IMPROVING MOTORCYCLISTS' SAFETY IN SPAIN BY ENHANCED CRASH TEST PROCEDURES AND IMPLEMENTATION GUIDELINES.

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ABSTRACT

Motorcyclist fatalities are a major road safety problem on Spanish roads. In 2006, 642 motorcyclists or cyclists fatalities occurred, which mean 21% of all road fatalities. More than half of them were run-offs. To address this safety issue, roadsides are equipped with so-called "Motorcyclist Protection Devices" (MPD). In 2005, the Spanish Standard UNE 135900 for the assessment of MPD was published, and Spanish National and Regional Road Administrations have been active in this field since then.

This paper describes research work aimed at improving motorcyclists' safety from a global approach, by two main activities:

- Upgrading the crash test procedure set by Standard UNE 135900, by implementing a new thorax injury criterion.
- Developing a methodology to recommend and warrant the installation of MPD on specific road stretches.

The implementation of a thorax injury criterion took into account the kinematics and injury causation process in the event of an impact of a motorcyclist sliding against a barrier. From the analysis of the response of bones, inner organs and vascular system it was concluded that loads measured on the vertebral column with a Hybrid III dummy are suitable to assess relevant thorax injuries. An injury criterion based on maximum vertical force measured on thorax was defined and implemented into the upgraded 135900 Standard.

The recommendations for the installation of MPD were based on analysing road sections and identifying bends with a higher risk of motorcyclist run-off collision, in order to install such devices with optimised cost effectiveness. The applied methodology comprised road inspections and epidemiological analyses in order to detect relevant risk factors.

As a result, a framework is provided that sets technical bases for the development and implementation of better motorcyclist protection devices, by assessing their performance through an enhanced standard, and by establishing scientifically–based criteria for their deployment.

INTRODUCTION

Run-off road accidents are those accidents involving vehicles that leave the roadway, encroach onto the shoulder and beyond, and impact any hazardous object located on the roadside, such as poles, trees, walls, or embankments. When a vehicle departs from the roadway, the severity of the accident can be reduced by removing obstacles or by installing appropriate protective devices. Road restraint systems, including safety barriers, are devices installed on roadsides to contain and redirect errant vehicles.

Motorcyclists or Powered Two-Wheelers (PTW) are vulnerable road users. In the event of a run-off accident, they have a high risk of suffering critical interaction with hazardous obstacles placed on the roadsides. To address this safety issue, roadsides are equipped with so-called "Motorcyclist Protection Devices" (MPD).

The safety performance of MPDs can be assessed by performing crash tests using anthropomorphic test devices (i.e. crash test dummies). Several crash test procedures have been developed in different countries [1] although the first Standard in this field was the Spanish Standard UNE 135900-2005 [2], published in 2005. This Standard became a reference for the development of new protection systems to be installed on roads. Since it was published in its first version in 2005, additional research has been performed to upgrade the Standard, which is presented in this paper.

Once that safe motorcyclist protection devices are available, road administrations are in charge of setting the policy for their installation on roads. However, given that resources are limited, it is not feasible to install MPDs on all bend sections of road networks. The choice of the locations where MPDs are to be installed should follow objective criteria that allow optimized safety benefits. The regional road administration of Castilla y León (CyL), in Spain, ordered an innovative research work with the objective to identify bends on roads where there is a higher risk of PTW run-off collision in order to install a MPD. The methodology followed in the research work is presented in this paper.

MAGNITUDE OF THE PROBLEM

The number of road accidents and fatalities has decreased during the last decade in areas such as North America and Europe. In the case of PTW users, while in United States nearly 10% of fatalities were PTW riders or passengers in 2004 [3], in Europe it increased to over 20% [4]. In the same year, 5,484 motorcycle and moped users (riders and pillion passengers) were killed in traffic accidents in 14 European Union countries, which is only 0.3% lower than the previous year. In the United States, this figure was 4,008 casualties, with an increase of 8% compared to 2003. In Spain, motorcycle and moped fatalities constituted the 18% and for the Spanish region of Castilla y León, motorcyclist and moped user stood at 11% of the fatalities.

Although PTW accident typology is wide, it has been found that impacts against fixed objects are more likely to provoke serious casualties in PTW run-off crashes. In the United States, collision with a fixed object was a significant factor in over half of the fatalities during single vehicle motorcycle crashes [5].

In Spain, from 2001 to 2006 PTW fatalities have decreased only by a 5.2%, while the overall reduction in the same period considering all types of vehicles has been 26.0%.

UPGRADING THE CRASH TEST PROCEDURE

Test procedure UNE-135900-2005.

The Spanish Standard UNE 135900-2005 sets the procedures to evaluate the performance of MPDs. They are based on launching a test dummy against a MPD installed on a safety barrier, which is assumed to feature vertical posts. The procedure covers MPD to be fitted on each post, as well as continuous ones. Depending on the kind of system to be tested, a different trajectory is chosen, from the following:

- Trajectory 1 – Centered post impact: applicable to individual post coverings and continuous MPDs with an approaching angle equal to 30º.
- Trajectory 2 – Eccentric post impact: applicable only to punctual MPDs. It follows a horizontal line that goes at a distance ‘W’ off the center of masses of the post, with an approaching angle equal to 30º.
- Trajectory 3 – Centered rail impact: applicable only to continuous MPDs.

The launching position is defined with the dummy spine axe coinciding with the approximation trajectory, and the dummy sliding along the ground, separated from the motorcycle, until it hits the protection system to be tested, with a specific entrance angle and speed. The dummy is a Hybrid III 50th Percentile Male, equipped with a pedestrian kit that allows a standing position, and is to be fitted with a full-front helmet, and a leather motorcyclist suit.

The assessment of the MPD performance is based on the evaluation of impact severity and additional acceptance criteria. For the evaluation of impact severity, the following measures are to be taken: HIC 36 for the head and Fx, Fy, Fz, Mx and My for the neck. The acceptance criteria regarding the behaviour of the safety device specify that no element of the crash safety barrier weighing 2 Kg or more should be separated from the device unless it is necessary for correct performance, and that the working width and dynamic deflection of the device on dummy impact should not be in any case equal or higher than those specified by the Standard UNE EN 1317-2 for vehicle impact. The acceptance criteria regarding the behaviour of the dummy specify that the dummy used for the test should not have intrusions, dummy breakage except the collar bone, be beheaded or suffer any dismemberment. Additionally, the dummy clothing should not be torn and, the dummy should not be caught on any part of the safety device.

The new thorax injury criterion

A potential improvement of the test procedure defined by UNE-135900-2005 that was proposed as an enhancement was the implementation of a thorax injury criterion.

For the definition of a thorax criterion, PMHS data were not available. It was decided to define a thorax injury criterion by using a crash test dummy, even taking into account that no dummy specifically developed for this kind of impact was available. The study was carried out applied to the Hybrid III dummy, taking into account that in an impact against a barrier, the injury causation process is as follows. Firstly the head and then the shoulder hit the lower plate of the barrier. The thorax loading initiates through the shoulder, fracturing the clavicle and deforming the upper ribs while the motorcyclist is guided along the barrier. Following this, the loading is transformed into an almost purely lateral one. Inner organs and the vascular system are bound to be affected by inertial effects. The main loads on the vertebral column are traction-compression and lateral-flexion.

Given that the Hybrid III thorax does not feature ribs, or measurement capabilities on organs and bones except for the vertebral column, it was decided that the proposed thorax injury criteria should be able to cover all relevant thorax injuries through the measurement capabilities available with the dummy instrumentation. This would be possible due to the inertial effects present as injury mechanisms for inner organs.

Thorax injuries had been analysed by military researchers [6], who studied the acceleration limits on PMHS and modified Hybrid III. They found correlations between the internal force limits of the column and the inertial effect on the organs. Rib fractures were not considered as a possible criterion, as multidirectional frangible ribs would have been needed, and in addition, once rib fractures occur, no additional information could be obtained beyond that point. Besides, the injuries with four or more rib fractures on one side or two, or three fractures with hemothorax or pneumothorax, are considered AIS3 (see Table 1).

Table 1.
Relationships between injuries and AIS severities

AIS Level	Rib Cage Injury	Thoracic Soft Tissue Injury
1	1 rib fracture	Contusions of the bronchus
2	2-3 rib fractures; sternum fracture	Partial thickness bronchus tear
3	4 or more rib fractures on one side; 2-3 rib fractures with hemothorax or pneumothorax	Lung contusion; minor heart contusion
4	Flail chest; 4 or more rib fractures on each of two sides; 4 or more rib fractures with hemothorax or pneumothorax.	Bilateral lung laceration; minor aortic laceration; major heart contusion
5	Bilateral flail chest	Major aortic laceration; lung laceration with tension pneumothorax
6		Aortic laceration with hemorrhage not confined to mediastinum

On the other hand, the force magnitude of an impact to the thorax is also transmitted directly to the column by the bones. It is for this reason that the most suitable place to calculate the severity of the impact is the vertebral column, particularly, when the dummy has available measurement points in that place.

An acceleration criterion can be used as it is done in military researchers but in case of motorcyclist test, the available point of interest to measure it is on t4 vertebra. The main problem to use an acceleration criterion was that the results are very sensitive to the spinal position, hyperextended, erect and flexed for example, that changes the fracture results 80% respect the others. On the other hand, acceleration criterion was quite sensible to a time dependency and the shape of the impact pulse. Thus, the investigations were focused on t9 vertebra, where Hybrid III dummy has an available force measurement point.

Research by Ruff [7] obtained values for average compression force causing vertebra fracture as a result of accelerations. In case of an ejection seat, these values correspond to a 21g for positive acceleration from pelvis and around 12g for negative acceleration applied on the shoulders. The force values depend on the age, and on the vertebra involved, as the percentage of body weight borne varies along the height of the vertebral column. The values obtained for the average force on t9 were 6.7

KN considering all ages, and 5.9 KN for people who are 23 years old. The latter value was deemed more suitable as young riders are often involved in accidents.

The measurement of compression force in thorax was introduced in the new updated Spanish Standard UNE-135900-2008 [8]. The enhanced procedure includes measuring and reporting vertical force Fz.

However, a limit value has not been set for this parameter. This is because current state of art has not yielded conclusive relationships between measured forces and injury severity, due to the fact that the load transfer by the different parts of the dummy during its interaction with the MPD may not be sufficiently biofidelic. Further research is needed, focused on the response of the dummy shoulder under oblique impact.

Discussion

Other studies that have been performed in parallel with the one presented in this paper suggest measuring Fy and Mx in the dummy thorax as suitable criteria to assess severity [1], [9]. Although their influence was not implemented in the current version of the Spanish Standard it is planned that ongoing and future revisions of the Standard will address this issue.

RECOMMENDATIONS FOR THE INSTALLATION OF MPD: METHODOLOGY

A methodology was developed for the regional Road Administration of Castilla y León, in Spain, in order to recommend and warrant the installation of MPD on specific road stretches. For that purpose, it was necessary to investigate which road infrastructure features have significant influence on PTW run-off accidents in order to detect those sections with higher probability of PTW run-off accidents. Among the features taken into account were curvature radius, bend length, road marking and signalling, road layout perception, and roadside configuration.

It was decided that the methodology would take into account the risk of a run-off regardless of the resulting severity, for two main reasons.

- Firstly, the severity of these accidents does not depend only on road infrastructure characteristics. Other aspects, such as rider speed, rider protection equipment and all the physical phenomena that occur during the complex event of the crash may condition the accident outcome.
- Moreover, studying all injury accidents makes a higher number of cases be available to be introduced in the statistical models.

In order to obtain reliable results about the road infrastructure risk factors, the following facts were taken into account:

- The accident study sample has to be precisely described, so that all cases where this problem cannot be isolated should be discarded.
- It is necessary to obtain highly detailed information about the accident and the road infrastructure features at the moment of the crash. Police record accident data are not enough to address this problem.
- Estimation of risk factors is based on information about those situations in which the accident does not take place (i.e. exposure to each of the possible risk factors). For instance, if the factor under analysis is "curvature radius lower than 100 metre (327.8 ft)" then it would be necessary to consider those motorcyclists who had suffered accidents at bends with radius below 100 metre, those who had suffered accidents at bends with radius above 100 meters, and as a counterpart, riders that had taken bends of both groups but had not been involved in an accident. Provided that these data are obtained, epidemiology is able to provide analysis methods for accident and non accident data.
- Possible sources of bias are controlled during the analysis as far as possible. For instance, differences between motorcyclists' and drivers' experience and capabilities were introduced in the analysis as co-variables in order to be controlled.

Based on such principles, the methodology applied to develop recommendations for the installation of MPD comprised the following main activities:

Descriptive Analysis

The first task set in the methodology was to describe the magnitude of motorcyclist run-off accidents within this regional road network. The Injury Accident Database of the Spanish region of Castilla y León was analyzed for this purpose. This database compiles all injury accidents. The variables in this database provide information relative to the three main components of safety, namely the road infrastructure (accident location characteristics), the vehicle (type and state of the motorcycle), and the rider (driving stereotype). This analysis provides macroscopic answers to the most relevant questions, i.e. where do PTW run-off crashes take place, how do they occur, and what kinds of riders are involved in them.

Once the problem is described at macroscopic level, a sample of representative road sections can be selected so as to obtain further information of all the possible factors of influence.

Integrated analysis of a selection of representative road sections

The objective of this phase of the project was to develop exhaustive data processing related to all the variables of the road infrastructure for PTW rider run-off crashes in the Spanish regional road network of Castilla y León.

Seven road sections were selected jointly with engineers from the Castilla y León regional road administration. All sections chosen complied with the following criteria: during three years prior to the study, each of the sections had had at least three PTW run-off injury accidents over a length of 1 km, and no main junctions were present within the section.

For all these sections the following set of analyses was performed:

- Specific road safety inspections were carried out by safety experts. The aim of these inspections was to assess the perception that riders may have of the road layout based on the fulfillment of a specific checklist.
- The road infrastructure inventory (software with all the road equipment and road layout geometry) of those road sections, owned by CyL regional administration, was crossed with the National Injury Accident Database and with accident files of the regional administration of PTW rider run-off accidents in those stretches of road.
- Then, all the road sections were recorded with video cameras. This enabled completion of the information of road safety inspections after the visits to the sections.
- Finally, 16 PTW rider's run-off accidents were investigated in-depth with to the methodology described in the following section (Figure 5).

This phase provided a complete matrix of data related to the rider, the vehicle and the road infrastructure features. It was used in the following phase for the application of epidemiologic methods in order to obtain the most significant road infrastructure risk factors for this type of accidents.

Risk Analysis

As stated previously, road administrations do not have unlimited resources implementing MPDs at every single problem area of road networks so it is necessary to know where a PTW run-off accident is more likely to occur and which road infrastructure parameters are the relevant risk factors associated with them.

Following an epidemiological approach, a risk factor can only be identified when data are available for four different parameters:

- How many PTW riders are exposed to the factor not having a run-off accident (a).
- How many PTW riders are exposed to the factor having a run-off accident (b).
- How many PTW riders are not exposed to the factor not having a run-off accident (c).
- How many PTW riders are not exposed to the factor having a run-off accident (d).

If these figures are available, the relative risk (RR) of a rider being involved in a run-off accident (if the factor is present compared to the situations when the factor is not present and assuming that other factors remain constant) can be estimated:

$$OR = \frac{a \times d}{b \times c} \qquad (1)$$

The above equation represents an odds ratio (OR). It can be considered as a relative risk always when the incidence of the accidents remains below 1% of the whole population [10]. In this situation, it can easily be assumed that much less than 1% of PTW displacements end with a run-off accident. Nevertheless, this approach only allows the study of one single factor at a time when all relevant factors could have influence simultaneously. In order to analyze the matrix of data developed in the previous stage, logistic regression models can be applied. They provide the estimation of the relative risks for all the relevant factors, taking into consideration the influence of the others.

With the available data, an observational epidemiological analysis was developed, as it is not possible to decide who is exposed to the different risk factors. A crossover case – control analysis was developed. The cases were motorcyclists involved in a run-off accident and the controls were motorcyclists not involved in a run-off accident. In order to properly identify cases and controls, the road sections analyzed in the previous step were selected so that no junctions were present in the section. Therefore, knowing the travelling direction of the motorcyclists that had an accident, the same motorcyclist was considered as a case in the bend where he had the accident and as a control in the previous bends where he did not have the accident. This can only be considered if the rider is known to have come from one of the ends of the road section. Therefore, the road section cannot include junctions to other roads.

This methodology enabled classification of the road network into four main groups (based on two initial parameters which were considered as risk factors) and then, for each of them, identification of the relevant road infrastructure risk factors for this type of accidents which were the basis for the development of the recommendations for the effective location of MPDs.

STUDY AND CHARACTERIZATION OF PTW RUN-OFF ACCIDENTS

The described methodology was applied specifically to the problem of motorcyclist run-off accidents in the road network of Castilla y León. The work was carried out as follows.

Descriptive Analysis

The first task in the study consisted of a descriptive analysis of the injury accident database that the government of the Castilla y León region has developed. The analysis was performed on all types of PTW injury accidents occurred in the regional road network over the last three years available (2002 to 2004). This analysis had the aim of finding out the main casuistry of these accidents (run-offs, side, front and sideswipe), characterizing them from a three angle research view (environment-human factor-vehicle). Special emphasis was placed on the information related to infrastructure (type of road, number of lanes, carriageway and lane width, road marking, hard shoulder, paved hard shoulder, road safety elements, road surface condition,…) as the project is focused on safety measures to be taken in the infrastructure management process.

The analyses included a variable that specified the type of PTW vehicle, due to the fact that a moped accident may have different mechanisms to one on a motorcycle. No significant differences were found in this study. 221 injury PTW run-off crashes were sorted out for the CyL road network from 2002 to 2004.

Figure 1 shows the distribution of motorcyclist accidents obtained from a sample of 242 accidents compiled from 15 regional Spanish road administrations

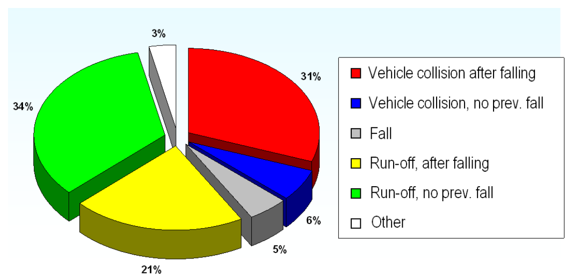

Figure 1. Accident types from a sample of PTW accidents in Spain.

Once PTW run-off accidents were identified as a relevant safety problem within the CyL road network and with the macroscopic overview from the descriptive analysis provided (type of roads, road layout, environmental conditions, day of the week, …), a sample of road sections was taken in order to obtain more detailed information about the rider, vehicle and all the road infrastructure characteristics in this type of accidents. The information included in police accident records is not detailed enough to analyze the real influence of the road infrastructure on this type of crashes. Therefore, it was necessary to obtain more data related to the accident itself and to the road infrastructure as a possible causal factor of PTW run-off accidents (e.g. it is not possible to know from police records: bend length, curvature radius or at which distance prior to the bend all the signals were visible).

The sample road sections were selected according to the following criteria:

- At least three PTW run-off accidents occurred within a road length under 1,000 m, during the period 2002 – 2004.
- No junctions with other roads (except local accesses to private properties) were present within the road sections.

All the road sections that complied with the above criteria were selected to apply the subsequent research activities.

In-depth accident analysis

One of the most important tasks of this project was the monitoring of all the PTW accidents over a period of one year in the regional road section with the highest number of motorcycle crashes.

This task had the aim of finding out, through the complete analysis of each accident, detailed information about these impacts: kinematics and dynamics of the accident (motorcycle and motorcyclist impact points, trajectories, impact angles, travelling and impact speeds for the motorcycle or the motorcyclist,…), complete scene characterization from the infrastructure point of view (layout, radius and length of curvature, element of sign-posting, alignment, slope, hump, surface status, pavement hard shoulders, embankments, benches,…), human factor information related to driver status before the impact, manner of driving and injury information in order to establish injury mechanisms. During that monitoring year, 16 injury accidents occurred on the road section selected (less than 20 kilometres length located in a mountainous area) involving 19 injuries and 2 fatalities.

The accident investigations developed at this stage are called 'in depth' investigations. They include all the inherent aspects to the accident which are analyzed in detail. The CIDAUT accident analysis and human factor team performed them. They can be classified into two types:

- Prospective, when the team, after receiving the accident notification from the police, attend the accident scene immediately;
- Retrospective, when it is not possible for the investigation team to be present at the accident scene immediately after its occurrence.

The main use of these investigations for this study were as follows: through the analysis of the accident scene, the checklist used in the road inspections was completed in order to consider road layout perception by the rider as this was essential in the 16 accident investigation. Moreover, some factors were identified as potential risk factors and therefore were included in the statistical analysis due to the outcome of these investigations (e.g. longitudinal slope, sighting distance of sign posts at the curve approach,).

Accident notification. The accident notifications (with or without injuries) were carried out by the police teams by forwarding information about the accident immediately after its occurrence. A specific direct collaboration with police patrols was established (immediate notification and supply of relevant information for the investigations).

Accident reconstruction. One of the advantages of the ‘in-depth’ investigations is the possibility of ascertaining some specific information which would be impossible to have in the so-called ‘basic’ investigations (which are carried out by police teams in all injury accidents). Through the information gathered by analyzing the scene (marks, debris or impact points which are drawn later in a detailed sketch) and the vehicles involved (deformations and impact points), it is possible to estimate some variables (e.g. travelling speeds) using different accident reconstruction techniques and specific software (PC Crash © [11].

Vehicle trajectory before and after the impact is one of the relevant issues of accident reconstruction. This is defined by the marks and debris found at the scene of the accident, and coincides with the deformations found in the vehicle and in the existing infrastructure (road restraint systems). The drawing of a detailed sketch, in which all the dimension-localization marks and debris are located, is fundamental for a reliable reconstruction of what really happened.

Considerations. The main aim of reconstructions is to find out all the useful information in order to determine which the possible concurrent factors in the accidents were. In addition to reconstructions, a speed radar was placed on the selected road section to observe what the traffic composition (number of passenger cars, light trucks, heavy trucks and PTWs) and the travelling speeds of each vehicle were. In 90% of the 16 accidents studied, high speed was clearly present. Data related to PTWs, showed, for instance, that in a 50 km/h speed limit bend, 85% of the PTWs were travelling at over 100 Km/h with a maximum registered speed of Km/h.

Road Safety Inspections

Road safety inspections were carried out on the seven selected road sections so as to investigate the infrastructure and its relationship with the present type of crashes. A checklist was developed in order to obtain detailed information about each bend of the selected road sections. It has a first general section in order to identify and describe the bend (location, length, weather conditions during the inspection, minimum curvature radius and its location within the bend and possible comments). Then, a questionnaire had to be filled out by road safety experts after driving and walking in both directions of each bend. The points addressed were as follows:

- Presence of hazardous elements for a motorcyclist in the event of a run-off accident on the outside of the bend or at its end.
- Location of the above hazards.
- Maximum depth of the roadside gutter.
- Perception of the road layout before approaching the bend and along it.
- Possible visibility restrictions within the bend.
- Possible road surface irregularities.
- Friction caused by the road surface.

The results of these checklists were put into the data matrix in order to be analyzed with the other information collated at this stage. Experts from the CyL regional road administration, CIDAUT and the PTW user group contributed in this activity.

Video recording and road infrastructure inventory

All the selected road sections were video recorded and GPS positioned. This allowed completion of the road safety inspections before and after visits to the sites. Precise data about road infrastructure data was a key element of this research. It was necessary to know for each selected bend reliable data about the real parameters of road infrastructure devices: bend length, curvature radius (along the bend as it does not remain constant), presence and location of signals and road markings, longitudinal slope and superelevation along the bend, lane width, description of the shoulder, presence of roadside restraint systems, …

The CyL regional administration provided the road infrastructure inventory software of the selected road sections. It contains a database where all the information about road network sections is covered together with the location of all variables. Combining the information from the police and in–depth accident files with the road infrastructure detailed information and also with completed road inspections checklists was made possible.

The result at this stage was basically a matrix with a detailed set of data prepared to be statistically analyzed in order to investigate which road infrastructure factors have more influence in PTW run-off accidents.

Obtaining risk factor for motorcyclist run-off accident

At this step of the research, statistical methods were applied to obtain the most relevant road infrastructure risk factors for PTW run-off accidents. The combined database used for the analysis contained 984 registers, of which 41 were cases (accidents) and 943 were controls (no accidents). P-values and confidence intervals were used for statistical significance testing. The variables considered from the data matrix were the following ones: Bend minimum curvature radius, curve length, location within the bend of the minimum curvature radius, decrease of the minimum curvature radius along the bend not predictable by the rider, bend sign posting and road marking, bend layout predictability at 150 m, 50 m and inside the bend, visibility restrictions, longitudinal slope, brow of a hill, superelevation, consecutive bends, PTW traffic flow, irregularities on the road surface, surface friction, paved shoulder, roadside hazard elements.

Due to the extent and type of CyL roads it was necessary to structure the network bends curves in different groups, easy to identify for traffic engineers, according to a few variables. Bend length and minimum curvature radius within the bend were chosen as the main variables to classify the segments. Nevertheless, it was necessary to define the critical values of those variables in order to classify the roads.

First, the variable bend length was statistically analyzed within the matrix data. Logistic regressions were developed in order to investigate which value of the bend length was statistically significant (level of confidence of 95%) as having influence in the PTW run-off accidents when the other variables were constant. Bend length values ranging from 20 meters to 390 were tested. The result of the test was the OR for the bend length codified as binary for each tested value and its corresponding p–value. The reference value 120 metres provided the narrowest confidence interval, the 'p–value' being less than 0,05 and was chosen as the value to divide the road network into two initial groups.

The minimum curvature radius within the bend for each group was similarly analyzed, for each group of roads according to bend length, in order to obtain which reference value for this variable had more influence on this type of crashes. This value was of 90 meters. Therefore, the road network bends were divided in four different scenarios (Table 2).

Table 2.
Description of the scenarios for bend classification

Scenario nº	Curve length	Minimum curvature radius
1	> 120 m	> 90 m
2	> 120 m	< 90 m
3	< 120 m	> 90 m
4	< 120 m	< 90 m

At a second stage, for each later group which road infrastructure variables having an influence as risk factors in PTW run-off accidents were investigated.

Crossover case–control analysis was applied for each group and the statistically significant risk factors were identified (p–value < 0,05 and confidence intervals not including '1' at a confidence level of 95%). A p-value below 0,05 for an estimation of an odds ratio shows that the probability of accepting the value of the odds ratio (alternative hypothesis) is real. Those road infrastructure significant factors presenting an odds ratio above '1' turned out to be risk factors.

A relative risk (estimated in this research through the odds ratio) above '1' for a factor means that it increases the probability of having an accident, compared to the same situation in absence of the factor, by (OR -1) x 100%.

Apart from the statistical results of each logistic regression model, a road safety interpretation of the validity of those results was also investigated by safety experts in order to give coherence to the results. This was the basis for the development of the recommendations for the effective location of MPDs.

RESULTS

The statistical analysis performed over the combined database created for this project enabled the definition of the final criteria for locating MPDs in CyL road network to be made. This complete database contained all the information from the different tasks detailed in the previous sections:

- Macroscopic statistical analysis of the regional accident database.
- Macroscopic statistical analysis of the road section with the highest number of PTW accidents.
- Detailed information from the 16 'in-depth' accident investigations.
- Information from the road safety inspections of all the bends from the seven road sections.
- 'Road Infrastructure Inventory' software related to the previous seven road sections.

The objective of structuring the road network in the four scenarios presented in the previous section is to analyze the specific casuistry of each scenario. The election of these 'main segmentation variables' has been based, besides being statistically significant, on the need of being able to decide, in a reliable, simple and effective way, whether a certain bend belongs to a certain scenario or another. For each scenario, the different statistical influence was analyzed for all the variables of risk that a motorcyclist suffers in a run-off. Thus, recommendations for the MPD installation were developed for each one of the four scenarios mentioned in the previous section of this paper.

The final variables that were more relevant for the geometric segmentation of all the bends from the total network ('main segmentation variables') were bend length and bend minimum curvature radius. The justification of choosing those 'limit values' for these two main variables is based on the statistical methodology applied:

The joining of these two 'segmentation variables' gives us the four scenarios for simple regional road network classification. Recommendations for MPD location were developed for each one.
Once the four scenarios were defined, new tests were performed to determine which variables were relevant as risk factors in run-off accidents. The selection of the final variables was based on the ‘p-values’ from the different statistical tests done over these variables.

The final variables considered as criteria for each scenario to determine where MPDs must be installed in the road network in Castilla y León were the following (Table 3):

Table 3.
Variables to be taken into account for MPD installation in each scenario

Scenario	Variables to be considered
1	1. Road Signs and road marking for the definition of bend layout. 2. Position of decrease of minimum curvature radius along the bend not predictable by the rider. 3. Isolated bend
2	1. Road Signs and road marking for the definition of bend layout. 2. Position of decrease of minimum curvature radius along the bend not predictable by the rider. 3. Isolated bend.
3	1. Road Signs and road marking for the definition of bend layout. 2. Location within the bend of the minimum curvature radius. 3. Position of decrease of minimum curvature radius along the bend not predictable by the rider.
4	1. Location within the bend of the minimum curvature radius. 2. Isolated bend. 3. Paved shoulder.

The position of the MPDs should be on the outer side of the bend and along its whole length. In bends fulfilling the conditions of one of the scenarios where there is no roadside restraint system, this should be installed together with an MPD. Besides, it was observed that in consecutive bends where at least one fulfilled criteria, MPDs must also be placed in areas of adjacent bends.

CONCLUSIONS

The present research has provided a scientific basis for the development and implementation of better motorcyclist protection devices, in two stages. The first one is assessing their performance through an enhanced standard, which will foster the development of products with increasing safety performance for users. The second one is the development of recommendations for an effective location of MPDs within the Spanish regional network of Castilla y León.

Specific recommendations were provided for four different scenarios, grouped according to the curve length and minimum curvature radius. The research has combined data from different and complementary sources: police data, in-depth accident investigations, road infrastructure inventory, road safety inspections, accident cases and non accident control data. Future improvements could be developed by carrying out a monitoring period after the implementation of MPDs as a result of these recommendations. No previous study was found on the application of epidemiological techniques on road layout design for motorcyclists, which underlines the innovation of this research.
Epidemiology applied methods enabled assessment of the relative risk of the significant road infrastructure factors on PTW run-off accidents. The road sections where those risk factors are present are subject to MPD installation.
The application of these recommendations is to contribute to reducing serious injury to PTW riders within the Spanish regional road network of Castilla y León. In addition, once the MPDs have been put in place according to these recommendations, their effectiveness in reducing PTW rider injuries is being monitored so that the safety benefit achieved is ultimately evaluated

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