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Statistical Analysis of the Occurrence and Severity of Crashes Involving Vulnerable Road Users

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Abstract

Cities have been often organized in terms of planning with special attention to motor vehicles and not well prepared for pedestrians and cyclists. In order to privilege active modes, there is the need to ensure the safety of these vulnerable road users.
The main objective of this paper is to implement a statistical analysis to assess the occurrence and severity of road crashes involving vulnerable road users. This research is focused on analyzing the trends and causes of road crashes involving cyclists and pedestrians and what are the main difficulties that people using active modes do face in their journeys. In order to reach this objective, a database of crashes registrations involving motor vehicles and vulnerable road users from Aveiro, Portugal, between 2012 and 2015 was created. This analysis intends to evaluate the evolution of the number of crashes and to create patterns of risk factors such as weather conditions, specific locations and singularities that might represent additional risk, profile of pedestrian or cyclist involved. Regarding the analyzed variables that characterize crashes participations, the dependent variables considered were: meteorological conditions, location, proximity to a pedestrians' crosswalk and gender of the VRU.
The probability of the vulnerable road user being a pedestrian increases by 2.7 times if the crash occurs on a urban street segment, 10.6 times if the crash occurs at a pedestrians' crosswalk, and 3.5 times if the VRU is a female.

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Keywords: Vulnerable road users (VRUs), cyclists, pedestrians, crashes, statistical analysis.

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1. Introduction and Objectives

Walking and cycling are active transportation modes that are being promoted as sustainable, healthy, environmentally friendly, inexpensive and convenient for short distance journeys. Despite the environmental and health benefits of walking and cycling, users of these transportation modes are exposed to a higher risk of injury and fatality in road crashes. Thus, pedestrians and cyclists are often referred to as "vulnerable road users" (VRUs).

In the European Union about 138.400 pedestrians and cyclists lost their lives on the roads between 2001 and 2013. These deaths account for 29% of all deaths on the road in the U.E. (Adminaite et al., 2015). For Portugal, the deaths among VRUs represent 27% of the total deaths. Regarding pedestrian deaths, Portugal is above the European average with 16.0 pedestrian deaths per million inhabitants, per year, being that European average is 11.7. Unlike pedestrians, deaths involving cyclists in Portugal are below the European average with 3.4 deaths per million inhabitants per year, being that European average is 4.2 (Adminate et.al. 2015). Some efforts have been developed for mitigating such numbers, for instance, the concept of Vision Zero. This road safety goal states that, in the long run, no person should be killed or seriously injured as a consequence of road traffic (Rosencrantz et al., 2007). Likewise, the white paper (European Union, 2011) also states as goal move close to zero fatalities in road transport.

Crash data analysis is a widely debated topic. Statistical models regarding crashes involving motor vehicles only and injury analysis of the vehicles' occupants were already developed (Torrao et al., 2014, 2016; Wu and Jovanis, 2012). Regarding crashes involving VRUs, according to Heydari et al. (2017) a non-restrictive joint modeling of pedestrian and cyclist injuries improves our collective understanding of VRUs' safety. According to this study, accepting the presence of VRUs can reduce the likelihood of crash involving pedestrians and cyclists; a joint analysis is expected to provide richer insights into the key influences on safety dynamics of active modes of transport. However, other study shows that, when there is a need to understand the effects that affect the occurrence of accidents between pedestrians and cyclists, significant differences were present between the predictors' sets for pedestrians and bicycle crashes (Siddiqui et al., 2012).

Several studies gather consensus that the motor vehicles speed and traffic volume increase the risk and severity of the crash for cyclists or pedestrians (Siddiqui et al., 2012, Chen and Shen, 106, Yuan and Chen, 2016). However, many other factors may be related to the likelihood of a crash and the increase in its severity. According to Chen (2015) the exposure to conflicts between intersecting vehicles increase as the number of intersections increase; however, road networks with more intersections may contribute to lower driving speeds and thereby less severe bicycle crashes.

Loidl et al. (2016) defend that the risk for becoming involved in a crash is between 5.5 and 12 times higher for cyclists. On the opposite side, Yuan and Chen (2016) concluded that pedestrians have higher risk in the road traffic compared with cyclists, since vehicle drivers tend to brake more in motor vehicle-cyclist conflicts situation than motor vehicle-pedestrian crashes; this study showed that night-time, intersection, older age of VRUs and higher vehicle speed increased the injury severity of crashes.

Li et al. (2016) also investigated factors affecting pedestrians' injury severity level under different weather conditions based on an accident database in Great Britain. Significant severity predictors under good weather conditions from the models included speed limits, pedestrian age, light conditions, and vehicle maneuver. Under adverse weather conditions, the significant predictors were pedestrian age, vehicle maneuver, and speed limit.

Chen and Shen (2016) conducted a study that relates the effects of the environment on the severity of cyclist injury involving motor vehicle accidents. They concluded injury severity decreased with employment density; severe injury or fatality is negatively associated with the use of the road by various types of mobility means; reflective clothing and street lighting can decrease the likelihood of cyclist injuries; posted speed limit is positively associated with the probability of evident injury and severe injury or fatality; older cyclists appear to be more vulnerable to severe injury or fatality and cyclists are more likely to be severely injured when large vehicles are involved in crashes.

The main objective of this paper is to implement a cross-variable statistical analysis to assess the occurrence and severity of road crashes involving VRUs. Characteristics such as VRU profile, location of the crash, proximity to pedestrians' crosswalk and meteorological conditions can be assessed in order to conclude if there is any relationship between them.

2. Methodology

This chapter includes, in a first part, the characterization of the case study and describes in detail the analyzed data. Secondly, the methodology used is explained, namely the statistical analysis software - IBM SPSS.

2.1. Characterization of the case study and crashes data involving pedestrians and cyclists

Aveiro is a medium-sized city and has unique conditions for the encouragement of active mobility (pedestrians and cycling) due to size, topography and weather. The region of Aveiro is also known for the use of cycling and the use of this incentive through many projects. Across the entire region of Aveiro 16% of the trips are performed walking and 4% performed by cyclists. These results are associated with favorable baseline conditions such as orography and the existence of cycle paths, but also reflect the commitment of local authorities to the development of these transportation modes (CIRA, 2014). The municipality of Aveiro has 78 440 inhabitants (2011 data) and 197.58 km^2 total area distributed by 10 parishes. The total volume of trips by the resident population in the Municipality of Aveiro is estimated at around 191 300 daily trips. This corresponds an average of 2.9 trips per day per inhabitant (CIRA, 2014). The car is the most used transport mode with more than 68% of the total number of trips. Pedestrian mode is the second most representative, with about 21% of total travel. Bicycle use represents 2.7% of the modal share.

In this paper, the analysis was developed on urban roads, where there is the highest concentration of pedestrians and cyclists. The exposure of VRUs was assessed. After an overall analysis on the zones with highest number of crashes involving pedestrians and cyclists (from ANSR data) VRUs were counted, by gender, in the following periods 8-10AM, 12-2PM and 5-7PM. This data collection was carried out in the summer along two weekdays with dry weather.

Crash data involving pedestrians and cyclists were analyzed, correspondent to crash participations registered by the Public Security Police (PSP) and statistical analysis data from the National Association of Road Safety (ANSR) for the years 2012 to 2015. 246 crashes involving both pedestrians and cyclists were analyzed in this 4-year period (143 crashes involving pedestrians and 103 crashes involving cyclists), for which 257 people were injured (140 female and 117 male). The variables indicated in the PSP registrations are: date and time, crash location, description of damages, driver and VRU profile, crash severity, meteorological conditions, description and sketch of the crash. The provided parameters in ANSR data are: date and time, number and severity of injuries, age and genre of VRUs, location, meteorological conditions, light conditions, adherence conditions, road conservation status, presence of traffic direction separators, presence and signaling of obstacles, traffic signs presence. The sketch included in the PSP data was analyzed in detail, in order to identify the crash location. In case of doubt of ANSR data, the intersection is identified from the geographical coordinates. Three categories were chosen: urban street segments, intersections and roundabouts (Fig. 1).

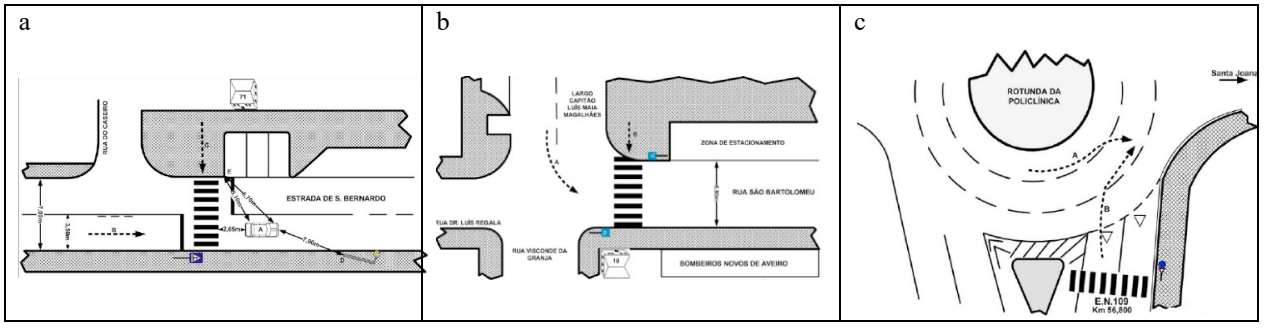


Fig. 1. Type of Intersection (a) urban street segment, (b) intersection, (c) roundabouts

Regarding meteorological conditions, good and bad conditions (related with the absence or presence of rain, respectively) were evaluated. Likewise, lighting conditions only refer to sunlight and not to the existence of artificial lighting.

2.2. Predictive modeling of Crash Severity involving VRUs

Statistical analysis was performed though IBM SPSS (Statistical Package for Social Sciences), which is the most widely used software to analyze quantitative data. IBM SPSS is a comprehensive system to generate descriptive statistics and complex statistical analysis. Among the SPSS functionalities is the logistic regression used in this work (McCormick et al., 2013).

Road crashes events were interpreted in a single database and the following parameters were analyzed with IBM SPSS: date and time, number and severity of the injuries, characterization of the VRUs and driver (genre and age), type and year of motor vehicle, location of crashes (type of intersection), proximity to the pedestrians' crosswalk, meteorological and light conditions. Variables are analyzed in order to gather the information related to the different data sources (ANSR and PSP). Data statistical analysis was performed in two stages: first, a study of each variable individually and, secondly, a bivariate study using contingency tables were used to analyze the hypothesis of association between variables using the chi-square test. Finally, a logistic regression model that relates whether the user is a pedestrian or cyclist depending on the variables VRU genre, road, crosswalk and meteorological conditions was developed – Table 1.

Table 1. Independent variable values obtained using IBM SPSS

	B	*p*-value	*Exp(B)*
VRU Genre (female)	1.252	0.000	3.496
Location (urban street segments)	0.987	0.004	2.682
Crosswalk (yes)	2.364	0.000	10.635
Meteorological Conditions (good)	-1.459	0.003	0.232

Table 1 refers the independent variables that are part of the logistic regression model. Thus, *B* represents the value of the coefficients in the logistic regression model and *Exp(B)* estimate the ratio of the dependent variables as a function of the independent variables, *i.e.*, pedestrian over cyclist. In the second column, *p*-value indicates whether the variable is significant for the model (*p*-value<0.05).

Since the dependent variable to be studied is nominal qualitative, with two categories and more than one independent variable, the multiple binary logistic regression was used. This model, as Hosmer and Lemeshow (2013) refers to, is a simple and easily interpreted mathematical model, and its expression is given by:

$$\pi(\boldsymbol{x}) = \frac{exp(\boldsymbol{x}^T\boldsymbol{\beta})}{1 + exp(\boldsymbol{x}^T\boldsymbol{\beta})} \quad (1)$$

where $\boldsymbol{x}$ is the vector of the explanatory variable, β is the vector of the coefficients of the model and $\pi(\boldsymbol{x})$ is the probability of VRUs being a pedestrian taking into account the dependent variables.

After selecting the independent variables (predictors) in the model, the following selection algorithms were used: forward and backward.

The coefficient vector (β) was estimated using the maximum likelihood model (LL) to evaluate the fit of model used Hosmer-Lesmeshow test. The significance of the individual coefficients was assessed using the Wald test (Lemeshow and Hosmer, 2013). Finally, through the value of odds ratio, we evaluated the risk of occurrence of the crash with pedestrian or cyclist.

3. Results and Discussion

From the statistical analysis it was concluded that 90.37% of VRUs involved in motor vehicle crashes result in light injuries. The remaining percentage (9.36%) represents serious injuries and fatalities.

Analyzing serious injuries and fatalities data from 2014 to 2015 we can observe a growth of 18%. From those, 64% are regarding pedestrians and 36% are cyclists' injuries. The fatalities occur with both pedestrians and cyclists, with a greater number of occurrences with male pedestrians and cyclists. The fatalities occurred with people with more than 37 years.

In general, the annual evolution of the crashes involving pedestrians stabilized over the 4 years (verified by chi-square test for independence p-value > 0.333). On the other hand, for cyclists the increase is significant over the years (verified by chi-square test p-value = 0). In relation to pedestrians, there was an increase of 36% in 2014, when compared to the previous year. For cyclists there is a growth percentage over year of 150% from 2012 to 2013, 75% from 2013 to 2014 and 14% from 2014 to 2015 (Fig. 2).

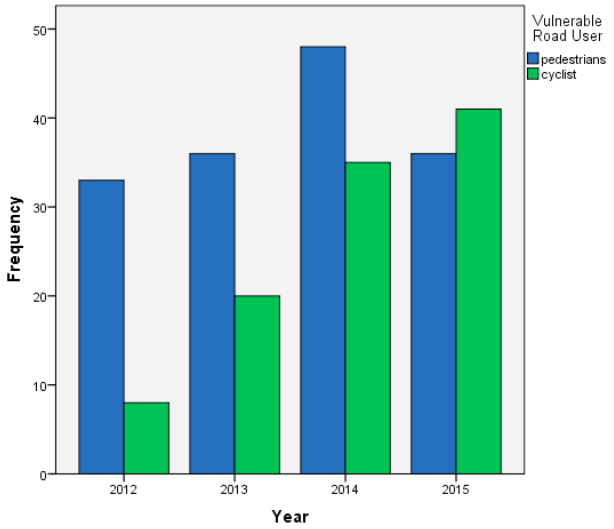


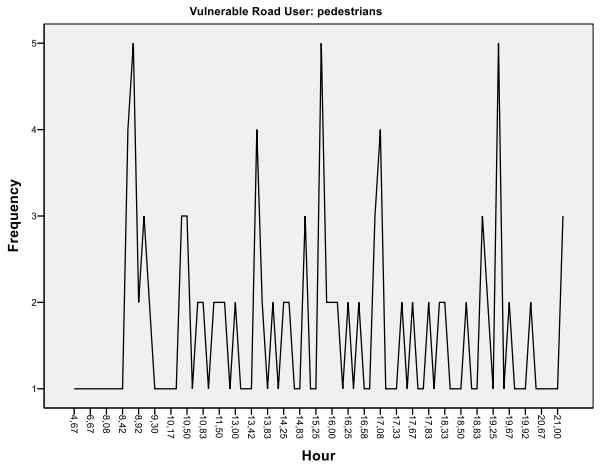
Fig. 2. Distribution of road crashes involving pedestrians and cyclists per year (obtained from IBM SPSS).

In terms of gender for pedestrians, 71.9% of the injured are female and 28.1% male. In contrast, for cyclists, 71.2% are male and 28.8% are female. These majority tendencies goes in line with Trigoso (2017), who refers that light injuries represent 56.5% for female pedestrians and 87.1% for male cyclists, according to the data from the Portuguese Road Prevention (Prevenção Rodoviária Portuguesa - PRP) for crashes occurred in urban areas in Portugal between 2010 and 2015. In terms of exposure, pedestrians and cyclists were counted during the hours with major congestion. On average, 231 pedestrian and 28 cyclists, approximately, circulated per hour on the city area. Regarding the exposure of pedestrians, 50% - 59% are women. On the other hand, there was 74% - 77% male cyclists, depending of the period of the day.

In terms of the overall age range, there is a predominance of crashes number for the age group from 16 to 26 years old (21.3%) followed by the age group of the oldest (71 years old or older – represents 16.3% the accidents number) or the younger age group (from 5 to 15 years old – represents 11.2% of the accidents). The two last age groups are recognized as more vulnerable. In relation to this factor, it was not possible to assess the age of pedestrians and cyclists in the data collection that was performed.

Approximately 35% of the accidents occur during late afternoon hours and this can be justified by the increase of traffic volume during peak hours (CIRA, 2014). However, pedestrians' crashes have peaks during three specific times of the day (when there is higher traffic of motor vehicles, morning peak period, lunch and afternoon peak period); for cyclists, crashes are higher under the afternoon peak period (Fig. 3).

a



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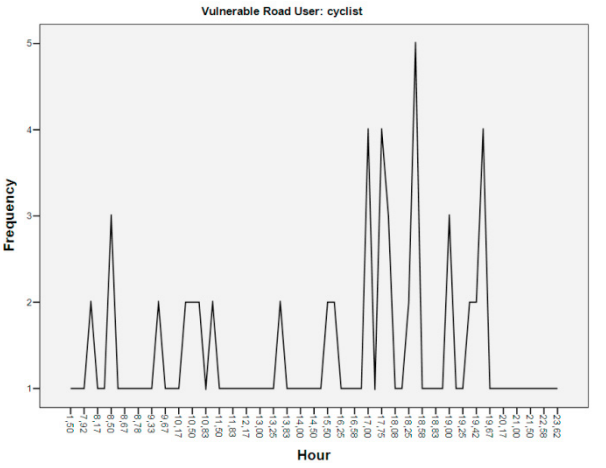
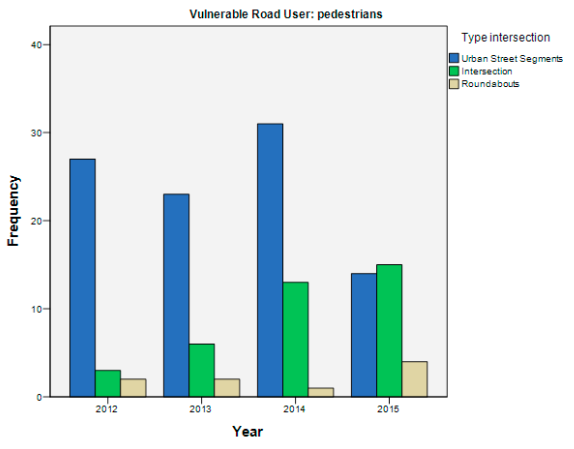


Fig. 3. Distribution of road crashes per time during day (a) pedestrians; (b) cyclists (obtained from IBM SPSS).

Regarding the location, there is an increase in the number of crashes nearby intersections (crossings or junctions) with emphasis on the year 2015 when this value was higher than the number of crashes in urban street segments. For both pedestrians and cyclists, the number of crashes close to roundabouts shows a downward trend until the year 2014. 2015 faced an increase in the number of accidents in roundabouts, while in 2014 there was a significant increase in accidents occurring in urban street segments (Fig. 4).

a



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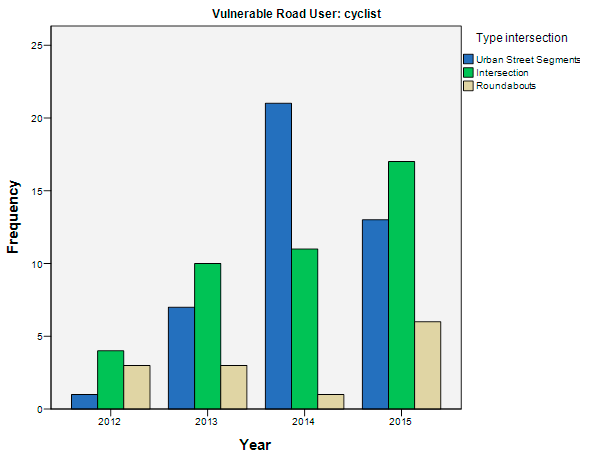

Fig. 4. Distribution of road crashes per type of intersection, per year (a) pedestrians; (b) cyclists (obtained from IBM SPSS).

From another point of view, 56.2% of these crashes occur in pedestrians' crosswalk. It was also concluded that meteorological conditions influence the occurrence of accidents, since most accidents occur under good meteorological conditions (73.2%). This number is even more significant for cyclists with 90.4% of total crashes occurring under good meteorological conditions.

The binary logistic regression model was developed to predict the probability of the vulnerable user being a pedestrian. The statistically significant variables are: genre of the VRU (Genre), location, accidents near pedestrians' crosswalk (crosswalk) and meteorological conditions (MC) (Table 2).

Table 2. Frequency table of variables.

		Frequency	Parameter Coding
Type of VRUs	Pedestrians	153	1
	Cyclists	104	0
Meteorological Conditions (MC)	Good (G)	190	1
	Bad (B)	48	0
Location	Urban Street Segments (USS)	137	1
	Other Intersections	101	0
Crosswalk	Yes (Y)	96	1
	No (N)	142	0
Genre VRU	Female (F)	132	1
	Male (M)	106	0

Using software IBM SPSS, the obtained model was:

$$\hat{\pi} = \frac{\exp\left(0.987\text{Location(USS)} + 2.36\text{Crosswalk(Y)} + 1.25\text{Genre(F)} - 1.46\text{MC(G)}\right)}{1 + \exp\left(0.987\text{Location(USS)} + 2.36\textit{Crosswalk(Y)} + 1.25\textit{Genre(F)} - 1.46\textit{MC(G)}\right)} \quad (2)$$

where $\hat{\pi}$ represents an estimate of the probability of the VRU being a pedestrian.

In the evaluation of the significance and quality of the adjusted model, the likelihood-ratio chi-square test was used for which a *p*-value = 0 was obtained, which proves that the model is statistically significant. The quality of fit was verified by the Hosmer and Lemeshow test for which a *p*-value = 0.914 (close to 1) was obtained and Cox & Snell R square = 0.352 and Nagelkerke R square = 0.474, which ensures that the model fits well the data. The significance of the individual variables was assessed using the Wald test. Observing equation 2 and Table 1, the probability of VRU being a pedestrian increases by 2.7 times if the crash occurs on an urban street segment, 10.6 times if the crash occurs at a pedestrians' crosswalk, and 3.5 times if the VRU is a female. If meteorological conditions are good, crashes involving pedestrians decrease about 77% when compared to a cyclist.

4. Conclusion

Improving safety is a vital factor to promote active modes of transport. Thus, it is important to examine factors that correlate most strongly with pedestrians and cyclist injury frequencies. The main objective of this paper is to implement a statistical analysis to assess the occurrence and severity of road crashes involving vulnerable road users.

Over the years under study, the number of accidents involving cyclists has grown significantly. From the variables analyzed that characterize crash registrations involving pedestrians and cyclists, the independent variables were considered: meteorological conditions, location, proximity to a crosswalk and gender of the VRU. Compared with a cyclist, pedestrians are 2.7 times more likely to experience crashes in urban street segments, 10.6 times more likely to experience crashes on a crosswalk and 3.5 times more likely to have a female pedestrian involved. Regarding the meteorological conditions, the probability of the pedestrian crashes occur with good meteorological conditions decreases 77% when compared to a cyclist. It has also been found that the number of crashes at intersections has increased for both (pedestrians and cyclists). About 35% of all crashes analyzed occur during afternoon peak time (5–8PM). However, while pedestrians have a three peak crash during the day (morning, lunch and afternoon), accidents involving cyclists are concentrated in the afternoon peak period. In terms of gender

division, regarding pedestrians, 71.9% of the injured are female and 28.1% are male. In contrast, for cyclists, 71.2% are male and 28.8% are female. About 21% of these crashes occur in the age group from 16 to 26 years old, 16.3% in the age group above 71 years old, and 11.2% occur for pedestrians with 5 to 15 years old. Unfortunately, we did not have access to further detailed data related to the use (or not) of protection devices such as bicycle helmets; from our data collection, about 19% male cyclists and 13% female cyclists were wearing helmet. It is worthwhile mentioning that the methodology can be applied to other case studies. Furthermore, it should be emphasized that these studies are relevant in order to establish relationships between different crash scenarios, allowing to improve and develop new safety measures and help decision makers in the definition of road safety policies.

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