IATSS Research 37 (2013) 21–29

Contents lists available at SciVerse ScienceDirect

IATSS Research

Observations on the relationship between European standards for safety barrier impact severity and the degree of injury sustained

Carlos Roque [a,*], João Lourenço Cardoso [a]

[a] Laboratório Nacional de Engenharia Civil, Departamento de Transportes, Núcleo de Planeamento, Tráfego e Segurança, Av do Brasil 101, 1700-066 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 30 November 2012
Received in revised form 19 April 2013
Accepted 25 April 2013

Keywords:
Safety barrier
Injury risk
Injury criteria
Crash frequency model
EN1317

ABSTRACT

Road restraint systems are roadside structures that include safety barriers, crash cushions, terminal of barriers, the transitions among different road restraint systems, motorcyclist protection devices, etc. These systems are used to protect vehicle occupants from dangerous roadside elements and are a key issue in roadside safety.

In Europe, safety barriers are currently designed for different performance levels using three main criteria: containment, impact severity and deformation of the barrier.

The impact severity level is exclusively associated with injury risk to vehicle occupants and assumes that different severity levels correspond to different levels of injuries.

From these observations, three questions emerge: what consequences can be expected for the passengers of an errant vehicle when it is contained by a safety barrier? Systems with different impact severity levels lead to diverse severity consequences? What are the benefits of using barriers with lower impact severity levels?

To answer these questions this paper examines how the number of run-off-the-road crashes and victims – associated with different safety barriers impact severity levels – changes as traffic grow.

The empirical results show that the effect of safety barriers functional characteristics on road safety only depends on impact severity levels adopted if level C is considered. As a result impact severity levels A and B are similar and their discriminating thresholds need to be revised.

1. Introduction

Road restraint systems (RRS) are roadside structures that are used to protect vehicle occupants from dangerous roadside elements such as critical slopes, utility poles and other rigid obstacles. RRS include safety barriers, crash cushions, terminal of barriers, the transitions among different road restraint systems, motorcyclist protection devices, etc. They are a major issue on roadside safety and the underlying requirement for their installation is that an impact with RRS will result in a collision severity that is lower than a collision with an unshielded roadside obstacle.

Results from recent studies carried out at the *Laboratório Nacional de Engenharia Civil* — LNEC (National Laboratory for Civil Engineering) show the importance of RRS in road accidents and their potential for preventing road fatalities in Portugal [1]. In fact, safety barriers represent almost half of the total number of roadside hazards collided in dual carriageway Portuguese roads (and half of the fatalities).

Safety barriers are currently designed for different performance levels, which are set according to current CEN performance standards [2] using three main criteria: vehicle containment, impact severity to occupants and deformation width of the barrier.

In Europe, safety barriers are treated as a construction material, requiring CE marking. In accordance with relevant CEN standards (in this case European Standard EN 1317), prior to their installation, safety barriers must pass standardized crash tests as mandated in their approval procedures. This requirement has allowed a reduction in the severity of the roadside accidents involving this type of systems.

Standard crash tests are assumed to be representative of real accidents. Nevertheless the mechanics of real accidents rarely are an exact match of installation and impact conditions as simulated on test tracks. In addition, there are many miles of obsolete safety barriers, installed prior to the adoption of current standards and that are unlikely to be replaced or improved soon, unless they are damaged by an errant vehicle.

A framework for cost-effective decisions as regards roadside safety benefits from being based on the analysis of registered data and observation of in-service performance of installed equipments. This is the context in which LNEC started in Portugal the *SAFESIDE — Roadside safety* research project. The main objective is to develop a method for assessing the influence of roadside characteristics on Portuguese road safety, which may be

---

* Corresponding author. Tel.: +351 218 443 970; fax: +351 218 443 029.
E-mail address: croque@lnec.pt (C. Roque).

Peer review under responsibility of International Association of Traffic and Safety Sciences.

Production and hosting by Elsevier

0386-1112/$ – see front matter © 2013 International Association of Traffic and Safety Sciences. Production and hosting by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.iatssr.2013.04.002

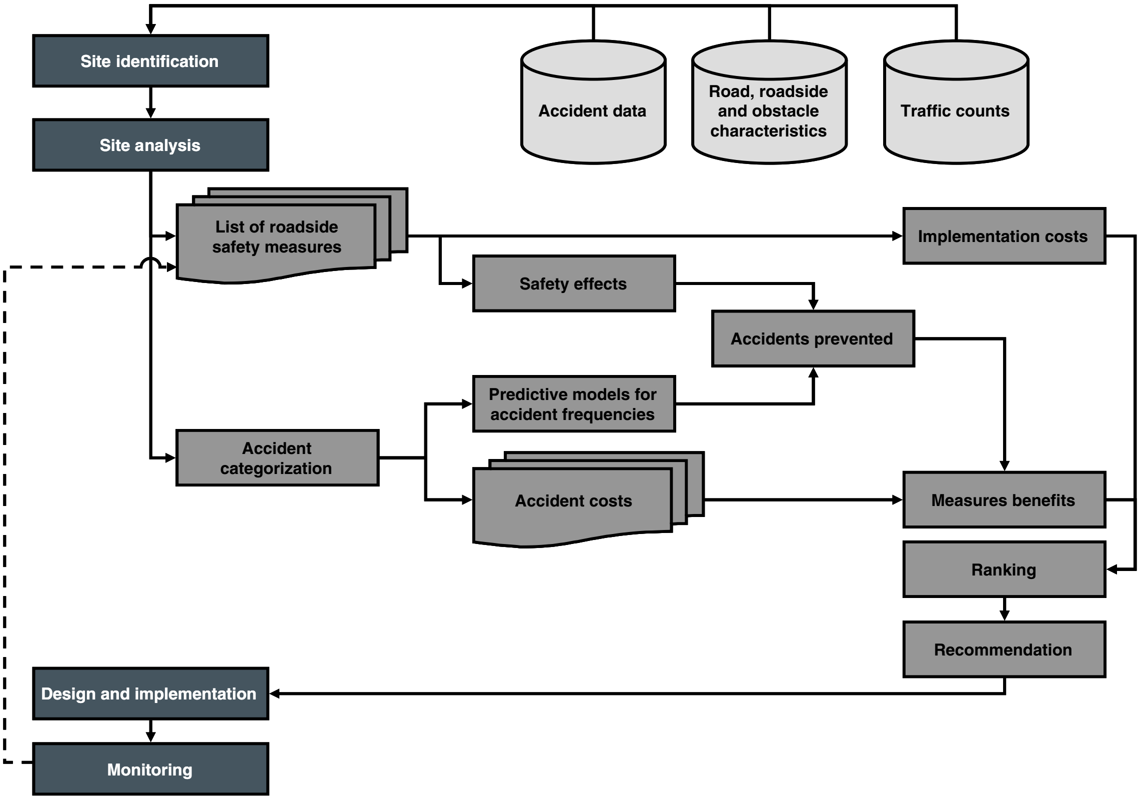

Fig. 1. General structure of the procedure to support decisions concerning roadside safety design and installation and selection of road restraint systems.

used to support roadside safety decisions concerning the design of new roads and the redesign and maintenance of operating roads.

Knowledge on the road safety effects of safety barriers functional characteristics is a key aspect of this method. These effects depend largely on the adopted containment and impact severity levels, whereby investigating the relationships between these levels and the safety effects of installing these RRS is a major task to develop the mentioned method for supporting roadside safety decisions. The developed method involves the calculation of expected crash and injury frequencies, as well as their costs.

Due to experimental and observational limitations, estimates of the potential for injury to human vehicle occupants involved in a crash with a safety barrier were calculated based on biomechanical indicators as reported in published studies.

It is also necessary to predict the number of run-off-the-road injury crashes (RORIC) involving safety barriers, to estimate the benefits of lower impact severity levels. In what concerns the accident frequency predictive models, the negative binomial modeling framework was used.

2. Research questions and methods

The main focus of SAFESIDE research activity was concerned with the development of statistical models for predicting roadside crash frequency and severity, fitted to general crash data from the traffic authority, and the identification of prevailing characteristics of RORIC through analysis of in-depth data collected on pilot road sections.

The roadside safety evaluation model, which contains a model for simulating and evaluating the safety effects of alternative roadside scenarios, is based on selected characteristics of a list of roadside safety measures (including their implementation costs' present values and safety effects) and accident categorization, which are combined into predictive models for crash frequencies and costs. In order to estimate the number of yearly crashes that may be prevented, calculation of two components is required: the expected number of target crashes expected to occur per year, and the safety effect of the safety measure on target accidents (Fig. 1).

The evaluation of the effects of measures is intended to assess quantitatively the change in the expected crash and victim frequencies, due to the application of a roadside corrective intervention.

In a list of roadside safety measures, RRS belong to the group of those that should be used as a last resort. The presence of these devices is the engineer's acceptance that the elimination of a roadside hazard is practical or economically unfeasible, and it is necessary to protect the traffic from that obstacle. The high number of fatalities in crashes with roadside hazards (collisions with safety barriers being considered the most frequent situation [3]) shows that this protection is not a fully effective solution from the safety point of view.

It is therefore important to retain that these systems are obstacles that may be hit by a vehicle. However, they are designed, constructed and tested to ensure that any collision with them will be less severe than a collision, of equivalent kinematic characteristics, with an unshielded roadside hazard.

A comprehensive survey of studies evaluating the safety effects of safety barriers has been made. These studies have been identified by means of a systematic literature search; no studies were found evaluating the safety effect of changes in containment and impact severity levels according to EN 1317. An observational before–after study[1] would be an alternative way to estimate the safety effect of installing safety barriers. Unfortunately, this type of study needs data that, presently, cannot be obtained, at least in Portugal.

---

[1] A commonly employed study design used to evaluate the effects of road safety measures, by comparing the number of accidents before and after the measure was introduced.

As mentioned before, the safety effect of measures including safety barriers depends heavily on the selected containment and impact severity levels.

The primary concern in determining the containment level is to assess the risk of an errant vehicle colliding violently with the system, and therefore penetrate it, invading the sensitive area. Thus, the choice of an appropriate containment level not only contributes to the safety of occupants of an errant vehicle, but also for the safety of others. It ought to be borne in mind that the containment level indicates, in terms of kinetic energy, the maximum capacity of the system. This means that, for the same impact speed, a safety barrier with a containment level N2 can contain a car but cannot ensure the retention of a heavier vehicle, for example a bus, at the same impacting speed.

The impact severity level was defined as a way of representing occupant injury risk on a vehicle crashing onto a safety barrier, the implicit assumption being that each severity level captures its own level of injury severity.

From these observations, three questions emerge: what consequences can be expected for the passengers of an errant vehicle that is contained by a safety barrier? Do barriers with different impact severity levels indeed lead to diverse severity consequences? Are there significant benefits from using barriers with low impact severity levels, as compared to higher severity level barriers?

To answer these questions this paper examines how the number of run-off-the-road accidents and victims – associated with different safety barrier impact severity levels – changes as a function of the average daily traffic flow. Identifying a recognizable relation between injury risk and traffic gives an indication of the level, if any, at which safety barriers with lower consequences for vehicle occupants are effective. Understanding when this occurs is very important for developing a procedure to evaluate alternative roadside safety interventions involving safety barriers, as the one that was outlined under the research project SAFESIDE.

2.1. Criteria for assessing run-off-the-road accident severity

In road safety, injury criteria are a means for estimating the potential for injury to an occupant of a motor vehicle involved in a crash. Broadly, two types of injury criteria may be used to assess occupant injury risk in the event of a motor vehicle crash test (see Fig. 2):

- Anthropometric test device based injury criteria;
- Vehicle-based injury criteria.

An anthropometric test device (a crash test dummy) is an instrumented replacement of a human being, designed to evaluate injury potential in a repeatable manner [4]. In general, injury potential is assessed by body region, based on acceleration and displacement measurements in the anthropometric device during the crash impact phase.

Vehicle-based injury criteria refer to theoretical indicators that describe occupant injury potential based solely on the response of the vehicle during the crash impact phase. These criteria are mainly used for risk assessment through non-dummy equipped vehicle crash tests with RRS, including safety barriers.

According to the EN 1317, injury risk while crashing onto a RRS is estimated on the basis of vehicle-based injury criteria, by means of three indicators: Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV) and Post-impact Head Deceleration (PHD). According to the mentioned standard, three levels of impact severity are considered; however, they only differ on the established allowable limiting ASI values [2]. There is no reference in the standard to the expected injury severity associated with each of these limits, nor to the theoretical or empirical evidence that supported the establishment of impact severity level threshold values.

2.2. Statistical models for predicting roadside crash frequency

In road safety analysis there is a large consensus that Poisson and negative binomial regression count models are an appropriate methodological technique for modeling crash frequency, i.e., the number of crashes on a roadway element during a predefined time period [5]. In applying Poisson regression to crash frequency analysis, let n_{ij} be the number of RORIC on roadway section i during period j. The Poisson model is,

$$P\left(y_{ij}\right) = \frac{\exp\left(-\lambda_{ij}\right)\lambda_{ij}^{y_{ij}}}{y_{ij}!} \tag{1}$$

where $P(y_{ij})$ is the probability of y crashes occurring on highway element i during time period j and λ_{ij} is the expected value of y_{ij},

$$E\left(y_{ij}\right) = \lambda_{ij} = \exp\left(\beta X_{ij}\right) \tag{2}$$

for a roadway section i in time period j, β is the vector of parameters to be estimated and X_{ij} is a vector of explanatory variables describing roadway section geometric characteristics, environmental characteristics

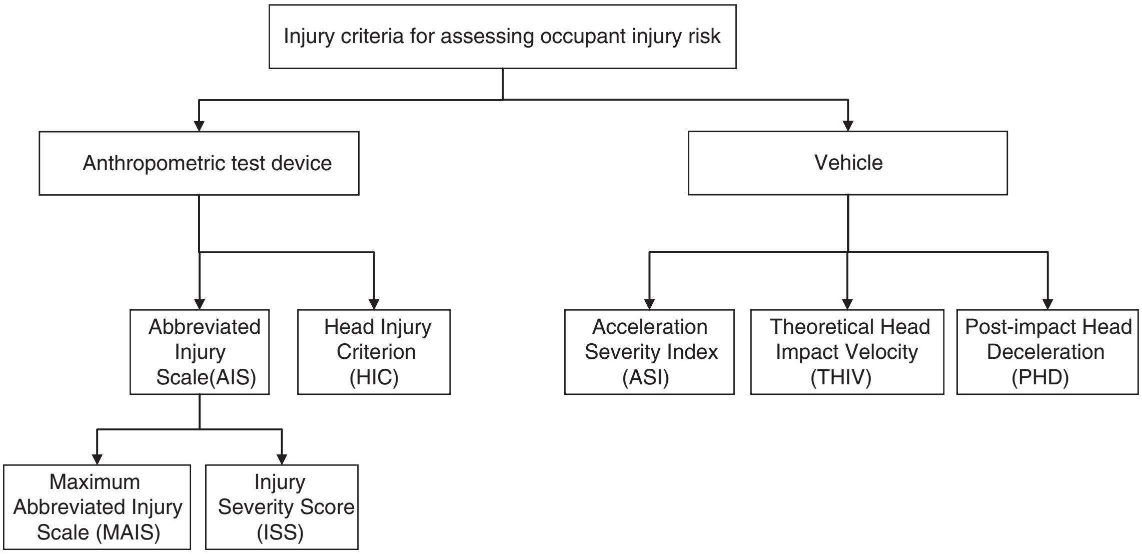

Fig. 2. Injury criteria for assessing occupant injury risk for a motor vehicle crash test.

and other relevant roadside features that may affect crash frequency, such as traffic.

A feature of the Poisson distribution refers to the equality between the counts expected value and its variance. However, it is not always possible to assume that λ_i is constant. On the one hand, the decreasing trend in time of accident risk, as observed in countries like Portugal, weakens the validity of the Poisson hypothesis of constancy in time of the probability of occurrence. On the other hand, there are unknown factors that may contribute to crash occurrence as well as factors which, although known, are quantified with measurement errors; in both cases the individual risks on each entity in a homogeneous group of entities are not identical. Thus, the ratio of the variance to the expected value differs from one, i.e., overdispersion or subdispersion will be observed [6].

The negative binomial model is an extension of the Poisson regression model adapted to the possible existence of overdispersion in the data. The negative binomial model is derived by rewriting Poisson parameter for each observation *i* in a given time interval *j* as [5]:

$$\lambda_{ij} = \exp\left(\beta X_{ij} + \varepsilon_{ij}\right) \tag{3}$$

where exp (ε_{ij}) is a random error term that follows a Gamma probability distribution with mean 1 and variance α. This addition allows the variance to differ from the mean as stated below,

$$VAR[y_i] = E[y_i](1 + \alpha E[y_i]) = E[y_i] + \alpha E[y_i]^2. \tag{4}$$

3. Calculation of injury accidents prevented as a function of impact severity level

As noted above, analysis of trauma resulting from vehicle collisions with safety barriers may correspond to the determination of the risk of injury to the occupants of an errant vehicle, for the various impact severity levels considered in EN 1317.

3.1. Literature review

Existing studies capable to relate the injury criteria recommended in EN 1317 with the consequences to occupants of errant vehicles were used to estimate the expected injuries associated with different impact severity levels.

Published literature on this specific subject is scant, only three studies being identified. Shojaati [7] studied the correlation between ASI, HIC and vehicle occupants injury risk; Sturt and Fell [8] analyzed the relationship between injury risk and impact severity in collisions with safety barriers; and Klootwijk and Hoogvelt [9], used a multi-body simulation program to analyze the sensitivity of injuries to some parameters in car-guardrail collisions, as part of the EC-funded project, RISER (Roadside Infrastructure for Safer European Roads).

In the first study, nine side impact crash tests with a Hybrid III dummy were performed, measuring the ASI and then determining the corresponding head injury criterion (HIC).

The results suggest an exponential relationship between HIC and ASI. For ASI values lower than 1.0, the HIC value is below 100. For ASI values between 1.5 and 2.0 estimated values for HIC were between 350 and 1000. Due to the limited number of tests conducted, the correlation between ASI and HIC was only calculated on an approximate basis.

Sturt and Fell [8] performed three crash tests with anthropometric test device equipped vehicles and ran 50 computer simulations. The results confirmed the existence of a correlation between the measured head and neck injury marks using anthropometric test device based injury criteria (in particular HIC) and the accident severity as estimated with the EN1317 vehicle-based injury criteria (ASI and THIV). According to this study, the neck and head are the body regions more vulnerable to harm in safety barrier impacts.

According to Sturt and Fell [8], the boundary as defined in EN 1317 for impact severity levels B (ASI greater than 1.0 and not more than 1.4) and C (ASI greater than 1.4 and not more than 1.9) does not match any significant increase in injury risk. Also according to the same authors, the threshold value established in EN1317 for THIV (below 33 km/h) is, by itself, reasonable: below this value it is unlikely that significant injuries may be inflicted.

As in the study by Shojaati [7], the results obtained by Sturt and Fell suggest an exponential relationship between HIC and ASI. However, the values obtained by Shojaati are significantly greater than those estimated by Sturt and Fell [8] for HIC (see Fig. 3).

It should be noted that ASI is determined based on the accelerations and decelerations at the vehicle's center of gravity. On the other hand, HIC describes the injury severity based on the accelerations acting on the vehicle's occupant. It also states that, in reality, this occupant is not rigidly connected to the vehicle structure. Factors such as vehicle size and stiffness, seat characteristics and seat belt slackness may account for significant differences between accelerations measured at the vehicle center of gravity and those measured on the occupants.

Klootwijk and Hoogvelt [9] only used simulation techniques in their study. The simulations give insights in the infrastructure–vehicle interaction and the vehicle–occupant interaction. One of the aims of this study was to analyze the sensitivity of selected parameters on the impact response and to investigate whether there is a relationship between the anthropometric test device based injury criterion HIC and the vehicle-based injury criteria ASI. The study showed a relationship between ASI and HIC for the simulated scenarios of impact, with speeds ranging from 35 to 100 km/h at impact angles between 5° and 35°. The result indicates that ASI is a reasonable predictor for injury due to safety barrier impacts.

3.2. Estimation of AIS values for different impact severity levels

Combining HIC values from the studies by Shojaati, and Sturt and Fell [8] with results from a study of Prasad and Mertz[2] (quoted in [7]) it is possible to estimate a corresponding value for the Abbreviated Injury Scale (AIS) (see Fig. 4) The AIS is a standardized system for categorizing the type and severity of injuries arising from vehicle crashes, which is based on medical diagnosis. It is the injury scale most widely used worldwide [10].

ASI thresholds for the three impact severity levels considered in EN 1317 may be established from the results of the mentioned combination of HIC values (see Table 1).

It is noted that AIS is not a linear scale in the sense that the difference between AIS1 and AIS2 is not directly comparable to the difference between AIS5 and AIS6. Therefore, it does not make sense to calculate mean values for AIS [10]. From Table 1 both impact severity levels A and B correspond to a possible minor injury ($0 < \text{AIS} \leq 1$). However, values obtained for impact severity level C are significantly different from levels A and B. Based on the study by Sturt and Fell [8] it is possible to admit that level C corresponds to minor injuries; while the study of Shojaati [7] points to moderate to severe injuries ($\text{AIS} \approx 3$) for the same impact severity level.

One important problem in trauma-biomechanics is the assessment of the relationship between injury severity and the mechanical impact that causes this injury [10]. It is a matter of identifying a mechanism and calculating the probabilities that describe the likeliness that a specific impact will cause a particular injury (defining variables such as HIC). Hence, it is necessary to determine biomechanical responses and

---

[2] P. Prasad and H. Mertz (1982). The position of the United States delegation to the ISO working group 6b on the use of HIC in the automotive environment. SAE Paper 821246.

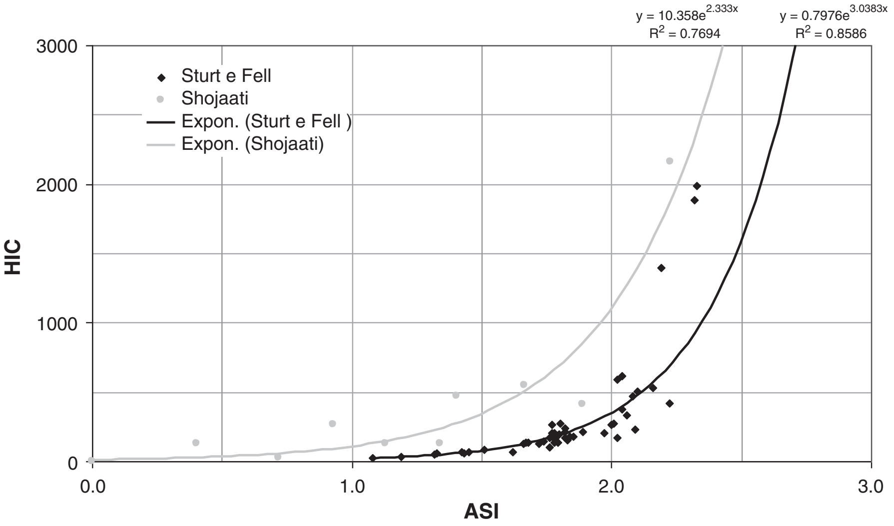

Fig. 3. Relationship between ASI and HIC (adapted from [7] and [8]).

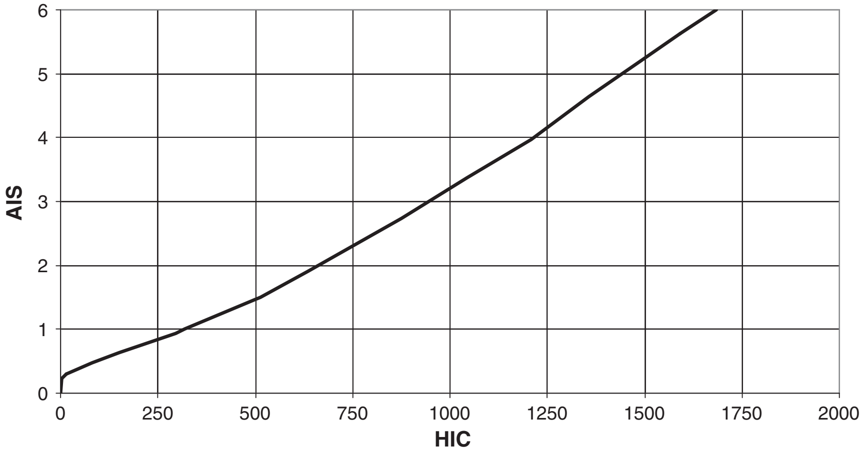

Fig. 4. Relationship between HIC and AIS [7].

corresponding injury tolerance levels to establish the appropriate injury risk functions.

To determine the relationship between HIC and brain and skull injuries, Hertz (quoted in [10]) analyzed statistically existing test data and fitted the log-normal distribution to the data set. Thus, the head injury probability for a particular value of AIS was obtained by subtracting the cumulative injury probability P (AIS $\geq j$) from the subsequent elevated cumulative probability of injury (AIS $\geq j + 1$) [11] using for this purpose the following formula [12]:

$$\mathrm{P}(\mathrm{AIS} \geq j) = \phi\left(\frac{\ln\left(\mathrm{HIC}_{15}\right) - \mu_j}{\sigma_j}\right) \tag{5}$$

where Φ is the probability density function of the standardized normal distribution and the values of μ_j and σ_j are defined in Table 2.

Table 3 presents the results of applying Eq. (5) to the values in Table 1 based on the ASI thresholds for the three impact severity levels considered in the EN 1317.

Values obtained from Sturt and Fell [8] data indicate an approximately zero probability of serious injury to any level of impact severity considered, whereas the values obtained from the Shojaati [7] study show a significant probability of serious injury for impact severity level C. Of note is the fact that the Sturt and Fell [8] data based values presented in Table 3 are not congruent with the accident reduction factors empirically estimated by Elvik et al. [13] for corrective interventions involving the replacement of existing safety barriers by more flexible ones; the estimated average reduction in injury crashes is 32%.

Table 1
AIS values for different impact severity levels.

Impact severity level	ASI	AIS	
		Sturt e Fell	Shojaati
A	1.0	0.30	0.50
B	1.4	0.39	0.90
C	1.9	0.86	2.71

Table 2
Values of μ_j and σ_j.

j	μ	σ
2	6.96352	0.84664
3	7.45231	0.73998
4	7.65605	0.60580

Table 3
Probability of head injury for different impact severity levels.

Impact severity level	ASI	P (AIS ≥ 2)		P (AIS ≥ 3)		P (AIS ≥ 4)	
		Sturt e Fell	Shojaati	Sturt e Fell	Shojaati	Sturt e Fell	Shojaati
A	1.0	0%	0%	0%	0%	0%	0%
B	1.4	0%	5%	0%	1%	0%	0%
C	1.9	5%	41%	1%	18%	0%	7%

Table 4
Parameter estimates and goodness-of-fit statistics for run-off-the-road injury crashes involving collision with safety barriers on freeway sections.

	Estimates			
	Coefficient	Standard error	z-Value	Pr(>|z|)
Intercept	-9.94242	0.781	-12.72	$<2 \times 10^{-16}$
log(AADT)	0.83146	0.067	12.32	$<2 \times 10^{-16}$
log(length)	0.66229	0.062	10.66	$<2 \times 10^{-16}$
Dispersion parameter, α	0.717			
Number of observations	794			
AIC	2041.095			
G^2	1267.904			
MAD	0.930			
Elvik's index	0.620			

It is also important to note that great care is required when using these results, as the number of base tests is small and there are differences as regards the biomechanical response of human beings and the anthropometric test devices used in the crash tests. Furthermore, it is noted that crashes may involve a high number of injury mechanisms and several types of injury may occur.

The values obtained from the study of Shojaati [7] (Table 3) were used as reference in the developed method, due to its greater compatibility with the safety barrier installation effects, as estimated by Elvik et al. [13] through meta-analysis.

3.3. *Crash frequency model estimation*

Crash data available for this study were collected on three different complementary Portuguese data sources: the crash database; the National Road Network inventory database, with roadside and obstacle characteristics; and the traffic database, with annual average daily traffic (AADT) estimates from road traffic counts. All three databases are managed by different organizations.

After integrating these three databases into one, the resulting data were segmented into a total of 794 freeway unidirectional road sections (over 4700 km), over the period from January 2007 to December 2010. During this four year period, a total of 815 run-off-the-road injury crashes involving a collision with safety barriers were reported. Data from these freeway sections formed the basis for fitting crash frequency models.

The equation used in this paper to estimate the number of RORIC involving a collision with safety barriers on freeway sections is based on the assumption that road crashes are negative binomially distributed. The estimates for the model parameters and selected statistics are presented in Table 4.

The resulting relation between the expected number of analyzed crashes in four years, the annual average daily traffic over the four-year period (AADT) and length of the motorway section (between interchanges) in kilometers is given by:

$$\lambda_i = 4.809 \times 10^{-5} \times \text{AADT}_i^{0.831} \times \text{Length}_i^{0.662}. \tag{6}$$

4. Results and Discussion

The graph of the predicted number of RORIC involving collision with safety barriers against AADT for two section lengths (1 km and 10 km) and for a period of four years is shown in Fig. 5.

The accident frequency model developed does not explain the average number of accident victims nor their injury severity — fatal, severe, or only slight injury. However, it is possible to obtain a rough calculation of these numbers using the average number of victims per RORIC.

Thus, results based on cross section analysis of Portuguese RORIC data were calculated for all sections of the National Road Network with estimated AADT values (in 2007–2010 period). Three types of rate were defined, as related to the severity of accidents:

- Mortality rate per crash (MRC), concerning the number of deaths per RORIC;
- Serious injury rate per crash (SEIRC), concerning the number of persons seriously injured per RORIC;
- Slight injury rate per crash (SLIRC), concerning the number of persons slightly injured per RORIC.

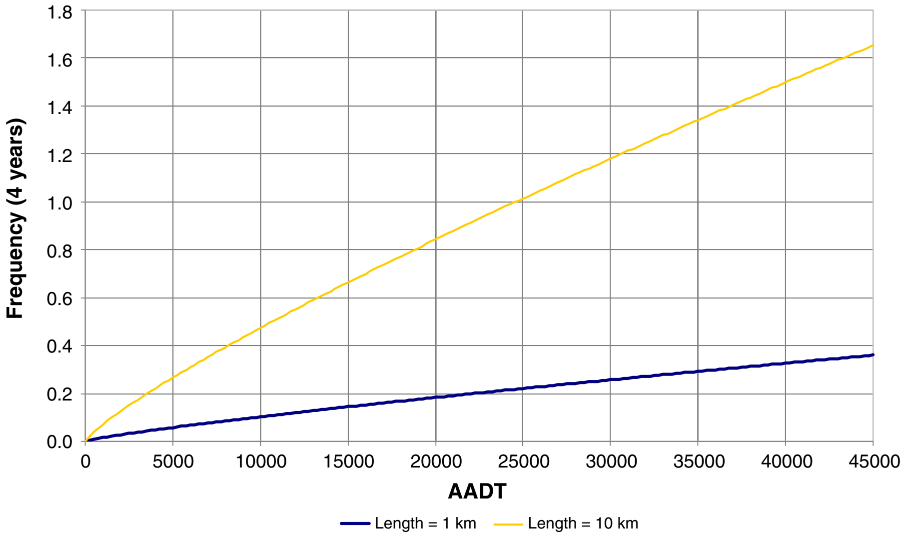

Fig. 5. Predicted number of run-off-the-road injury accidents involving collision with safety barriers for two section lengths.

Table 5
Average number of deaths, seriously injured and slightly injured per 1000 RORIC.

MRC	SEIRC	SLIRC
38	81	1297

The average values of RORIC rates in 794 dual carriageway road sections are presented in Table 5.

The number of killed and seriously injured victims in RORIC involving a collision with safety barriers may be estimated (as a function of its impact severity level) with the accident frequency model presented above, if the following assumptions are accepted:

- serious injuries occur whenever AIS is greater than 2;
- head injuries are the most severe that occur in RORIC impacts, as indicated by Sturt and Fell [8] and implicitly assumed in EN 1317, since two out of three injury criteria used in this standard are related to the head;
- the probability of injury for different impact severity levels may be calculated using the values resulting from the study of Shojaati [7] (see Table 3);
- impact severity level A is the existing default situation;
- the traffic stream is composed solely of cars with masses up to 1500 kg.

Fig. 6 shows the predicted number of killed and seriously injured victims for each safety barrier impact severity level, for 1 km and 10 km long road sections.

As depicted in Fig. 6, road sections with safety barriers with impact severity level C have considerably higher expected values of killed and seriously injured victims than road sections equipped with impact severity levels A and B safety barriers. However, the difference may be relevant only for longer sections. Also, the expected numbers of fatalities and serious injuries are quite similar in RORIC on roads equipped with impact severity levels A and B safety barriers.

Moreover, the difference between the calculated expected numbers of killed and seriously injured victims for all impact severity levels increases with AADT.

4.1. Compatibility of indicators and definitions

It should be noted that the definition of serious injury (AIS ≥ 3) used in the Abbreviated Injury Scale [10] does not match the definitions used for serious or slight injured victims in Portuguese road accident data nor in most countries. Usually, the injury severity classification of an accident victim depends on the hospital length of stay. In Portugal, a victim is classified as a serious injury when he/she stays more than 24 h at the hospital; and as a slightly injury when he/she is discharged from hospital on the admission day.

According to data from a U.S. study by the National Highway Traffic Safety Administration (NHTSA) [14] which analyzed the costs of road accidents in the United States of America in 2000, it is possible to relate the period of hospitalization stay with the injury criteria Maximum Abbreviated injury Scale (MAIS). The MAIS represents the highest AIS code sustained by a crash victim on any region of his body, even if the person in question sustained several injuries of the same severity level at

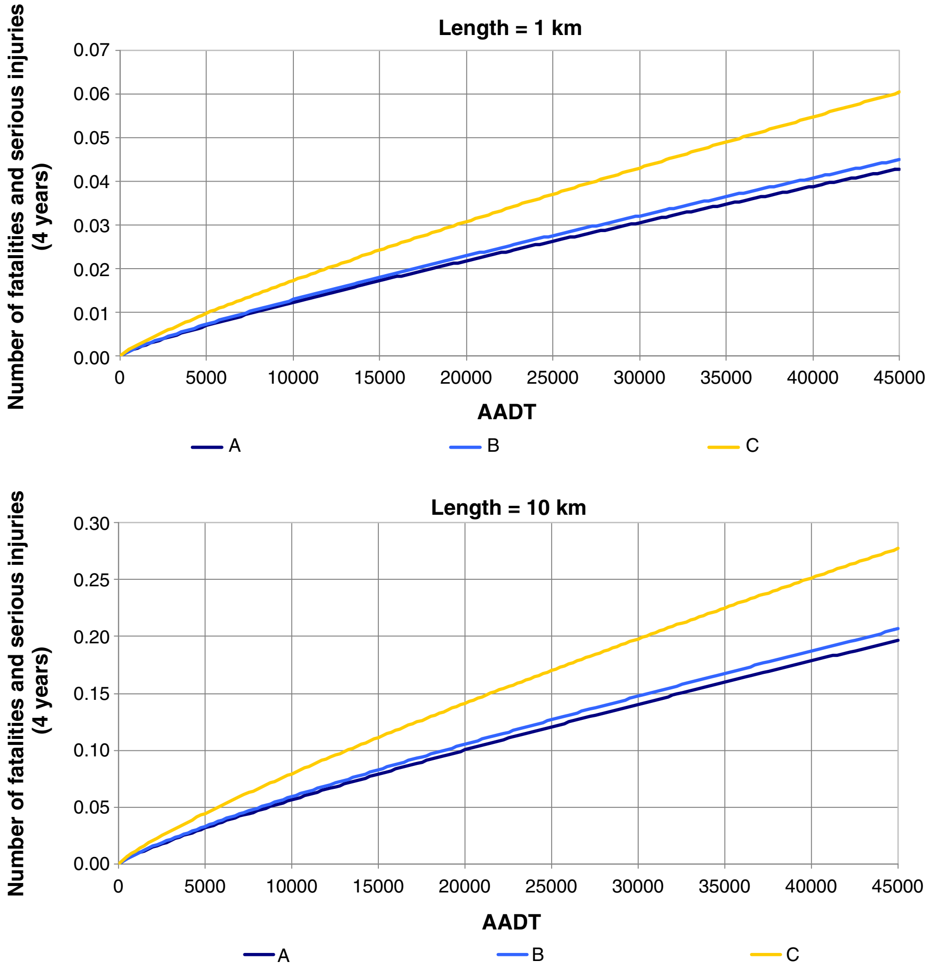

Fig. 6. Predicted number of killed and seriously injured victims against AADT for the different impact severity levels considered and for two section lengths.

Table 6
Hospital length of stay for different MAIS severity levels (adapted from [14]).

MAIS	Days
1	2.6
2	2.8
3	8.3
4	11.4
5	17.8

different body regions [10]. The average hospital length of stay for nonfatal injuries stratified by severity level depending on the value of MAIS is presented in Table 6.

The average hospital length of stay is more than 1 day for all MAIS severity levels considered. There is a clear mismatch between AIS and the traditional crash database (slight or serious) injury classification (see Fig. 7).

Further to the values in Table 6, results from the NHTSA study [14] also show that MAIS values above 1 are associated with average hospital length of stay that exceeds 24 h. This suggests the need to revise the Portuguese definition of serious injury. The same may be said as regards international definitions, as there are several countries that use similar criteria (for example, Belgium, Canada, Germany, Luxembourg and Spain [15]).

4.2. Coherence different criteria

In order to evaluate the potential for human injury, crash tests are carried out on the other two elements of the road transport system (the vehicle and infrastructure).

Ideally, anthropometric test devices would be used in road restraint system crash tests, to assess vehicle occupant injury risk. However, responsible authorities for this matter have been avoiding this option due to several practical considerations. This type of crash tests is complex and includes a structural evaluation of the restraint system, in addition to the assessment of the potential for injury to vehicle occupants, and diversified standard conditions. For example, in the case of safety barriers, crash tests are performed at high speeds and with small angles of collision (less than 30°). Furthermore, these devices are normally tested in natural soil, which may seriously hamper the repeatability of tests with dummies. A vehicle that collides with one of these systems will probably run through a rather uneven surface, displacing dummies and compromising the repeatability of measurements made. Furthermore, the use of such equipment burdens considerably the testing procedures and the high accuracy of measuring instruments introduces an added degree of variability. Under these conditions significantly different values may be obtained under the same test conditions, depending on the vehicle make and model used. These difficulties led to the development of simplified models of injury and derived criteria, such as the Acceleration Severity Index (ASI) cited above, which only measure vehicle kinematics and are only used for indirect estimates of occupant injury risk.

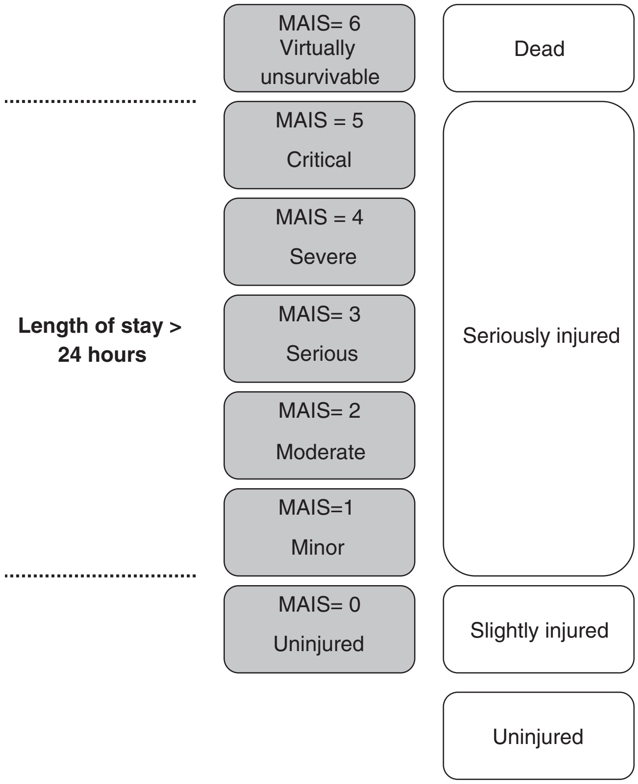

Fig. 7. Relationship between MAIS values and Portuguese accident records injury severity classes.

Nevertheless, crash testing under standardized conditions is the most widespread method for safety evaluation of both vehicles and roadside safety equipment. Starting with different injury criteria, the aim is to evaluate the injury potential for vehicle occupants.

Knowledge on how the various test injury criteria relate to each other is not comprehensive yet. In some cases the relationship between these criteria has obvious discrepancies. For example, the anthropometric test devices used in vehicle crash tests are designed to evaluate the performance of passive safety systems such as seat belts and airbags, in terms of injury to vehicle occupants. However, in the case of vehicle-based injury criteria like THIV and PHD it is assumed that the occupant has the possibility of free movement, i.e., he/she is not wearing seat belt nor are airbags active. This represents, in practice, what will be the worst case scenario for passive safety, typical of the early 1980s, when this type of indicators appeared (such as the Flail Space Model). At that time, the utilization rate of seat belts was very low (in the U.S. that rate was around 11% [4] and the market penetration of airbags was scarce). However, since the 1990s, in Europe and in North America, airbags became standard equipment in almost all new vehicles and seat belt use is widespread, thus justifying the development and adoption of novel indicators, representing more accurately the passive safety devices currently available to protect car occupants.

4.3. Conclusions

The purpose of this study was to evaluate the relationship between safety barrier severity levels and the safety effects of installing RRS complying with the European Standard EN 1317.

The results obtained suggest that differences in the effect of safety barriers functional characteristics on road safety are significant only if impact severity level C barriers are considered. As a result impact severity levels A and B are similar and their discriminating thresholds need to be revised. However, further studies are recommended, as the correlation between HIC and AIS as reported by Prasad and Mertz is based on frontal crash tests, which do not fully represent EN 1317 test conditions.

As future work, there are several interesting topics to focus on and explore. First, the inclusion of additional explanatory variables in accident frequency models related to the roadside environment, which depends on enlarging data availability, may improve the models' predictive power. Secondly, to estimate the safety effects of safety barriers, it is important to collect crash injury data at hospitals (using a standardized injury scale) and to classify safety barriers using anthropometric test device injury criteria. Statistical roadside safety analysis models adjusted to these improved data sets will allow an improved representation of relevant mechanisms.

Acknowledgments

The authors wish to thank the Portuguese Science and Technology Foundation Agency (*FCT — Fundação para a Ciência e a Tecnologia*) for providing financial support to this research through the PDTC/TRA/74520/2006 grant.

References

[1] C. Roque, J.L. Cardoso, Definição de Cenários Tipo para Acidentes envolvendo a Área Adjacente à Faixa de Rodagem, 4° Relatório Safeside — Sinistralidade Envolvendo a Área Adjacente à Faixa de Rodagem, Fundação para a Ciência e Tecnologia, Laboratório Nacional de Engenharia Civil, Lisboa, 2012.

[2] European Committee for Standardization, N 1317-2 road restraint systems—part 2: performance classes, impact test acceptance criteria and test methods for safety barriers, Technical Committee CEN/TC 226, Brussels, 2007.

[3] C. Schoon, Criteria for Safe Roadside in Relation With the Installation of Safety Barriers (Steel and Concrete), SWOV Institute for Road Safety, Leidschendam, 1998.

[4] D. Gabauer, Predicting Occupant Injury with Vehicle-Based Injury Criteria in Roadside Crashes, Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Biomedical Engineering, Blacksburg, Virginia, 2008.

[5] M. Karlaftis Washington, F.L. Mannering, Statistical and Econometric Methods for Transportation Data Analysis, Second edition Chapman and Hall/CRC978-1-4200-8285-2, 2011.

[6] João L. Cardoso, Métodos Racionais de Apoio à Intervenção da Engenharia em Segurança Rodoviária, Programa de Investigação apresentado para a obtenção do título de 'Habilitado para o exercício de funções de Coordenação de Investigação Científica, LNEC, 2007.

[7] M. Shojaati, Correlation between injury risk and impact severity index ASI, Proceedings of the 3rd Swiss Transport Research Conference Monte Verita/Ascona, March 19–21 2003.

[8] R. Sturt, C. Fell, The relationship of injury risk to accident severity in impacts with roadside barriers, International Journal of Crashworthiness (2009) 165–172.

[9] C.W. Klootwijk, R.H. Hoogvelt, Sensitivity of car with guardrail impacts with a multibody simulation tool, 2nd International Conference on ESAR "Expert Symposium on Accident Research": Reports on the ESAR-Conference, Hannover Medical School, 2006, pp. 194–196.

[10] K. Schmitt, P.F. Niederer, M.H. Muser, F. Walz, Trauma Biomechanics. Accidental Injury in Traffic and Sports, Second edition Springer, Berlin Heidelberg New York978-3-540-73872-5, 2007.

[11] W. Liu, J. Doong, S. Tsai, C. Lai, M. Jeng, Integrated model of simulated occupant injury risk and real medical costs, Journal of Safety Research 40 (2009) 461–468.

[12] S. Kuppa, Injury Criteria for Side Impact Dummies, National Transportation Biomechanics Research Center. National Highway Traffic Safety Administration, 2004.

[13] R. Elvik, A. Høye, T. Vaa, M. Sørensen, The Handbook of Road Safety Measures, Second edition Elsevier Science, Oxford, 2009.

[14] L. Blincoe, A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter, R. Spicer, The economic impact of motor vehicle crashes 2000, NHTSA Technical Report, Report No. DOT HS 809 446, 2002.

[15] OECD, IRTAD special report, Definitions and data availability — compilation and evaluation of a-level roads and hospitalised victims in OECD countries — accident and injury definitions, OECD — RTR Road Transport Research Programme BASt Germany, 1998.