ROAD SAFETY REVIEW: CRITICAL ASPECTS OF POWERED TWO WHEELERS

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ABSTRACT

Powered two wheelers (PTW) differ in their use of the road in a number of ways from other vehicles and they have different needs. Predictable road geometry, good visibility, obstacle free zones and good quality road surface with high levels of skid resistance are some major examples. While important for all road users, they are essential for PTW.
So the design of safe infrastructures for all travellers categories, included the motorcyclists, becomes a primary requirement. To obtain these results, Road Safety Audits and Road Safety Reviews are very useful tools. In this way, in fact, it is possible to examine a project or existing road, reporting its crash potential and safety performances and detecting its deficiencies without waiting for accidents accumulation.
In this paper the author, starting from data collected in numerous Road Safety Reviews on urban streets, provide significant results regarding roads project and maintenance in according to safety needs of all users, included the PTW drivers.

1. INTRODUCTION

Powered two wheelers in the increasing congestion of European roads offer an efficient form of transport allowing easy access to crowded cities and streets.
However motorcyclists form one of the most vulnerable groups of road users and accidents involving injuries to them are a major social concern [1]. As reported by the European Road Safety Action Programme - Midterm Review, the analysis of the statistics by category of users, vehicles and accident types, shows that “the number of motorcyclists killed as a proportion of total road deaths, which was relatively stable at around 9.5% until 1996, has risen relentlessly to 14% in 2003. In overall terms, the number of motorcyclists killed rose by 5.6% between 2000 and 2003, while the total number of people dead on the roads fell by 12% over the same period. The PTW riders are the only category of users for which the fatality rate is rising in contrast to the overall downward trend” [2] (figure 1).
Since, moreover, the majority of these accidents involve people younger than 35 years old, it becomes essential that all parties work together to improve the safety of this vulnerable category.
To obtain these results, is very important to take into consideration that motorcyclists are more vulnerable than car drivers. This exposure is particularly due to the lack of a body-work, a lesser perceptibility of the PTW by other road users and to the fact that motorcycle is a vehicle with unsteady balance.
Numerous studies show that human failure is the primary cause of PTW accidents; nevertheless a large number of them are produced by infrastructure shortcomings [4] (table 1). So the evaluation of what elements of the road may present a safety concern and what opportunities exist to eliminate or moderate them becomes very important. In this way Road Safety Audits (RSA) and Road Safety Reviews (RSR) are very useful tools.

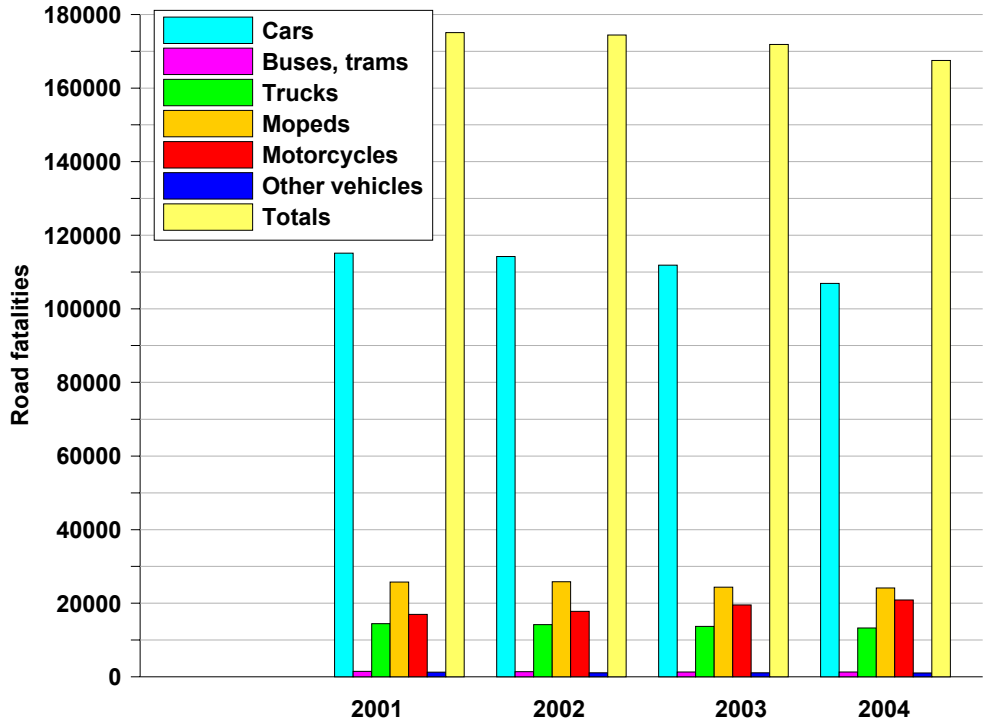

Figure 1 – Road fatalities: the Italian scenario [3]

Table 1 – MAIDS Report: contributory factors in PTW accidents [4]

Contributory factor	Frequency	Percent
Total of accident analyzed	921	100%
Defective roadway design	57	6.2%
Defective roadway maintenance	146	15.9%

After an overview on the RSR state of practice, starting from numerous data detected on different urban roads, the aim of this paper consists in providing useful results for designers, construction and maintenance contractors, in order to obtain safe infrastructures for all users, included the motorcyclists.

2. THE ROAD SAFETY REVIEW PROCESS

Road Safety Review (RSR) is an evaluation of an existing road by an independent and qualified audit team, focusing upon safety issues [5]. It is aimed at identifying the possible safety defects which could cause unexpected dangerous situations for vehicles.
People involved in RSR process are [5]:

- the client or local agency, that requests the review, selects the audit team members and replies to the RSR report;
- the RSR team, chosen by the client and formed of trained and experienced transportation professionals. Its members should be selected independent of the project being reviewed and therefore able to look at it without bias. It qualitatively estimates and reports on potential infrastructure safety deficiencies and identifies opportunities for improvements in safety for all road users.

To conduct an RSR, a formalized and systematic process should be followed [5] (figure 2):

- client calls an initial meeting to which the audit team members and any other who have knowledge of the project should attend. During this assembly the client turns over the relevant data and documents that the team needs;

- auditors review the documentation, record its initial impressions and plan the site inspection(s). They consider appropriate checklists and prompt lists to refer during the site visit. From these data they begin to identify safety-related issues and concerns;
- RSR team inspects the site considering all possible road conditions and users. More than one visit might be necessary, with nighttime and daytime;
- auditors write the report which identifies all safety issues and deficiencies, noting those that require immediate attention, and draw conclusions in the form of recommendations or suggestions for possible corrective actions if requested. A RSR report should be concise and not too long and should be include the following sections:
  - road description;
  - audit team members, by name and title;
  - initial documentation;
  - site visits: identify the dates and times when inspections have been conducted and any conditions present at this time (e.g. weather), and describe the site's layout and its physical characteristics;
  - findings: clearly state safety observations identifying in detail all safety issues and concerns;
  - conclusions and recommendations.
- audit team calls a final meeting where it presents the findings and answers any questions that client might have;
- client responds to the audit recommendations by a "Corrective Action Report" (table 2), a written document that indicates which corrective actions are accepted and which are rejected, as well as reasons associated with the decisions made;
- client implements the agreed-on changes.

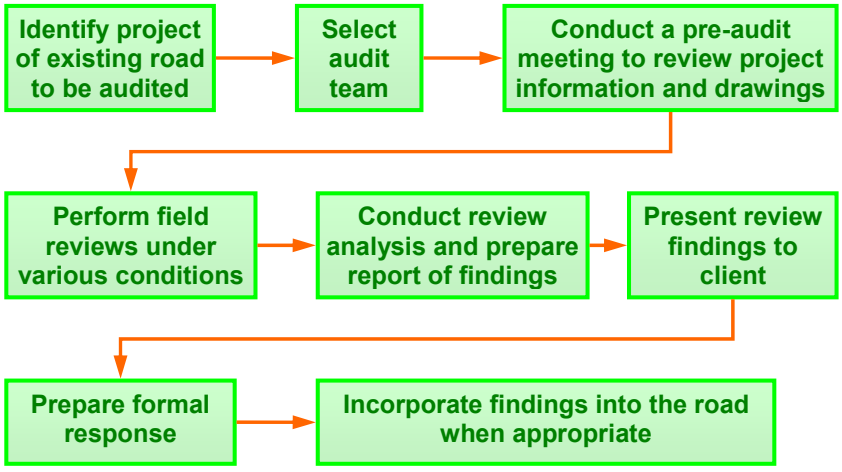

Figure 2 – RSR process

Table 2 – Layout of the "Corrective Action Report" [6]

Reference	Problem	Recommendation	Client answer	Client reason for answer
2.2.1	Concise description of the problem	Concise description of the recommendation	Client decision about the recommendation (accepted, rejected)	Client reasons to explain the rejection of the recommendation
2.2.2	…….	…….	…….	…….
….	…….	…….	…….	…….

The major benefits of RSR procedures are that them [5]:

- identify safety issues of an existing road so as to remove or reduce them without waiting for accidents accumulation;
- warrant for all road users the safety measures necessary to minimize the number and severity of crashes;
- promote awareness of safe design and maintenance practices;
- may reduce lifecycle costs since safer management often carries lower maintenance costs;
- may reduce societal costs of collisions by safer roads.

3. THE EXPERIMENTAL INVESTIGATION

3.1. Introduction

The study involved seven urban streets, placed in north and middle Italy, with variable cross section (table 3, figure 3). The lane width varies from 2.50 m to 3.25 m, while the shoulders, in the great part of alignment, are not wide enough to include sidewalks. The investigation kept into consideration a segment of different length on each roadway. The analyzed routes cross level terrains and are characterized by low longitudinal grades. The adjacent land uses include industrial and commercial and there are numerous driveway accesses, intersections and bus stops.

Table 3 – Streets subjected to RSR experimental investigation

Name [reference figure 3]	Location [county, region]	Analyzed segment length [km]
SP n. 253 San Vitale [A]	Bologna, Emilia Romagna	4.40
Andrea Costa street [B]	Bologna, Emilia Romagna	3.00
Ghinaglia street [C]	Cremona, Lombardia	0.65
Dante street [D]	Cremona, Lombardia	1.35
Manzoni street [E]	Modena, Emilia Romagna	1.70
Giolitti street [F]	Pesaro, Marche	2.50
Nuova Bazzanese street [G]	Bologna, Emilia Romagna	3.60

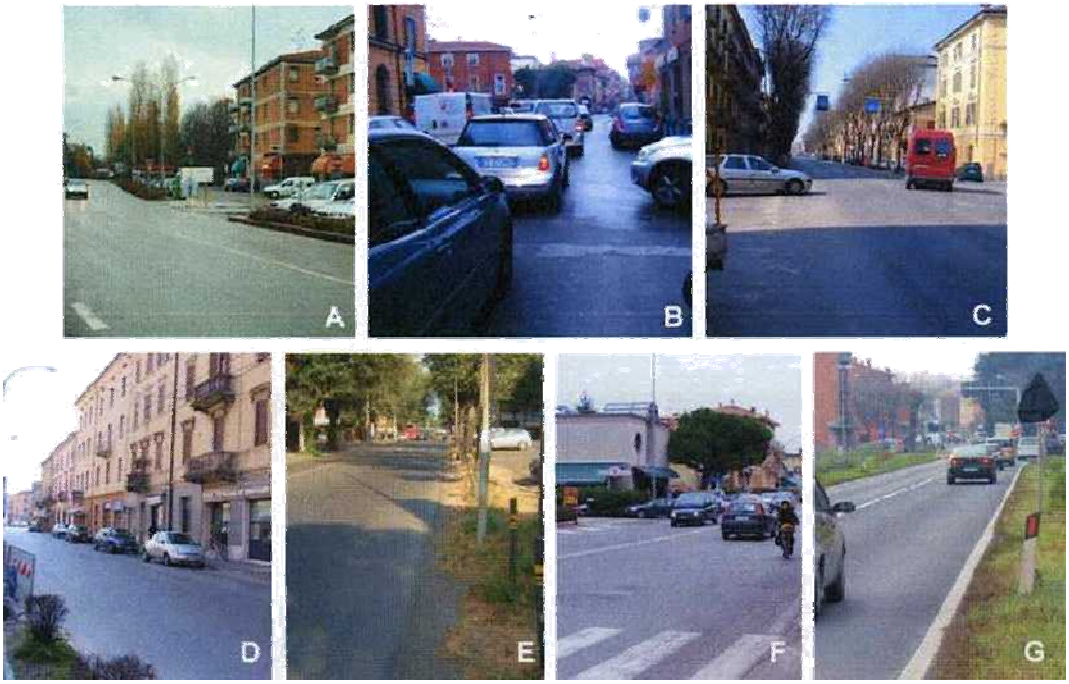

Figure 3 – Streets subjected to RSR process

The experimental study has been composed of two phases:

- examination of CTR 1:5000 cartography, in order to obtain an initial view of the roads to be audited;
- in site investigation of the possible issues capable to generate accidents, founded on the analysis of the physical characteristics of the roads environment. The site inspections have been conducted in good weather conditions, with daytime and nighttime.

3.2. Results

The RSRs conducted on the examined roads show many common safety issues; for clarity they have been grouped in the following categories:

- road alignment (horizontal, vertical, sight distance, cross section, …);
- shoulders (unprotected obstacles, guardrails and barriers, terminals,…);
- signs and lights (road markings, vertical signals,...) ;
- pavement (texture, friction, …);
- intersections (location, sight, perception, manoeuvres,…).

3.2.1Road alignment

Numerous black spots resulted from RSRs are placed in correspondence of curves, which in urban areas are frequently characterized by small radii and poor sight distances. These circumstances are very dangerous especially for PTW drivers because of the necessity of leaning the motorcycle to counter centrifugal forces. While the vehicle is leaning, it is critically vulnerable to skidding.
In these conditions specific protective measures should be taken in order to allow riders to regulate and minimize the difference between the approach speed and speed in curve:

- improvement of visibility, which allows for detection of hazards in time and planning the riding accordingly. It can be increased by the elimination of lateral elements such as sign posts, parked cars, garbage-bins, vegetation, that impair driver's field of vision;
- use of indication signs: when adequate signals are being used, PTW riders can anticipate curves more easily. It should be noted that signs must be installed in safe locations;
- avoid obstacles that may aggravate the severity of injuries to a PTW driver in case of overturning or driving off the road, such as sign posts or lighting poles. When such installations cannot be avoided, they should be equipped with motorcycle friendly devices and they should be placed as far as possible away from the edge of the road. In curves, moreover, alternatives to metal guardrails must be evaluated, because they are extremely dangerous for motorcyclists (these problems are more discussed below).

Many of the reviewed curves, moreover, are characterized by a lack width of the edge strips. This issue is very common along the whole road alignments, whose cross section foresees narrow shoulders, almost not enough for the installation of guardrails correctly working. The roadsides, moreover, are often unpaved and a vertical gap between them and roadway is present (figure 4). These are important contributing factors in crossroad accidents, especially for PTW riders, whose crash consequences will most be more serious than a well-protected car occupant. From a gravel shoulder, in fact, dirt and debris has been thrown on the road surface with a dramatic decrease of skid resistance. Especially at point where braking or steering is necessary, poor friction might also cause the motorcyclist to loose control.
In order to obtain a consistent road surface with proper skid resistance and clear of refuse and rubbish, specific protective measures should be taken:

- pave the shoulders, selecting correct materials;
- keep roadway cleaning trough an efficient maintenance program, able to guarantee a good grip between wheels and pavement.

Figure 4 – Narrow and unpaved shoulders

Much attention should be address also to sidewalks, which suffer of the same safety problem of shoulders. Most of them, in fact, are in a lack of maintenance (figure 5); especially for block pavements, is very high the risk that a detached block comes on the roadway, becoming very dangerous for PTW drivers. So the adoption of an efficient maintenance program is essential.

Figure 5 – Sidewalks on reviewed roads

To improve road safety, another important feature of sidewalks is the type of their edges. Most of them are caracheterized by high corners with sharp ends, very dangerous for motorcyclists (figure 6).

Figure 6 – Sidewalks with sharp edges

Sidewalks design, in fact, is an area where differences in the approach to safety from cars and PTW users are almost diametrically opposed; from motorcyclists' point of view, in fact, sharp edge is an extremely hazardous obstacle, which can turn a fall into a fatal accident.
In order to make sidewalks edges less aggressive to a fallen two-wheeler, a possible solution is modifying and trimming off theirs section or tilting theirs assemblage (figure 7) [8].

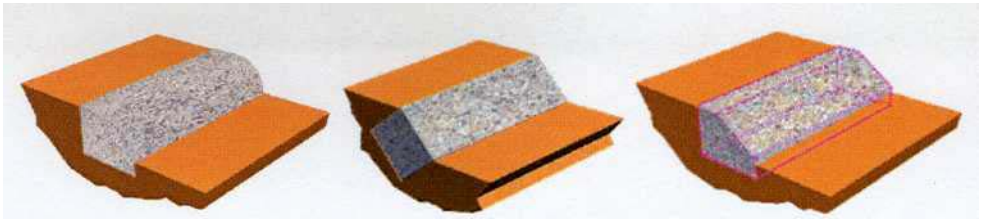

Figure 7 – Motorcycle friendly sidewalks [7]

3.2.2Shoulders

Shoulders are frequently caracheterized by the presence of unprotected obstacles, which can be very hazardous in case of vehicles driving off the road (figure 8). Sign posts, lighting poles, garbage-bins, sidewalk poles, high edged curbs, placards are located near the roadway so as to represent a greater injury for PTW drivers.

Figure 8 – Unprotected obstacles in shoulders

When it is possible, these installations should be placed as far as possible away from the edge of the road; otherwise they should be equipped with motorcycle friendly devices, as break-away roadside poles or special impact attenuators for posts.
A break-away roadside pole is a system designed to break quickly and cleanly upon impact, thus saving lives and reducing property damage costs (figure 9). In this way the decrease of accident severity is obtained not screening the post, but designing it so as to generate smaller stress during the crash.

Figure 9 - Break-away roadside poles [7]

Special impact attenuators, instead, can be applied to sign posts or lighting poles and they cover the vertical elements preventing contact with them and absorbing part of the impact energy (figure 10). Some available models are made of foam (polystyrene, polyurethane or similar material) or crumb rubber coming from the recycling of heavy vehicles tyres. They are very easy to install and their positive effect is however reduced with higher speed of impact [7].

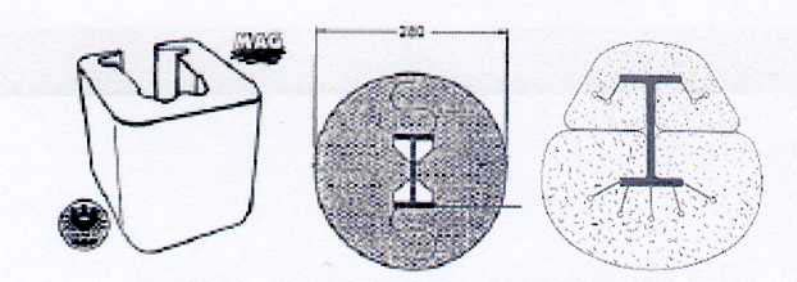

Figure 10 – Crash impact attenuators [7]

These impact attenuators are very useful especially for guardrail posts, which can represent very dangerous elements for PTW drivers. The metal crash barriers in common use, in fact, with their exposed and sharp edged posts, the height and profile of their guardrails, their proximity to the carriageway an their use of steel ropes, result in greater injuries for motorcyclists. They, in fact, are not contained within a vehicle and consequently it is often the rider that makes contact with the crash barrier.
In the most of reviewed alignments, in particular, metal crash barriers are in a lacking maintenance condition and numerous unconnected devices are present (figure 11).

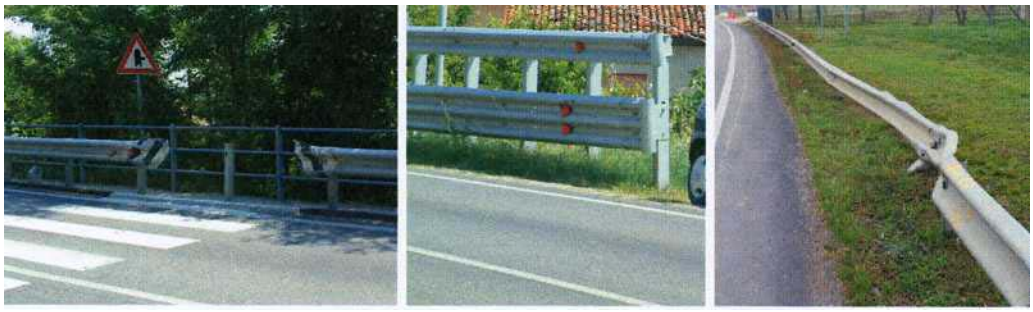

Figure 11 - Safety barrier on reviewed alignments

So these equipments have to be modified or substitute with others, able to reduce the severity of accidents of PTW drivers. Posts, in particular, have been identified as the main impact point because they have edges that act a razor when hit a speed above 30 km/h [7]. In this way different solutions are available [8]:

- replacement of posts with smooth surface elements that will prevent danger of impacting sharp edge by the fallen motorcyclist: very useful is the substitution of IPE-100 with the sigma-shaped posts, because the last ones are less harmful to PTW drivers as they have a large, thin walled, sigma-shaped cross section with rounded edges [9];
- protection of exposed edges of guardrail posts fitting of special impact attenuators to guardrail posts (figure 10);
- changing the entire design to achieve a safer barrier system: using metal or plastic shield or plate that can be fixed under the rail is possible to prevent contact with the posts. These elements, in particular, are designed with minimal aggressive shapes and have turned in edges in order to combine both energy assumption properties and impact spreading properties (figure 12) [10].

Figure 12 – Motorcycle friendly devices [11]

The use of a PTW-safe road barrier system should be considered at least in places, for example in bends, where motorcyclists will be most a risk.
In design or maintenance of road restrain systems, however, it is essential to bear in mind that:

- safety barrier must be placed away from the edge of the road: a motorcyclist who falls off his PTW will normally continue in the direction of travel and seldom the ends up far from the edge of the road. Therefore it is important to keep the first few meters from the edge free of fixed obstacles;
- it must be avoided erecting road safety barriers if alternative safety measures suffice: removing hazardous obstacles often is preferable to protecting them with crash barriers. On road embankments, in particular, is important to evaluate the possibility of removing safety barriers by reduction of escarpments slope. In same cases, in fact, the lowering of the embankment height can be safer than the barriers installation. To take into consideration this problem, the Isoseverity Curve can be a very useful tool (figure 13) [12]. It represents the combinations between height and slope of an embankment that cause crashes of the same severity of the impact against a barrier. The areas over and under the curve describe situations in which the barrier installation is safer than the fall from the embankment and back.

Another problem stood out from RSRs is that safety barrier terminals are often very dangerous devices because unprotected. So it is very important to insert special elements able to absorb most of the impact energy, producing a gradual vehicle stop with no excessive deformations and reducing passengers' injuries.

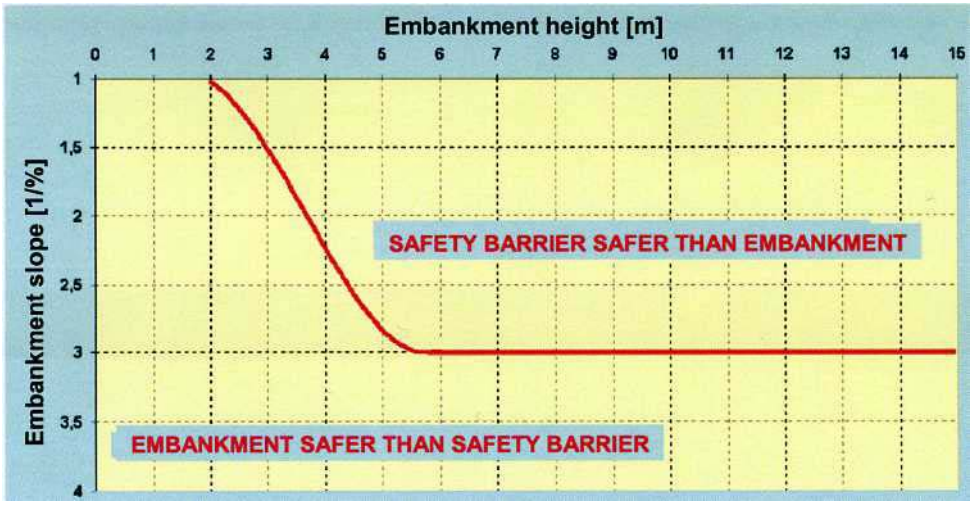

Figure 13 – Isoseverity Curve [12]

3.2.3Signs and lights

The sites inspections, with nighttime and daytime, have shown that vertical signs are not always perceived by travellers. This can be caused by different problems (figure 14):

- numerous signs are old with poor discernibleness;
- too many signals are positioned at one location, so the road users are not able to comprehend them all at once;
- there are some signs placed so as to be hardly visible because of the presence of lateral obstacles as vegetations or placards.

Figure 14 – Vertical signs not well perceivable by travellers

So, to improve road safety, become very important cleaning of signs, replacement of old ones, clearing sight obstructions near signals and removing of those superfluous.
Another problem is the signs location, because, being often positioned near the roadsides, their posts can represent a greater injury for PTW drivers (figure 15).

Figure 15 – Vertical signals placed in dangerous points

Route installations such as light poles and sign posts, in fact, shall be impact absorbing when hit by a car, but can be fatal when hit by a motorcyclist. For this reason is essential:

- select devices that will minimize possible injuries to motorcyclists, avoiding sharp and protruding details;
- place these elements as far as possible away from the edge of the road and, when it is not possible, equip them with motorcycle friendly devices as break-away roadside poles or special impact attenuators for posts (figures 9 and 10).

In special critical points, as curves or intersections, it can be useful to insert supplementary signs for PTW drivers, in order to provide them the necessary information to adapt their speed as approaching a dangerous element (figure 16).

Figure 16 – A specific sign warns the motorcyclists in approach to an intersection [4]

Where possible, the concept of the self-explained road should be adopted and the level of signing and marking should be proportional to the degree of potential hazard along the whole infrastructure.
Road markings, in particular, tend to be more slippery than the rest of the road surface, especially when wet. For motorcyclists this can create problems when braking and turning.
So is very important to select road marking materials with favourable frictional properties and to follow an efficient maintenance program able to guarantee a perfect condition and visibility of road markings. Often, in fact, they are old and with poor discernibleness, especially in critical points as intersections or pedestrian crossings (figure 17).

Figure 17 – Road markings in poor maintenance condition

3.2.4Pavement

One of the most common safety problem founded during RSRs is the poor maintenance conditions of road pavement, which are caracheterized of potholes, cracks, resurfaced patches and sunk manholes, with a great degradation of surface evenness and skid resistance (figure 18).

Figure 18 – Poor maintenance conditions of road pavements

Since pavement damages can greatly influence road safety and in particular the motorcycle's handling, potholes and patches must be repaired quickly using correct method. The patching material must be level with the adjoining pavement and the frictional conditions must be very similar. When patching/filling cracks, loose material from the operations shall not remain at the site when opened to traffic, in order to guarantee a good skid resistance. PTWs, in fact, have a much greater need for consistent and high coefficient of friction between tyres and road surface than four-wheeled vehicles. To obtain these results different safety measures can be taken:

- use of asphalt mixtures with good frictional properties;
- keeping of roadway cleaning trough an efficient maintenance program;
- placing manholes and cattle guards outside travelled way, especially in curves, because they tend to be more slippery than the rest of the road surface, especially when wet.

3.2.5Intersections

The intersections reviewed are in general characterized by a poor visibility caused by obstacles located in sight zones, such as parked cars or vegetation (figure 19). This is an important contributing factor in crossroads accidents, especially for PTW crashes, because, having a relatively small frontal area compared to other vehicles, they are often overlooked by four-wheelers road users.

Figure 19 - Poor visibility in intersections reviewed

So it is preferable to free sight zones from obstacles that reducing visual distance, in order to have an intersection that provides crossing traffic the opportunity to see the whole

vehicle, especially PTW, in the entire sight zone. Consequently an efficient organization of parking on the crossroad sides becomes very important.
Inside traffic islands are also present many unprotected obstacles, such as sign posts and lighting poles, which can be very dangerous for PTW safety (figure 20). So is very important to equip these installations with motorcycle friendly devices, as special impact attenuators for posts or break-away roadside poles, able to reduce the severity of accidents of motorcyclists against these obstacles (figures 9 and 10).

Figure 20 - Unprotected obstacles in intersections

To poor sight distance for some manoeuvres, a lacking vertical signal is added; many reviewed intersections, in fact, are not correctly signalized and so are not well perceived by users on the main road. So is very important to increase and improve the signs, with particular attention to theirs location and features with respect to safety of all road users, including PTW drivers (§ 3.2.3).
Also road markings often need of maintenance: in many cases, in fact, they are lacking or not visible (§ 3.2.3). Because of the damaged state of pavement, they guarantee moreover a poor skid resistance. For PTW drivers this can create many difficulties when braking and turning; so an efficient maintenance program is very necessary.

4. A NEW CHECKLIST FOR RSR FROM MOTORCYCLISTS' POINT OF VIEW

Starting from obtained results, it has been possible to identify roads elements critical for motorcyclists, whose analysis is very important to conduct a significant RSR. These features, in particular, have been inserted in a checklist, specific for PTW, which can be integrated to the existing ones, reported in Italian code [6]. This standard, in fact, takes into consideration the motorcyclists only in the part about pedestrians and cyclists (table 4), in which it examines only the state and evenness of the road pavements. So the new checklist proposes itself to fill this safety gap (table 5).

Table 4 –Checklist reported in Italian code [6]

EXISTING ROADS - Checklist 8 – Pedestrians and cyclists	
Pedestrian crossings…	
Cyclists…	
Motorcyclists	
33	Is the pavements state adequate to the motorcyclists needs?
34	Are there on the road elements, as edges or manhole covers, which represent a risk to motorcyclists?

Table 5 – New checklist proposed for RSR from motorcyclists' point of view

EXISTING ROADS - Checklist 8/a - Motorcyclists	
1	Are pavement conditions adequate so that motorcyclists will not encounter unexpected problems as loss of friction, cracks, potholes, resurfaced patches, sunk manholes, gravel, dirt, etc?
2	Are safety barriers designed and placed so that they do not represent a risk to motorcyclists?
3	Can safety barriers be replaced by alternative solutions that will provide more safely for motorcyclists?
4	Are road shoulders properly designed to prevent motorcyclists from injuries when driving off the road?
5	In dangerous sites, as bends or intersections, is the motorcyclist course clear of obstacles such as signs posts, garbage-bins, lighting poles, manhole covers, cattle guards, large areas of road marking, etc?
6	Are the sidewalks properly designed to prevent motorcyclists from injuries when hit them?
7	Are signs placed properly so that they do not represent additional hazard to motorcyclists?
8	Are signs concerning motorcyclists sufficiently visible?
9	Is supplementary signing advisable, including auxiliary warning signs for motorcyclists?
10	Is the illumination adequate at locations where road conditions change?
11	Is the street lighting sufficient for a good visibility for motorcyclists?
12	Is there a need for removal of signs and/or vegetation in intersections so that motorcyclists and other road users may obtain a better view on the roadway and the oncoming traffic?

Completing this checklist during the site inspection, the auditors can analyze many of the road critical elements which can turn a motorcyclist fall into a fatal accident.
To obtain more significant results, moreover, is very useful comparing the black spots resulted from RSR with the crashes location evaluated by accident prediction models (APM). Estimating the expected number of accidents on intersections or road sections, they are typically used in the identification of sites for possible safety treatments [13]. An APM is, in essence, a mathematical equation that expresses the average accident frequency of a site as a function of traffic flow and other its characteristics. To obtain a significant comparison, is very important to apply models that take into consideration heterogeneous traffic which includes four and two wheeled vehicles [14-18].

5. CONCLUSIONS

In this paper it has been analyzed the results came from Road Safety Reviews of urban roads, placed in north and middle Italy. They shown that the safety measures carried out on Italian roadways are often effective only for four-wheeled vehicles and not for PTW drivers. The analyzed urban roads, in fact, are caracheterized by the presence of sign posts, lighting poles, sidewalk poles, high edged curbs, trees, which can turn a motorcyclist fall into a fatal accident. Since PTWs provide a growing contribution to Italian mobility, filling this safety gap becomes very important. To obtain these results, the potentialities of the Road Safety Review process are examined and confirmed; in fact it proves itself to be a rapid and effective tool, able to detecting the safety deficiencies of an existing road, without waiting for accidents accumulation. To improve RSR potentialities, in

particular, has been defined a checklist, specific for PTW, which can be integrated to the existing ones, reported in Italian standards [6].
Conscious of the PTW safety problem, moreover, the research team of DISTART Road Department of the University of Bologna have written a design guide for motorcyclists' safer roads [20].

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