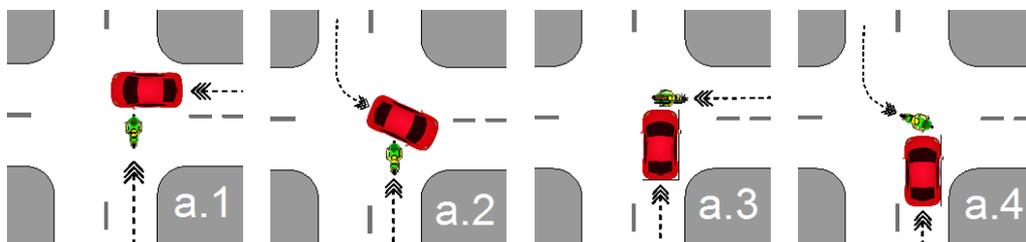


Appendix A – Pictograms (KBMS)

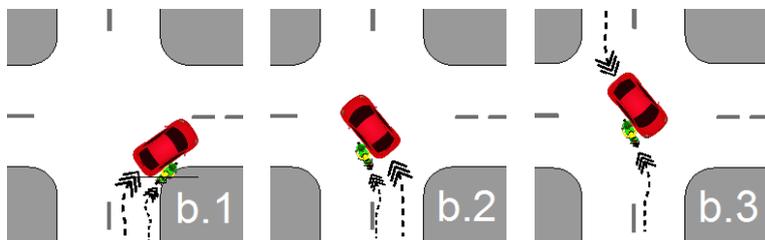
The following rows of pictograms represent the general crash scenarios to assess (named from A to I). The cases represent the same kind of a crash scenario but with more resolution or definition (i.e. labeled from a.1 to a.4). The present organization corresponds to the nine general scenarios of PTW crashes defined by the queries performed in the ISTAT road accident database. A different set of queries will rearrange each single pictogram in other organization.

Note: each pictogram (created in vector graphic format) may be downloaded and edited. The free graphical repository is: <https://openclipart.org/user-cliparts/Gusta>

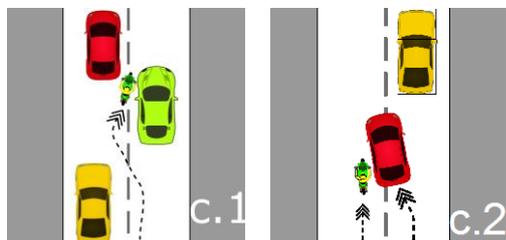
Scenario A: PTW crashes that happened in “intersection of streets” AND “angle collision type”.



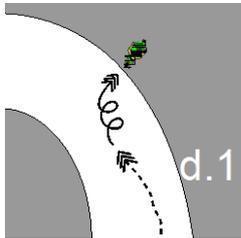
Scenario B: PTW crashes that happened in “intersection of streets” AND “sideswipe collision type”.



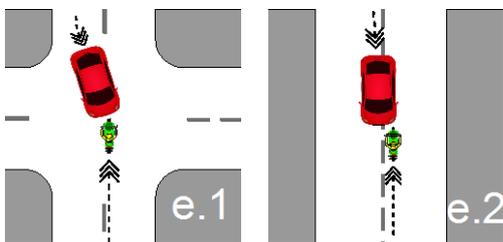
Scenario C: PTW crashes that happened in “straight street” AND “sideswipe collision type”.



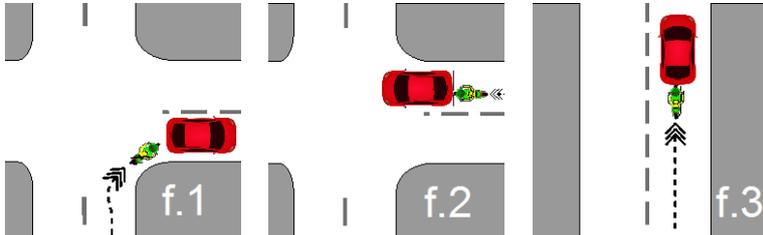
Scenario D: PTW crashes that happened in “rural road” OR “urban road” AND “single vehicle accident type” OR “run-off-the-road accident type” AND “curve layout”.



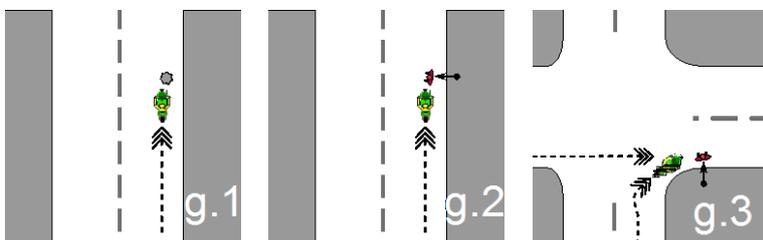
Scenario E: PTW crashes that happened in “head-on collision type”.



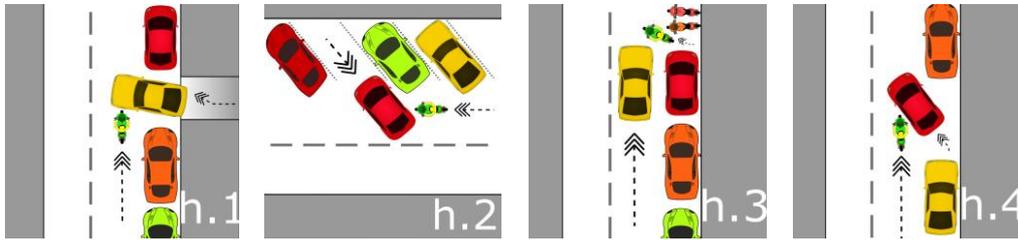
Scenario F: PTW crashes that happened in “rear-end collision type”.



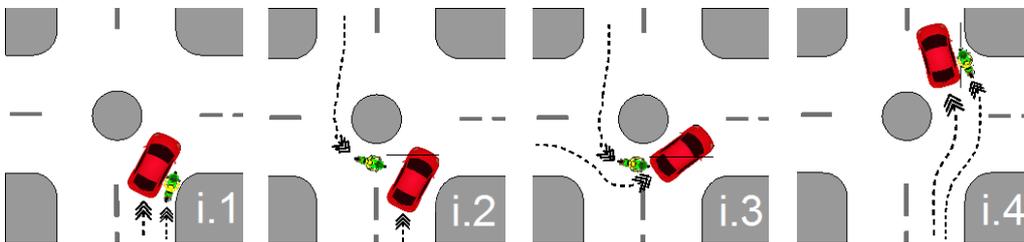
Scenario G: PTW crashes that happened in “hit-obstacle collision type” OR “hit pedestrian collision type”.



Scenario H: PTW crashes that happened in “straight street” AND “angle collision type”.



Scenario I: PTW crashes that happened in a “roundabout”*.



Note: “roundabout” is a very particular case of “intersection” well studied in literature (Gross et al., 2013; Montella, 2011). For this reason, in the present methodology the crashes that happened in a roundabout are separated of the intersection crashes.

Appendix B – List of Queries

In the default framework, the above nine groups of scenarios were established performing the following queries on the traffic accident database.

PTW crashes that happened in:

- 1) Scenario A: “intersection of streets” AND “angle collision type”.
- 2) Scenario B: “intersection of streets” AND “sideswipe collision type”.
- 3) Scenario C: “straight street” AND “sideswipe collision type”.
- 4) Scenario D: [“rural road” OR “urban road”] AND [“single vehicle accident type” OR “run-off-the-road accident type”] AND “curve layout”.
- 5) Scenario E: “head-on collision type”.
- 6) Scenario F: “rear-end collision type”.
- 7) Scenario G: “hit-obstacle collision type” OR “hit pedestrian collision type”.
- 8) Scenario H: “straight street” AND “angle collision type”.
- 9) Scenario I: “roundabout”.

Gross, F., Lyon, C., Persaud, B., Srinivasan, R., 2013. Safety effectiveness of converting signalized intersections to roundabouts. *Accid. Anal. Prev.* 50, 234–241. doi:10.1016/j.aap.2012.04.012

Montella, A., 2011. Identifying crash contributory factors at urban roundabouts and using association rules to explore their relationships to different crash types. *Accid. Anal. Prev.* 43, 1451–1463. doi:10.1016/j.aap.2011.02.023

Appendix C – List of Safety Function for the KBMS

The list of Safety Functions (SFs) was conceived for the analysis that the experts in the field will perform for each road crash scenario. It is divided in seven main functionalities as: Crash avoidance or mitigation, PTW Stability managing, etc. aiming to simplify the process of classification and elaboration of these functionalities.

Acronyms used: OV (Other Vehicle) and PTW (Powered-Two Wheeler)

Crash avoidance or mitigation

1. Distribute more properly the braking action on the two wheels even if one brake is actioned
2. Assist the rider to perform a hard braking without falling from the PTW
3. Anti-stoppie (avoidance of the rear wheel lifting off the ground)
4. PTW Manoeuver advisor: Brake vs. Swerve (1)
During risky situations, indicates to the rider the best maneuver to perform: a hard straight line braking or evading the obstacle with a soft braking.
5. OV Manoeuver advisor: Brake vs. Swerve (1)
During risky situations, indicates to the driver the best maneuver to perform: a hard straight line braking or evading the obstacle with a soft braking.
6. PTW send a signal to Slow/Stop other vehicle (autonomous braking for collision avoidance) (2)
7. OV send a signal to Slow/Stop other vehicle (autonomous braking for collision avoidance) (2)

Remarks:

(1) requires precise obstacle distance detection and dynamic state of the vehicle

(2) requires vehicular communication network

PTW Stability managing

8. Enhance stability in straight paths
9. Enhance stability in curved paths
10. Avoidance of oversteer at high speed. Steering bar with additional and adaptive angular stiffness as a function of the velocity

Rider protection (injury reduction in a crash)

11. Head: kinetic energy dissipation element (3)
12. Neck: kinetic energy dissipation element
13. Thorax: kinetic energy dissipation element
14. Abdomen: kinetic energy dissipation element
15. Limbs: kinetic energy dissipation element
16. Anti-abrasion
17. Energy dissipation element placed in the PTW to dissipate vehicle kinetic energy during a crash. Case: frontal collision of the PTW
18. Energy dissipation element placed in the PTW to dissipate rider kinetic energy during a crash. Case: frontal collision of the PTW
19. Energy dissipation element placed in the OV to dissipate vehicle kinetic energy during a crash. Case: frontal collision of the PTW

20. Energy dissipation element placed in the OV to dissipate rider kinetic energy during a crash. Case: frontal collision of the PTW
21. Energy dissipation element placed in the PTW to dissipate vehicle kinetic energy during a crash. Case: rear collision of the PTW
22. Energy dissipation element placed in the PTW to dissipate rider kinetic energy during a crash. Case: rear collision of the PTW
23. Energy dissipation element placed in the OV to dissipate vehicle kinetic energy during a crash. Case: rear collision of the PTW
24. Energy dissipation element placed in the OV to dissipate rider kinetic energy during a crash. Case: rear collision of the PTW
25. Energy dissipation element placed in the PTW to dissipate vehicle kinetic energy during a crash. Case: lateral collision of the PTW
26. Energy dissipation element placed in the PTW to dissipate rider kinetic energy during a crash. Case: lateral collision of the PTW
27. Energy dissipation element placed in the OV to dissipate vehicle kinetic energy during a crash. Case: lateral collision of the PTW
28. Energy dissipation element placed in the OV to dissipate rider kinetic energy during a crash. Case: lateral collision of the PTW
29. Human body confinement (4)

Remarks:

- (3) *It does this by converting the kinetic energy of the shock into another form of energy; typically plastic deformation, sound energy and heat which is then dissipated*
- (4) *i.e. Protection system of BMW C1 four-point seat-belt*

Accident prevention

30. OV - Alert of oncoming PTW (from front)
31. OV - Alert of oncoming PTW (from rear)
32. OV - Alert of oncoming PTW (from right side)
33. OV - Alert of oncoming PTW (from left side)
34. PTW - Alert of oncoming vehicle (from front)
35. PTW - Alert of oncoming vehicle (from rear)
36. PTW - Alert of oncoming vehicle (from right side)
37. PTW - Alert of oncoming vehicle (from left side)
38. PTW - Pedestrian/cyclist in the path (notification)
39. Notification of non-correct pressure in the tires
40. Notification of approaching hazard (i.e. steep decline)
41. Prevent the crossing of wild animals on the road by means of additional infrastructure (e.g. eco-ducts, wildlife corridors)

Perception augmented

42. PTW Enhanced vision at night
43. OV Enhanced vision at night
44. Improvement of PTW conspicuously (help to the PTW to be seen for others)

Rescue

45. Crash signalization. Beacon that help to find the PTW crashed (most useful in rural areas)
46. Emergency call. System uses the cell phone network (or other) to inform the coordinates of the accident (GPS position) to the local authorities

Safe riding/driving

47. Rider state detection (guarantees a minimum level of alert)
48. Driver state detection (guarantees a minimum level of alert)
49. PTW Alcohol interlock
50. OV Alcohol interlock
51. PTW - Adaptive to road adherence condition. Change the acceleration and braking response of the vehicle according with the level of adherence to the road.
52. OV - Adaptive to road adherence condition. Change the acceleration and braking response of the vehicle according with the level of adherence to the road.
53. PTW restricts its maximum speed to street top speed
54. OV restricts its maximum speed to street top speed
55. PTW Adaptive cruise control
56. OV Adaptive cruise control
57. PTW Adaptive speed to traffic speed
58. OV Adaptive speed to traffic speed
59. PTW Lane keeping
60. OV Lane keeping
61. PTW autonomous-braking
62. OV autonomous-braking
63. Elimination of blind spot in PTW (side of vehicle)
64. Elimination of blind spot in OV (side of vehicle)

Appendix D – Selection of experts for the assessment

The ‘expert’ is a person with a recognized knowledge on the topic of interest. For the KBMS the experts could come from a variety of disciplines (e.g. crash analysis reconstruction, crash test analysis, energy absorbers design, traction & braking control, traffic control, driver/rider training, injuries assessment, etc.). In order to manage the degree of heterogeneity of the sources of knowledge involved, a categorization of the technical background of the experts involved in the KBMS was defined (e.g. Biomechanics, Mechanical Engineers, etc.).

The process of recruitment of experts, for the KBMS research, can be summarized by fulfilling a set of requirements:

Main activity	Research in Vehicle Safety
Years of experience	≥ 5
Geographical region of expertise	Tuscany, Lazio, Italy
Background	Mechanical Engineer
Name of best three publications on the topic	Paper #, Tech. Report, Book chapter...
Patents related with the topic	Patent ...
Participation in projects	Project 1 (tasks performed), ...

Table 1 Expert legitimization table for KBMS assessment (it is filled as an example)

In this way, it is possible to consider if the applicant could be accepted as a recognizable expert for the purpose of the KBMS or not, allowing recognizing bough: academics and industrial experts.

Appendix E – Guidelines

Defining boundaries to the analysis is vital to help the experts during the process of evaluation. We defined the next five directives to this intent based on the statistical results of more than one million of motorcycle accidents (ISTAT: 2000-2012 year).

Five directives:

1. *Pessimism*, in case of doubts about the potential benefit of a particular safety function for a specific crash scenario, the evaluation must be directed towards the less effective case. For example, if the scale of this study (Table 2) is used to determine the quantity of water in a glass that seems to be half full of water, the queried participant must respond without hesitation the score value 2.
2. *Clear visibility conditions* during the moment of the crash are assumed. No fog, smoke, trees or other external elements of the scenario that can decrease the field of view of the rider/driver.
3. *Good weather conditions* during the moment of the crash are assumed. Non rain, wind-shear, or other less favorable weather conditions.
4. *Correct pavement adherence* during the moment of the crash is assumed. No slippery conditions or irregularities on the surface of the pavement.
5. *Speeding in urban scenarios* is assumed in at least 70%. Motorcyclist's fault (In-Safe database: near to 13 km/h more than the road top limit – 50 or 60km/h in Italian roads).

Note: pedestrians, cyclist and PTWs are not considered as Other Vehicle (OV) in the safety function description

Appendix F – Technical terminology

In order to retrieving comparatively information from the expert consultation process, it is necessary to define a common vocabulary to guide the experts during the traffic accident evaluation. Indeed, for some safety functionalities to analyze already exists a safety system that can fulfill the requirements, but for others is not the case. The following terms are defined as follows in order to offer a common vocabulary to the experts' ideas during communications and workshops:

- **Crash mitigation:** making the consequence of the crash less severe in terms of people injured level. Example: 20% crash mitigation means "in 20% of accidents, the crash severity can be reduced".
- **Crash avoidance:** preventing the crash from happening. Example: 30% crash avoidance means "30% of accidents can be reduced in number".
- **Technology:** technical aspects that have made possible the development of a specific system.
- **Safety system:** specific system in charge of a determinate safety function. Different safety systems may use the same technology for accomplishing different objectives. For example in cars, the ABS (anti-lock braking system) and the ESP (Electronic Stability Programme) are sharing technology.

- Safety function: unequivocally describes the desired outcome for a safety solution, emphasizing in goals regardless the constitutive mechanisms or sub-systems. For instance, the safety function of the ABS is to avoid the wheel locking on different pavement conditions in order to maximize the deceleration. For the system ESP (for cars), the safety function is to ensure that the vehicle follows a trajectory consistent with the steering wheel action.
- Primary safety or Active safety: its main objective is to improve the vehicle safety through technology with the aim of preventing or avoiding a vehicle crash (e.g. alcohol lock, ABS).
- Secondary safety or Passive safety: systems designed to protect and reduce the risk of injury to the rider/driver (e.g. seat belt).
- Tertiary safety: a concept referred to alerting to rescue services after an accident occurrence to provide them the exact location of this event.

Appendix G – Prioritized safety functionalities list (PISa study)

The following lists present the SFs from the most to the less important (43 safety solutions assessed). For simplification we present only the 15 more relevant.

PISa outcome 1: General ranking of safety functionalities

- 1) Automatically stop other vehicle without input from driver
- 2) Warn other vehicle of PTW presence
- 3) Communicate and warn PTW that vehicle travelling from left, right or oncoming is crossing PTW's path
- 4) Automatically stop PTW without input from rider
- 5) Detect and warn PTW that vehicle travelling from left, right or oncoming is crossing PTW's path
- 6) Improve PTW conspicuity
- 7) Avoid locking of wheels
- 8) Amplify braking force
- 9) Balance front to rear braking force
- 10) Warn PTW of traffic signal/pedestrian crossing (status change from green to red)
- 11) Reduce closing speed
- 12) Warn PTW leading vehicle slowing/stopping
- 13) Protect fallen/rolling rider's body
- 14) Restrict PTW to posted speed limit
- 15) Help PTW rider to remain upright post impact

PISa outcome 2: Coarse ranking (contain only the maximum scores) of safety functionalities

- 1) Warn other vehicle of PTW presence
- 2) Automatically stop other vehicle without input from driver
- 3) Communicate and warn PTW that vehicle travelling from left, right or oncoming is crossing PTW's path
- 4) Automatically stop PTW without input from rider
- 5) Avoid locking of wheels

- 6) Warn PTW of traffic signal/pedestrian crossing (status change from green to red)
- 7) Reduce closing speed
- 8) Balance front to rear braking force
- 9) Warn PTW leading vehicle slowing/stopping
- 10) Help PTW rider to remain upright post impact
- 11) Detect and warn PTW that vehicle travelling from left, right or oncoming is crossing PTW's path
- 12) Improve PTW conspicuity
- 13) Warn PTW that oncoming vehicle is in the same lane as PTW
- 14) Warn PTW rider of diagnostic status of PTW (brake, tire pressure, etc.)
- 15) Restrict PTW to posted speed limit

Remark: only the first 4 safety functionalities are almost matching in type and priority order of the safety importance between the previous outcomes.