UNIVERSITÀ
DEGLI STUDI
FIRENZE

FLORE
Repository istituzionale dell'Università degli Studi di Firenze

A comparative analysis of MAIDS and ISO13232 databases for the identification of the most representative impact scenarios for

Questa è la Versione finale referata (Post print/Accepted manuscript) della seguente pubblicazione:

Original Citation:

A comparative analysis of MAIDS and ISO13232 databases for the identification of the most representative impact scenarios for powered 2-wheelers in Europe / Grassi, Alessandro; Baldanzini, Niccolò; Barbani, Daniele; Pierini, Marco. - In: TRAFFIC INJURY PREVENTION. - ISSN 1538-9588. - ELETTRONICO. - 19:(2018), pp. 766-772. [10.1080/15389588.2018.1497791]

Availability:

This version is available at: 2158/1147477 since: 2021-03-29T12:02:25Z

Published version:

DOI: 10.1080/15389588.2018.1497791

Terms of use:

Open Access

La pubblicazione è resa disponibile sotto le norme e i termini della licenza di deposito, secondo quanto stabilito dalla Policy per l'accesso aperto dell'Università degli Studi di Firenze (https://www.sba.unifi.it/upload/policy-oa-2016-1.pdf)

Publisher copyright claim:

Conformità alle politiche dell'editore / Compliance to publisher's policies

Questa versione della pubblicazione è conforme a quanto richiesto dalle politiche dell'editore in materia di copyright.
This version of the publication conforms to the publisher's copyright policies.

(Article begins on next page)

23 July 2024

Cite as "Alessandro Grassi, Niccolò Baldanzini, Daniele Barbani & Marco Pierini (2018) A comparative analysis of MAIDS and ISO13232 databases for the identification of the most representative impact scenarios for powered two-wheelers in Europe, Traffic Injury Prevention, DOI: 10.1080/15389588.2018.1497791"

A comparative analysis of MAIDS and ISO13232 databases for the identification of the most representative impact scenarios for powered two-wheelers in Europe

AUTHORS

Alessandro Grassi[1]; Niccolò Baldanzini[1]; Daniele Barbani[1]; Marco Pierini[1]

AFFILIATIONS

1) *Department of Industrial Engineering, University of Florence. Via di Santa Marta 3, 50139 Firenze, Italy*

Emails:

a.grassi@unifi.it

niccolo.baldanzini@unifi.it

daniele.barbani@unifi.it

marco.pierini@unifi.it

ABSTRACT

Objective: The ISO13232 standard provides guidelines and methodologies for research on the effectiveness of protective devices fitted to motorcycles. The accidentological database used to develop the standard was comprised of two datasets from Hannover and Los Angeles, dating from 1996. This study aims to apply the methodology outlined in the standard to a more recent European accident database to determine whether the set of the seven most relevant impact configurations identified in the ISO13232 are representative of the European context.

Methods: The ISO13232 database was rebuilt from the data tables attached to the standard and processed according to the procedure described in Part 2, to ensure reproducibility of the results. The comparison dataset was extracted from the Motorcycle Accidents In-Depth Study (MAIDS) database. Data were then coded, processed and analysed using the ISO13232 methodology. To eliminate any subjectivity in the selection process of the configurations, a new ranking criterion (Configuration Risk Index, CRI) was implemented. The CRI combined the evaluation of an accident configuration's frequency of occurrence and its harmfulness.

Results: Comparison of the frequency ranking of the impact configurations from the two databases revealed some notable differences. Five of the ten most important configurations were common to both databases, although ranking order differed. CRI based selection led to differences in ranking orders. The CRI allowed better identification of the most important configurations and it was employed to define the proposed new set of configurations.

Conclusion: A new set of seven accident configurations was defined by applying the ISO13232 procedure to the MAIDS data and ranking the results with a newly proposed method. The final set had only one configuration in common with those defined in the ISO13232, testifying to the importance of defining an updated and more representative set of configurations for the European context.

Keywords: Powered Two-Wheelers, accident statistics, ISO13232, MAIDS, impact scenarios, protective devices.

INTRODUCTION

Since the early 1970s, researchers have investigated the effects of protective devices installed on Powered Two-Wheelers (PTWs) to improve rider passive safety (Bothwell et al. 1973, Hirsch and Bothwell 1973, Happian-Smith et al. 1987, Happian-Smith and Chinn 1990, Nieboer et al. 1993, Yettram et al. 1994, Chinn et al. 1996). However, without standardised procedures and methods it was very difficult to compare the results of these studies. In the '90s the International Organization for Standardization (ISO) developed the ISO13232 standard (ISO 2005), which was released in 1996 (Van Driessche 1994) and updated in 2005. The methodology defined in ISO13232 was promptly adopted by the research community (Yamazaki et al. 2001, Withnall et al. 2003, Deguchi 2003, Deguchi 2005, Van Auken et al. 2005, Ibitoye et al. 2006, Barbani et al. 2014, Aikyo et al. 2015).

Exploiting an accident database, ISO13232 defined impact scenarios, identified variables to be measured, and specified methods for crash tests and risk/benefit analyses. ISO13232 is the only standardized framework for performing analyses on protective devices fitted to motorcycles. Two hundred

PTW–car collision scenarios were defined and coded with a three-digit code: the first and the second digits indicate the contact points of the Opposite Vehicle (OV) and of the Motorcycle (MC), while the third digit refers to the Relative Heading Angle (RHA) between vehicles (Figure A1). This code was followed by the speed values at impact (in m/s) of the OV and the MC.

The accident case selection criteria, and the seven impact configurations recommended for use in the preliminary assessment of safety devices (Figure A2), were the most relevant outcomes of the ISO13232. The selection method combines real accident data with prior know-how on experimental testing. Berg et al. (1998) and König and Berg (2007) highlighted discrepancies between scenarios obtained from national databases and the ISO13232 one.

The aim of this work was to apply the ISO13232 methodology to the more recent and European focused MAIDS database (ACEM 2009), and then perform a comparative analysis of the two sets of the seven most critical accident configurations derived from each. A set of scenarios derived from European data would either reinforce ISO13232 methodology or highlight the need for a review.

METHODS

Databases

The ISO13232 database is the combination of two datasets with accident cases located in Hannover (211 cases) and Los Angeles (410 cases) regions. The dataset can be expanded using the same inclusion criteria applied for its creation, that being, a region can be added to the database if: 1) at least 200 motorcycles vs passenger car accidents are available; 2) accidents are randomly selected from among all available ones within the region; 3) accident records have been created from in-depth analyses of the incidents, including on-site measurement and reconstruction; 4) the minimum set of impact variables are available: identification data of vehicles (collision category, vehicle type and engine size), contact points, RHA, impact speeds, injury data, helmet use, and protective clothing (recommended). All PTWs with an engine capacity exceeding 50cm3 or, independently from the engine size, with a maximum design speed exceeding 50km/h were included (category L3 vehicles). The dataset consists of 611 accidents, but the analysis was limited to 501 cases after the application of the inclusion criteria (i.e. presence of at least one injury, configuration classified as testable).

The MAIDS database was created by ACEM (Association of European Motorcycle Manufacturers) with the support of the European Commission. The database consists of 921 accidents collected in Italy (200), The Netherlands (200), Spain (121), Germany (250) and France (150) and 923 control cases, collected in the same areas, balanced against the accident cases for time of day. Investigation teams implemented the OECD (Organisation for Economic Co-operation and Development) methodology for onsite in-depth motorcycle accident investigations. For each record approximately 2,000 variables were coded, including vehicle data, human and environmental factors. The vehicle type distribution is 398 cases involving category L1 (mopeds and mofas) and 523 cases for category L3. The accident subset with passenger car as the collision partner includes 262 records of L1 and 291 of L3 vehicles.

Extraction and processing of database subsets

The ISO13232 method for defining the seven most relevant impact scenarios was applied to the MAIDS database, in order to evaluate whether the ISO13232 derived configurations are still relevant and representative of the current European accident scenarios. To validate the correct application of the ISO methodology, the ISO13232 accident database was reconstructed from the raw data provided in the standard and each event was processed to create the configuration code on the basis of Tables A1, A2, A3, and Figure A1. This step also allowed verification of minimal differences in global descriptive data between databases: 511 cases were identified compared to 501 cases used in the standard. The additional cases impacted on the number of accident cases of specific configurations (711, 414, 115, 313, 513, 131, 514 and 241). After a double procedural check involving reclassification, grouping and selection of raw data, differences were ascribed to the ISO13232 data processing. However, the lack of intermediate processing results in ISO13232 didn’t allow the identification of the origin of the differences. Since the results of re-processing the ISO13232 database showed no indication of a systematic processing error, the reconstructed dataset was adopted as our ISO13232 reference database for the comparative analyses.

A subset of MAIDS data coherent with the ISO13232 sampling policy (i.e. *L3 vehicles*, *passenger car* as opposing vehicle, PTW *without pillion rider*, rider in *seated position at impact*, and testable configuration) was similarly processed to allow comparison of results. This selection process returned 142 accidents. MAIDS injury data, originally coded according to AIS1998/2005, were recoded, using Tables A4 and A5, to comply with ISO13232 database. These operations yielded two homogeneous and comparable datasets, used in a frequency analysis (Figure 1).

Injury frequency analyses by configuration and body region

A frequency analysis of injury region and occurrence was performed using all thirteen body regions listed in Table A4. All analyses, if not otherwise specified, were performed on injuries of moderate or greater levels of severity (i.e. AIS2+).

The comparison of the concussion analysis results revealed some differences. The standard specified limiting the selection of head concussive injuries to helmeted records (ref. part 2, annex F.3). However, it was evident that in actual fact all concussion injuries had been included in data processing: for configuration 114, 11 records were reported in ISO13232, but 5 cases with, and 6 cases without helmets were in the raw data. For the sake of comparability with ISO13232 data, the analyses performed on the MAIDS data included all head injuries, with or without helmet.

Configuration Risk Index

The ISO13232 guidelines base the selection of impact configurations upon a combination of determinants, including the accidentology statistics, test facility and know-how of testing protocols. Factors related to test facility and testing protocols influence the choice of the OV and MC speeds used in analyses, whereas the selection of impact configurations is only based on occurrence frequency.

Occurrence frequencies alone could not be a suitable determinant for choosing the best accident scenarios to test the effectiveness of protective devices. To overcome such limitations, we propose a new index which takes into consideration both occurrence frequencies and the dangerousness of a specific configuration: the Configuration Risk Index (CRI, Equation 1). Other parameters such as vehicle impact speeds and kinetic energy of the impact were considered, however, no correlations with injuries were found. In fact these parameter values have different levels of relevance depending on the specific configuration geometry. In the CRI formulation the configuration dangerousness was included using the frequency and AIS severity levels of injuries. In the CRI, accident occurrences and injuries are combined for each specific configuration and weighted according to total the number of accidents and injuries in the database.

$$C.R.I._{(x)} = \left(\frac{A_{(x)}}{A_{(t)}} \cdot \frac{\sum_{i=2}^{n}\left(I_{(x,AISi)}\right)\cdot i}{I_{(t)}\cdot\left(\sum_{i=2}^{n} i/n-1\right)}\right) \cdot \mathrm{SF} \qquad n = 6, \qquad (1)$$

Where:

- x: configuration code
- $A_{(x)}$: number of accidents by configuration
- $A_{(t)}$: total number of accidents across all configurations
- i: AIS level (from 2 to 6)

- $I_{(x,AISi)}$: number of injuries for configuration x at each AIS level
- $I_{(t)}$: total number of injuries across all configurations
- SF: scale factor (set to 100)

The first ratio defines the occurrence frequency of a specific impact configuration. The second ratio, in parentheses, defines the weighted severity of injuries for a specific impact configuration. The rationales for its definition were as follows: 1) AIS2+ injuries were considered, since these are more relevant for evaluating the effectiveness of a new protective device; 2) the greater the number of injuries, the higher must be the configuration risk; 3) injuries with higher AIS values were weighted more by multiplying their frequency of occurrence by the AIS value. The ratio was made non-dimensional by dividing the configuration specific contribution by the total number of injuries across all configurations and by the AIS average value. The Scale Factor (SF) was introduced to improve index readability.

RESULTS

Impact configurations and frequency of occurrence

The set of configurations for each of the two databases are reported in Figure 2. A frequency analysis of the impact configurations highlighted some key differences between data sets. In the ISO13232 data, the most frequently occurring impact configuration was 114 (12.7% of total crashes), followed in descending order by 143 (10.0%), 413 (9.8%), 711 (8.2%), 414 (6.5%), 115 (6.3%), and 412 (6.1%). In the MAIDS data, the most frequent configuration was 313 (12.7%; Figure B2), followed in descending order by 115 (11.3%), 312 (10.6%), 114 (9.9%), 711 (9.2%), 314 (7.0%), and 512 (6.3%).

Injury frequencies by configuration and body region

Figure 1 (right) shows the ratios of the number of injuries recorded for a configuration to the total number of accidents for that specific configuration. Within each database, the ordered ranking of the configurations based on average number of injuries versus occurrence frequency of the configuration is different. This result implies that the most probable accident scenario is not necessarily the most dangerous. Comparing rankings based on the average number of injuries yielded differences between databases: configuration 243 is ranked twentieth in the ISO13232 database (0.7 injuries on average), but first in the MAIDS database (5.0 injuries on average). However, in terms of occurrence frequency the same configuration is ranked fourteenth both in ISO13232 and MAIDS.

Figure 4 reports the injury distribution (AIS2+ injuries) for each of the thirteen body regions listed in ISO13232. In both databases, the same three body regions were found as those most often injured but they were ranked differently: in ISO13232 these were head (6.6%), lower leg (5.1%), and upper extremities (including shoulder; 3.9%); in MAIDS they were upper extremities (including shoulder; 9.4%), lower leg (8.0%), and head (5.0%).

Configuration risk

The CRI was proposed for an objective rating of the configurations, aiming to emphasise configurations with higher AIS values and/or greater number of injuries. The results are reported in Figure 3, showing alterations in the ranking order and in the relative importance of the configurations for CRI versus frequency. This predictable result is due to the different distributions of average injury severity for each configuration compared to injury occurrence frequency by configuration. In the ISO13232 data (Figure 2 and 3) the first three positions are occupied in both cases, in the same order, by 114, 143 and 413, but the CRI index better highlights the higher danger inherent in 114 compared to the second and third placed scenarios. In fact, configuration 114 not only occurred most frequently, but on average it registered a higher number of injuries than either 143 or 413. Similarly, configuration 413 presented a lower average injury value, or less serious injuries than 143, and thus they have different CRI values although their occurrence frequencies are very similar. The latter result provides strong support for the capability of the CRI to integrate the injury information into the ranking, to improve the decisional process for the selection of the most relevant scenarios. Use of the CRI also resulted in the inversion in ranking order of configurations 711 and 414 (due to lower average number of injuries for configuration 711), and the substitution of configuration 131, in place of configuration 412, in the set of top seven configurations. In addition, the CRI more precisely identifies the level of risk in the first three scenarios to be at least double that of the fourth ranked scenario.

In the MAIDS data (Figure 2 and 3) we see no ranking differences in the first seven positions, but an amplified importance of the most dangerous configurations when ranked according to CRI-obtained values. Differences are observed beyond the seventh position, where CRI-obtained values show a sudden decrease: CRI value 3.0 (configuration 512) vs CRI 1.1 (configuration 413).

DISCUSSION

The goal of this study was to assess whether the ISO13232-determined seven required (i.e. most relevant) configurations of PTW-car impact scenarios were representative of current European accident configurations. The ISO13232 most relevant configurations were compared with a corresponding set of MAIDS configurations, derived through the application of the ISO13232 methodology to the MAIDS dataset.

The application of the ISO13232 methodology to the MAIDS database triggered some considerations on impact configurations excluded or omitted from the ISO13232 standard. Configuration 214 was removed because of the stated difficulty in implementing an experimental test procedure that would ensure accuracy and repeatability. This motivation appears questionable because the vehicles' relative positions are very similar to the ones in configurations 314, 414 and 514, all included in the standard. In terms of occurrence frequency, configuration 214 was found to be relevant in the MAIDS database, where it would have ranked seventh if considered. Configuration 718 was not listed among either the reclassified or removed configurations, but it should have been included within the reclassified ones, being very similar to the valid configuration 711. Finally, a great number of sideswipe impact configurations were excluded from the original ISO13232 analysis despite being very common in real life. In order to obtain comparable datasets from the respective databases, all results regarding configurations 214 and 718 were thus excluded from analysis. However, we suggest that these configurations should be re-considered for inclusion in a future revision of the standard.

The preliminary processing of the ISO13232 database allowed separate analyses for the Los Angeles and Hannover data. Figure 5 shows the number of valid records per configuration for each of the two databases. Interestingly, the Hannover data were found to be concentrated mainly in the first seven ISO13232 configurations, and only marginally in other configurations (131, 132 and 712). In contrast, the Los Angeles data were evenly distributed among all configurations. Importantly, the distribution of the Hannover data generates an over-weighting of some configurations, with a clear impact on the final outcome of the ISO13232 set of configurations.

In comparing the results of the frequency analyses performed on the two datasets, configurations 412, 413 and 414 within MAIDS represent a smaller proportion of the total dataset compared to ISO13232, whereas 312, 313 and 314, make up a larger proportion (Figure 1). These discrepancies may derive from different determinations of the car contact points: since car models were not provided in the MAIDS database and the OVs' lengths were unknown, the contact points were codified only on the basis of the contact point's description, assuming corresponding locations on a sedan car. This coding activity represents a limitation of the current study, which should be improved upon in future studies.

The AIS2+ injury analyses performed on the MAIDS data showed some differences compared to the ISO13232 data (Figure 4). Higher frequencies of occurrence were found for neck, upper extremities (including shoulder), spine, abdomen, thigh, knee and lower leg; lower values for head and face, and comparable data for the remaining body regions.

The occurrence frequency ranking of configurations showed significant differences between ISO13232 and MAIDS databases (Figure 2). Limiting the discussion to the most important seven rankings, configurations 114, 711 and 115 were present in both sets, differing only in order of importance. Configurations 413, 414 and 412 (third, fifth and seventh position in ISO13232) were not among MAIDS configurations, having been replaced by configurations 313, 312 and 314. Configuration 143 (second position in ISO13232) was replaced by configuration 512 (seventh position in MAIDS), which represents a different type of configuration and of accident kinematics.

Berg et al. (1998) showed similar results. Their study was based on a subset (65 cases) of 302 PTW accidents in Germany spanning 1989 to 1996 and collected by the DEKRA Accident Research & Crash Test Center. The configuration ranking in Berg's works was 114, 226, 413, 313, 412, 115 and 314. Four configurations are common to the results obtained from ISO13232 and MAIDS databases (Figure 2), while configuration 226 has no correspondence with our results; configurations 313 and 314 have no correspondence with ISO13232 results, while configurations 413 and 412 with MAIDS ones. In another study, König and Berg (2007) analysed the accident configurations based on two accident databases: 350 cases collected by DEKRA in Germany over the period 1996-2005, and 200 accidents collected by TNO in the Netherlands (this dataset was the regional contribution to the MAIDS database). This study also showed configuration rankings that were quite different from those of ISO13232. Specifically, the ranking based on the DEKRA data was 115, 114, 314, 312, 143, 514 and 131 (having only configurations 114 and 143 in common with ISO13232), while the ranking based on TNO data was 143, 313, 413, 114, 412, 513, 115 (configurations 143, 413, 114 and 412 in common with ISO13232).

The implementation of the CRI provided a more robust and sound method for the definition of the required set of accident configurations. Figures 1, 3 and 6 show that the CRI highlights the most critical configurations and reduces the importance of secondary ones. Results (Figure 3) show differences not only in the ranking order within the seven recommended configurations defined in the standard but a new definition of a set which should more closely represent the current European context. It is worth recalling that, in the ISO13232 standard, six configurations were selected based on occurrence frequencies (114, 143, 413, 414, 412 – configuration 413 was considered twice with different impact speeds); configuration 711 (ranked fourth according to frequency) was discarded without a clear rationale; the seventh configuration, 225, was selected based on considerations related to previous research on leg protectors, and on the physical exposure of the lower leg in the scenario.

The results of this study support the need to define a new set of impact configurations, more representative of the European context and confirmed as to relevance based on the CRI ranking. Our initial proposal of the new configuration set, in descending order of relevance, is 313, 115, 312, 114, 711, 314, and 512. Proposed configurations can be categorized in three groups, sharing similar characteristics: MC impacting the side of the car (313, 312, 314, and 512), head-on impacts (114 and 115), and rear-end impacts (711). In the set there is no car impacting the side of the MC, which is a relevant scenario for the injuries to lower extremities. Since in the set there are four configurations with MC impacting the side of the car, and configuration 512 differs from 312 only in OV impact point, configuration 243 (tenth position in the CRI-based ranking of the MAIDS results) replaced 512. Configuration 243 has low CRI value, but the highest average injury value in the MAIDS database. Configuration 225, not relevant in MAIDS, may be employed as a preferential additional configuration for further testing specific leg protection devices. Previous considerations defined the following final set of the most relevant configurations for the initial development and testing of protective devices: 313, 115, 312, 114, 711, 314 and 243 (Figure B2).

In conclusion, only one out of seven configurations is common to the ISO13232 required configuration set and the new set proposed in this paper. This result confirms the inadequacy of the ISO13232 impact configurations to accurately represent the European context. Moreover, the new set enables better protective device evaluation compared to the ISO13232 set, because it considers all five possible RHAs (ranging from 0° and 180°), and all types of contact pairs.

To thoroughly define impact configurations as in ISO13232, respective vehicle impact speeds (speed pairs) and the model/type of the OV must be specified. During this research, a preliminary analysis on the speed pairs was carried out, but the results were not included in this paper since an initial assessment showed limitations in statistical data consistency. In addition, ISO13232 considered some practical limiting factors in the definition of its selection criteria, which should be revised based on technological advances.

A future study will be conducted to develop a ranking of vehicle speed pairs. The model/type of the OV needs to be updated as well, since the use of the passenger sedan as the representative vehicle model, is less and less relevant in the current European market context. In addition the use of a single generic OV model to represent all the available model types should be reassessed (Barbani et al. 2015).

Acknowledgments

The authors wish to thank ACEM (Association des Constructeurs Européens de Motorcycle) for granting access to MAIDS database.

References

ACEM (Association of European Motorcycle Manufacturers) *MAIDS: In-depth Investigations of Accidents Involving Powered two wheelers. Final report 2.0.* Brussels, Belgium. 2009.

Aikyo Y, Kobayashi Y, Akashi T, Ishiwatari M. Feasibility study of airbag concept applicable to motorcycles without sufficient reaction structure. *Traffic Inj Prev*. 2015;16(Suppl 1):S148-S152.

Barbani D, Baldanzini N, Pierini M. Development and validation of an FE model for motorcycle–car crash test simulations. *Int. J. Crashworthiness*. 2014;19:244–263.

Barbani D, Baldanzini N, Pierini M, and Grassi A. Valutazione dell'influenza della tipologia di autoveicolo in crash test motociclistici. Paper presented at: 44° convegno nazionale AIAS - Associazione Italiana per l'Analisi delle Sollecitazioni, September 2-5, 2015; Messina, Italy.

Berg FA, Bilrkle H, Schmidts F, Epple J. Analysis of the passive safety of motorcycles using accident investigations and crash tests. 1998. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.455.1142&rep=rep1&type=pdf. Accessed July 2, 2018.

Bothwell PW, Knight RE, Peterson HC. *Dynamics of motorcycle impact. Volume I: summary report - results of crash test program and computer simulation. Final report*. Washington, D.C.: National Highway Traffic Safety Administration; 1971.

Deguchi M. Modeling of a motorcycle for collision simulation. Paper presented at: the 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 19-22, 2003; Nagoya, Japan.

Deguchi M. Simulation of motorcycle-car collision. Paper presented at: the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV); June 6-9, 2005; Washington, D.C., USA.

Chinn BP, Okello JA, McDonough PJ. Development and testing of a purpose built motorcycle airbag restraint system. Paper presented at: the 15th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 13-16, 1996; Melbourne, Australia.

Happian-Smith J, Macaulay MA, Chinn BP. Motorcycle impact simulation and practical verification. Paper presented at: the 11th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 12-15, 1987; Washington, D.C., USA.

Happian-Smith J, Chinn BP. Simulation of airbag restraint systems in forward impacts of motorcycles. *SAE Technical Paper 900752*, 1990.

Hirsch AE, Bothwell P. Airbag crash protection for motorcycle application. *American Society of Mechanical Engineers*, 1973.

Ibitoye AB, Hamouda AMS, Wong SV, Radin RS. Simulation of motorcyclist's kinematics during impact with W-Beam guardrail. *Advances in Engineering Software*. 2006;37(1):56–61.

International Organization for Standardization (ISO) (2005). Motorcycles—Test and Analysis Procedures for Research Evaluation of Rider Crash Protective Devices Fitted to Motorcycles, Parts 1 to 8. 2nd ed. 2005. Geneva, Switzerland.

König J, Berg FA. Powered two-wheeler accidents: first results of the APROSYS SP 4 implying GIDAS 2002 data. Paper presented at: the 2nd International Conference on ESAR "Expert Symposium on Accident Research"; September 1-2, 2006; Hannover, Germany.

Nieboer JJ, Wismans J, Versmissen ACM, van Slagmaat MTP, Kurawaki I, Ohara N. Motorcycle crash test modelling. Paper presented at: 37th Stapp Car Crash Conference; November 7-8, 1993; San Antonio, Texas, USA.

Van Auken RM, Zellner JW, Smith T, Rogers NM. Development of an improved neck injury assessment criteria for the ISO13232 motorcyclist anthropometric test dummy. Paper presented at: the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV); June 6-9, 2005; Washington, D.C., USA.

Van Driessche H. Development of an ISO Standard for Motorcycle Research Impact Test Procedures. Paper presented at: the 14th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 23-26, 1994; Munich, Germany.

Withnall C, Shewchenko N, Wiley KD, Rogers N. An improved dummy neck for the ISO13232 Motorcycle anthropometric test dummy. Paper presented at: the 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 19-22, 2003; Nagoya, Japan.

Yamazaki T, Iijima S, Yamamoto T. Exploratory study of an airbag concept for a large touring motorcycle-Further Research. Paper presented at: the 17th International Technical Conference on the Enhanced Safety of Vehicles (ESV); June 4-7, 2001; Amsterdam, The Netherlands.

Yettram AL, Happian-Smith J, Macaulay MA. Computer simulations of motorcycle tests. Paper presented at: the 14th International Technical Conference on the Enhanced Safety of Vehicles (ESV); May 23-26, 1994; Munich, Germany.

Figure 1. Configuration occurrence frequency (left) and Average number of injuries per configuration (right) - MAIDS vs. ISO13232. Configuration ranking shown in accordance with ISO13232 standard (required accident configurations are boxed).

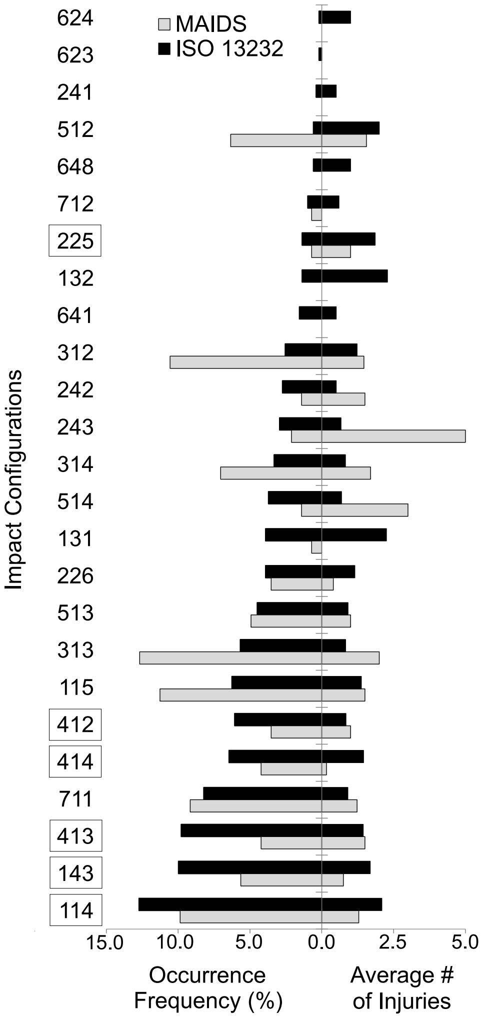


Figure 2. Comparison of configuration rankings by occurrence frequency (%total crashes, in decreasing order bottom-up).

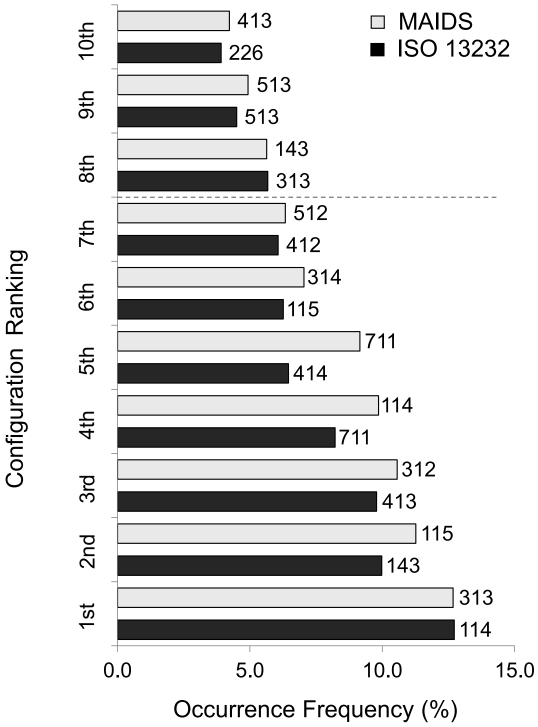


Figure 3. Comparison of configuration rankings by CRI (non-dimensional, in decreasing order bottom-up).

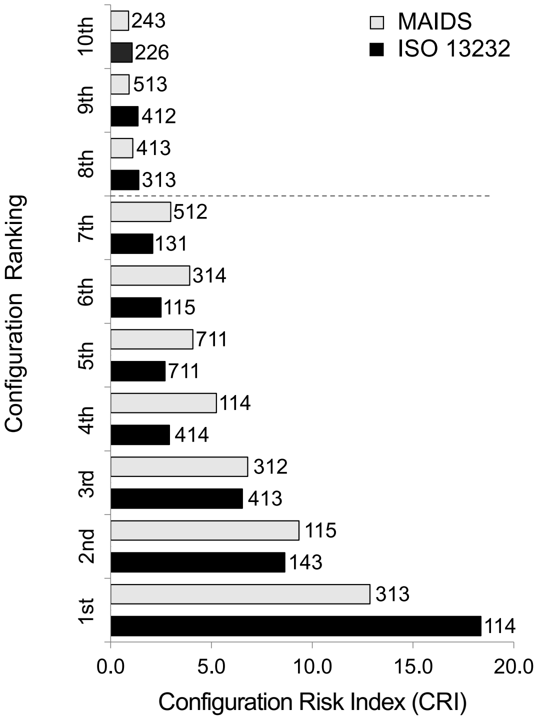


Figure 4. Distribution (%) of generic injuries (AIS2+): MAIDS vs ISO13232.

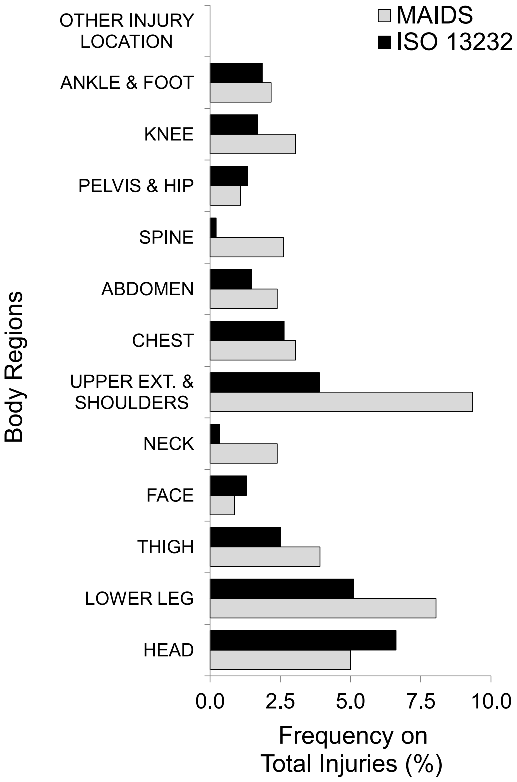


Figure 5. ISO13232: Comparison of valid impact configurations in Los Angeles and Hannover databases (ISO13232 database).

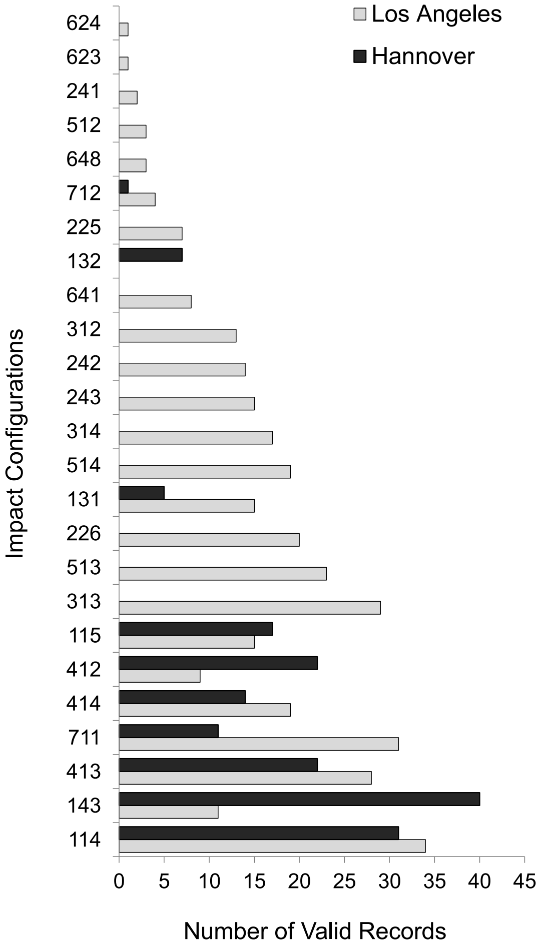
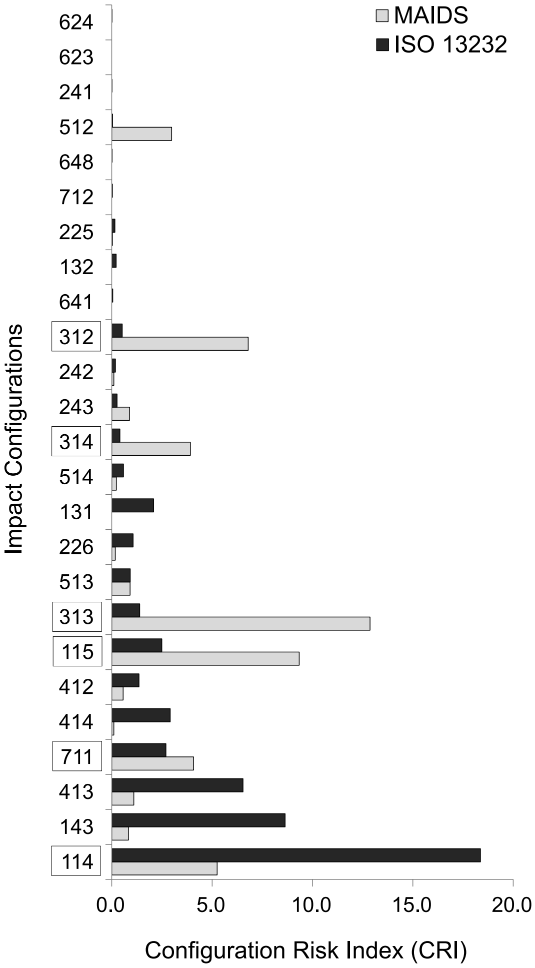


Figure 6. Configuration Risk Index (CRI) distribution for MAIDS vs ISO13232 datasets. Accident configurations for the newly proposed set are boxed.



Appendix A: ISO13232 coding scheme

Figure A1. (a) OV contact point codes; (b) MC contact point codes; (c) RHA (to be used together with Table A1 and A3). W: width of OV; L: length of OV.

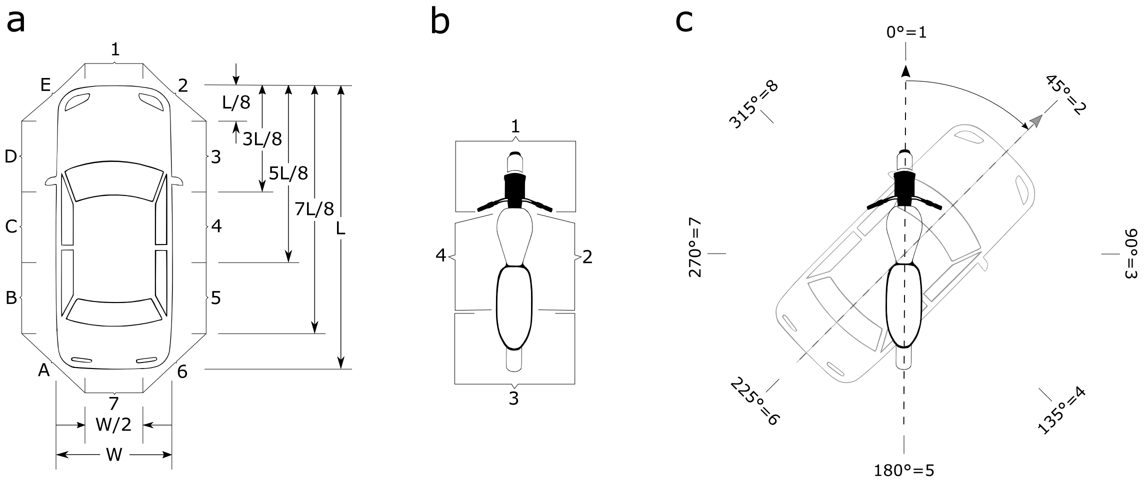


Table A1. Heading angle of OV relative to MC.

Cell range [deg]	Nominal value [deg]	Code number
337.5 < RHA ≤ 22.5	0	1
22.5< RHA ≤ 67.5	45	2
67.5< RHA ≤ 112.5	90	3
112.5< RHA ≤ 157.5	135	4
157.5< RHA ≤ 202.5	180	5
202.5< RHA ≤ 247.5	225	6
247.5 < RHA ≤ 292.5	270	7
292.5 < RHA ≤ 337.5	315	8

Table A2. OV and MC speed.

Cell range [m/s]	Nominal value [m/s]
0 ≤ speed ≤ 4.0	0
4.0 ≤ speed ≤ 8.5	6,7
8.5 ≤ speed ≤ 13.3	9.8
13.3 ≤ speed ≤ 17.5	13.4
17.5 ≤ speed	20.1

Table A3. Reclassification for left side OV contact point codes.

Sorted	Reclassified
OV contact point code	
A	6
B	5
C	4
D	3
E	2
MC contact point code	
2	4
4	2
Relative heading angle code	
2	8
3	7
4	6
6	4
7	3
8	2

Table A4. Injury body region codes.

Body region	Code
Head	1
Face	2
Neck	3
Upper extremity, including shoulder	4
Chest	5
Abdomen	6
Thoracic spine and/or lumbar spine	7
Pelvis and/or hips	8
Thigh	9
Knee	10
Lower leg	11
Ankle and/or foot	12
Other injury location	13

Table A5. Injury type codes.

Body region	Code
Abrasion and/or contusion	1
Laceration	2
Rupture	3
Dislocation	4
Fracture	5
Amputation	6
Concussion	7
Crush	8
Hematoma	9
Other type of injury	10

Appendix B: accident configurations

Figure B1. Schematic representation of the seven required ISO13232 impact configurations (413 is counted twice since it has two impact speed pairs); W: width of OV; L: length of OV; LMC: length of MC.

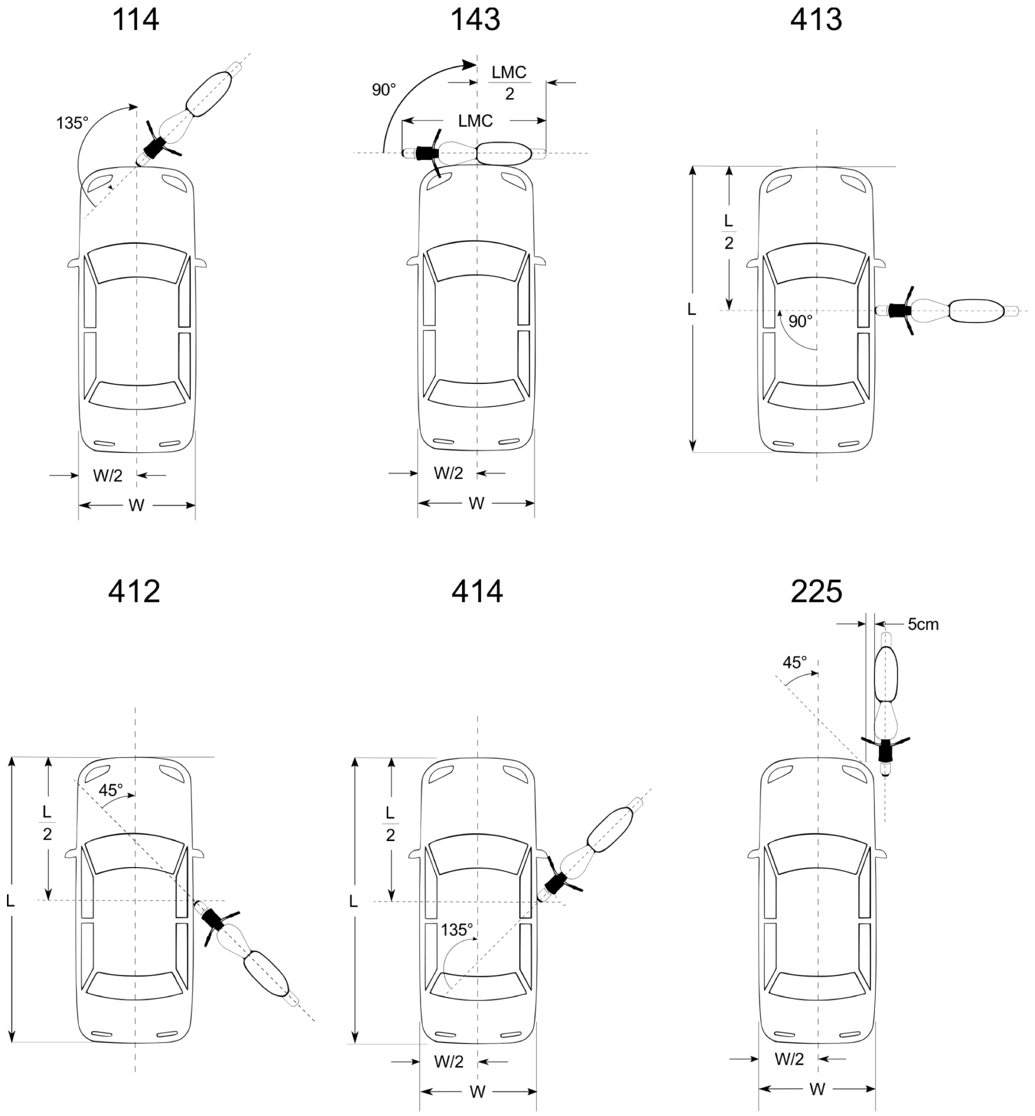


Figure B2. Schematic representation of the additional impact configurations (i.e. not included in the ISO13232 set) identified in this study. For other configurations please refer to Figure B1. W: width of OV; L: length of OV; LMC: length of MC.