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Bicycle crashes on two-lane rural roads in Spain

Memoria

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Abstract

This study is an exploratory one to characterize bicycle crashes, including both single and multiple-vehicle crashes, and analyzing the effect of road elements or traffic participants. It is based on real statistic report from police in Spain during 2009-2013.

Crashes involving bicycle were identified and 6,786 were discovered matching the selected conditions, accidents on two-lane interurban roads.

Most events occurred between a cyclist and another vehicle (74 %) as well as on roads with greater width (40%). Moreover, 43% of crashes took place at intersections.

In general, crashes involving cyclists are seldom reported to the police unless someone is killed or severely injured (usually the bicyclist) hence the small number of the data base. Serious injury is defined as an injury requiring admission to hospital for more than 24 hours. The rate of bicycle riders killed or severely injured has remained relatively constant over the period 2009 to 2013 and the average percentage of cyclist deaths by accidents is equal to 4% in Spain.

In summary, results of the research have been valuable in proving insight into understanding the factors influencing bicycle accidents on two-lane rural roads. Directions for further research have also been suggested.

1. Introduction

The following Master Thesis details some of the aspects regarding the bicycling in Spain on the street. This study aims at identifying critical factors what influence bicycle collision.

The location of the study is in Spain, a sovereign state located on the Iberian Peninsula in Southwestern Europe.

Injuries caused by accidents are the eighth leading cause of death worldwide, and the first among young people, 15 to 29 years. Current trends indicate that without urgent action, road traffic injuries will become 2030 in the fifth cause of death.

Aware that traffic accidents are a matter of great social and economic importance and do not affect only road users, it is necessary that all citizens are aware that thousands of deaths each year on the roads cannot simply be considered as natural, unstoppable disaster, but, on the contrary, mortality on roads should be considered as a real social plague.

As such it is necessary to find the most appropriate solutions to heal this problem. Road safety, until now, is considered a major national emergency. According to a study published in Mapfre Foundation, in the last ten years (period 2003-2012), the main numbers affecting cycling safety in Spain are:

- 711 fatalities: 537 and 174 in rural roads and urban roads, respectively.
- 4,896 seriously injured: 2,706 and 2,190 in rural roads and urban roads, respectively.
- 25,400 slightly injured: 7,631 on interurban roads and 17,769 in urban roads.
- 31,007 total casualties: 10,874 on interurban roads and 20,133 in urban roads.

The number of deceased cyclists in recent years in Spain is increasing, in 2012, for example, that number increased significantly compared to 2011, going from 49 to 72 deaths total deaths in 2012. The number of seriously injured cyclists in cities has increased in the last ten years, from 202 in the year 2003 to 268 in 2012 (an increase of 33% over the last decade). The number of cyclists minor injuries in cities has increased even more in the last ten years, from 1,150 in the year 2003 to 3,170 in 2012 (an increase of 175% in the last decade).

The increasing number of accidents is a warning for the need to regulate a newer and stricter normative regarding traffic safety.

This Master Thesis is an investigation, using statistical data, of the causes and factors that can influence traffic accidents on interurban roads involving cyclists.

2. Previous studies

This part is a very important part of any scientific study, regardless of the subject matter. It is a profound and accurate revision and compilation of all accumulated studies in a particular field in which is introduced into question knowledge. It collects and analyzes all knowledge found in previews studies and constitutes in the starting point and theoretical basis for the study in hand.

This chapter, then, will consist of a review of all available sources, the literature, especially composed for research articles published in special interest magazines, books and national and international regulations. The aim will be to estimate the level of existing knowledge on the various topics covered in this study. Doing this, through the collection of information found in the available sources, the study will deepen in the most important aspects of cycling safety on rural roads.

The objective of this chapter is to estimate the existing knowledge regarding bicycle accidents and their analysis; the information depends on the field of study, from the behavior of the traffic participants till the road topology.

In the world there are about 800 million bicycles, double the number of cars. Only in Asia, bicycles carrying more people than all the cars in the world. However, in many countries, not enough attention is given to accidents involving cyclists as part of the road safety problem.

From the beginning and still today bicycles have been and will be used for different activities, from recreational purposes , such as bicycle touring, mountain biking , fitness or they can be used in a utilitarian way like transport or an work asset (curriers). Utility cycling meaning the use of bicycle as a means of transport is the most common type of cycling in the world. Overall, the bike was and is considered a means of transportation for those with low income, which explains the large number of bicycles reported to motor vehicles particularly in low income countries. If for pedestrian protection facilities were made, cyclists should handle the existing traffic on their own among larger vehicles and faster. In many European countries, cycling is considered a means of transport for persons with any kind of income, who want to protect the environment and to keep fit, to avoid problems of traffic jam in urban areas at peak hours, such that they have created facilities for cyclists, even at the expense of drivers.

Green transport has become a key concept in development strategies the mobility of the perimeter of metropolitan areas, with particular reduce individual car use. Traffic in general is the cumulated vehicle and pedestrian traffic and can be active or passive. Because of the popular growth of bicycle use in transport the risk of incidents occurring has grown also. It is important to have a regulation of bicycle safety to reduce the number of incidents/accidents and unsure the safety of all traffic participants. In order to promote and unsure a safe environment in traffic studies must be made to see the influence of factors involving bicycle accidents.

Bicycles are a means of transport particularly timely in current circumstances due to the mobility that ensures the benefits. In terms of mobility, bicycle allows faster mobility in busy traffic jams on roads and, especially, requires no searching for a parking place space.

The bicycle is a non-polluting means of transport, which benefits health and personal budget. Unfortunately, this means of transportation is quite dangerous in terms of increased traffic on narrow streets without clear regulations and without adequate road education. Transport policy is needed to promote sustainable urban friendly cycling so the percentage of individual motorized transport can be reduced.

Road safety is a matter of global importance because accidents are a major cause of death worldwide. The human factor is the most important risk factor, and roads were partially to blame. Analyzing the factors involved in accidents, their causes and their consequences, is important way to find effective measures in the direction of increasing traffic safety.

A problem is the lack of data necessary to realize the study because they rely on police data, there are a high number of unreported cases of accidents, and this is due to the nature of bicycle collisions, which often do not involve a second, or third party or damage to property, rarely leading to the involvement of the police. For a better data set its necessary a larger effort and research (voluntary patient reports, hospital records, and police records).

Roadway offers a number of obstacles due to deficiencies in the design, implementation or maintenance, which is why although cyclists are forced to move on the right lane of the road, must reserve margin:

- drains or channel discovered, aligned to upper elevation of the roadway or framed by a roadway surface that is damaged
- road imperfections of execution or degradation of the roadway, structural type - longitudinal fissures and cracks,
- Locking, grooves, pits affecting road structure or surface – degradation edge cracks submitted to working joints, cracks and crannies transverse holes affecting the surface layer creases, the surface exudates, surface ground, disposals shoulders.
- portions covered with the granular material from the material skid in winter or transport of materials made inadequate
- portions of roadway covered with dirt
- maintenance of the roadway or urban networks unmarked or poorly signposted

Also drivers can create unexpected situations posing hazard to cyclists:

- Driver suddenly opened the car door in front of a bicyclist, situation which can injure or even kill the rider.
- Driver stops, turns or does any direction changes without signaling and without ensure that it can comply with the traffic flow.
- Driver carrying out irregular maneuvers such as overcoming the curve when the vehicle has a tendency to leave the band was passing lane of meaning opposite. The visibility is reduced, he observed a bicyclist traveling.
- Driver uses audio signalization when in close proximity of cyclists, causing panic attack, and unbalance and even slip them on roads, with serious consequences.

There are times when collusions or injury occur by the fault of cyclists due to the fact they do not follow the rules and road signs, do not aim to be as visible to others road users or cannot ensure that safe maneuvering.

A traffic accident is the result of the coincidence of a series of users, vehicles and infrastructure, traffic and environment factors. Improving the characteristics infrastructure can help reduce accidents and their consequences. In this sense, the accident concentration sections become a very important indicator.

Accident black spots are (in the management of road safety) segments of the public road in which crashes are frequent in time. If we can identify those segments in a specific area (police, the administrators of the roads, other institution having legal obligations on the safety of traffic) we can study them scientifically and systematically. Spending money and human resources, institutions which do not identify out question these segments will be not be able to contribute to the reduction of the car accidents and their consequences for the society.

Given the randomness of data there is no exclusive definition of ACS but there are various aspects to be considered generally:

• *Risk Exposure*: taking into account the traffic intensity as it is the most explanatory variable in accidents, from the point of view of infrastructure.

• *Review period*: should be long enough to ensure the reliability of the sample of accidents, but not too lengthy as they can substantially vary the boundary conditions along its analysis. It must be at least 1 year, and it is recommended to use a period between 3 and 5 years.

• *Length of section*: should be able to ensure the representativeness of the sample for the section analyzed, at least 1 km long.

There are situations in which accidents happen frequently but cannot be classified as high risk sections because the impose conditions are not meet.

They are three main criteria for defining ACS:

- Density of accidents: section with specific length that presents an accident density mean (acc./km)superior to a predefined value
- Frequency of accidents: section with specific length were at least “x” number of accidents where registered in the last “y” years.
- Risk indicator: function of the number of accidents registered and the traffic volume over a predefine time and location

Also it is necessary to do a diagnosis of the accidents, meaning identifying the cause contributing to their occurrence; the diagnosis depends on the criteria which led to the accidents.

Depending on the different definitions of ACS we can encounter the following situations:

- Multiple and high rate of accidents; this situation requires immediately attention,
- Low accidents but high rate; occurs in roads with low traffic density,

- Multiple accidents but low accident rate; the number of accidents in low for the volume of traffic in this section
- Low accidents and rate; does not require attention.

The main purpose of the analysis is looking for patterns in accidents that may reveal deficiencies in certain situations, for example: lack of illumination.

Currently the concept of ACS is defined by the Ministry of Development "as roads section with length not exceeding 3 km, exceptions are justified, with more than three years in exploitation, in which statistics recorded of accidents indicates that the level of risk of is significantly higher than in those parts of the network with similar characteristics.

The Department of General Traffic defines for conventional roads as ACS "in which the risk indicator is higher than the established limit over a period of 3 years with more than five accidents". According to DGT a black spot is a section "in which during a year has been detected 3 or more injury accidents, with a maximum separation between one and another of 100 meters."

Figure 1. Road sign for accident concentration sections in Spain.

2.1. Research studies

We will make a review of some of the many existing publications on this topic in order to get a clearer picture of the characteristics, factors and influences of bicycle accidents on roads. It should be pointed that most of studies are focused on urban areas, or on both rural and urban environments.

2.1.1. Studies of factors affecting cyclist crashes

As the number of cyclists on the road continues to increase, the potential for cyclist collisions is a growing concern, particularly collisions with drivers that result in the most severe injury outcomes and poorest survival rate for cyclists, according to Bostrom and Nilsson (2001).

One interesting study was done by Juhra et al. (2011) that analyzes the actual number of bicycle accidents, the types and locations of these accidents, the use of protective gear, the injury pattern and severity, the age distribution and the distribution of bicycle accidents over time. They also concluded that the real number of bicycle accidents is dramatically underestimated.

Other studies show that age is not a casual factor in cyclist accidents (Maring and Van Schagen, 1990) but relates to the cognitive resources available and suggest more that the lack of knowledge and/or inability to apply it in practical situations is a higher risk cause. Collecting data from different sources (police, hospital and voluntary) they reach the conclusion that less than 20% of accidents implicating bicycles are reported to the police, this show the underestimation of the necessity for a more better planning and prevention of road safety. Also the lack of data is based on the presumption that many accidents are falls without external force (namely single-bicycle accidents) and they are not reported to the police.

A study done by Bíl et al. (2009) evaluates different critical factors that influence the cyclists with motor vehicles in Czech Republic resulting in fatal injuries , the study data base is from 1995 to 2007. The study shows that that the accidents are caused in an almost equilibrium part from both motor vehicle driver and cyclist. The severity of the accident depends on which of the participant is at fault. The most fatal situation is obtained when the car driver exceeds the speed limit, representing 41% of cyclist deaths. The most fatal situation, if the cyclist is at fault, is denying the right way to a car representing 63% of deaths due to cyclist fault. Considering only the road topology the most fatal are collisions in straight line (head-on crash). In terms of day-time and visibility, the most fatal are consequences of accidents that happen at night in places without streetlights.

In 2002 Wang and Nihan developed, based on a probability theory, a methodology for accident risk estimation. They did a classification of intersection accidents between bicycles and motor vehicles and studied their frequency in risk model estimation. The study was done in the Tokyo metropolitan area.

Gårder et al. (1994) studied safety implications of bicycle paths at signalized intersections using the Bayesin method; they show that more cyclist accidents with motor vehicle happen in intersections.

Rasanen and Summala (1997) studied the awareness and attention that both motor vehicles drivers and cyclists have in traffic before the accident. The study was done in based on reconstruction and was done in four different cities. The study concluded that in only 17% of the total accidents involving a bicycle did both participants not notice the other before the accident occurred , in all the rest at least one participant notice the other , but the reaction time was to slow. The accident type most frequent involved a cyclist’s who has a driving license and also who daily uses the bicycle. Result show also that the accident site also plays an important role, having a familiar route may give a sense of security and cyclist may not pay as much attention to the road, resulting in a collision with the car.

Jensen et al. (1997) did a research in Denmark. The object of the research was separate lanes marked for cyclists and bicycle paths built into circulation when used simultaneously, their main goal was to encourage the use of bicycles and capitalize acceptable safety conditions for cyclists. The conclusion of the study is that these horizontal marks can improve the safety of cyclists.

A study done in Palo Alto in 1992 by Wachtel and Lewiston, analyses the risk factors of bicycle-motor vehicle collision in intersections.

A study done by Daniels et al.2008 studies the influence of roundabouts in bicycle crashes, the studies concludes that although the roundabout reducers the number of car collisions, the effects on cyclist is the opposite, rising the number of crashes regardless of the design type of cycle facilities.

Nyberg (1996) performed a survey study among bicyclists treated as inpatients and outpatients at the University Hospital of Northern Sweden. Only crashes of 314 victims who deemed the road or bicycle track surface to be the major contributing factor to the crash were studied. The road surface factors that had contributed to the injuries included snow, ice, wet leaves and gravel on the roadway, cracks, holes, uneven paving and a steep lateral slant. Victims also collided with curb and stationary objects.

In the United Kingdom, helmet mounted cameras have been used in mobility research to investigate the experiences of mountain bike riders (Brown, 2008) and riding styles in London (Brown and Spinney, 2010). However, these studies focused on the development and critique of video ethnography as a method that could provide researchers with a virtual ride-along experience that had not been achieved via other methods. It is believed that to date, this method has not been used to investigate how cyclists and drivers interact on the road and the risk factors associated with collisions and near-collisions.

Billot-Grasset and Hours (2014) studied how cyclist behavior affects accidents configurations; almost all cyclists have a preventive behavior avoiding other road users.

2.1.2. How to improve road safety

In 1970, William Haddon Jr., doctor and engineer who had worked and led what is now the National Highway Traffic Safety Administration, in U.S, created a framework for analysis of the events, a conceptual model that applies the basic principles of public health at traffic safety issues. This analytical framework was materialized in a matrix intended for traffic accidents, but can be used for any kind of event. The matrix of Haddon expresses interactive relationship between the factors involved in the accident: the person suffering the event, agencies that produce or contribute to the accident, environmental factors, physical and social.

Table 1. Haddon matrix applied to roads.

Factors	Human factors	Vehicle	Environment factors	
			Physical	Social
-Pre-event **-Event** **-Post event**	- Driver behavior -Alcohol/drugs -Experience -Illegalities	-Bad state of vehicle -Technical problems	-Road state and configuration -Safety elements - Atmospheric	-Bad or lack of normative

By using the matrix we can be identified new ways to improve the formula for the prevention of accident consequences and attitude immediately following the event. It can assess the relative importance of various factors and interventions required. All items that can be identified by matrix require attention and finding solutions to relieve the effects they can produce.

To find the most effective measures to prevent accidents and improve traffic safety, it is necessary to identify as many factors involved in an accident. The next step is to prioritize them and establish solutions for each. The matrix value in fact illustrates a different area where you can make interventions to improve traffic safety. For example, factors that depend on driver can be controlled or removed only by the firm application of the legislation, with zero tolerance and education programs that empower drivers. Firm application of penalties for violations would be welcome.

According to Räsänen and Summala (1998) there are limitations in using post-event data to understand pre-crash factors and it is difficult to determine the looking behavior of a cyclist prior to a collision .The data is typically generated by statements from the driver involved or witness accounts, both subject to reporting biases and errors; or from crash scene investigations which are not able to provide details on all salient cyclist-related pre-event actions. In fatal crashes, clearly the deceased cyclist is unable to contribute; however, additional cyclist-related data may be generated if the cyclist was riding in a group. To better understand the role of cyclist looking behavior and the contributing factors of other situational and behavioral factors it is important to understand what cyclists see when riding and their reactions to the traffic environment.

There have been many studies that have utilized bicycle traffic accidents to model roadways for planning and safety (Pawlovich ,1998 and Garder, 1994). One way to assess bicycle travel safety is to understand what factors relate to incidences of bicycle crashes. It is noted that the most important factors depend on human conditions which is less controllable, being highly variable. Human reactions in traffic are extremely varied depending on age, education, experience and emotional conditions. The human factors are also influenced by conditions and typology of the existing road.

Wagenaar and Reason (1990) identified two distinct classes of causes in road traffic accident scenarios, direct causes and latent factors. Direct causes occur immediately prior to the accident, while latent factors refer to those causes that might have been present in the system for a long time. We base our crash categorization on direct causes. The direct causes consist of causes related primarily to the infrastructure, the cyclist, or the bicycle, depending on where the force that resulted in the accident came from. This subdivision may help in finding latent factors. Note that direct causes may be explainable by several latent factors. For instance, while the force may have come from hitting an obstacle the latent factors may be a combination of the design decision to put the obstacle on the road way, alcohol use by the rider, and malfunction of the bicycle light making it more difficult to detect and avoid the obstacle.

In traffic engineering, the most important human factors are considered eyesight and reaction process. The reactions depend on how they perceive the situation where you have to take certain decisions. The most important factor determining response is the visual. First we see, hear and then react.

Of all deaths caused by road accidents in the EU, those involving cyclists 8% - slightly higher percentage. EU acts in various fields to enhance the safety of cyclists.

With respect to the prevention of crashes, one often tends to look at road-user level only: 'the unsafe actions of the road users'. This appears logical because research has also shown that an estimated 95% of all crashes resulted from an unsafe human action (Sabey & Taylor, 1980).

2.2. Regulations

This subsection summarizes applicable regulation for cyclists on both urban and rural roads.

According to the European Union cyclists are subject to traffic rules define in the Vienna Convention, some countries have additional rules and regulations.

The Vienna Convention defines a cycle as a vehicle with at least two wheels that is propelled solely by the muscular energy of the person riding it. The Convention also states that a cycle will:

a) have an efficient brake,

b) be equipped with a bell capable of being heard at a sufficient distance, and carry no other audible warning device,

c) be equipped with a red reflecting device at the rear, and devices ensuring that the bicycle can show a white or yellow light at the front and a red light at the rear

The European Directive No. 89/686/EC on personal protective equipment lays down the standards which could be adopted for cyclists' helmets. In Spain, cyclist are obligated to wear a helmet outside urban areas, except when going uphill.

In addition to the rules which normally apply to all public highway users and in accordance with the Vienna Convention, cyclists are subject to specific rules defined in their national legislation in order to ensure that they can travel safely and easily:

- Cyclists must not ride without holding the handlebars with at least one hand, must not allow themselves to be towed by another vehicle, and must not carry, tow, or push objects which hamper their cycling or endanger other road users.
- They must keep to the right of the carriageway (to the left in the United Kingdom and Ireland) and give an appropriate arm signal when they wish to turn.
- In principle, cyclists may not ride more than one abreast.
- They are required to use cycle lanes and tracks. They may not, however, use motorways and similar roads.
- When walking and pushing their bicycles on foot, cyclists are classified as pedestrians and may therefore use the pavement.
- The transport of passengers is prohibited, allows contracting parties to authorize exceptions.

In Spain, as a general rule, provided that their paths intersect, drivers have right of way for their vehicles in the driveway and onto the shoulder, for pedestrians and animals, except in the cases listed in *Article 65* and *Article 66*, in which must let them pass, have to a stop if necessary.

Bicycle drivers have right of way regarding motor vehicles:

- When running on a bike path, cyclists or berm step properly marked.
- When another way to enter the motor vehicle turn left or right, where permitted assumptions, and there is a bicycle nearby.
- When circulating in a group, the first has already begun crossing or has entered into a roundabout.

In other cases the general rules of way between vehicles shall apply.

Article 36 requires to:

1. Drivers of animal-drawn vehicles, special vehicles with maximum permissible weight not exceeding 3,500 kilograms, cycles, mopeds, vehicles for the disabled or vehicle tracking cyclists in case there is no road or part of that it is their specially designed, used on the shoulder of his right, if passable and sufficient for each of these, and if it were not, use the essential part of the road. They should also run on the shoulder of his right, or, in the circumstances referred to in this paragraph, the essential part of the

road, drivers of those vehicles with a maximum authorized mass not exceeding 3,500 kilograms, for emergency reasons , do so at abnormally low speed, thereby severely disrupting traffic.

In the long downhill curvy, when security reasons permit, bicycle drivers can leave the hard shoulder and driving on the right side of the road they need.

2. It is prohibited to vehicles listed in the preceding paragraph circulate in parallel position, except bicycles, which can be noted in column two, moving everything possible to the extreme right of way and standing in a row in sections without visibility, and when they are forming traffic jams. On motorways only be run on the hard shoulder, without encroaching on the road in any case.

Exceptionally, when the shoulder is passable and sufficient mopeds may move in column two by it, without encroaching on the road in any case.

Article 85 states that:

1. When forward out of town to pedestrians, animals or two-wheelers or animal traction, you must perform the maneuver occupying part or all of the adjacent lane of the road, as long as there are the conditions necessary for overtaking in the conditions necessary for overtaking under the conditions provided in these regulations; in any case, the lateral spacing is not less than 1.50 meters. It is expressly forbidden to overtake endangering or hindering cyclists moving in the opposite direction.

2.3. Research needs

As can be concluded after reviewing previous research, there is a need of continuing research on bicycle safety. The number of crashes, injured cyclists and deaths is not decreasing and the increase in the number of bicycles in many countries makes this decrease even more difficult.

With respect of the safety of cyclists on rural road, there is a lack of research on the causes, severity and typologies of accidents. This problem is especially relevant in some countries, such as Spain, where the number of sport cycling is high and still grows. At the same time, the current regulations that affect cyclists were defined without an accurate knowledge of the road safety problems, and have not been tested or verified.

Consequently, this Master Thesis will try to cover the lack of knowledge in this field and will focus on the characterization of a database of crashes involving cyclists in Spanish two-lane rural roads.

3. Objectives

3.1. Objectives

In this section the main objective of this work is presented, which is the study of the causes of cyclist crashes on two-lane rural roads in Spain.

The overall objective of the study is placed within a much larger and deeper study which is to improve road safety of the road network through the introduction of innovative roads, this is not achievable through a study of this magnitude. This implies the creation of reliable simulation models that can reproduce the characterization and configuration of this type of roads with the goal of understating how and which factors influence the appearance of crashes.

Accidents involving cyclists are increasing over the lasts years, and to implement a newer and better safety regulation is important to know where and why accidents occur and to understand what measures have the most beneficial potential. All this information will allow designing roads and safety measures in a safer and better manner to allow safe movement. The analysis is based on police-reported accident data with over 6,000 accidents between 2009 and 2013 from Spain.

The detailed objectives of the study are listed below:

- Present and describe a database of road crashes.
- Select and filter crashes involving bicycles on two-lane rural roads.
- Identify the main typologies of crashes involving bicycles.
- Analyze the different factors affecting cycling safety on two lane rural roads:
    - Temporal evolution.
    - Road design and geometry.
    - Involvement of other users.
- Analyze the frequency of crashes on a small network and compare it with exposure data.
- Determine the most important factors and further requirements to improve safety.

3.2. Hypotheses

The study was motivated by several hypotheses, listed as follows:

- There are a significant proportion of crashes involving only one bicycle. It means that a collision with a motor vehicle is not the unique cause of cyclist crashes.
- Roads presenting paved wide shoulders have less bicycles crashes, as cyclists can use a different part of the cross section.
- The wider roads will have less bicycles crashes, as cyclists and motor vehicles interaction is weak.

- Intersections account for a significant proportion of crashes as they concentrate crossing, merging and diverging trajectories.
- Roads with higher traffic volume (motorized) present a higher risk for cyclists.
- More collisions occur in curves than in tangents.

4. Methodology

This section describes the methodology that was used to achieve the study objectives. It was based on the analysis of crash data of Spanish rural highways, provided by the Spanish Traffic Directorate (DGT).

The consequences of a collision depends on a number of factors, some of the most important being the type and the vehicle's weight, place, direction and purpose impact, road characteristics and its surrounding environment, etc.

4.1. Investigation procedure

The investigation procedure of the accidents covers only the analysis of the statistical data collected from the police data source.

This part is mainly to classify the different types of accidents regarding a bicycle to determine the dimension of lanes and roads, road markings, the existence of safety barrier, direction panels, reflective signs, the type of intersection of roads and the location of the accident from the intersection and other factors like the status of the road surface, luminosity, weather factors, visibility, driver state (tired, on drugs or alcohol) , car status, road status etc.

The database consisted of three datasheet:

- the first one: accidents,
- the second one: vehicle,
- the third: persons.

It included reports from 2009 to 2013.The database was provided as separated text files. They were integrated into a Microsoft Access database file. After that, analysis was carried out using Microsoft Excel.

4.2. Selection criteria

As the crash database cover the entire country, including all types of roads and vehicles, it was necessary to filter the entire data according to the following criteria:

- Every accident involves at least one bicycle.
- All studied accidents are on two-ale rural roads.
- Accidents on urban areas are excluded.

After applying the selection criteria, the data base consisted of 6,786 entries. In order to facilitate the better understanding of the analysis, the database fields were grouped according to the following five points:

- General information : location, date, time, type of accidents, infractions, number of vehicles.

- Information road and environmental: type, number of lanes, length of road, lane, shoulder, information and safety elements, visibility, luminosity.
- Information about the vehicle: vehicle type, occupants, technical faulty.
- Information on road user: type, nationality, experience, lesions, driving license, age, gender, injuries, deaths.

5. Analysis

This section is the main core of the Master Thesis and contains the descriptive analysis of crashes involving bicycles on two-lane rural roads in Spain. It is divided into the following sections: temporal variation, analysis of crash configurations, study of all crashes, study of single bicycle crashes, study of multiple vehicle crashes and analysis of road segments.

An important attention should be paid to the fact that road safety analysis estimates the risk in the basis of the comparison between the number of events (either crashes or victims) with exposure (number of users). However, in this case, the data regarding exposure is not known. This is caused by the absence of cycle traffic counts on rural roads, which still remains as an unknown variable. Even the traffic counts for motorized traffic are not available for the entire network.

Consequently, sections 5.1 to 5.5 will take the absolute values of crashers and their victims as the main analyzed variable, proving a macroscopic approach of the problem. On the contrary, section 5.6 will account for motorized traffic exposure, as an initial approach of the problem of quantifying risks.

5.1. Temporal variation

According to data provided, the situation in Spain regarding bicycle accidents on conventional roads has increased substantially in the period 2009- 2013. This may be due to the increase of the national park vehicles on an obsolete road infrastructure and the lack legislative measures stricter road or failure to properly apply the existing legal norms, on the other hand.

Analyzing the data base they are a total of 6,786 accidents involving at least one cyclist over the past 5 years.

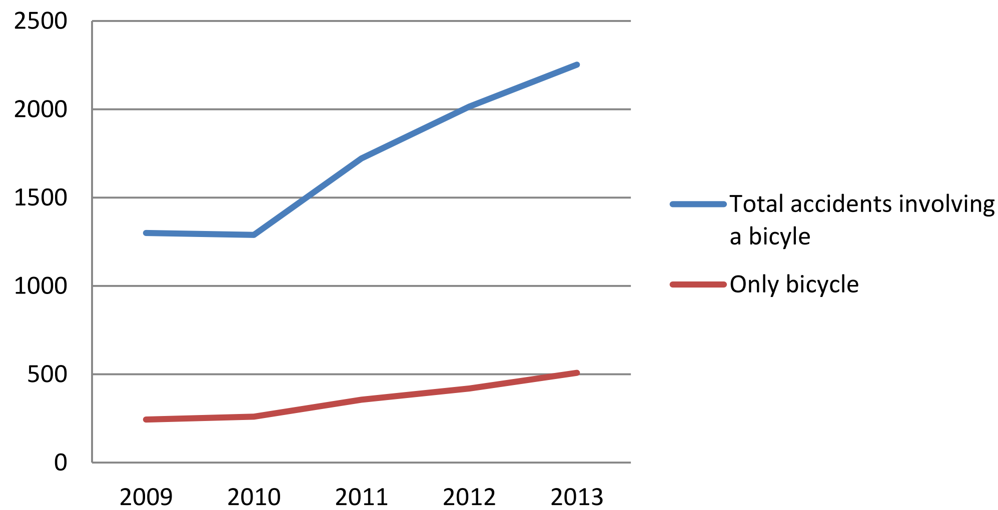

Figure 2 .Statistics regarding bicycle accidents in Spain during 2009-2013.

5.2. Accident configuration

The Figure 3 shows the classification of accidents according to their configuration or typologies.

Each accident was classified to obtain an overview of all accidents and then to categorize them by type. It was made a distinction between singular accidents committed by bicycle and where several vehicles were involved. All the percentages refer to the total number of studied accidents.

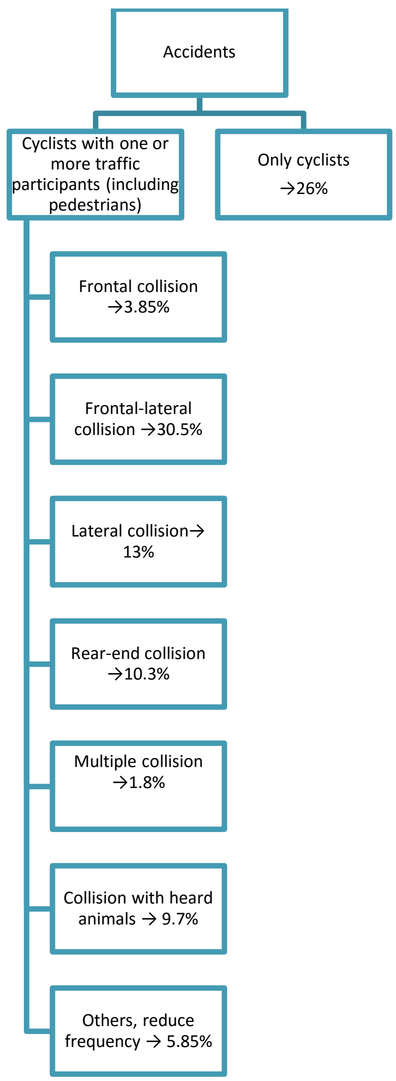

Figure 3. Accident configuration.

The main causes for accidents for single vehicle and between a cyclist and another road user have similar characterizations as will be presented in the next stage. However, the root cause of an accident varies according to the configuration of the accident. The following chapters present an overview of the main causes of accidents according to various configurations, from factors, such as weather, pavement and default of traffic, to road configuration or alcohol/drug abuse.

5.3. All accidents

5.3.1. Effect of road geometric design

Good road infrastructure provides a fundamental foundation for a safety traffic environment delivering, also, a wide range of economic and social benefits. Adequately maintaining road infrastructure is essential to preserve and enhance those benefits. An inadequate structure of the road and road elements can lead to increasing accidents witch will have serious consequences for economies and social well-being.

Elements and road design have a great influence on driver's behavior in traffic, a good design cannot prevent 100% all accidents but can substantially reduce them. Determining which of these has more influence in the appearance of accidents can help in developing regulations and norms for safer roads.

Several studies have shown that the installation or improvement of safety system protection on roads can provide a substantial reduction in the frequency of accidents.

To increase safety on public roads it is necessary that on certain sectors and positions to install elements that can prevent traffic participants to enter dangerous areas or to inform them about the stat of the road.

Regarding the road elements, median between lanes, crash barrier, directional panels, reflective signs and reflectors, we can observe that, as expected, the number of accidents is well increased on the road that do no present signs, signals or protective structures. As all are important and the lack of these elements increases the chance of accidents, the most significant one is the median between lanes.

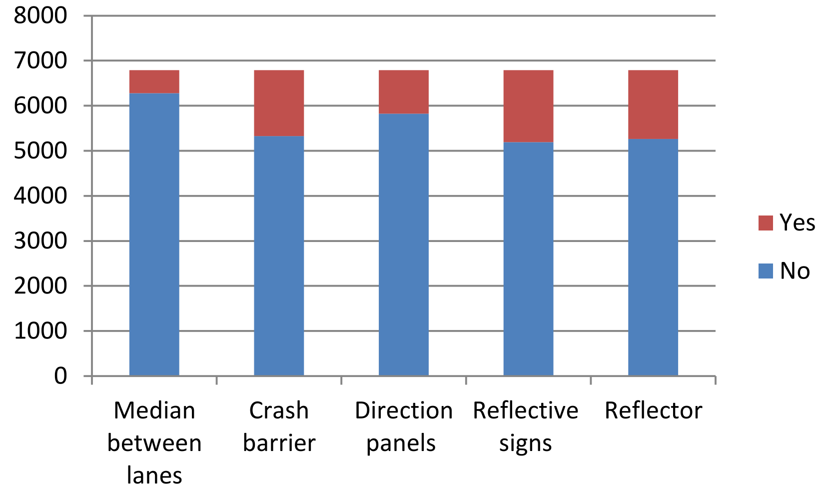

Figure 4. Number of accidents related with auxiliary elements.

As expected all of these elements have a great influence in the number of accidents that appear on conventional roads. Around 70% of accidents happen on roads with no safety elements.

The road plan consists of alignments, connected by curves having certain characteristics, depending on the design speed. The characteristics of these curves may be cause accidents if they are not properly designed and executed, mostly by influencing the behavior of the traffic participants.

Road width and shoulder width are two of the most important factors to ensuring a safe traffic environment. Every country has a minimal standard, in Spain for two-lane rural roads it is from 0.5 m to 2.5 m depending on the maximum velocity the road was designed for.

The relationships between road widths and vehicle speed is complicated by many factors, including time of day, the amount of traffic present, and even the age of the driver. Narrower streets help promote slower driving speeds which, in turn, reduce the severity of crashes.

40% of accidents occurred in roads with greater width, which is expected due to the higher traffic of motor vehicle and cyclists. On roads narrower than 5.99 m traffic is generally lower and proportion of accidents decreases.

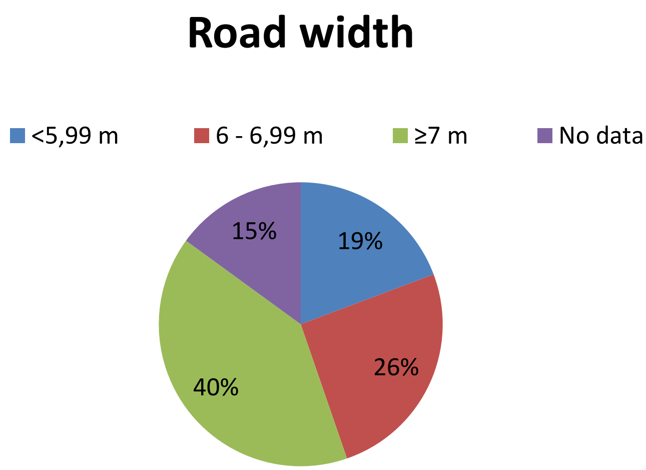

Figure 5. Accidents volume depending on road width.

Both narrow (less than 3.25 m) and wide (over 3.25-3.75 m) lanes have higher number of crashes in interurban settings, contrary to the received opinion that wider lanes are safer. Wider lanes (over 3.75 m) are associated with 6% of crashes, although this width is less common in two-lane rural roads.

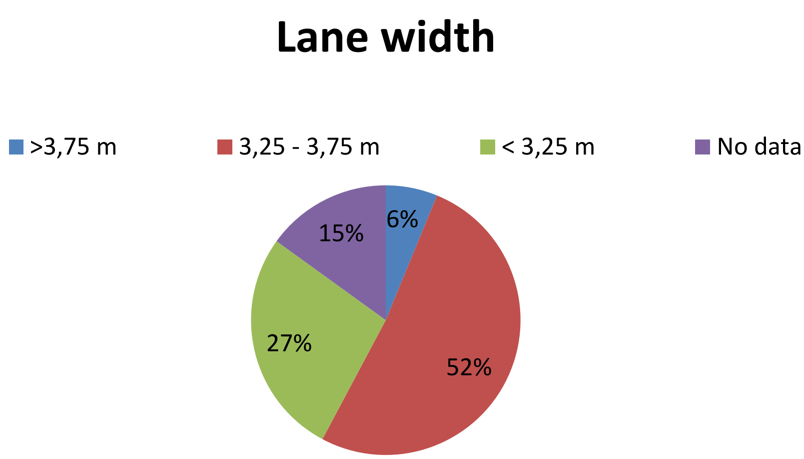

Figure 6.Accidents volume depending on road width.

Road markings are used to provide guidance and information to drivers and pedestrians. Uniformity of the markings is an important factor in minimizing confusion and uncertainty about the road configuration therefore crashes.

Road markings are extremely useful to draw attention to certain situations: intersections, traffic lights, curves, hazardous areas, etc. by marking them visible on the road, decision-making capacity of drivers is stimulated and they can react in much faster, avoiding accidents.

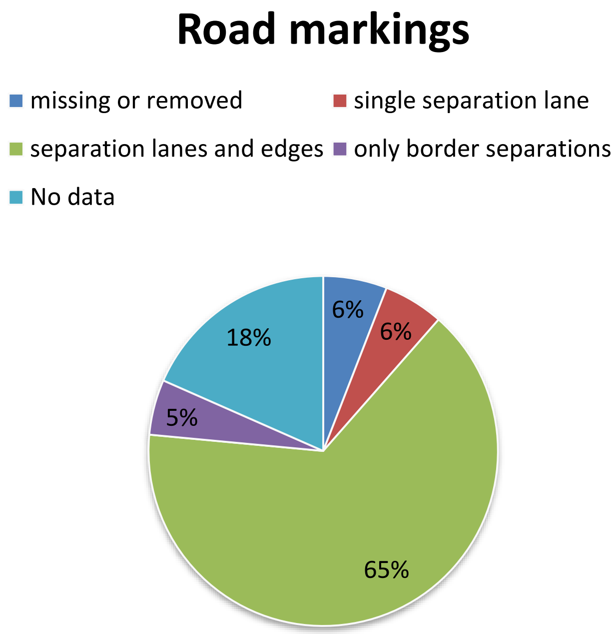

Figure 7. Accident percentage regarding road markings.

From 2009 to 2013, in Spain, a disturbing 65% of accidents involving a bicycle occurred on roads with separations lanes or edges, and only 6% in areas with missing or removed markings. One reason for this small rate may be the very low number of roads with areas with no markings and/ or bad design or configuration of the separations resulting in the confusion of distractions of the cyclists/drivers.

A road shoulder is a strip of land immediately adjacent to the traffic lane of a road not bordered, maybe separated by painted markings. Road shoulders are designed to provide a factor of safety for road users who accidently leave or are forced to leave the sealed pavement area and protect the sealed pavement from excess deterioration.

A shoulder, often serving as an emergency stopping lane, is a reserved lane by the verge of the road; they are not designed for interns traffic use. The use of appropriately designed segregated space on interurban routes appears to be associated with reductions in overall risk.

Cyclists may choose not to use it for reasons such as:

- it being too narrow, inviting dangerously close passes at high speed by motorists,
- it having a road surface unsuitable for cycling, as shoulders may not be intended for wheeled vehicles,

- putting the path of the cyclist in direct conflict with the paths of other road users, such as those turning across the shoulder.

Generally, the usable width of the road begins where one can ride without increased danger of falls, jolts or blowouts. A road may have a gravel shoulder, its edge may be covered with sand or trash and the pavement may be broken.

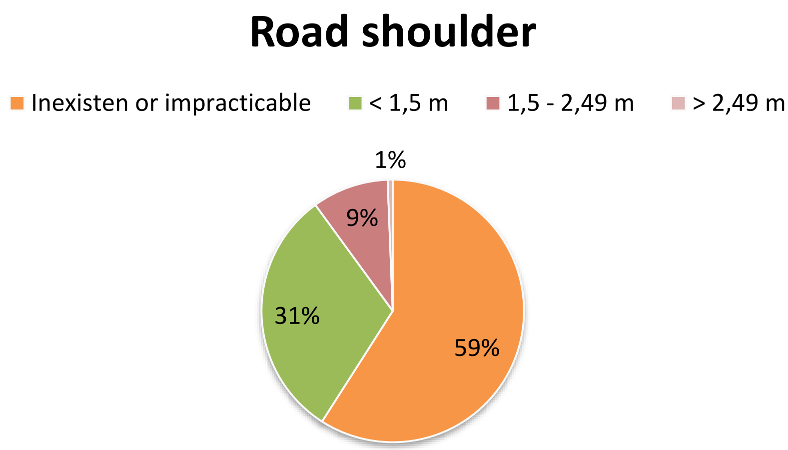

Figure 8. Accidents percentage depending on road shoulder.

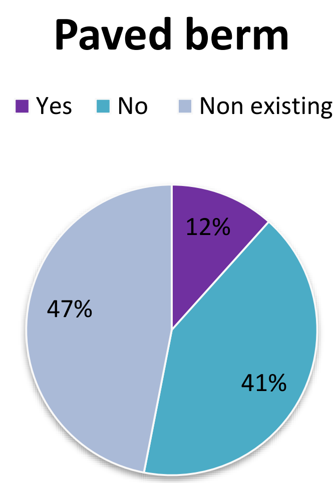

Figure 9. Influence of paved shoulder in accidents.

The above graphics show the importance of a road to have a shoulder, 59% of accidents take place where the shoulder is completely missing and 31% on roads where the width of the shoulder is smaller than 1,5m. A reason is the insufficient space cyclists have and as a result are obligated to enter the car lane to continue their trajectory, witch exposés them to a higher risk of accidents. Also if the existing shoulder is presenting inadequate conditions the cyclists are obligated by the circumstances to enter the car lane.

The presence of intersections may be another significant factor to increase risks. Analyzing the whole data base, 43% of accidents took place in an intersection. It represents a significant concentration of crashes into network nodes.

It is important that drivers entering the intersection to focus its attention without being distracted by following the trail intersection. This can be achieved by lighting the intersection and / or arrangement with central island plantations appropriate to shorten the street light.

In case of a crossroads roundabouts is required that, by landscaping of the center island, in conjunction with a possible choice of plantation, that helps vehicles crossing the intersection to be taken out of perspective , in this way drivers will be obligated to follow and be guided by road signs, going through the intersection in fluent conditions. On the central island of the roundabout ornamental shrubs of small height can be planted to obstruct vehicles on the main road direction.

The most frequent intersect type where collision take place are “T” or “Y”, 37% of total, followed by the roundabout with 32% of the total number. Entering and exiting lane have the smallest percentage of occurring accidents 3% respectively 2%.

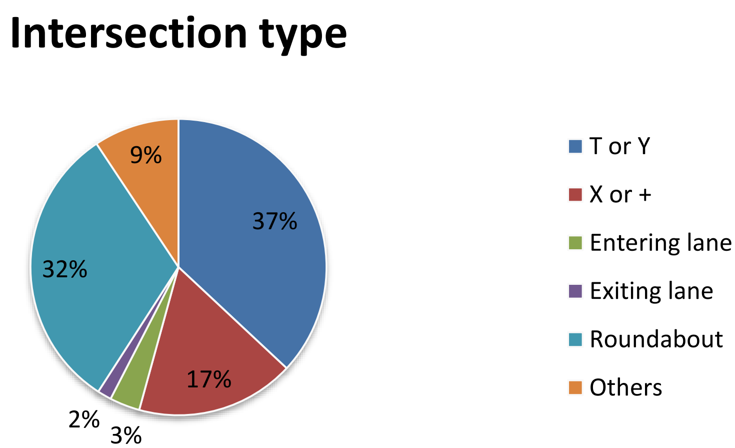

Figure 10. Accident percentage in types of intersections.

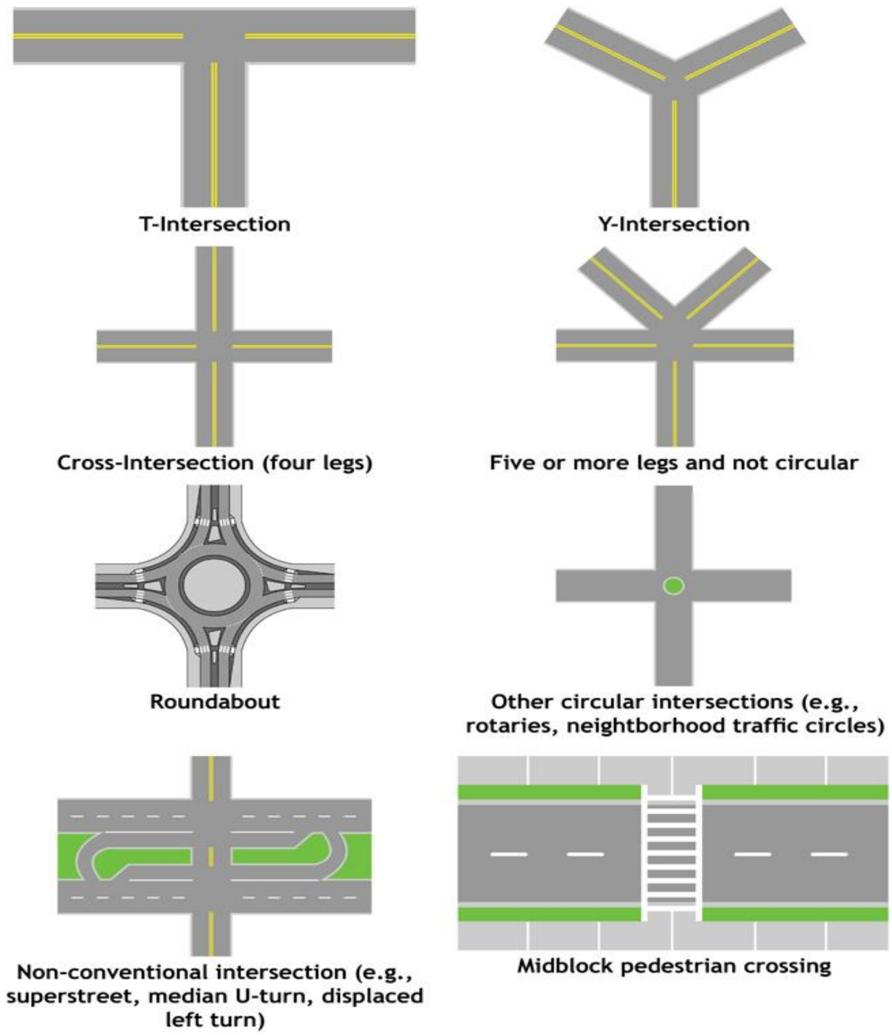

Figure 11. Intersection types (picture from *afety.fhwa.dot.gov*)

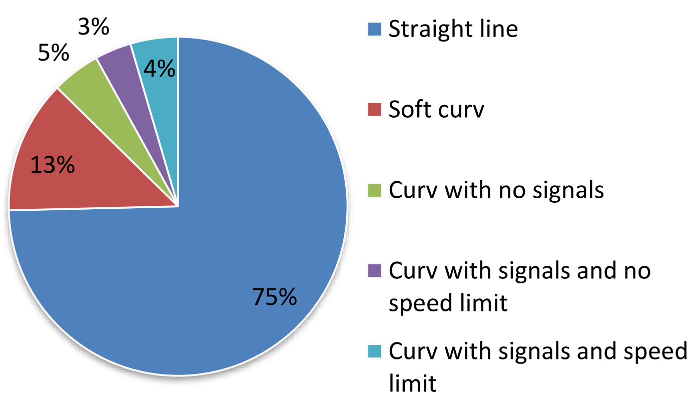

Figure 12. Accidents outside intersections.

An alarming 75% of accidents happened in straight line. This is caused by bad road geometric configuration. The alignment is the route of the road, defined as a series of horizontal tangents and curves.

Long straight alignments are not recommended because of the effect had on drivers:

- sleeping predisposition , due to the monotony of the road.
- blinding during the night, due to the headlights of the other traffic participants.

It is recommended to introduce soft curbs along the road to maintain the attention of the drivers.

5.3.2. Other concurrent factors

Based on the data we have the most frequent factors in causing accidents are distractions, 37%, and traffic rule violation, 44%. A great deal of traffic participants admit to not respecting the rules and law, considering that in that moment their action is no danger for themselves or others. We see that inadequate speed and tiredness/illness also influence the appearance of accidents.

These factors are based on human behavior and are the most unpredictable and hard to combat. Cyclists actions also deepening on the reasons of use of the bicycle (transport, pleasure, sports).

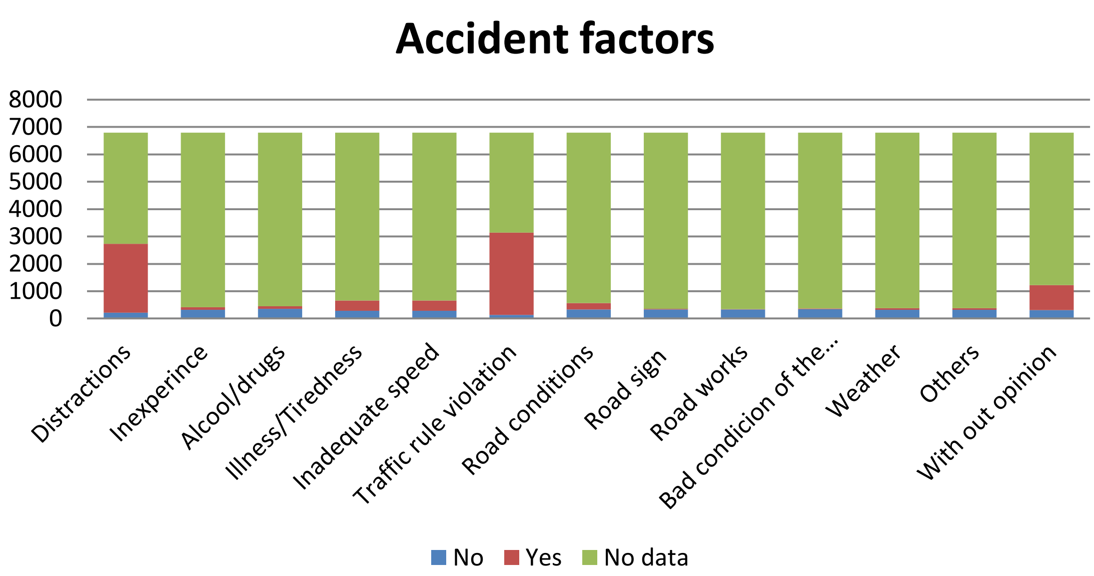

Figure 13. Accidents causes.

Environment factors such as atmospheric, luminosity and surface status seem not to influence crash conditions, on average almost 93% of accidents occurred in normal conditions.

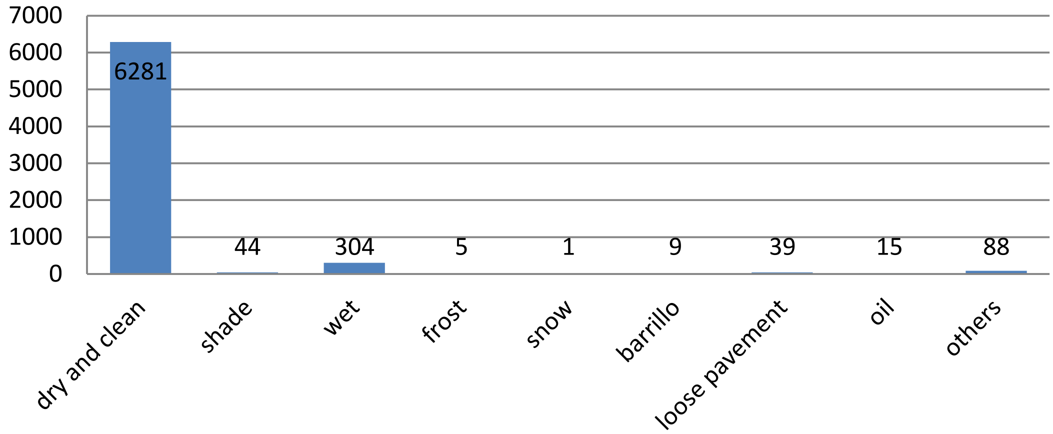

Figure 14. Accidents depending on surface status.

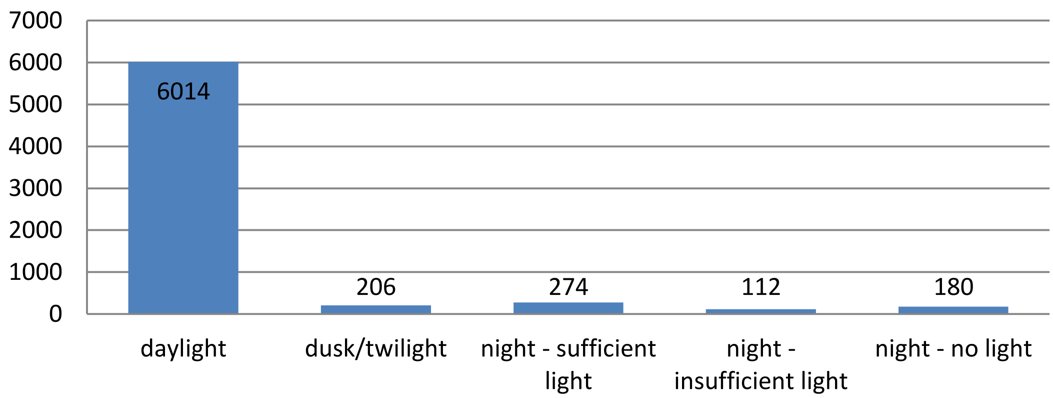

Figure 15. Accidents depending on luminosity.

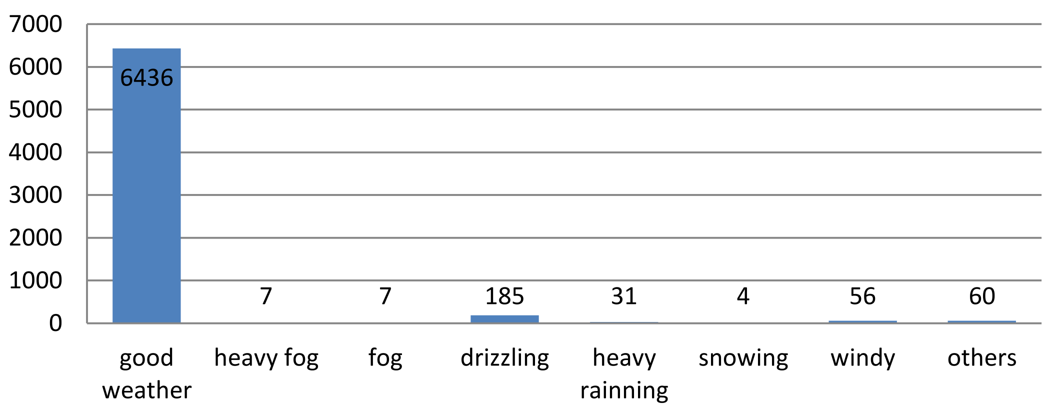

Figure 16. Accidents depending on atmospheric factors

They are various accidents types, but the most frequente in multiple vehicle crashes are frontal-lateral collision, 30.5% , followed by lateral collision 13% , rear-end collision 10.3% and collision with lead or herd animals 9.7%.

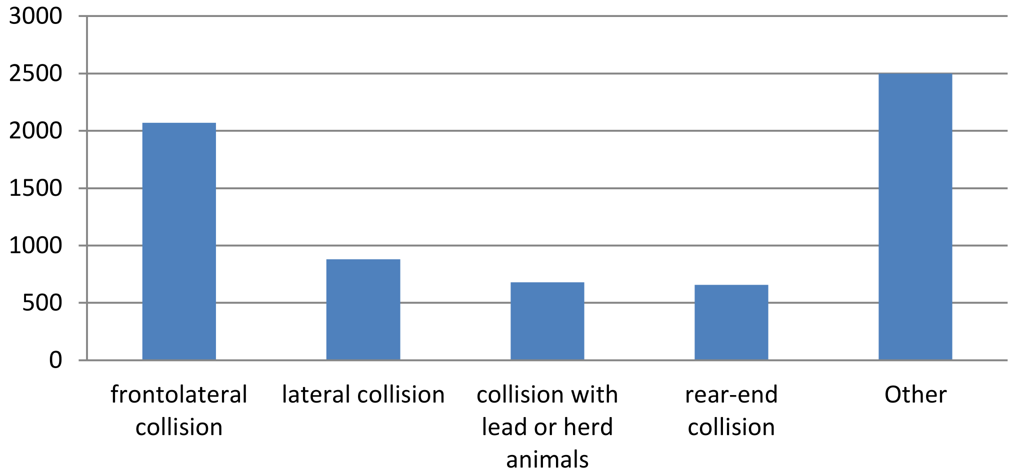

Figure 17.Accident type

5.3.3. Severity and temporal evolution

Table 2.Accident dynamic in Spain 2009-2013

Accident dynamic	2009	2010	2011	2012	2013
Total	1277	1158	1541	1809	1929
Deaths	35	39	27	46	32
Severe injury	354	245	273	283	293
Light injury	888	874	1241	1480	1604

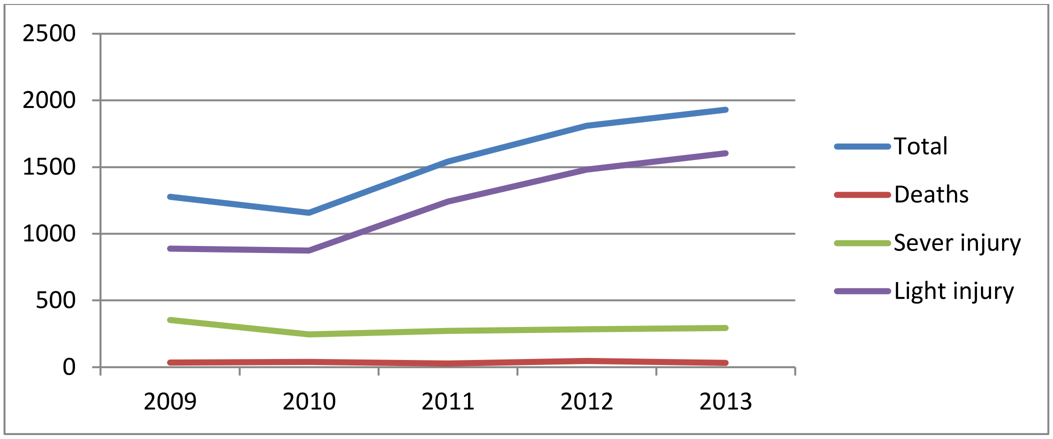

Figure 18.Evolution of accidents in Spain 2009-2013.

Observing from *Table 2.Accident dynamic in Spain 2009-2013* and *Figure 18.Evolution of accidents in Spain 2009-2013*, we can see a linear increase of 40% from 2010 until 2013. Even though the number of deaths and sever injuries slightly decreased, crashes resulting in light injuries has increased with over 45% from 2010 until 2013.

In general, severity of bicycle-related crashes is high. On average, there is a 2.3% of deaths and an 18.7% of severe injuries per 100 crashes.

5.4. Single bicycle crashes

Most research on cyclist safety are focused on collisions with other vehicle, very few studies address single bicycle crashes. This chapter is dedicated to single cyclist accidents, falling or collisions with obstacle.

Out of the total number of accidents 26% (1790) of them involve only bicycle. In this part we will analyze how the road elements, typology and geometric features affect the cyclist and which have a more influence in the occurrence of accidents.

5.4.1. Effect of road geometric design

We see in the graphic below in report with the road and safety elements if we only analyze accidents involving only one vehicle, the tendency is the same as we saw in the graphic of all accidents.

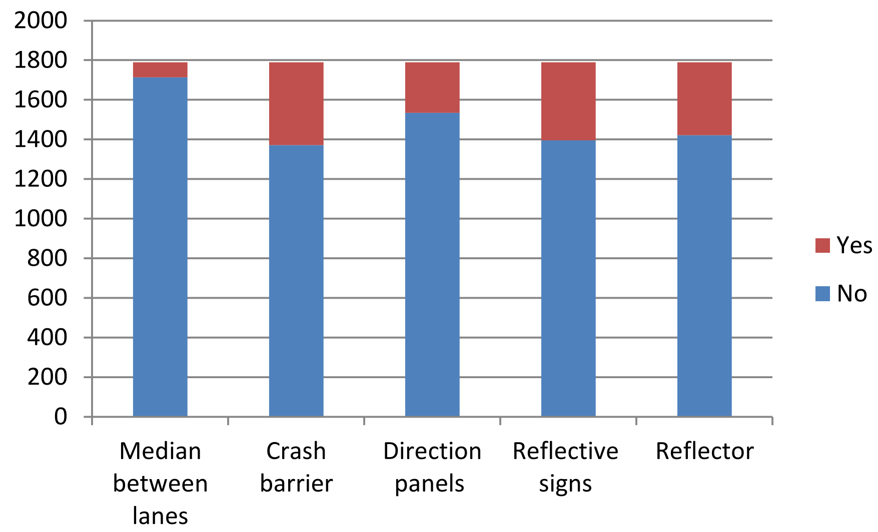

Figure 19. Road elements.

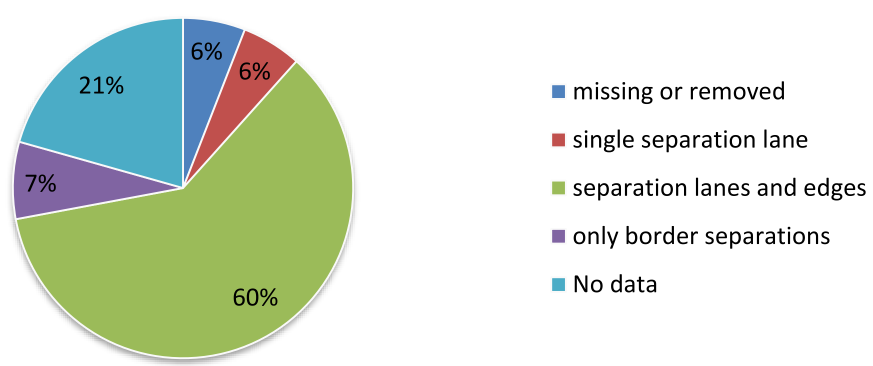

Figure 20. Accidents depending on road markings.

As we can see in the graphic above the lack of road markings does not influence the rate of accidents. On the other hand 60% of accidents happen in roads that present separation between lane and edges; this may be caused by bad design or configuration of the separations resulting in the confusion of distractions of the cyclists.

Looking at all the dimension of the road we can observe that the number of accidents is quite similar in all three types, greater width does not result in an increase number of accidents. But if we take only the dimension of the lane we can see that 44% of the accidents happen in lane width between 3.25 and 3.75 m, this may be a result of the increased traffic and an excessive number of cyclists which enter the car lane.

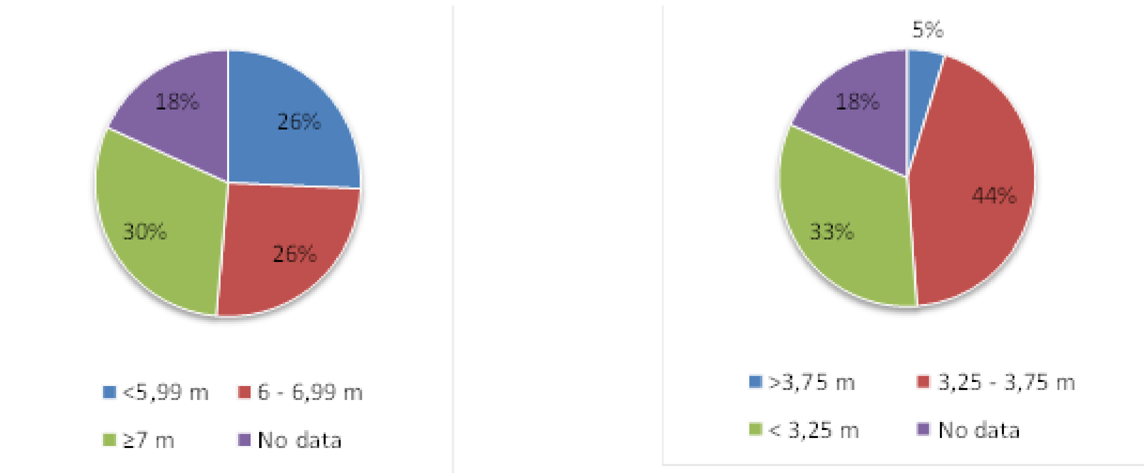

Figure 21. Accidents depending on width (entire section left and lane right).

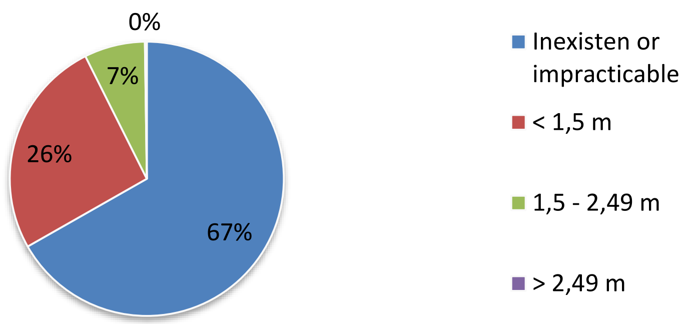

Figure 22. Accidents depending on road shoulder.

The number of accidents is highly increased on roads that do not have or have impracticable shoulders, while in road with shoulder dimension over 2.49 m present a significant lower number of accidents (0.22%). This is due to the extra significantly space cyclists have and as a result are not obligated to enter the car lane to continue their trajectory. The lack of berms on roads obligated cyclists to enter the traffic lane witch exposés them to a higher risk of accidents. Also if the existing shoulder is presenting inadequate conditions the cyclists are obligated by the circumstances to enter the car lane.

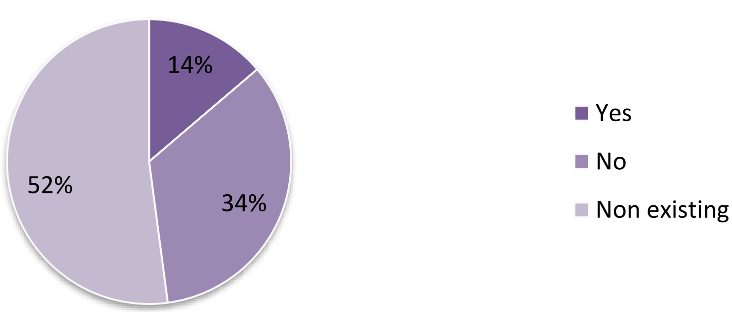

Figure 23. Paved shoulder.

Up to 39% of the accidents that occurred in intersections, being this number slightly lower compared to all accidents. In single bicycle crashes we encounter an increased number of accidents in other types of intersections, 34%, also representative are intersections in shape of T or Y, and roundabouts.

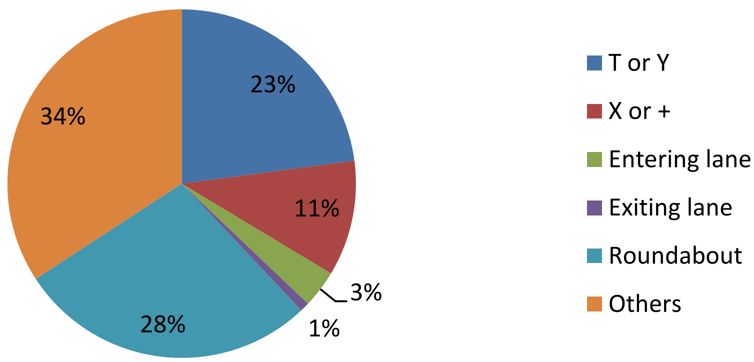

Figure 24. Accidents depending on intersection type.

The other 61% of accidents took place outside the intersection, as in multiple vehicle crashes, with an alarming number of them in straight line lane, while in curbs the numbers is encouraging low for what was expected, this may result as an increased precaution of the cyclist/and or drivers in curbs.

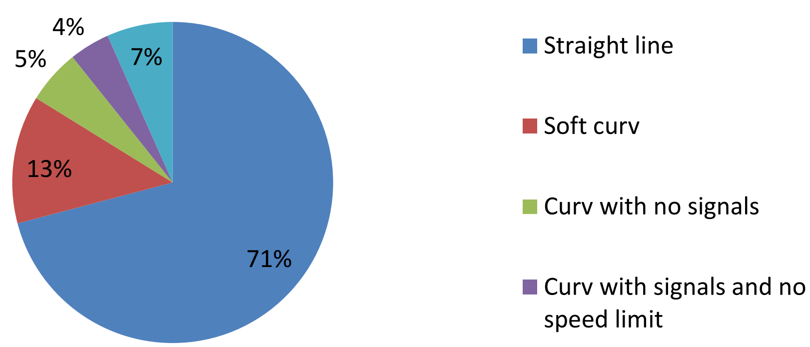

Figure 25. Accidents depending on lane configuration.

5.4.2. Concurrent factors

Analyzing the accident types, in single bicycle accidents a large number occur based on various and different motives, the most representative are collisions with lead or heard animals 30%, this may be a result of the lack of protective barrier and intrusion of the animals on the road.

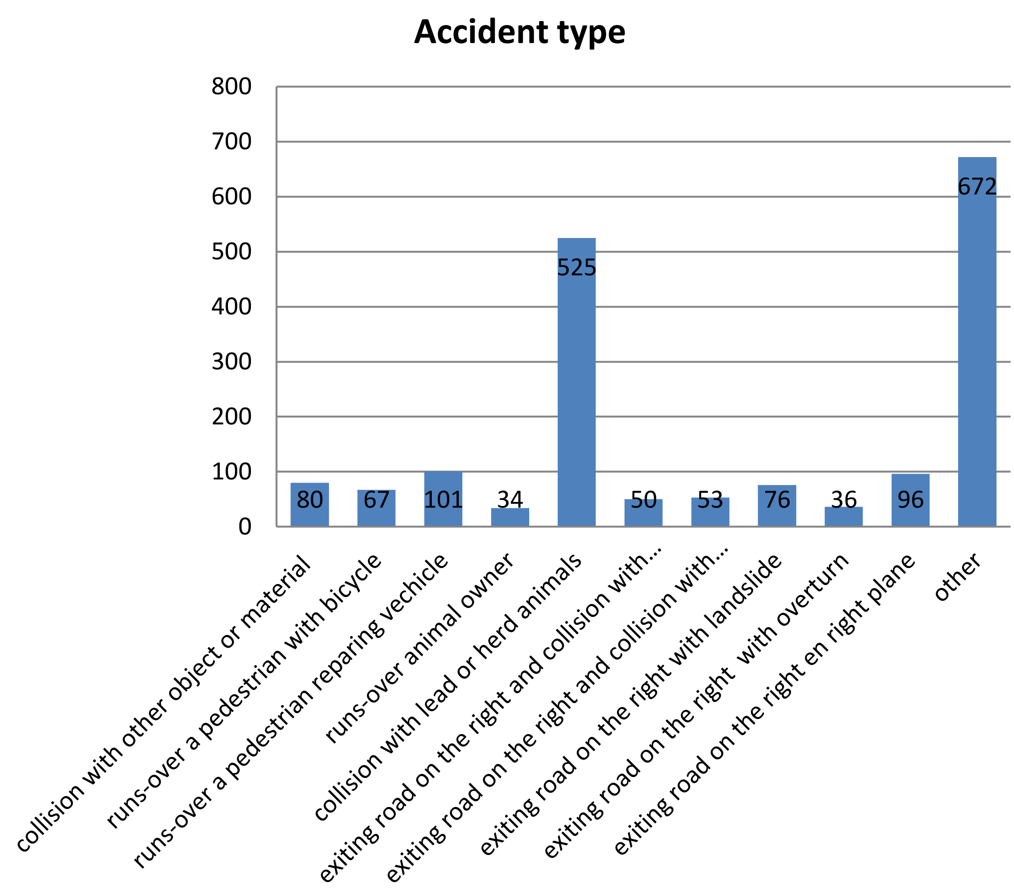

Figure 26. Accident types.

5.4.3. Severity and temporal evolution

Table 3.Accident dynamic of only bicycle in Spain 2009-2013

Accident dynamic	2009	2010	2011	2012	2013
Total	252	265	370	437	530
Deaths	3	5	4	2	3
Severe injury	62	60	60	70	83
Light injury	187	200	306	365	444

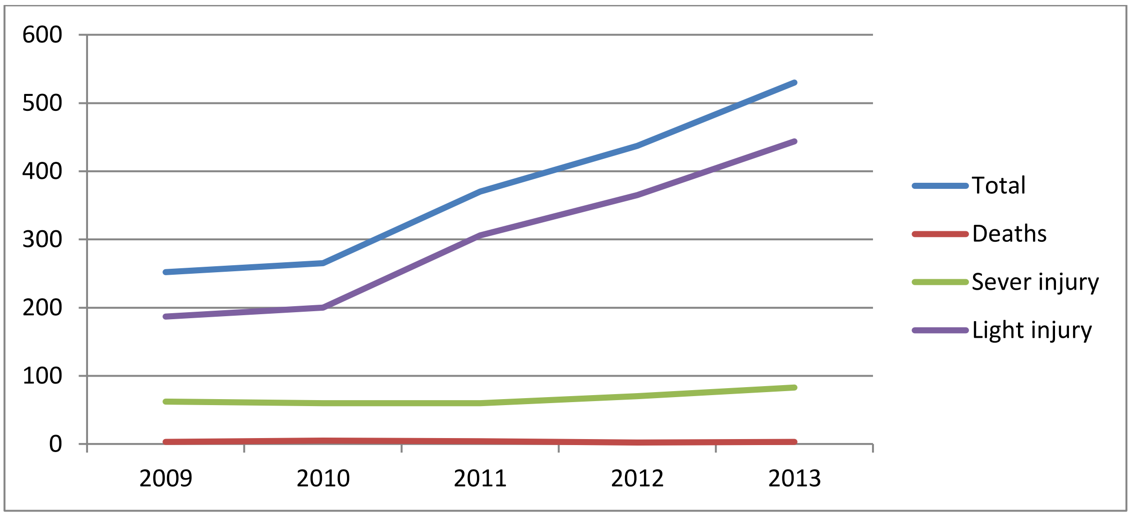

Figure 27. Evolution of single bicycle accidents in Spain 2009-2013.

Observing *Table.3 Accident dynamic of only bicycle in Spain 2009-2013* and *Figure.27 Evolution of single bicycle accidents in Spain 2009-2013* we can see that after 2009 the number of people injured in single bicycle accidents has increased dramatically with over 53%,. In general, crashes involving a single bicycle cause less deaths (under 1%) but similar severe injuries (18%).

5.5. Two-vehicle crashes

Almost 74% of the total number of accidents occurred with one then one vehicle. In accidents involving 2 vehicles, as expected the majority of accidents, 68%, happened with standard motor vehicle (personal cars) with or without trailer.

5.5.1. Characteristic of the second involved vehicle

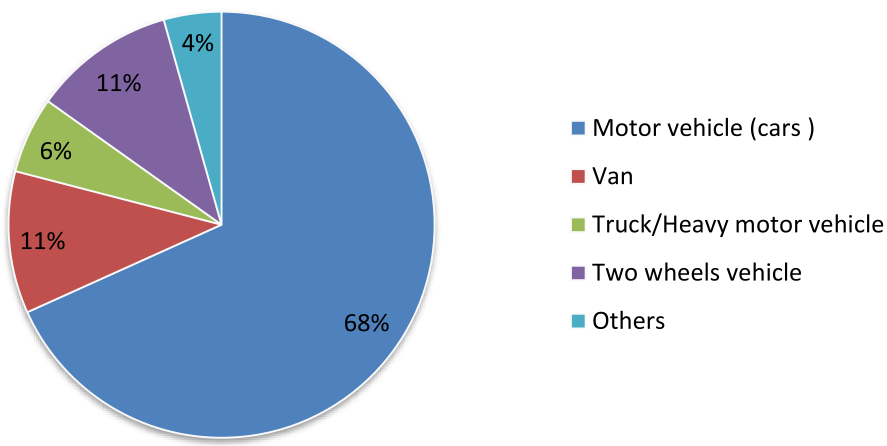

Figure 28. Percentage of other vehicles involved in bicycle accidents.

Accident severity is influenced by the relative speed of the two vehicles is an important feature of such impacts; we can relate the high number of accidents resulting in injuries with the high number of collision with standard personal cars and the number.

5.5.2. Effect of road geometric design

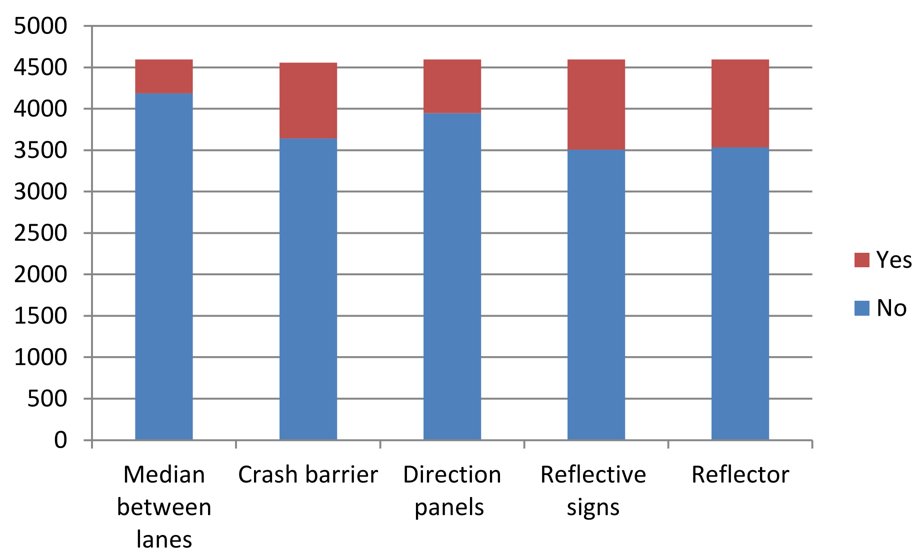

Figure 29. Number of accidents between 2 veh. related with auxiliary elements.

Road auxiliary components keep the same tendency in 2 vehicle collisions, the absence of this safety and guidance elements lead to a higher risk of occurring accidents.

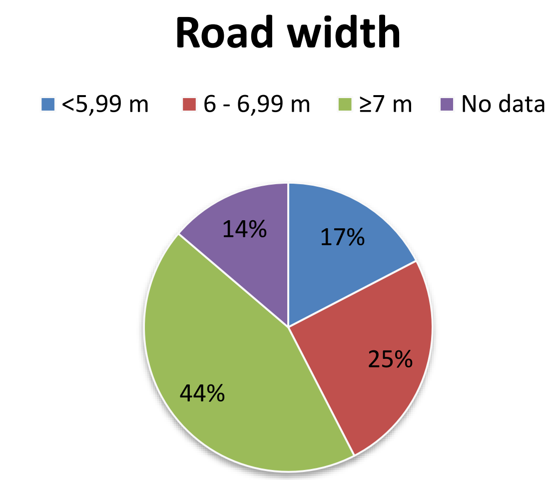

Figure 30.Accidents volume depending on road width.

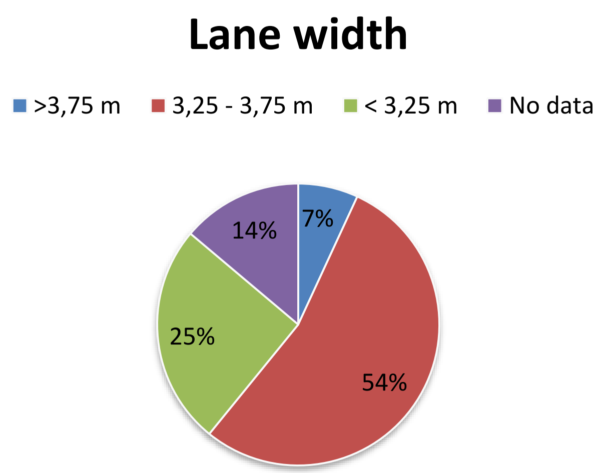

Figure 31. Accidents percentage depending on lane width.

Collision between two vehicles occur in a 44% in roads with width equal or higher than 7 m , followed by 25% on roads with width between 6 and 6.99 m , and only 17% of crashes happen where the span of the road is smaller the 5.99 m .But looking at the percentage of accidents depending on lane width , roads with lane dimensions higher and 3.75 m or lower than 3.25 m have a lower accidents rate, while lanes with dimensions between 3.25 and 3.75 m have a 54% accident rate. This may result as the increased volume of traffic on larger roads; the advantage of roads with a greater lane width is that it can allow a sufficient space between the motor vehicle and cyclist

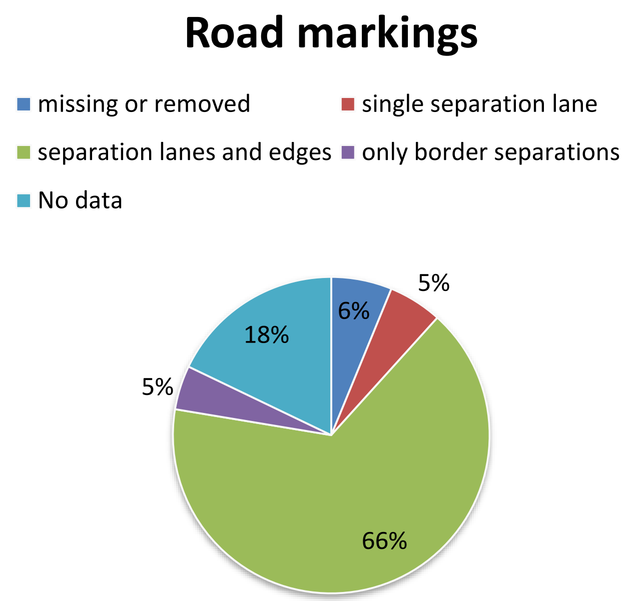

Figure 32. Accident percentage depending on road markings.

The influence of road marking on accidents is minimal, 66% of crashes take place in areas where separation lanes and edges are present. Road marking have the role to guide and help drivers/cyclists maintain a safe trajectory for them and other traffic participants, bad design , configuration and execution of this elements can influence occurrence of accidents.

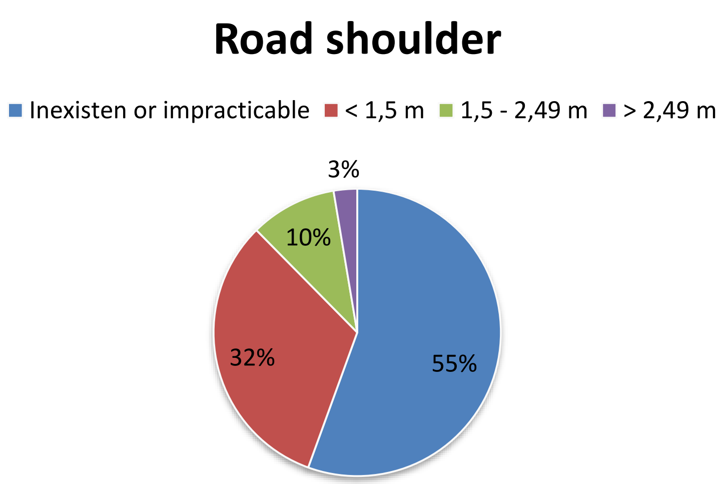

Figure 33. Accident percentage depending on road shoulder.

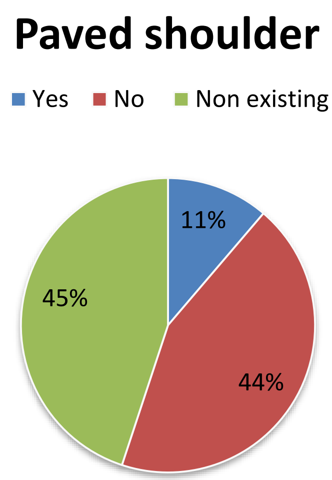

Figure 34. Accident percentage depending on paved shoulder.

Road shoulder offers cyclist a safe distance between them and other traffic participants, 55% of accidents took place on roads with no berm. Also the bad status of the shoulder can influence cyclist to enter the road lane resulting in an increased risk for crashes. In a good design and configured berm accident rates are at 11%.

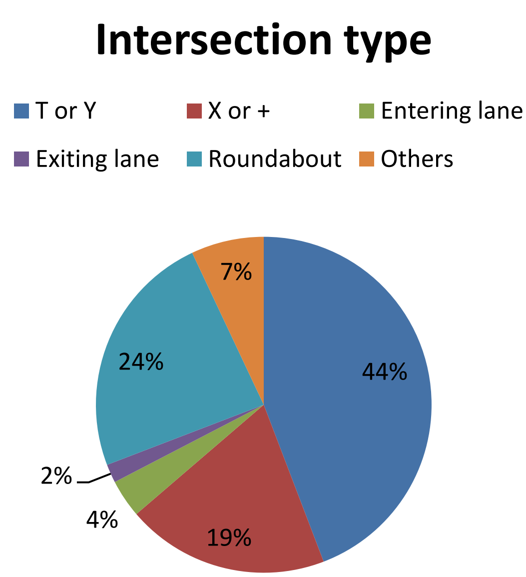

Figure 35. Accident percentage in types of intersections.

The tendency for accidents, between two vehicle, in intersection as the same as in multiple vehicle, 44% of collision occur in intersections type “T” or “Y” , followed by roundabout 24% and type “X” or “+” intersections, the lowest accident rate occur in exiting lane 2%.

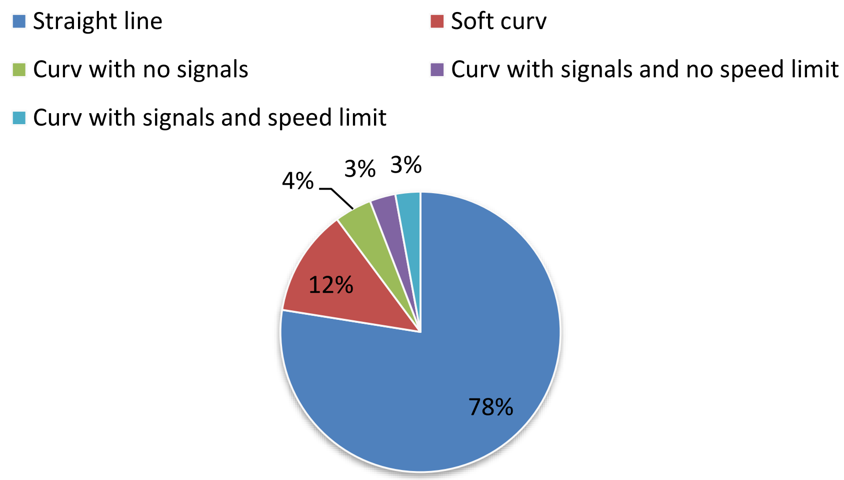

Figure 36.Accidents depending on lane configuration.

Curbs do not influence the occurrence of collisions, having the lowest rate of accidents, approximated 3% , while accidents in a straight and direct line are at an alarming rate of 78%. Road design and configuration as well as the increased attention of drivers/cyclists in curbs may be a reason for the values.

5.5.3. Concurrent factors

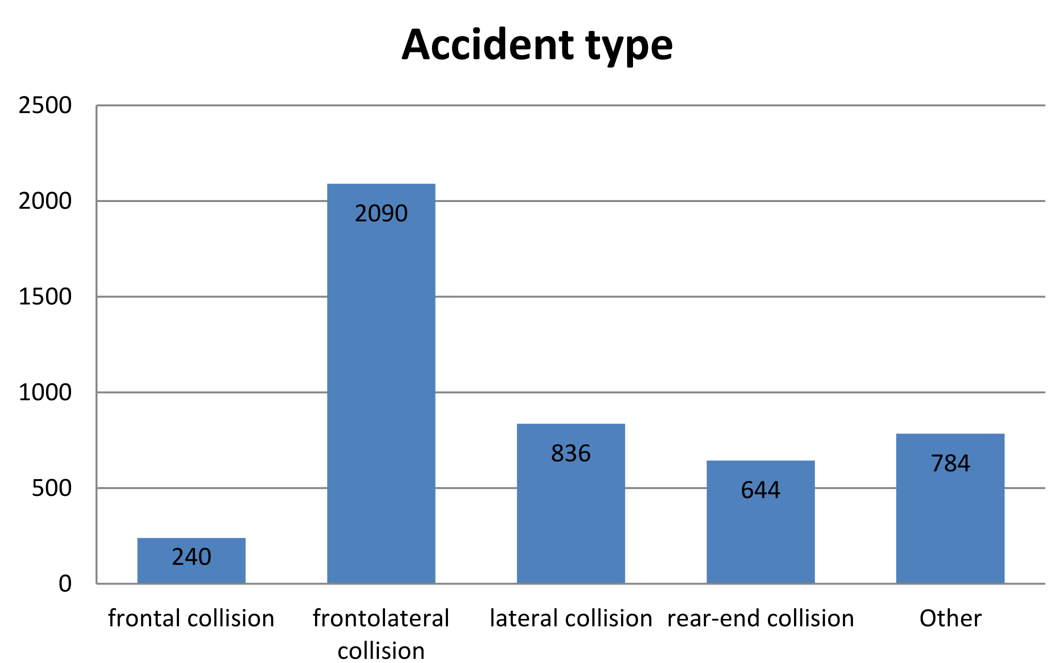

Figure 37. Types of accidents between bicycle and other vehicle.

In crashes between cyclist and another traffic participant over 46% are frontal-lateral collision, followed by lateral collisions 18%. Frontal collision are only 5% of the total number of accidents, the occurrence of type of accidents is found mainly when the cyclist is traveling opposite direction from the traffic.

5.5.4. Severity and temporal evolution

Table 4. Accident dynamic between a bicycle and other vehicle in Spain 2009-2013

Accident dynamic	2009	2010	2011	2012	2013
Total	817	739	990	1151	1212
Deaths	25	27	18	36	8
Severe injury	182	157	187	168	185
Light injury	610	555	785	947	1019

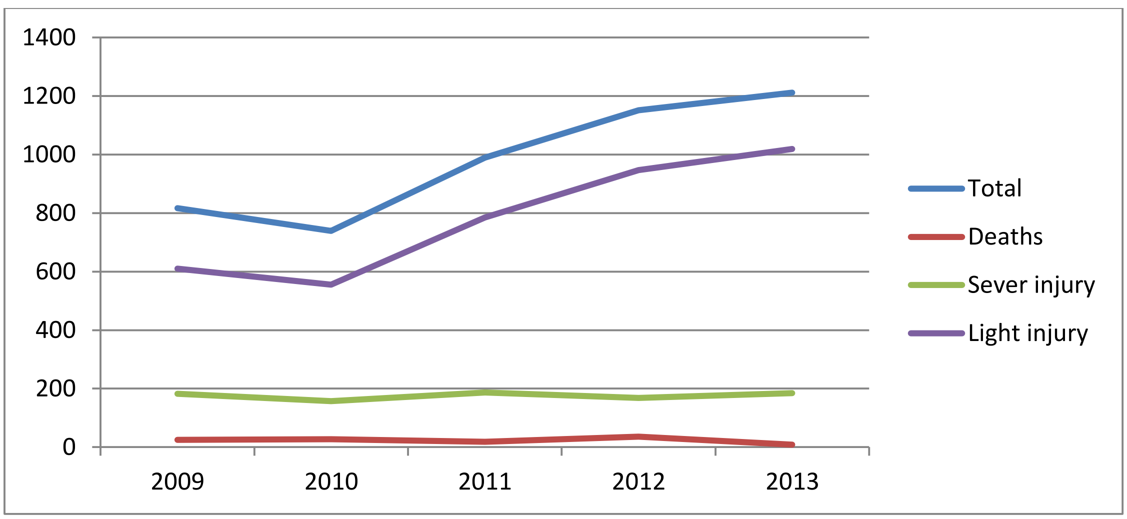

Figure 38. Evolution of accidents between a bicycle and other vehicle in Spain 2009-2013.

Unlike single bicycle accidents, that have an increasing tendency from the beginning we can observe in 2010 the number of people injured in accidents decreased with 10%, followed by an increase of 25% in 2011. Reporting the 2013 to 2009 the number of accidents resulting in victims increased with over 33%, due to the great number of light injuries but we see an encouraging decrease in crashes resulting in deaths of 68%. Severity of crashes is quite similar to the entire sample, resulting in a 2.3% of deaths and a 17.9% of severe injuries, respect of the number of crashes.

Looking at all the three graphics of multiple vehicle accidents, single bicycle and between two vehicles, there is a general increase following similar tendencies, even thou in 2010 the accidents rates had a slight decrease, after 2010 the number of crashes single or multiple have been only increasing.

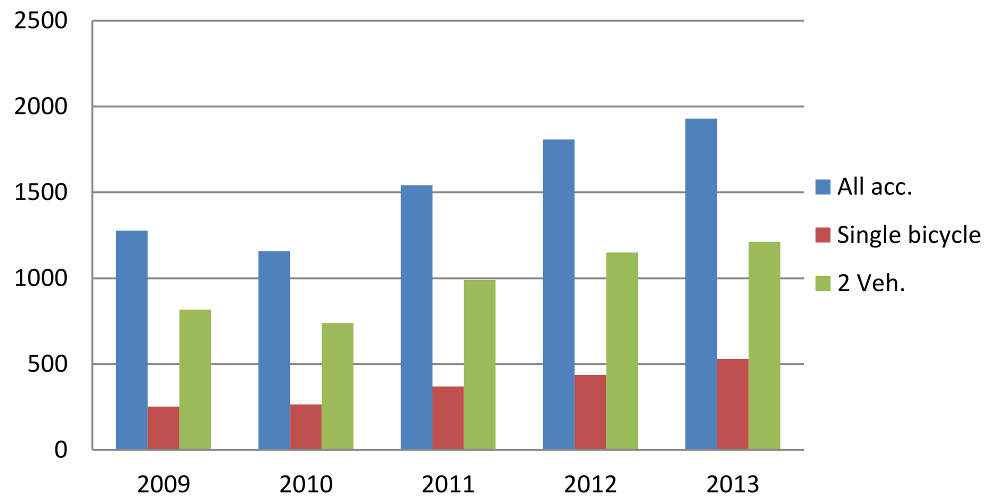

Figure 39. Compere accident dynamics in Spain 2009-2013.

5.6. Study of road segments

This section focused on the comparison between the already analyzed crash data and the exposure data (distance travelled and traffic volume). This step is necessary to identify the real risk of certain road segments. However, it was not possible to do it for the entire country, because of the unavailability of traffic data at every segment of the two-lane rural road network. Besides, the lack of bicycle traffic counts limits the quality of the results.

The analysis was done only for roads in the Valencia Community, resulting in the following in 155 road segments, with a total number of 332 victims, resulting in 7 deaths, 76 sever injuries and 287 light injuries.

Only roads from the Valencia Regional Government were selected. The reason behind this was the availability of traffic data (AADT, Average Annual Daily Traffic) for the same period as crash data.

To identify the higher risk sections, crash rate indicators were determined for each specific segment. The risk indicator is a function of the mean traffic volume and accidents with victims (or other variable) in a specific section.

$RI = n(t) / (q(t) * l)$

- $n(t)$= number of registered accidents in an established period "t" in the segment
- $q(t)$= volume of traffic in the established segment during a period of "t"
- l = length of the segment.

*The product q(t)*l is called exposure to risk.*

Table 5. Top 10 segments with high risk indicator.

CV	AWV 09-13	Deaths	Sever injury	Light injury	VT_m	Lengh (km)	RI (AWV/10e8veh·km)
CV-219	2	0	1	1	64.72	11.231	150.78
CV-705	1	0	0	1	159.76	6.44	53.26
CV-215	2	0	0	2	222.08	10.74	45.95
CV-773	1	0	1	0	237.17	5.8	39.83
CV-195	2	0	1	2	193.1	16.9	33.59
CV-827	2	0	1	1	321.1	10.75	31.75
CV-25	3	0	1	2	356.15	14.65	31.51
CV-775	2	0	2	0	234.61	18.15	25.74
CV-736	11	0	3	10	3598.04	6.95	24.10
CV-715	3	0	0	3	311.43	26.1	20.22

*CV- roads from Valencia Community, AWV 09-13 – accidents with victims between 2009-2013, VTm- exposure , RI- risk indicator

As we can see this RI is not such a very reliable indicator of ACS. We see in the table above the highest RI is in CV-219, a 12 meters section in which in the last 5 years only 2 accidents resulting in injuries happened, the risk indicator is the highest because of the small volume of traffic. Although this presents the highest RI this section should not be classified as an accident concentration section.

Looking at CV-736 we observe a risk indicator of only 24, 6 times lower than in CV-219, even thou the number of accidents resulting in victims is significantly high in CV-736, because the high volume of traffic in this segment.

Table 6.Top 10 segments presenting accidents with victims.

CV	AWV 09-13	Deaths	Sever injury	Light injury	VT_m	Lengh (km)	RI (AWV/10e8veh·km)
CV-821	17	0	5	16	22015.15	5.15	8.22
CV-736	11	0	3	10	3598.04	6.95	24.10
CV-41	8	0	1	8	7849.16	7.01	7.97
CV-720	6	0	3	5	2206.84	12.1	12.31
CV-821	6	0	2	4	12769.30	3.05	8.44
CV-300	6	0	2	5	16473.5	3.75	5.32
CV-500	6	0	0	6	17911.84	4.13	4.44
CV-70	6	1	1	4	25240.13	4.95	2.63
CV-300	5	0	5	3	13464.89	1.45	14.03

*CV- roads from Valencia Community, AWV 09-13 – accidents with victims between 2009-2013, VTm- exposure , RI- risk indicator

We see the section with the highest number of accidents with victims is in CV-821, a section of 5 meters long, but the RI is in a smaller percentage in comparison with the first 10 highest risk sections roads in the Valencia Community, again this is because of the very high volume of traffic in the sections. CV-821 presents another smaller section of 3 meters with 6 accidents with victims in the last 5 years.

Also again we notice the same section in CV-736 with 11 accidents in the last 5 years.

Table 7. Top 10 segments with high mortality rate.

CV	AWV 09-13	Deaths	Sever injury	Light injury	VT_m	Lengh (km)	RI (AWV/10e8veh·km)	MR
CV-86	4	2	1	3	8110.13	3.55	7.61	3.81
CV-500	3	1	0	4	9333.8	2.9	6.073	2.02
CV-715	4	1	0	3	4767.13	8.5	5.41	1.35
CV-32	2	1	0	1	15190.48	3	2.40	1.20
CV-70	6	1	1	4	25240.13	4.95	2.63	0.44
CV-865	3	1	0	2	15074.43	8.7	1.25	0.42
CV-821	17	0	5	16	22015.15	5.15	8.22	0
CV-736	11	0	3	10	3598.04	6.95	24.10	0
CV-41	8	0	1	8	7849.16	7.01	7.97	0
CV-720	6	0	3	5	2206.84	12.1	12.31	0

*CV- roads from Valencia Community, AWV 09-13 – accidents with victims between 2009-2013, VTm- exposure , RI- risk indicator ,MR- mortality rate

To take into account the severity of accidents is necessary to introduce the mortality rate or death rate, MR. This is another indicator which depends on the number of deaths and exposure in the selected section.

$$MR = \frac{Deaths*10^8}{VTm*5*365};$$ [1]

Bicycle accidents resulting in deaths have actually a small value in the Valencia Community; the highest mortality rate is in section CV-86 with 2 deaths in a period of 5 years. Other section presenting only death in the last 5 years are CV-500, CV-715, CV-32, CV-70, CV-865.

Reviewing all three tables we see CV-736 appears in the table with the highest risk indicator and highest number of accidents with victims. Another interesting section is CV-70

[1] We consider the mortality rate for all 5 years.

which has a high number of collisions with victims and also a high mortality rate. High risk is CV-821 with the higher number of accidents resulting in victims.

Classification of the high risk sections was done using risk and mortality indicator but as we can observe they are subjective to traffic volume, an increase exposure result in the decrease of this indicators and vice versa.

The roads from Valencia Region present different characterization in multiple sections, this combined with a small number of accidents does not allow for a deeper study of factors influences, being as a result impossible to establish more specific patterns for cyclist accidents.

Figure 40. Section CV-736, Pk 0 - Pk 7.

Figure 41. Section CV-736.

Figure 42.CV-821, Pk 0 – Pk 9.

6. Discussion

All identified collisions were analyzed to identify the risk factors. The majority of the events involved a cyclist with a vehicle (74%), and only 26% are single bicycle accidents, this value may actually be a lot higher due to the large number of unreported single cyclist crashes (Juhra et al., 2011; Maring et al., 1990). This points out the need of a segregated lane for bicycle users, however a stricter legislation and better education on traffic rules and safety is required as well. The segregation of cyclist and motor vehicle can increase the number of accidents in intersections due to blind conflicts, though (Wachtel and Lewiston, 1992).

Around 70% of accidents happened in straight line, even thou other studies show a higher occurrence of collision in intersections (Gårder et al., 1994). Intersections account for around 30% of crashes. In accidents regarding more than one vehicle, intersections “T” and “X” are more probable to have a crash, where in single bicycle accidents roundabouts have a higher risk probability, which is in accordance with Daniels et al. (2008). Most collisions with motorized vehicles are frontal-lateral collision.

Traffic rule violation and distraction are one of the main human influence risk factors, drivers depending on the reason of use of the bicycle may differ in behavior (Sabey & Taylor, 1980), also a familiar route can give a self-confidence to cyclist and inadvertently pay less attention to other traffic participants (Räsänen and Summala H., 1998).

Environment factors (wet surface, snow, luminosity, etc.) have no influence in bicycle collisions. Previous studies show a somehow influence of this factors in cyclist accidents (Bíl et al. 2009). Another most important factor is the road design and configuration that may or may not facilitate the safety of cyclists. Considering out data the lack of safety elements (median lane, direction pales, reflector, crash-barrier, reflective signs) are the highest risk elements on road infrastructure, road markings have very little influence in cyclist accidents even thou they are considered to improve road safety (Jensen et al., 1997).

Accidents are not caused by only one of these factors, they are a conglomerate of various and different characteristic, every crash is unique, depending on so many and various factors. Finding a pattern and the highest risk causes help develop and create a better traffic management. Appling Haddon matrix to our study case we can extract and point out the most influential factors in bicycle collisions.

The most influential factors in cyclist accidents resulting from applying the results analyzed to the Haddon matrix are:

- Human: distractions, traffic rule violations.
- Physical: greater road width (>7 m), lane width 3.25-3.75 m, road markings, road shoulder.
- Median lane, direction panels, reflectors, reflective signs, crash-barrier.
- Social: lack of strict normative, report to police.

Table 8. Haddon matrix applied to our study case.

Factors	Human Factor	Vehicle	Environment factors	
			Physical	Social
Pre-event	Distractions, Traffic rule violations	-	Greater road width (>7 m), Lane width 3.25-3.75 m, road markings, road shoulder	Lack of strict normative
Event	-	-	Median lane, Direction panels, Reflector, Reflective signs, Crash-barrier	-
Post-event	-	-	-	Report to police

* Analyze regarding the technical details of the vehicle status was not done.

7. Conclusions

This chapter will present the final conclusions drawn from the whole analysis done in this Master Thesis.

After examining the factors, statistical data, existing reports, is found that Spain has made greater progress regarding bicycle collision, situating second after Greece with the lowest number of cyclist deaths. Results allow describing characteristics of crashes circumstances involved and also providing insight into understanding the occurrence of accidents.

Auxiliary elements are the most important and influential factors, the lack of this safety elements increase substantially the risk of accident occurring. Installing or improving protection systems on roads may provide a substantial reduction in fatal and serious injuries, taking into account that over 70% of accidents occurred on roads with no protective elements.

The highest rate of of accidents takes place in roads with greater width, which is expected due to the higher traffic of motor vehicle and cyclists. On roads narrower than 5.99 m traffic is generally lower and proportion of accidents decreases.

Both narrow (less than 3.25m) and wide (over 3.25-3.75m) lanes have higher number of crashes in interurban settings, contrary to the received opinion that wider lanes are safer. Wider lanes (over 3.75m) are associated with a low rate of crashes, although this width is less common in two-lane rural roads.

Road and lane width have the same influence in accidents with other vehicle and in single crash type. Small width offers an insufficient space for cyclist and vehicle to use the lane and larger width is associated with larger intensity of traffic which has a more probability of accidents.

Road markings are the cheapest and easiest to realize safety element, the main role is to attracted attention on certain situations and ensure traffic participants continue their trajectory in a safety manner, but most accidents happen in roads that present road markings (separation between lane and edges); this may be caused by bad design or configuration of the separations resulting in the confusion of distractions of the cyclists.

Majority of accidents take place on road where the shoulder is completely missing and on roads where the width of the shoulder is smaller than 1.5 m. A reason is the insufficient space cyclists have and as a result they are obligated to enter the car lane to continue their trajectory, which exposes them to a higher risk of accidents. Also if the existing shoulder is presenting inadequate conditions, cyclists are obligated by the circumstances to enter the car lane. Shoulders with greater width have a very low crash rate; this is due to the extra significantly space cyclists have and as a result are not obligated to enter the car lane to continue their trajectory.

The roads which accounted for the maximum number of accidents were those with lanes around 3.5 m, road marking, and without shoulders and force the cyclist to enter on the roadway increasing the risk of collisions.

As observed, there is a close link between road characteristics and the risk of accidents by the combined effect road-driver. Road elements must be design taking into consideration the effect on the driver behavior, they must complete a variety of tasks and decide in very short time what works best action. Because human behavior is varied and reaction times vary from person to person, the road must be designed to help drivers take the best decision in the shortest time without negative consequence. Thus, the elements of the road, designed and built properly, can help create safer roads for traffic participants. It is very important to take into account the correlation between the plan and longitudinal profile, and visibility distances.

Considering intersection types, multiple vehicle collision take place more often in intersections type “T” or “X”, while single bicycle accidents occur more in other type of intersections. Also, roundabouts represent a significant risk area for both single and multiple crashes. Accidents outside intersections happened more frequently in straight line. This is caused by bad road geometric configuration. Also curves present a surprising low accident rate.

Depending on accident configurations, in multiple vehicle collision frontal-lateral impacts are the most frequent, followed by lateral, rear-end and heard animal impacts, while in single bicycle crashes collisions with heard/lead animals are more numerous.

Environment factors such as atmospheric, luminosity and surface status seem not to influence crash conditions, on average almost all of accidents occurred in normal conditions. We should take into consideration the effect of the sun on impacts, 88% of accidents happened during daylight.

Even though all structural and safety elements are designed and configured properly, the human factor remains unpredictable, thus solutions to intervene in this part and provide a traffic education from the elementary school is necessary.

The most important is developing a traffic management to ensure a functional system. This includes a strategy that requires all public and private administrative to have a unique data system and work together. After implementing any system/element/strategy/action it is necessary to do a real impact evaluation for a better feedback. Softwear analyzing accidents and creating a data base allow authorities to act precise and rapid in sever accidents and to identify the causes of crashes, sharing this data publicly and between all administrative parties allows for a better design and configuration of road and road elements.

The European Union has set a goal to decrees significantly the number of accidents by 2020. The increasing number of people who choose to travel by bicycle instead of vehicle is increasing, so it is necessary to improve and develop, where need it a regulation, infrastructure and traffic education regarding all traffic participants.

In the Valencia Community, even though the number of accidents is not an alarming one, it should be taken into account the increase in bicycle use and start implement safety and prevention measurements.

With the final results, it can be concluded, based on the initial hypotheses, the following:

- There are a significant proportion of crashes involving only one bicycle. It means that a collision with a motor vehicle is not the unique cause of cyclist crashes:

True. The number of accidents involving only one cyclist is around 26% of total number of accidents, also the number of single bicycle accidents has an increasing tendency since 2010.

- The roads presenting paved wide shoulders have less bicycles crashes, as cyclists can used a different part of the cross section:

True. Roads that present paved shoulders with higher width than 1.5m have a significantly lower accidents rate, allowing the cyclist sufficient space between him and other traffic participants.

- The wider roads will have less bicycles crashes, as cyclists and motor vehicles interaction is weak:

False. Wider roads present a higher number of accidents; this may be caused by the increased volume of traffic in this sections. However, wider lanes present low accident rate, but this type of lane is rarely used on conventional roads.

- Intersections account for a significant proportion of crashes as they concentrate crossing, merging and diverging trajectories:

True. All most half of the total number of accidents occurred in intersections, the most frequent one is type “T” or “Y” and roundabout. Exiting and entering lanes show a very small accident occurrence.

- Roads with higher traffic volume (motorized) present a higher risk for cyclists:

True. Even thou a higher traffic exposure can reduce the risk indicator, the risk of occurring accidents increases.

- More collisions occur in curves:

False. A very small rate of accidents take place in curves and an alarming rate happen in straight line; this may be caused by bad road configurations and/or decreased attention.

8. *Further research*

The present Master Thesis shows the descriptive analysis of bicycle crash data on Spanish two-lane rural roads. Below potential research interests that may incorporate the results of this work are listed:

- Researchers on bicycle safety must take on the task of developing between counter measures and traffic safety.
- Additional research on cyclist behavior is needed to understand certain types of accidents and to implement greater safety measurements.
- Cyclists in crashes not involving motor vehicles. This type of collision is on a steep increase in figures, whereas no background data is available in the existing registrations it should be determined how information about the characteristics of these crashes can be collected reliably.
- A larger sample size is necessary to confirm the findings of this report. Ideally, this sample could be expanded to other countries in Europe.
- More research is required on how best to design the road integrating safety and guidance elements for cyclists.
- Further research considering roundabout and T-intersections, where bicycle crashes have showed to be the most frequent.
- Education about traffic rules. It should be investigated how familiar young cyclists are with safety regulation and with following them and how could training enhance it.

9. *References*

Bíl M. , Bílová M. and Müller I. ,2009,Critical factors in fatal collisions of adult cyclists with automobiles, Accident Analysis & Prevention ,Volume 42, Pages 1632–1636.

Billot-Grasset A., Hours M. ,2014, How cyclist behavior affects bicycle accident configurations?

Daniels S., Brijs T., Nuyts E., Wets G. ,2008, Roundabouts and safety for bicyclists: empirical results and influence of different cycle facility designsGårder P., Leden L., Thedéen T. ,1994, Safety implications of bicycle paths at signalized intersections, Accident Analysis & Prevention, Volume 26, Issue 4, August 1994, Pages 429–439

Johnson M., Charlton J., Oxley J. and Newstead S.,2010, Naturalistic Cycling Study: Identifying Risk Factors for On-Road Commuter Cyclists , Annals of Advances in Automotive Medicine, Volume: 54, Pages 275-283

Juhra C. , Wieskotter B. , Chu K. , Trost L. , Weiss U. , Messerschmidt M. ,Malczyk A., Heckwolf M., Raschke M. , 2011, Bicycle accidents – Do we only see the tip of the iceberg? A prospective multi-centre study in a large German city combining medical and police data, Injury, Volume 45, Issue 12, Pages 2026- 2034

Maring W., van Schagen I.,1990, Age dependence of attitudes and knowledge in cyclists, Accident Analysis & Prevention Volume 30, Issue 1, Pages 127-136

Nyberg P., Bjornstig U., Bygren L-O. , 1996, Road Characteristics and bicycle accidents, The Umen Accident Analysis Group, Vol. 24, No. 4, Pages 293-300

Räsänen M., Summala H., 1998, Attention and expectation problems in bicycle-car collisions: an in-depth study. Accident Analysis & Prevention ,Volume 30, Issue 5, September 1998, Pages 657–666.

Räsänen M., Summala H., 2000, Car drivers' adjustments to cyclists at roundabouts, Transportation Human Factors. 2, 1, Pages 1-17

Sabey B.E. , Taylor H. ,1980, The known risks we run: the highway, Pages 43-70

Spinney J. ,2013, A chance to catch a breath: using mobile video ethnography in cycling research, Pages 161- 182

Wachtel A. , Lewiston D., 1994, Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections, ITE Journal, Pages 30-35

Wang Y., Nihan N.L.,2009,Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. Accident Analysis & Prevention, Volume 40, Issue 1, Pages 313-321

10. *List of Tables*

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