Improved design of motorcycles and road barriers can save lives

Background
Motorcycles are becoming increasingly popular in Sweden - their number has doubled over the last fifteen years. Today, motorcycles and other powered-two-wheelers fill important transport needs for their users, and it is argued that increased congestion in urban areas will make their use even more popular in the future. However, motorcyclists are still vulnerable in a crash, especially at high speeds where their protective gear has limited benefits.

In order to reduce serious injuries among motorcyclists in the future, an holistic perspective is needed, i.e. all components of the road transport system must interact and compensate each other. A relevant example in this matter is represented by road barriers, which improve the safety for the majority of road users, but not to the same degree for motorcyclists. While a median barrier protects motorcyclists from oncoming or crossing vehicles, it still poses high injury risks for motorcyclists in a crash, similarly to side road barriers. Unfortunately, side and median barriers often imply higher injury risks than roadsides without fixed objects.

Road barriers represent the most common collision object in single-vehicle crashes with motorcycles in Sweden. In a previous study, Folksam Research and the Swedish Transport Administration (STA) have shown that about 5 motorcyclists are killed every year in collisions with road barriers (more than 10% of all killed motorcyclists in Sweden). The same study also showed that today's crash scenarios are distributed fairly evenly between sliding into the barrier, upright on the motorcycle impacting the upper side of the barrier, and upright on the motorcycle being thrown over the barrier (Rizzi et al, 2012).

“Motorcycle-friendly” barriers, usually a W-beam barrier fitted with Motorcyclist Protection Systems (MPS), have been installed in other EU countries to a greater extent than in Sweden, for example, in Spain, Italy, France and Germany. There is no scientific evidence of the effectiveness of these types of barriers in real-life crashes. Crash testing represents a motorcycle crash in which the rider slides on the road surface, but at the present stage there is no requirement for testing of the barrier performance in upright collisions, i.e. the rider remains on the motorcycle (Grzebieta et al, 2013). STA has launched a trial of guardrails with MPS in five locations in the country and assessment of this is in progress.

It should be also noted that the Swedish motorcycle fleet is changing due to the rapid implementation of anti-lock brakes (ABS) and other electronic support systems such as Traction Control and Motorcycle Stability Control (MSC). It is likely that fewer motorcyclists will slide into barriers in the future, as suggested in previous research showing that ABS improves stability and reduces the risk of falling off the motorcycles (Rizzi et al, 2014; Teoh 2013; HLDI 2013; Role et al, 2009). This also suggests that integrated protections and the design of motorcycles will have a growing importance in the future.

Analysis of motorcycle designs in real-life crashes
Motorcycles provide limited injury protection in the case of a crash. Previous research has indicated that 70% of motorcyclists sustain some kind of leg injury during a crash (Otte 1998). While other studies have reported that leg injuries account for approximately 50% of all AIS 2+ injuries among motorcyclists (MAIDS 2004; NTHSA 2008), the majority of the fatal injuries are to the head, even among riders with helmets (DaCoTa 2012; NTHSA 2008).

The majority of the original research in the area of leg protection for motorcyclists has been conducted in the 80’s and 90’s (DaCoTa 2012). A rather simple countermeasure to address leg injuries has been conventional crash bars, usually made of loops of steel tubes projecting to the side of the motorcycle (Rogers et al. 1998). Studies based on in-depth investigations of 133 real-life crashes showed no overall benefits, as the proportion of injured leg regions was nearly identical for...
motorcycles with and without crash bars (Ouellet et al. 1987). While there was evidence suggesting that crash bars were sufficient to preserve the leg space in many of crashes, it was argued that leg space preservation was not strongly related to serious leg injuries, mainly because the leg often did not remain in the leg space during the collision (Ouellet et al. 1987). Furthermore, frontal crash tests with conventional crash bars showed greater chest and head accelerations due to the rotation of the upper body (Rogers et al. 1998; Noordzij et al. 2001).

However, the possibility that some motorcycle designs may inherently offer some degree of leg protection may have not been investigated thoroughly by previous research. The overall motorcycle design can vary across different categories and manufacturers. For instance, some motorcycles are equipped with a horizontally opposed flat-twin engine, which means the cylinders are overhanging horizontally in front of the riders’ legs. This engine configuration is also known as boxer-twin engine (see Figure 1).

In a new study, Folksam Research has compared similar ABS-motorcycles of the same categories. Approximately 180 Swedish medical reports from 2003 to 2014 were analyzed and the risk for permanent impairment was compared for different body parts and for the whole body. The result showed that for ABS-motorcycles with boxer engines the risk for impairing leg injuries was reduced by approximately 50% (Rizzi et al, 2015). The results were statistically significant and also showed that injuries to the head and upper body did not increase among riders with boxer engines.

However, the study by Folksam does not recommend a broad implementation of boxer engines on motorcycles as a solution to address leg injuries. In other words, the benefits of boxer engines in terms of leg protection may be only an example of what could be achieved: the present results suggest that the concept of protecting motorcyclists’ leg with vehicle technology is indeed feasible, and therefore more focused engineering efforts should be put to address this issue. This is the first study in the world to show that it is possible to protect motorcyclists with vehicle design and study has been published in the scientific journal Traffic Injury Prevention during the spring 2015.

Figure 1: A front-view illustration of a motorcycle equipped with a boxer-twin engine (left) and a similar one with a single-cylinder engine (right).

**Crash tests of motorcycles against road barriers**
Based on the results of the new study by Folksam, showing that a certain type of motorcycle design reduces the risk for impairing leg injuries among motorcyclists in real-life crashes, four crash tests were performed to visualize the influence of motorcycle design and how this interacts with motorcycle-friendly barriers.

It is currently discussed in Sweden whether motorcycle-friendly barriers should be implemented as broadly as in other EU countries. However, the real road safety benefits remain somewhat unclear.
Therefore, the present crash tests may provide important input for road authorities and other stakeholders regarding the real potential of motorcycle-friendly barriers in the future.

**Method**

During April 2015 four crash tests were conducted at the Swedish National Road and Transport Research Institute (VTI) in Linköping, Sweden. The tests involved an upright motorcycle driven into a road barrier with a 10° impact angle at 60 km/h. A standard Hybrid III crash test dummy with motorcycle protective equipment (helmet, boots, etc) was used. The choice of the collision speed and angle was based on data from real-life crashes, as the average impact speed in Swedish fatal motorcycle crashes is reported to be approximately 85 km/h (Savino et al, 2014) and the impact angle is less than 20° in 70% of injury crashes involving motorcycles against road barriers (Rizzi et al, 2012).

The motorcycle and the crash test dummy were placed on a platform guided by a rail, so that they could move freely about 1-2 meters before the impact with the barrier. The crash tests were filmed with ordinary cameras, high-speed cameras as well as two GoPro cameras.

It was argued that the test procedure according to ISO 13232 (ISO 2005) was far too complex and costly for the present project, therefore no acceleration or force measurements were performed on the crash test dummy. Contact points between the dummy and the barrier were analyzed using white paste, and injury mechanisms were analyzed with the high-speed films and the damage sustained by the protective gear. The following combinations of motorcycles and barriers were tested.

**Test 1:** Baseline motorcycle (Ducati Monster 900) against a conventional W-barrier (EU-2).
**Test 2:** Motorcycle with boxer engine (BMW R1150R) against a conventional W-barrier (EU-2).

![Figure 4: the motorcycle and barrier used in Test 2.](image)

**Test 3:** Motorcycle with boxer engine (BMW R1150R) against a W-barrier (EU-2) fitted with MPS, same type under evaluation by STA.

![Figure 5: the motorcycle and barrier used in Test 3.](image)

**Test 4:** Motorcycle with boxer engine (BMW R1150R) against a W-barrier (EU-2) fitted with MPS, same type under evaluation by STA, as well as a prototype top protection. This protection was built on site by installing the same W-beam on the back of the posts and a plastic tube pressed in between the beams (see below).

![Figure 6: the motorcycle and barrier used in Test 4.](image)
The logic behind the experimental sequence was that Test 1 would represent a baseline, i.e. a regular motorcycle crashing upright against a conventional W-beam barrier. Test 2 would visualize the difference with a motorcycle design that offers leg protection. Test 3 and 4 would visualize the difference when two further countermeasures are implemented, i.e. the barrier design includes protection under the beam (Test 3) and also on the top of the beam (Test 4).

**Results**
All tests could be carried out as planned. Only minor adjustments or repairs of the dummy, the motorcycles and the test barrier were needed between the tests. The motorcycle protective gear on the dummy was replaced after each test.

**Test 1 – baseline motorcycle against a conventional W-barrier (w/o MPS)**

Crash description: the first impact with the W-beam occurred with the left leg of the dummy. The lateral movement was significant and the front wheel came near to the posts. However, it did not contact them. The dummy slid against the side of the beam for about 5 m and part of the pants melted on the left leg. The dummy was then thrown on the top of the barrier without getting stuck, and fell off it impacting the road surface.

Visible injuries: left underarm, left lower leg and knee, only small scratches on the helmet.

Final position: motorcycle continued upright dummy 30 m, by the barrier, roadside
Test 2 – motorcycle with boxer engine against a conventional W-barrier (w/o MPS)

Crash description: the first impact with the W-beam occurred with the engine cylinder. This meant that the front wheel remained far from the posts, but because the beam stiffness the motorcycle fell to the ground immediately after the initial collision. The dummy was thrown on the top of the barrier and slid on it for a few meters. The right arm got stuck in a post on the rear of the beam.

Visible injuries: left underarm and right arm, thorax. Left leg and helmet undamaged.

Final position: motorcycle 30.5 m, by the barrier
dummy 18.5 m, on the barrier
Test 3 – motorcycle with boxer engine against a W-barrier fitted with MPS

Crash description: the first impact occurred between the engine cylinder and the MPS, which is softer than the beam itself. The MPS absorbed part of the impact energy which made the motorcycle slide against the barrier for a considerable distance. The dummy slid on the top of barrier and came close to the posts with the head and the left arm. However, it did not get stuck and continued on the motorcycle to the final position.

Visible injuries: left underarm and helmet. Left leg uninjured.

Final position: motorcycle and dummy 36 m, 1.2 m from the barrier, roadside.
Figure 9: crash test sequence and injuries in Test 3.
Test 4 – motorcycle with boxer engine against a W-barrier fitted with MPS and top protection

Crash description: The first impact occurred between the engine cylinder and the MPS. Similarly to Test 3, the MPS absorbed some of the impact energy. However, this time the motorcycle fell to the ground after about 11 m. The dummy was thrown off the motorcycle and slid on top of the barrier without getting stuck or near the posts.

Visible injuries: Left underarm and helmet. Left leg uninjured.

Final position: Motorcycle 35 m, dummy 29 m, by the barrier, roadside
Comparison between the crash tests

Analysis of Test 1, i.e. a baseline motorcycle crashing upright against a conventional W-barrier, showed that the most serious injury was to the left leg, and that the front wheel came dangerously close to the posts during the initial collision. If the front wheel had contacted a post, it is likely that the motorcycle would have stopped abruptly, thus resembling a frontal collision, which would give even higher injury risks for the motorcyclist.

Test 2 showed that these issues can be addressed by the design of the motorcycle, as the cylinder preserved the leg space and kept some distance between the front wheel and the posts. Of course it is important to point out that the MPS would also address the front wheel issue, but the leg injuries would probably still occur, being these the result of the contact between the leg and the beam itself (not the posts). Although the impact angle was small (10°), the collision between the cylinder and the beam made the motorcycle fall to the ground, which threw the dummy on the top of the barrier. This implied that the overall injury risks in Test 2 were still high since the right arm of the dummy got stuck in a post.

Test 3 showed that the issue of falling off the motorcycle right after the initial collision can be addressed by a combination of MPS and motorcycle design. The combined contribution of the engine cylinder and the MPS made the motorcycle and the dummy continue along the barrier after the first collision. However, the issue regarding the top of the barrier remained unaddressed: the dummy slid on it and came dangerously close to the top of the posts, although it did not get stuck.
Finally, Test 4 showed that this issue can be addressed by covering the top of the barrier with some form of smooth structure. The purpose of this test was to demonstrate the principle of protecting the rider from the top of the posts, rather than testing a specific product or technical solution. However, the test showed that this principle is applicable and that the injury risks would be greatly reduced. The combination of boxer engine and MPS protected the leg in the first collision, and the top protection made the dummy slide on the top of the barrier without getting stuck.
General discussion
The results of the analysis of real-life crashes may seem somewhat surprising, as boxer engines were not developed to provide leg protection to motorcyclists. The basic idea was (and still is) that, being these engines air-cooled, the position of the cylinders would be more favorable for the cooling airstream. However, this may not be the first case of vehicle safety being improved as a result of coincidence, rather than focused engineering (Strandroth et al. 2012), and the location of the injury reductions associated with boxer engines seemed to be consistent with the orientation of the leg. If confirmed by future research, the findings of this paper could have important implications for motorcycle safety. The present paper does not recommend a broad implementation of boxer-twin engines on motorcycles as a solution to address leg injuries. In other words, the benefits of boxer-twin engines in terms of leg protection may be only an example of what could be achieved: the present results suggest that the concept of protecting motorcyclists’ leg with vehicle technology is indeed feasible, and therefore more focused engineering efforts should be put to address this issue. Other technologies could be also used, such as knee airbags. In other words, the concept of integrated rider protection could be taken to a new level, without drastically modifying the look and handling of a motorcycle. Also, consumer acceptance may be higher today than in the past. For instance, in a 2010 Swedish survey, 80% of the interviewed motorcyclists stated that their next motorcycle will be fitted with ABS (Nordqvist et al. 2010). This may not have been the case some 20 years ago.

The crash tests showed that an holistic approach for improving the protection given to motorcyclists in collisions with barriers may have a great potential. Improved motorcycle stability with i.e. ABS is a requirement to design a more effective integrated protection, as the rider would be more likely to remain on the motorcycle prior to collision. Given the great injury risks for motorcyclists involved in crashes with conventional barriers, it is evident that these need to be modified and improved. However, the importance of the motorcycle design seems to be of at least the same magnitude, as suggested by the Folksam study. Moreover, the interaction between these two factors may have a higher potential than the sum of the individual potentials. The same basic idea applies to passenger cars, where the interaction between the vehicle crashworthiness and the road barriers optimizes the occupant protection.

However, further development of motorcycle designs and barriers is needed in order to confirm the real combined benefits. It is also important to point out that the barrier top protection used in Test 4 was a prototype built on site to demonstrate the principle of protecting the rider from the top of the posts. These types of barriers are still uncommon, although at the present stage there is a commercial product with the same functionality that, technically, could be retrofitted on existing W-beam barriers.

Conclusions
- The design of a motorcycle plays an important role for the injury risk in a collision. Analysis of real-life crashes showed that a certain type of motorcycle design (i.e. with boxer engine) reduces the risk for impairing leg injuries by 50%, even though this design was not originally designed to protect motorcyclists.

- The crash tests showed that the MPS is beneficial even in upright collisions, as it can make the lower side of the barrier smoother and softer, thus reducing the risk that the front wheel, other motorcycle parts or the rider’s leg get stuck into the lower posts.

- In upright collisions there is a significant risk that the rider gets injured by the top or the rear of a W-barrier, suggesting that top protection is also necessary. This most likely applies to all steel guard rails.

- A smoother and softer barrier (with MPS and a prototype top protection) was crash tested in combination with a motorcycle fitted with a boxer engine. This combination significantly reduced the injury risks.


ISO 13232:2005 “Motorcycles - test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles”.


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