln \cdot (QMn) + \alpha_5 \cdot Ln \cdot (QPED) + z \quad (4)$$

where:

$$z = \beta_1 \cdot SPEED + \beta_2 \cdot LWm + \beta_3 \cdot LWn + \beta_4 \cdot LNm + \beta_5 \cdot LNn + \\ \beta_6 \cdot NL + \beta_7 \cdot SHDW + \beta_8 \cdot LU + e \quad (5)$$

Both multivariate and univariate analyses were conducted for model.

For signalized intersections, the multivariate analysis shown that all terms, except QPED, LNn, and NL were significant at the 5% level. So these factors were excluded from any further analysis and the final model is:

$$MCA = 0.002822 \cdot QNMm^{0.3241} \cdot QNMn^{0.0835} \cdot QMm^{0.0683} \cdot QMn^{0.1296} \cdot EXP^{Z} \quad (6)$$

where:

$$z = 0.02602 \cdot SPEED - 0.0727 \cdot LWm - 0.0718 \cdot LWn \\ - 0.01758 \cdot LNm - \beta_7 \cdot SHDW + \beta_8 \cdot LU \quad (7)$$

where MCA is motorcycle crashes per year, $\beta_7 = 0.0$, 0.01755 and 0.02554 for SHDW = 1, 2 and 3 respectively, $\beta_8 = 0.0$ and 0.01591 for LU = 1 and 2 respectively (table 1).

For three-legged priority intersections, the final model is:

$$MCA = 0.0059294 \cdot QNMm^{0.2188} \cdot QNMn^{0.0665} \cdot QMm^{0.132} \cdot QMn^{0.1808} \cdot EXP^{Z} \quad (8)$$

where:

$$z = 0.02279 \cdot SPEED - 0.0969 \cdot LWm - 0.0706 \cdot LWn \\ - 0.00738 \cdot LNm - \beta_5 \cdot SHDW + \beta_6 \cdot LU \quad (9)$$

where MCA is motorcycle crashes per year, $\beta_5 = 0.0$, 0.00903 and 0.02099 for SHDW = 1, 2 and 3 respectively, $\beta_6 = 0.0$ and 0.00755 for LU = 1and 2 respectively.

For non-signalized intersections, the analysis shown that the term QPED and NL were not significant at the 5% level. So the final model is:

$$MCA = 0.01315 \cdot QNMm^{0.1597} \cdot QNMn^{0.0973} \cdot QMm^{0.1071} \cdot QMn^{0.1336} \cdot EXP^{Z} \quad (10)$$

where:

$$z = 0.02418 \cdot SPEED - 0.0967 \cdot LWm - 0.0907 \cdot LWn \\ - 0.01079 \cdot LNm - \beta_6 \cdot SHDW + \beta_7 \cdot LU \quad (11)$$

where MCA is motorcycle crashes per year, $\beta_6 = 0.0$, 0.01809 and 0.0502 for SHDW = 1, 2 and 3 respectively, $\beta_7 = 0.0$ and 0.01789 for LU = 1and 2 respectively.
The models reveal that traffic flow, approach speed, intersection geometry and land use are significant factors in explaining motorcycle accidents at junctions. The number of crashes is proportional to the level of traffic entering the intersections. An increase in motorcycle accidents is associated with a larger total vehicle flow on major and minor roads and with a higher approach speed, while wider lanes, a greater number of lanes, and wider shoulders bring a reduction in these crashes. Furthermore, more motorcycle accidents occur at signalized intersections located within commercial areas than at ones in non-commercial districts.

The difficulty of developing new APMs drives the researchers to consider the possibility if models calibrated for one site in one period of time could be applied for a different period in another places. It seems reasonable to adopt this approach since traffic volumes are the major contributing factor in explaining accidents occurrence and the nature of this interaction is unlikely to vary among sites with reasonably similar driver, road and vehicle characteristics [17]. This is the approach adopted in this paper, whose aim consists in validating the models described upon for application in the intersections of interest. In this way it can be possible to provide useful results for designers, construction and maintenance contractors, in order to decide the appropriate level of intervention for crossing treatment with respect to motorcycle crashes.

3. THE EXPERIMENTAL INVESTIGATION

3.1 The data

3.1.1 Selected intersections

The study involved two intersections located on urban roads in the town of Bondeno (Ferrara), Italy. The one is signalized four-legged, while the other is a three-legged priority junction (figure 4). The major and minor road approaches are indicated in table 2 (figure 4); the principal features are shown in table 3.

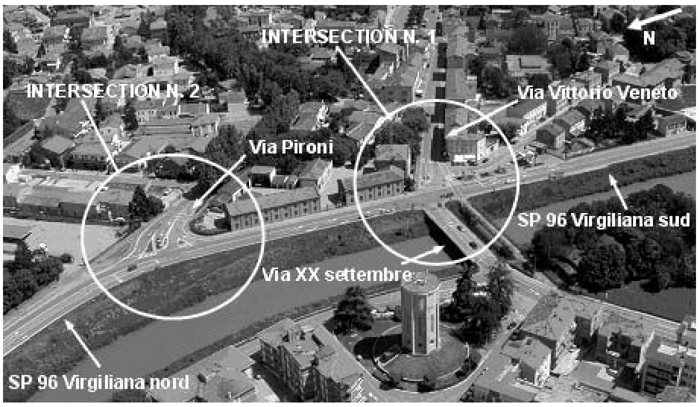

Figure 4: Intersections involved in the study

Table 2: Major and minor road approaches of the selected intersections

Intersection	1	2
Major road approach	SP 96 Virgiliana Sud SP 96 Virgiliana Nord	SP 96 Virgiliana Sud SP 96 Virgiliana Nord
Minor road approach	Via Vittorio Veneto Via XX Settembre	Via Pironi

Table 3: Principal features of the analyzed intersections

Intersection	Coding system	1	2
Average lane width on major road [m]	LWm	2.5	3
Average lane width on minor road [m]	LWn	2.5	3.75
Number of lanes on major road	LNm	1.5	1.5
Number of lanes on minor road	LNn	2	1
Number of legs	NL	4	3
Average shoulder width [m]	SHDW	0	0
Land use category	LU	Commercial area	Commercial area

3.1.2 Traffic flow data

In this study the hourly traffic volume, disaggregated by nonmotorcycles and motorcycles, was counted for one week on major and minor road approaches during October 2006. These data were determined based on five 24-hour permanent traffic count station (CT) located as shown in figure 5. To analyze the route of the vehicles in the intersections, two cameras were used. The data are expressed in terms of the number of nonmotorcycles per day and motorcycles per day (tables 4-7).

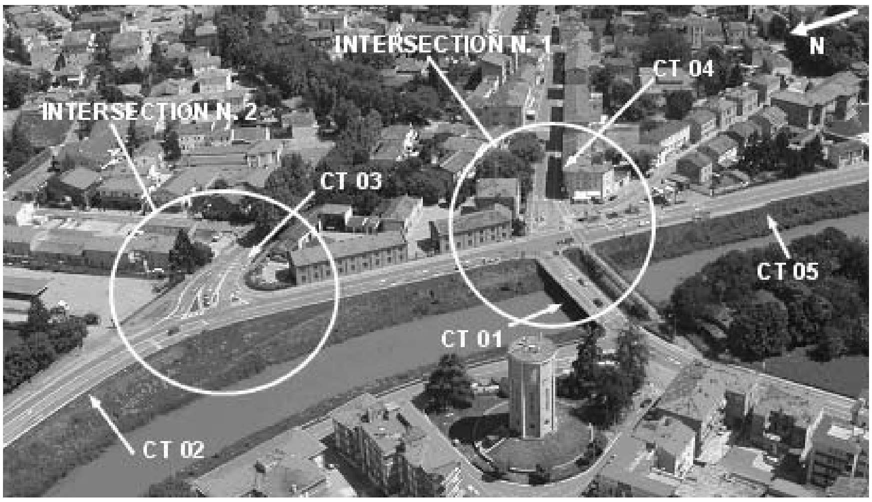

Figure 5: Traffic count stations (CT)

Table 4: Intersection 1, nonmotorcycle vehicles per day

		Destination			
		Via XX Settembre	Via Vittorio Veneto	SP 96 Virgiliana Sud	SP 96 Virgiliana Nord
Origin	Via XX Settembre	-	934	1271	1219
	Via Vittorio Veneto	2174	-	1540	337
	SP 96 Virgiliana Sud	2161	0	-	2629
	SP 96 Virgiliana Nord	1717	1182	3301	-

Table 5: Intersection 1, motorcycle vehicles per day

		Destination			
		Via XX Settembre	Via Vittorio Veneto	SP 96 Virgiliana Sud	SP 96 Virgiliana Nord
Origin	Via XX Settembre	-	215	50	72
	Via Vittorio Veneto	562	-	56	15
	SP 96 Virgiliana Sud	47	29	-	39
	SP 96 Virgiliana Nord	20	19	19	-

Table 6: Intersection 2, nonmotorcycle vehicles per day

		Destination		
		Via Pironi	SP 96 Virgiliana Nord	SP 96 Virgiliana Sud
Origin	Via Pironi	-	899	1912
	SP 96 Virgiliana Nord	766	-	5017
	SP 96 Virgiliana Sud	1546	3972	-

Table 7: Intersection 2, motorcycle vehicles per day

		Destination		
		Via Pironi	SP 96 Virgiliana Nord	SP 96 Virgiliana Sud
Origin	Via Pironi	-	23	22
	SP 96 Virgiliana Nord	20	-	57
	SP 96 Virgiliana Sud	56	97	-

3.1.3 Speed data

Speed data was collected on major and minor road approaches during October 2006. They were determined based on different radar counter located in traffic count station (CT) as shown in figure 5. The data are expressed in figure 6 where the caps at the end of each box indicate the extreme values (minimum and maximum), the box is defined by the lower and upper quartiles, and the line in the centre of the box is the median.

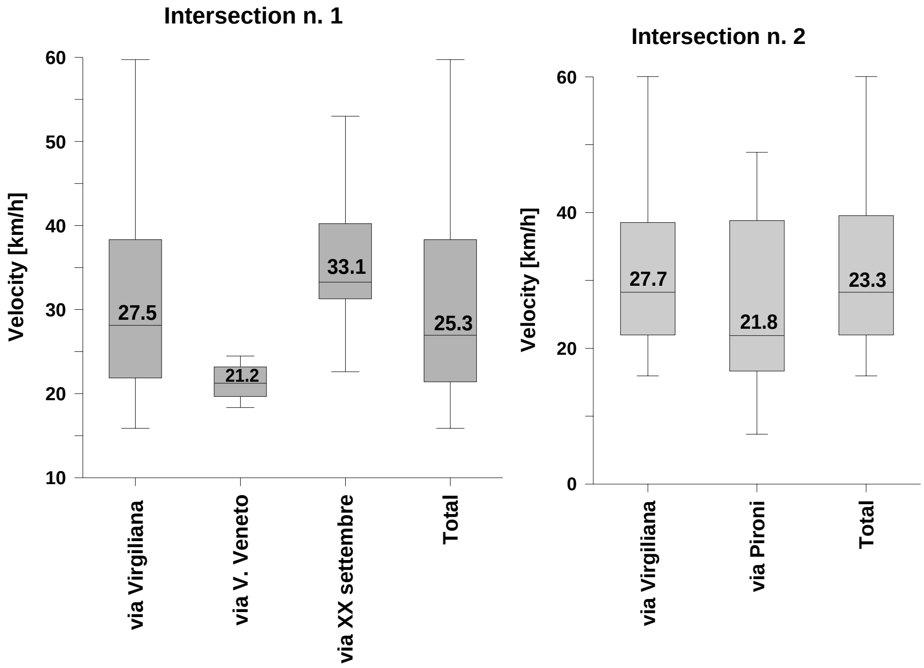

Figure 6: Speed data

3.1.4 Crash data

Crash data on selected intersections, from 2001 to 2006, were collected by the police office of the county, disaggregated by motorcycles (PTW) and nonmotorcycles (NPTW) (table 8).

Table 8: Accident data of the selected intersections

		Intersection n. 1			Intersection n. 2	
		Via XX Settembre	Via Vittorio Veneto	SP 96 Virgiliana	SP 96 Virgiliana	Via Pironi
2001	PTW	-	-	-	-	-
	NPTW	2	-	1	-	2
2002	PTW	1	-	1	-	-
	NPTW	-	-	1	1	2
2003	PTW	-	-	1	-	-
	NPTW	1	1	1	-	2
2004	PTW	-	-	-	-	-
	NPTW	-	1	1	-	2
2005	PTW	-	-	1	1	-
	NPTW	2	-	1	1	-
2006	PTW	-	-	-	-	-
	NPTW	2	-	4	-	2

These accident data have been used for comparison with the model results (tables 9, 10 and 11), in order to evaluate the potentialities of the APMs described upon (§ 2.2) for the analyzed intersections.

3.2 Model results

Tables 9 and 10 presents the results obtained from the models in terms of motorcycle crashes at the selected intersections. Table 11 shows the comparison between modelled and on site data.

Table 9: Motorcycle crashes at intersection n. 1

Data		Parameters (§ 2.2)	
table 1	tables 3,4,5	k_1	0.002822
QNMm [nmpd]	10990	α_1	0.3241
QNMn [nmpd]	7475	α_2	0.0835
QMm [mpd]	173	α_3	0.0683
QMn [mpd]	970	α_4	0.1296
SPEED [km/h]	25	β_1	0.02602
LWm [m]	2.5	β_2	-0.0727
LWn [m]	2.5	β_3	-0.0718
LNm	1.5	β_4	-0.01758
SHDW [m]	0	β_7	0.0
LU	2	β_8	0.01591
MCA = 0.56			

Key: mpd = motorcycles per day; nmpd = nonmotorcycles per day.

Table 10: Motorcycle crashes at intersection n. 2

Data		Parameters (§ 2.2)	
table 1	tables 3,6,7	k_1	0.0059294
QNMm [nmpd]	11301	α_1	0.2188
QNMn [nmpd]	2811	α_2	0.0665
QMm [mpd]	230	α_3	0.132
QMn [mpd]	45	α_4	0.1808
SPEED [km/h]	23	β_1	0.02279
LWm [m]	3	β_2	-0.0969
LWn [m]	3.75	β_3	-0.0706
LNm	1.5	β_4	-0.00738
SHDW [m]	0	β_5	0
LU	2	β_6	0.00755
MCA = 0.31			

Key: mpd = motorcycles per day; nmpd = nonmotorcycles per day.

Table 11: Comparison between modelled and in situ results

	Intersection n. 1	Intersection n. 2
Modelled result (tables 9 and 10)	0.56	0.31
On site result (table 8)	0.66	0.17
Δ [%]	-15	+82

The APMs for signalized four-legged junctions (intersection 1) reveals an agreement between numerical results and experimental ones better than the three-legged priority one (intersection 2) (table 11). These models, therefore, provides themselves to be a useful tool for selecting which treatment is needed at intersection to minimize motorcycle conflicts. Based on these models, in fact, appropriate design parameters for the junctions could be determined for a given cut-off level of powered two-wheeler (PTW) accidents.

4. CONCLUSION

This paper describes the application of motorcycle crash prediction models for signalized and three-legged priority junctions on two urban intersections in Italy. From the comparison between numerical results and accident data collected on site, the potentialities of these APMs are confirmed; they prove themselves to be an effective tool for road designers and construction contractors in selecting the appropriate level of intervention for crossing treatment with respect to motorcycle crashes. Using these models, in fact, design parameters for intersections may be changed to achieve appropriate safety levels. The obtained results, in particular, reveal that traffic flows, approach speed and intersection geometry are significant factors in explaining motorcycle accidents at junctions. The number of crashes, in fact, is proportional to the level of nonmotorcycle traffic on major and minor roads. Wider shoulders and a high number of lanes, moreover, bring a reduction in crashes. The approach speed, however, is the most significant variable. In this way, consequently, it is possible to improve the motorcyclist's safety on Italian roadways, whose protection measures are often effective only for four-wheeler vehicles and not for PTW drivers.

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