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Identification of the main risk factors for vulnerable non-motorized users in the city of Manizales and its relationship with the quality of road infrastructure

Carlos Fabian Flórez Valero[a], Camilo Patiño Puerta [b]*

[a]*Pontificia Universidad Javeriana, Carrera 7 # 40-62, Bogotá D.C., Colombia*
[b]*Pontificia Universidad Javeriana, Carrera 7 # 40-62, Bogotá D.C., Colombia*

Abstract

This investigation aimed to identify the main risk factors for the occurrence of traffic accidents that involve vulnerable non-motorized users (V.N.M.U.) in the city of Manizales. To do so, a descriptive analysis of the accidents that involved pedestrians and cyclists in the city, between January 2008 and July 2013, was performed. A calculation of the odds ratio was also accomplished to quantify the risk that pedestrians have of dying in a traffic accident in Manizales. Finally an observational study of pedestrian infrastructure was performed in the critical areas for the occurrence of traffic accidents with vulnerable non-motorized users in the city, with the purpose of bringing forward intervention measures to decrease the exposure to the identified risk factors.

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Keywords: Risk factors in traffic accidents, Traffic accidents with pedestrians, Traffic accidents with cyclists, Relationship between traffic accidents and infrastructure.

1. Introduction

The current transport models contemplate with great importance mobilizing people in clean transport systems, which do not generate congestion or pollution and improve the quality of people's life. Within these, the look has turned over to non-motorized transportation, which generates less pollution of any kind and produces less congestion in cities. Pedestrians and cyclists begin to regain importance as road users, but it is seen that mainly in countries of low and middle income, infrastructure is giving the car a privileged position, being common to find that the designs of facilities in cities of countries like Colombia tend to exclude vulnerable motorized users and discriminate them within the transport system.

This added to the fragility that the human being has within the road environment, makes vulnerable non-motorized users one of the

* Corresponding author. Tel.: +57-1-3002645213; fax: +57-1-3208320-ext. 5398.
E-mails address: florez.carlos@javeriana.edu.co , camilo.patino@javeriana.edu.co

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most affected group of road users with deaths related to traffic accidents. Traffic accidents are now a major cause of death in the world and in Colombia, with the group of vulnerable non-motorized users being one of the most affected by this problem; this is due in great part to the lack of appropriate infrastructure that fulfill the needs of those road users different to vehicle drivers and passengers.

Traffic accidents are the leading cause of violent deaths in the world and second in Colombia, being surpassed only by homicides (WHO, 2010). In 2011, pedestrians accounted for 31% of deaths from traffic accidents in the country, while cyclists accounted for 6%, as seen in Fig. 1 (FPV, 2011). Vulnerable Non-motorized users have a disproportionate share in traffic accidents for middle and low income countries; this is due largely to the fact that the infrastructure in these countries is often designed from the point of view of the vehicle, marginalizing other road users (WHO, 2004).

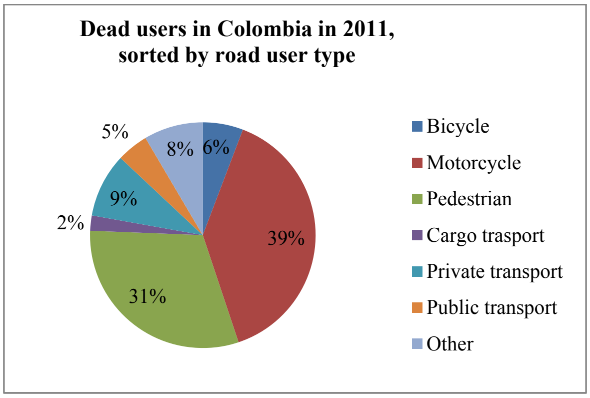

Fig. 1 Dead users in Colombia in 2011, sorted by road user type.

Around the world, studies on accidents involving vulnerable non-motorized users have been carried; seeking human, vehicle and environment related factors that increase the risk of occurrence of accidents and their severity. A literature review found some global studies that focused in accidents with non-motorized users, mostly concerning a descriptive analysis of accidents of this type, the characterization of its main associated factors and the relationship between them.

Mabunda, Swart and Seedat (2008) conducted a study in 2004 in 4 cities of South Africa on demographic and temporal factors associated with pedestrian deaths in a given period of time. The authors, through a typological analysis identified groups of pedestrians at risk, on which specific measures to help reduce accidents could be implemented; meanwhile, Harruff, Avery and Alter-Pandya (1998) conducted a study in Seattle on 217 pedestrian deaths which occurred during six years in a mixed but primarily urban environment; analyzing demographic and environmental variables to conclude which were the most repetitive in the occurrence of the accidents.

Moudon, et al. (2011) conducted a study in King County, WA. United States; which studied the factors influencing the risk that a pedestrian has to die or to be injured in a traffic accident. The study sought to find correlations between some human, environment and vehicle related factors; to the severity of the accident, and thus move to propose measures that could reduce deaths and serious injuries from traffic accidents that involved pedestrians.

Prato, Gitelman and Bekhor (2012) conducted a study that sought to map behaviors of pedestrians in fatal traffic accidents, for which they used data on fatal accidents in Israel between 2003 and 2006, with data on the location, infrastructure characteristics, environmental, vehicles and people conditions for each accident. The study used a multivariate analysis for mapping a multi-mode behavior, combining the variables considered most important by means of an algorithm called "Kohonen".

Gitelman, et al. (2012) conducted a similar study to the one proposed in this study, making a detailed analysis of accidents involving pedestrians occurred in Israel between 2006 and 2007, with emphasis on the characteristics of infrastructure involved. The authors identified critical points for the occurrence of accidents and diagnosed infrastructure problems that may be involved in the problem, to then identify infrastructure solutions that could improve the safety of pedestrians.

Other studies found, presented intervention measures to the infrastructure that could help reduce the risk of N.M.V.U. Rettig, et al.

(2003) conducted a review and assessment of intervention measures made to existing infrastructure to reduce the risk of pedestrian injury. The authors classified the measures into three groups: the first, related to the speed of the vehicles, the second related to the separation of pedestrians and vehicles, and the third related to the visibility of pedestrians; meanwhile, Yannis, et al. (2007) conducted an assessment of some general measures conducted in Europe to increase the safety of non-motorized users on the road. They also proposed some general intervention measures that could have a positive impact on reducing accidents.

This paper presents the main results of the research from a descriptive analysis and calculation of the odds ratio for the death of pedestrians who were involved in traffic accidents, and the methodology for their development. Also, the main findings of the observational study of infrastructure and intervention measures proposed to mitigate the identified risks.

2. Method

The epidemiological study conducted was of the observational type in an analytical form, because of not having the possibility to manipulate the exposure factors and have to limit to observe the population with its own characteristics. The epidemiological study was divided into two phases, the first corresponding to a descriptive study, in which a primary approach to the "health event" corresponding to the problem of traffic accidents involving cyclists and pedestrians in the city of Manizales during the period between January 2008 and July 2013. The descriptive study was centered to identify variables and find for each of them the occurrence ratio expressed as a percentage.

The second phase of the epidemiological study corresponded to the identification of risk factors using the odds ratio. Departing from the descriptive study, we proceeded to identify factors that may be causally associated with the health event (death from traffic accidents involving pedestrians), and calculating the odds ratio was sought to prove the existence of a causal association between the exposure factor and the occurrence of accidents involving vulnerable non-motorized users.

The odds ratio in a case-control study is defined as the ratio between the odds that the cases or individuals affected by a health event, may have been exposed to the risk factor, and the probability that the controls or individuals not affected by a health event may have been exposed to the same risk factor.

Table 1. Typical design of a case-control study.

	Cases	Controls
Exposed to a risk factor	a	b
Not exposed to a risk factor	c	d

Table 1 (Gordis, 2009), shows a typical design of a case-control study, in which 4 groups of people are separated in cases or controls, and in turn, also separated according to their history of exposure to a risk factor. When calculating the odds ratio, the rate must be found between the amount of cases that were exposed ($\frac{a}{c}$), and the share of the controls that were exposed ($\frac{b}{d}$). Thus, equation (1) is used to calculate the odds ratio in a case-control study.

$$\frac{\frac{a}{c}}{\frac{b}{d}} = \frac{ad}{bc} \tag{1}$$

Also, the critical areas for the occurrence of accidents that involve vulnerable non-motorized users in the city of Manizales were identified, and an observation on the existing infrastructure study was performed in order to associate trends in the occurrence of accidents and possible infrastructure problems that these areas could have, then we proceeded to propose some intervention measures, based on a literature review on intervention measures that were successful in other parts of the world to mitigate the risks identified as relevant.

3. Results

The data of accidents involving cyclists and pedestrians showed that since 2008 the number of cyclists killed or injured has decreased significantly and intermittently until 2012. Of the 2048 accidents involving pedestrians in Manizales between January 2008 and July 2013, 20 were found in which the pedestrian involved in the accident died, corresponding to about 1% of the total. Meanwhile, of 105 accidents that involved cyclists, only 2 accidents ended with the death of the cyclist, corresponding to 1.9% of all accidents. Table 2 presents the annual rates for injured and dead pedestrians and cyclists involved in traffic accidents in Manizales from 2008 to 2012.

Table 2. Annual distribution of dead and wounded pedestrians and cyclists.

	Pedestrians		Cyclists	
Year	Dead	wounded	Dead	Wounded
2008	6	453	0	28
2009	4	363	2	11
2010	1	362	0	29
2011	6	374	0	11
2012	1	309	0	9

For the descriptive study, relevant variables found in the database were selected to which a trend analysis was conducted for a better understanding of the problem and for identification of some important features related to the traffic accidents. The following figures (2 to 23) show the results obtained for accidents involving pedestrians and cyclists in Manizales between January 2008 and July 2013. Graphs are presented for each of the variables segregating cyclists and pedestrians.

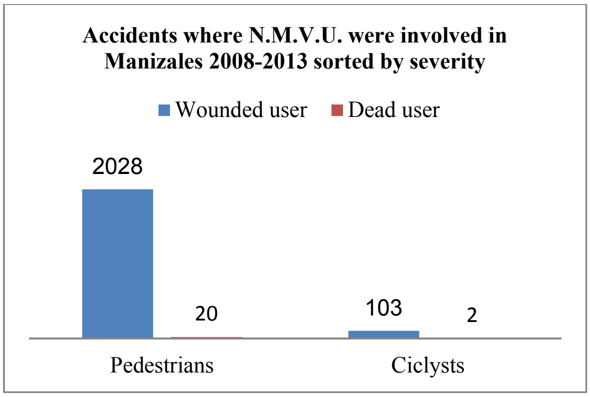

Fig. 2. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by severity .

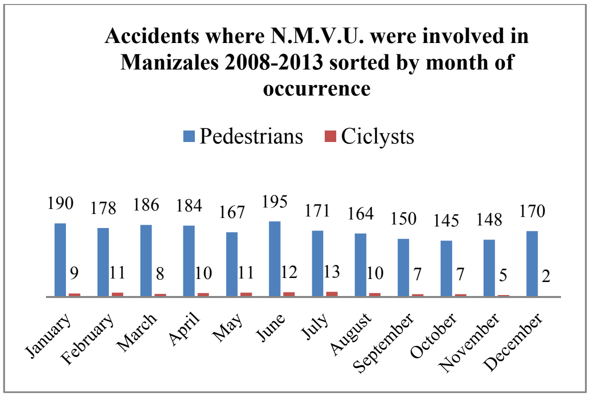

Fig. 3. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by month of occurrence.

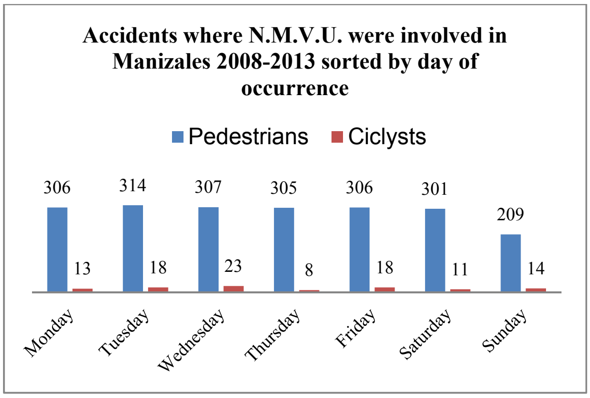

Fig. 4. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by day of occurrence.

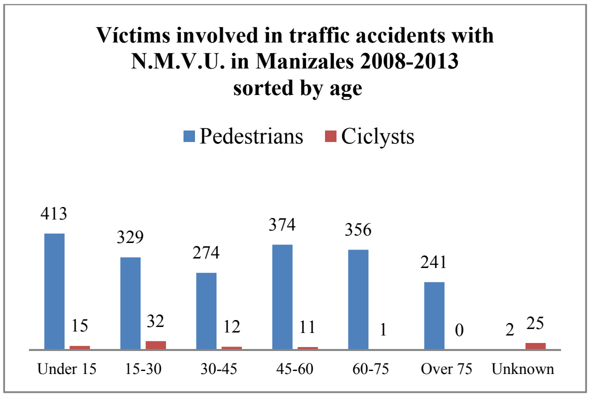

Fig. 5. Victims involved in traffic accidents with N.M.V.U. in Manizales 2008-2013.

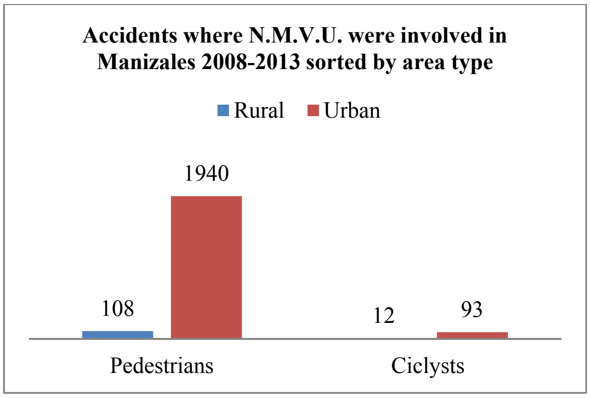

Fig. 6. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by area type.

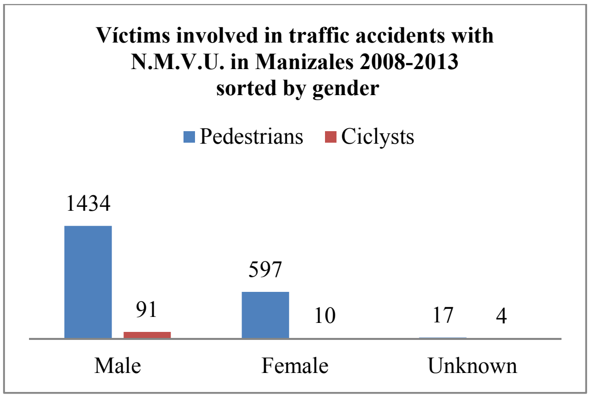

Fig. 7. Víctims involved in traffic accidents with N.M.V.U. in Manizales 2008-2013.

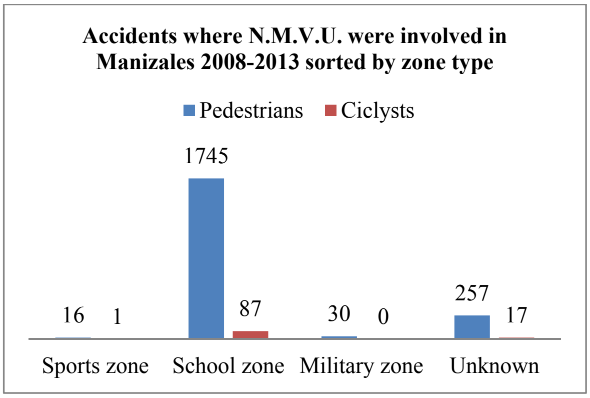

Fig. 8. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by zone type.

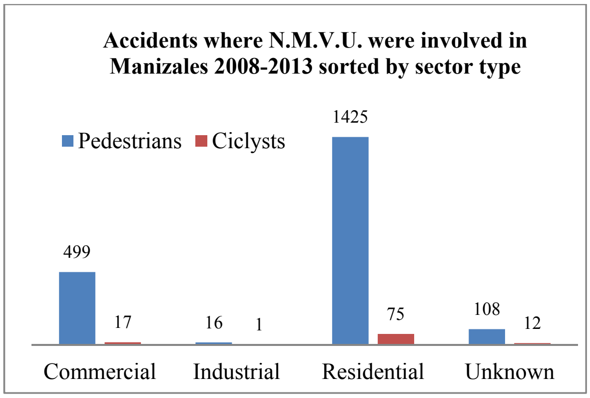

Fig. 9. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by sector type.

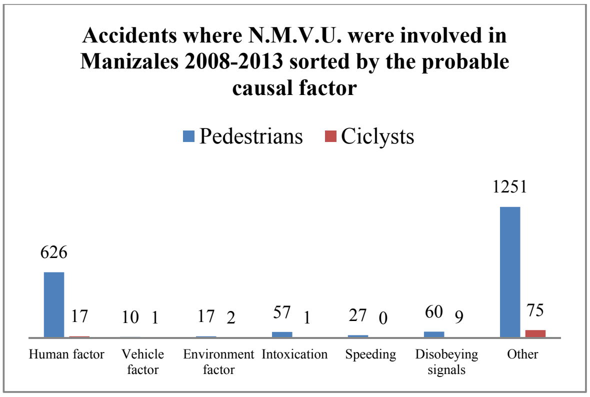

Fig. 10. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the probable causal factor.

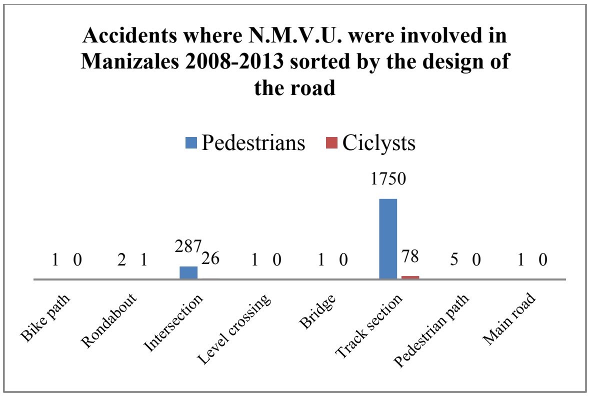

Fig. 11. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the design of the road.

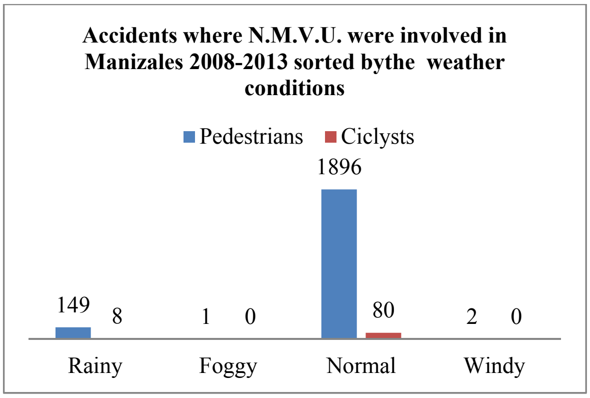

Fig. 12. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the weather conditions.

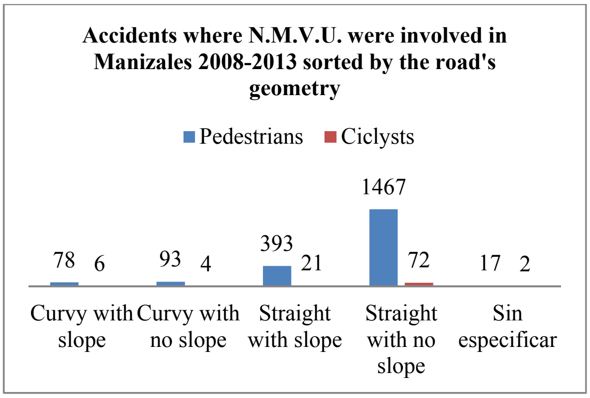

Fig. 13. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the road's geometry.

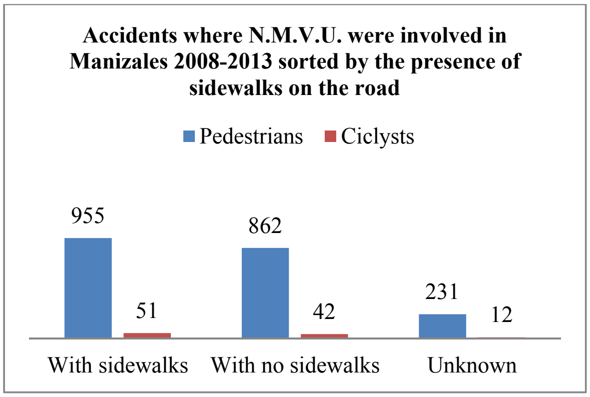

Fig. 14. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the presence of sidewalks on the road.

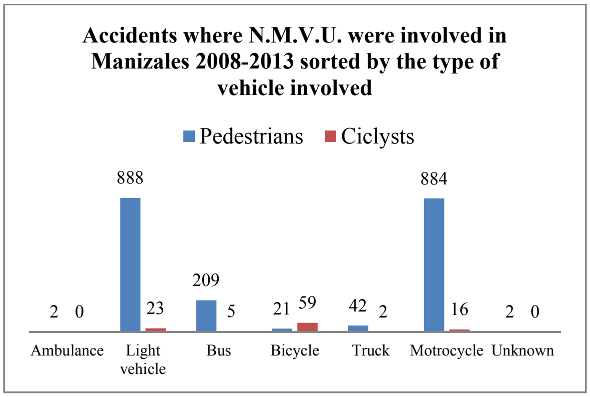

Fig. 15. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the type of vehicle involved.

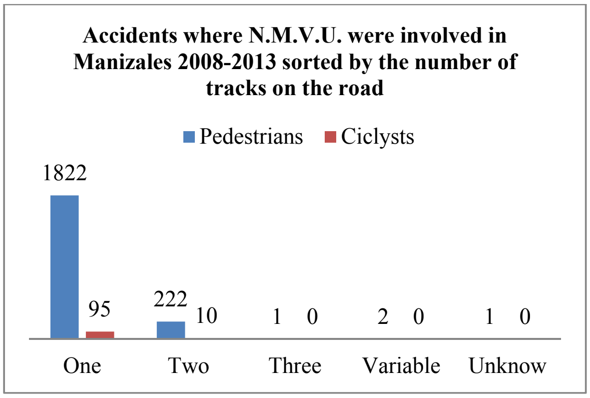

Fig. 16. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the number of tracks on the road.

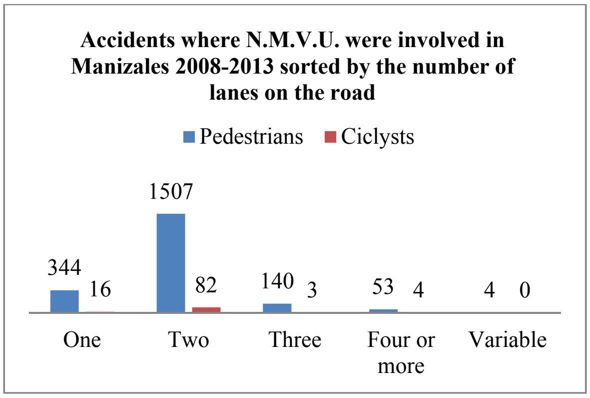

Fig. 17. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the number of lanes on the road.

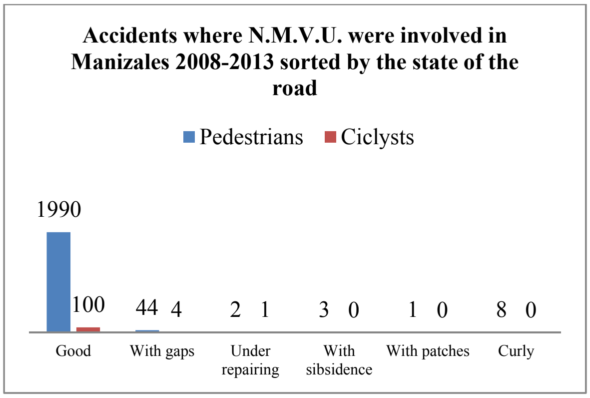

Fig. 18. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the state of the road.

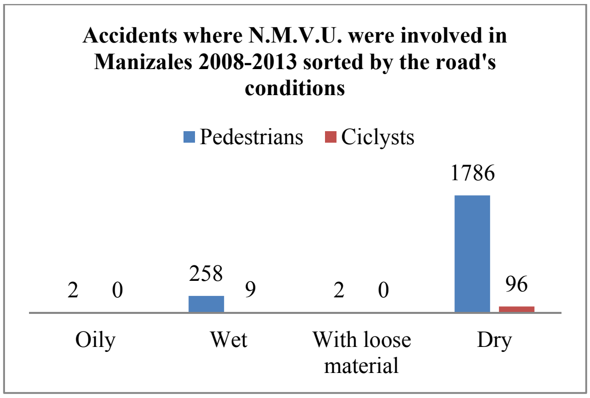

Fig. 19. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the road's conditions.

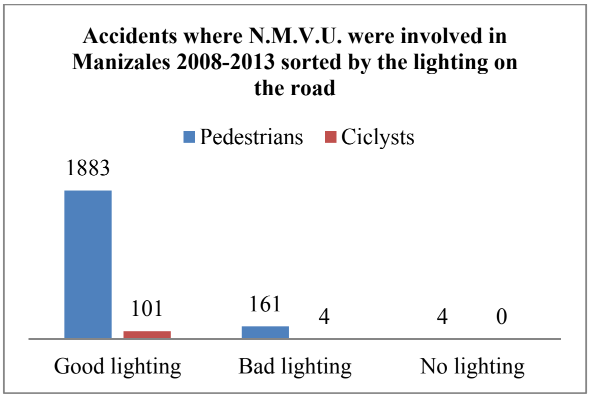

Fig. 20. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the lighting on the road.

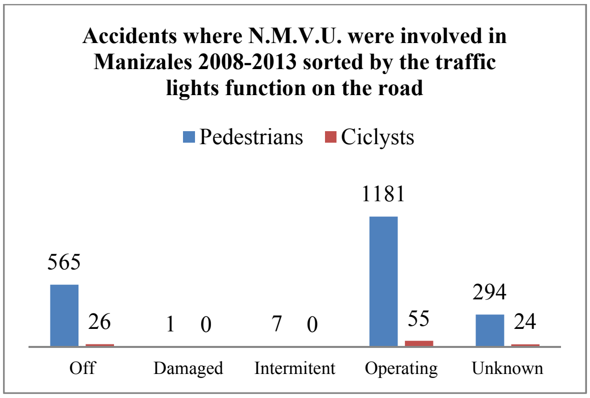

Fig. 21. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the traffic lights function on the road.

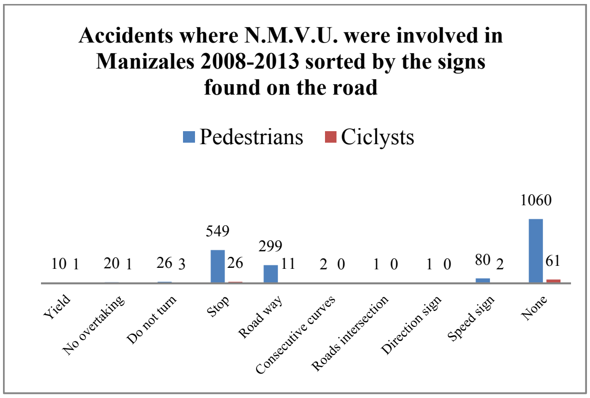

Fig. 22. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the signs found on the road.

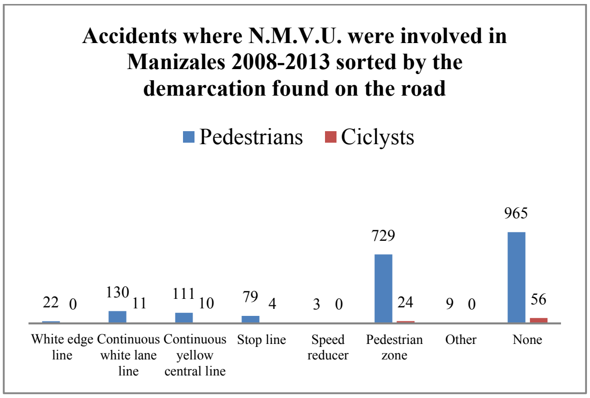

Fig. 23. Accidents where N.M.V.U. were involved in Manizales 2008-2013 sorted by the demarcation found on the road.

The main factors that increase the risk of pedestrians dying in a traffic accident, as concluded from the calculation of the odds ratios are: that the accident occurs in the month of April, on Wednesdays, between 22:00 and 23:00, in rural areas and in residential sectors. Accidents at intersections, on curved roads with slopes, on roads without sidewalks, on three rail roads, in curly and wet roads, with stop lights off, no signs and no demarcation were also identified as risk factors for the death of a pedestrian. Within the human factors, being in the age range between 60 and 75 years old and being a male pedestrian were identified as risk factors for mortality in accidents that involve pedestrians. Accidents involving trucks and bikes also pose greater risk for pedestrians to die. Table 3 shows the results of the calculation of the odds ratio for the different variables.

Table 3. Results of the calculation of the odds ratio for the death of pedestrians in traffic accidents.

Age	**Odds Ratio**	**CI 95%**		**State of the road**	**Odds Ratio**	**CI 95%**	
Under 15	0.66	0.09	4.73	Good	1.00	0.52	1.93
15-30	0.41	0.04	4.60	With gaps	2.55	0.33	19.52
30-45	1.00	0.14	7.15	Curly	15.65	1.83	133.84
45-60	1.84	0.35	9.57	**Road conditions**	**Odds Ratio**	**CI 95%**	
60-75	2.73	0.56	13.24	Wet	1.74	0.58	5.25
Over 75	1.71	0.28	10.35	Dry	1.00	0.50	2.01
Gender	**Odds Ratio**	**CI 95%**		**Lighting**	**Odds Ratio**	**CI 95%**	
Male	1.67	0.56	5.02	Good lighting	1.00	0.53	1.89
Female	1.00	0.25	4.02	Bad lighting	0.61	0.08	4.61
Area type	**Odds Ratio**	**CI 95%**		**Traffic lights**	**Odds Ratio**	**CI 95%**	
Rural	1.00	0.14	7.23	Off	1.40	0.50	3.95
Urban	0.50	0.11	2.17	Operating	1.00	0.40	2.53
Sector type	**Odds Ratio**	**CI 95%**		**Signs**	**Odds Ratio**	**CI 95%**	
Commercial	1.00	0.14	7.13	With signs	1.74	0.69	4.38
Residential	2.82	0.65	12.32	With no signs	1.00	0.35	2.86
Design of the road	**Odds Ratio**	**CI 95%**		**Vehicle type**	**Odds Ratio**	**CI 95%**	
Intersection	2.05	0.74	5.69	Light vehicle	1.00	0.25	4.01
Track section	1.00	0.49	2.05	Bus	2.14	0.39	11.74
Road geometry	**Odds Ratio**	**CI 95%**		Bicycle	23.26	4.01	134.84
Curvy with slope	1.26	0.16	9.64	Truck	36.83	9.95	136.28
Curvy with no slope	1.05	0.14	8.05	Motorcycle	1.51	0.42	5.37
Straight with slope	0.74	0.21	2.59	**Probable causal factor**	**Odds Ratio**	**CI 95%**	
Straight with no slope	1.00	0.49	2.05	Human factor	1.00	0.32	3.12
Demarcation	**Odds Ratio**	**CI 95%**		Vehicle factor	11.48	1.25	105.39
with demarcation	3.05	0.86	10.84	**Sidewalks**	**Odds Ratio**	**CI 95%**	
with no demarcation	3.47	0.82	14.59	With sidewalks	1.00	0.37	2.68
Pedestrians marked zone	1.00	0.20	4.97	With no sidewalks	1.53	0.61	3.82

Critical areas for the occurrence of accidents that involved vulnerable non-motorized users were selected by dividing the city into zones that had similarities in its use of land and typology of the existing roads within it, to then choose those in which occurred the most number of accidents.

The selected critical areas were: the commercial zone of the city's downtown, Gilberto Alzate Avendaño Avenue, the hospitals sector, the residential zone of the city's downtown, Kevin Angel Avenue, the El Cable sector and the Fundadores sector. For each of the selected critical areas, an observational study and characterization of the pedestrian and bicycle infrastructure was performed.

Major shortcomings were found for the critical areas, some general problems found were: the lack of signs at pedestrian crossings, lack of facilities for disabled people, the need for speed reducers in non-signalized intersections, and a deficiency in the markings and signs on secondary roads. The topography of the city sometimes difficult the designs of pedestrian facilities and in the city's downtown sidewalks are sometimes narrow and with lack of continuity, some avenues also need improvements in sidewalks and pedestrian facilities. Pedestrian bridges are not very inviting and have no facilities for the disabled people.

4. Conclusions

The investigation allowed to conclude that some of the main factors that increase the risk for pedestrians to die in a traffic accident are that the accident occurs between 22:00 and 23:00, in urban areas and in a commercial sector, which probably has to do with leisure activities of young people in the evening hours, thus, it is recommended that the city takes action to reduce speed for vehicles in commercial areas in which activities are being developed in the evening hours.

Accidents that occurred at intersections were identified as a risk factor for death of pedestrians, so measures to improve road signs and demarcation at crossings, especially in secondary or local roads is recommended. It is also advised to spatially or temporally separate pedestrians from vehicles, with pedestrian bridges or independent light phases on the most contentious crosses. It was also identified as a risk factor that accidents occur on curved roads with slopes; this probably should deal with issues of visibility, so it was suggested on roads with these features to reduce speed limits, improve lighting and prohibit the parking of vehicles on the track.

Happening in a road with no sidewalks is also a risk factor for the death of a pedestrian in traffic accidents in the city, this due to the lack of spatial separation between vehicles and pedestrians. It was considered important that the city built sidewalks on roads where needed, especially in those with high pedestrians flow. Also, it was advised to improve pedestrian facilities in some major avenues as Kevin Angel Avenue and Colón Avenue, this to ensure separation between vehicles and pedestrians in the roadway. Another risk factor found was that the accident occurred on curly or wet roads, so it was recommended to the city in ways that are curled, or have any dangerous characteristics to be given signals that warned the risk to pedestrians.

On the other hand, accidents that occurred on roads where traffic lights were off, with no signs and no demarcation were also identified as risk factors for the occurrence of fatal accidents involving pedestrians. Therefore, it was suggested that the city should improve signs and demarcation, especially in non-major roads. The operation of traffic lights 24 hours straight can also help reduce pedestrian deaths in traffic accidents. Within the human factor, to be in the age range between 60 and 75 was found as risk factor for pedestrian deaths. Therefore, it was suggested to create special campaigns and differentiated education for people in this age range in order to teach them to understand the language of the road and take special precautions to avoid accidents.

Accidents where trucks were involved also pose greater risk for pedestrians to die, as found in the research. This is because the kinetic energy released in a collision with such a large vehicle is very high, creating a strong impact to the pedestrian. It was recommended to the city to take measures to control truck traffic on roads with high pedestrian flow, and in these to have very strict spatial and temporal separation between pedestrians and vehicles, creating exclusive traffic light phases for pedestrians, pedestrian bridges and barriers to avoid crossings on forbidden places.

For future research, it is recommended further study of the human component and the behavior of pedestrians as this is one of the most important factors for the occurrence of accidents involving vulnerable non-motorized road users. A study that probes the vehicle design factors that can be useful for reducing injuries in crashes that occur in the city is also considered important. Similarly, a study to identify the major points of cyclists flows to inquire more about the little bicycle infrastructure that exists in the city is recommended.

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