

THE POTENTIAL OF DIFFERENT COUNTERMEASURES IN REDUCING MOTORCYCLE FATAL CRASHES: WHAT IN-DEPTH STUDIES TELL US

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ABSTRACT

Every year approximately 50 motorcyclists are killed on the Swedish roads and almost 400 are severely injured according to police records. The objective of this study was to analyze the relationship between a number of risk factors related to motorcycle fatal crashes in Sweden and to investigate the potential of different countermeasures aimed to motorcycle safety. The study used in-depth studies of fatal motorcycle crashes conducted by the Swedish Transport Administration during the period 2005–2008 (n=182). Proven or reasonable relationships between a specific countermeasure and the reduction in the number of fatalities were used as the basis for every calculation. Every fatal crash was analyzed and critical events throughout the chain of events leading to the crash were identified. An assessment was then made of whether certain countermeasures could have prevented the crash or mitigated the injury outcome. However, for natural reasons, the reliability of these assessments could vary depending on the problem area. In certain cases they were very dependable, whereas in other cases they could merely represent assessments of the maximum benefit. The potential (number of saved lives per year in Sweden) of different countermeasures or intervention areas included in the study were presented depending on which element of the road system (user, vehicle and infrastructure) they related to, and were successively grouped depending on the reliability of the assessment. It was also shown how no use of helmet, drunk-driving, no motorcycle driving license or excessive speeding may occur in the same crashes. For instance, it was found that all killed motorcyclists who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license.

This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. However, it is also important to note that Swedish conditions may differ from other countries. Furthermore, these calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures.

INTRODUCTION

In 2009, more than 5000 motorcyclists were killed in road crashes across the European Union [1], as shown in Figure 1.

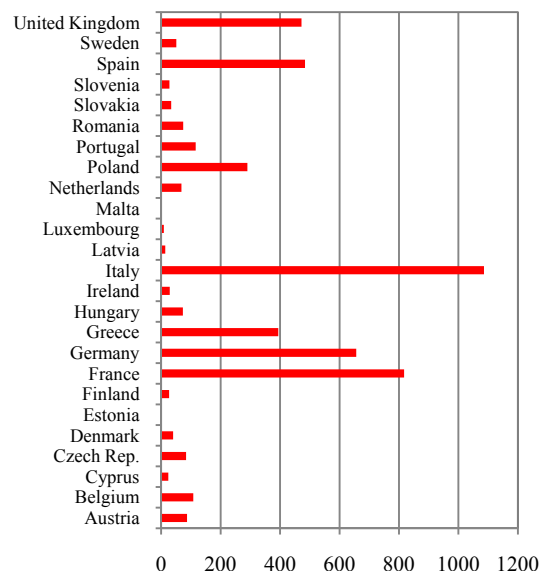


Figure 1. The number of killed motorcyclists in the European Union in 2009.

Every year approximately 50 motorcyclists are killed on the Swedish roads (see Figure 2) and almost 400 are severely injured [2].



Figure 2. Number of killed motorcyclists in Sweden during the last 12 months (rolling 12 month average).

Motorcycles are becoming increasingly popular in Sweden – the number of motorcycles on the road has doubled during the past decade [2]. While motorcycles may meet important transport needs for their users, due to the growing congestion in urban areas and the demand for more energy-efficient transports, they may also meet important future needs for the whole society. However, a disadvantage associated with motorcycles is their shortfall in safety, compared to passenger cars. While the risk of being killed or severely injured per 1000 casualty crashes in Sweden has been almost the same since the 1980s for motorcyclists, the same risk for passenger car occupants has been decreased by more than 50% (see Figure 3).

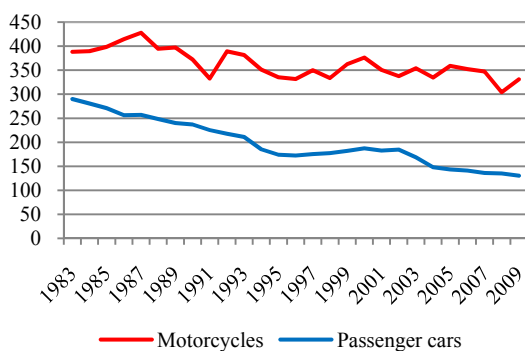


Figure 3. Number of persons killed or seriously injured in Sweden per 1000 casualty crashes with passenger cars and motorcycles.

Motorcycles and power-two-wheelers in general are a natural element of the road transport system and it is therefore of great importance to continually improve our knowledge and understanding of how

motorcycle crashes can be prevented and injuries can be mitigated.

STUDY OBJECTIVES

The objectives of this study were:

- to analyze the relationship between a number of risk factors related to motorcycle fatal crashes in Sweden during the period 2005-2008;
- to investigate the potential of different countermeasures in reducing those fatal crashes.

MATERIAL

The Swedish Transport Administration (STA) has been carrying out in-depth studies for each fatal road crash since 1997. The vehicles involved and the crash site are inspected by crash investigators at STA and further information is provided by forensic examinations, questioning and witness statements from the police and reports from the emergency services. These in-depth studies therefore represent a uniquely detailed material that is well suited for a qualitative analysis.

This study used 182 in-depth studies of fatal motorcycle crashes that occurred in Sweden during the period 2005-2008. Crashes with any kind of motorcycle with an engine displacement of at least 125 cc were included in this study (see Table 1). All available in-depth studies for the period 2005-2008 were used which should guarantee a representative material for Swedish conditions.

Table 1. Types of motorcycles included in the study

Motorcycle category	n	%
Sport	65	36%
Custom	35	19%
Standard/naked	22	12%
On/off	16	9%
Cross/enduro	15	8%
Sport touring	12	6%
Scooter	7	4%
Supermotard	5	3%
Touring	5	3%
Sum	182	100%

METHOD

This study used a qualitative approach to investigate motorcycle crashes. The entire chain of events (see Figure 3) leading to motorcycle fatal crashes in Sweden during the period 2005-2008

was analyzed to identify factors that contributed to the crash itself or to the fatal injury outcome.

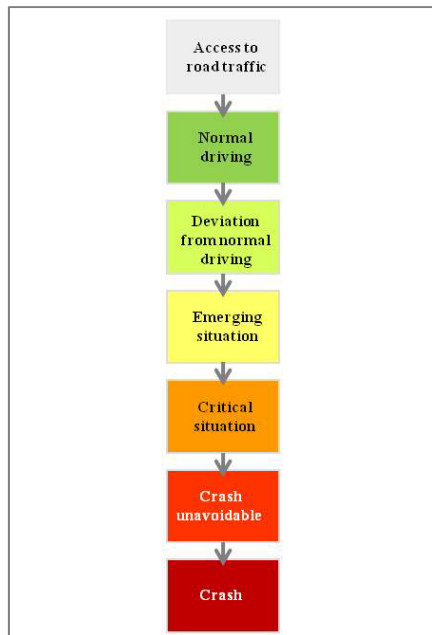


Figure 1. The chain of events, from access to road traffic to the actual crash [3].

A number of risk factors generally known to be associated to motorcycle crashes were studied in order to determine whether they occur simultaneously in these same crashes or not. The analyzed factors were no use of helmet, drunk-driving, no motorcycle driving license and excessive speeding. This analysis was carried out by simply checking in each crash if/how many of these risk factors were present. For instance, if it was found that a killed motorcyclist was under the influence of alcohol, it was checked if he or she did use a helmet, had a valid motorcycle driving license and drove at a speed that was judged to be within the speed limit by the STA crash investigator.

An assessment was then made of whether certain countermeasures could have prevented the crash (back to normal driving, see Figure 3) or mitigated the injury outcome. Two different crash investigators analyzed each crash separately. A number of crashes were further analyzed in a consensus group in order to guarantee objective assessments. For instance, if excessive speeding was involved in the crash, it was discussed at which extent a lower driving speed could have affected the crash. While this method provides an understanding of the effect that may be expected from a certain countermeasure, it is evident that the true effectiveness may only be calculated with real-world evaluations. Besides, for natural reasons, the reliability of these assessments may vary depending on the problem area. In certain cases, they were very dependable, whereas in other cases they could

merely represent assessments of the maximum benefit. Therefore, the potential (number of saved lives per year) of different countermeasures or intervention areas were grouped depending on the reliability of the assessment. Countermeasures were also grouped depending on which element of the road system (user, vehicle and infrastructure) they related to.

The countermeasures or intervention areas to be included in this study were discussed with a number of stakeholders within the joint strategy for improved safety for motorcycle riders in Sweden for the period 2010-2020 [2] and are listed below. The basis for each assessment is explained separately.

- Antilock brake systems (ABS) on motorcycles
- Improved motorcycle conspicuity
- Traction Control systems (TC) on motorcycles
- Airbags on motorcycles
- Intelligent Speed Adaptation (ISA) on motorcycles
- Immobilizers on motorcycles
- Alcolocks on motorcycles
- E-call on motorcycles
- Improved visibility in other vehicles (i.e. A-pillar etc.)
- Approved motorcycle technical inspection
- Median barriers
- Improved sight distance in the road environment
- Safe intersections in urban areas
- Safe roadsides
- Motorcycle-friendly side barriers
- Clean and regular road surface
- Proper road repairs
- Safe intersections on rural roads
- Motorcyclists' speed limit compliance
- Improved motorcycle rider conspicuity/other road-users' attention
- No drunk-driving
- Motorcycle riders' proper risk judgment or capability
- Use of helmets
- Use of full-body protective clothing
- No motorcycle lending
- More strict medical requirements for motorcycle driving
- Other road-users' proper risk judgment or capability
- No use of unregistered motorcycles on the road
- Safe motorcycle riding in groups
- Rested motorcycle riders
- Motorcycle riders' appropriate driving license category
- Improved motorcycle riders' attention

The vehicles

Antilock brake systems (ABS) on motorcycles were estimated to decrease all types of fatal crashes by 40%. This assessment was considered to be certain, since a study based on Swedish real-life crash data [3] as well as others [4, 5] have shown that ABS has approximately this effect.

Improved motorcycle conspicuity was based on the number of crashes in which the critical event was another road-user not seeing or spotting the motorcycle. Crashes in which the line of sight was obstructed due to obstacles in the road environment (i.e. trees) were not included in this assessment. However, this potential was considered to be uncertain, since in in-depth material it can be difficult to discern visibility from attention, i.e. to distinguish between scenarios in which the crash was due to the other road-user actually not seeing the motorcycle and those crashes in which the other road-user did not pay enough attention.

Traction Control systems (TC) on motorcycles were considered to be effective in crashes in which the critical event was a power skid or the rider pulling a “wheelie”. This potential was considered to be certain as Traction Control systems could prevent this kind of situations.

Airbags on motorcycles were considered to be effective in crashes in which the motorcycle rider remained seated on the motorcycle during the collision and in which the speed was not in excess of 70 km/h. The potential was considered to be uncertain, since no evaluations based on real-life crashes have been carried out yet.

Intelligent Speed Adaptation (ISA) on motorcycles is not common. However, it was considered that this system could theoretically prevent all crashes in which the motorcycle speed was a critical factor for the crash. This assessment was uncertain, possibly even very uncertain, since no evaluations based on real-life crashes have been carried out yet. Moreover, at the moment it is not possible to assess the (probably large) potential in form of injury mitigation. It is reasonable to assume that reduced impact speed would have a considerable injury mitigating effect in all types of motorcycle crashes, and therefore the calculated potential is likely to be an underestimation.

Immobilizers and alcolocks on motorcycles would eliminate crashes involving stolen motorcycles and crashes in which motorcyclists who were under the influence of alcohol were killed due to their own mistakes. Both potentials were considered to be certain, since the riders in these crashes would not have had access to road traffic (see Figure 3) if the motorcycles had been fitted with immobilizer and alcolock systems.

E-call on motorcycles was considered to be effective in single crashes in which the killed motorcyclist was found more than one hour after

the crash and in which the forensic examination estimated that they did not die immediately after the collision. However, the potential was somewhat uncertain, since it was difficult to estimate how many of these fatalities could have been prevented if the crash had been reported earlier.

Improved visibility in other vehicles (i.e. A-pillar etc.) had a potential in crashes in which the driver of another vehicle stated that the motorcycle was concealed by the vehicle structure itself (i.e. A-pillar) or by some other vehicle. This potential was considered to be somewhat uncertain, since it was impossible to guarantee that the crash could have been avoided if the visibility had been improved.

Approved motorcycle technical inspections were considered relevant in those crashes in which the motorcycle had significant technical faults (i.e. malfunctioning brakes) that could be expected to be detected in a technical inspection.

The infrastructure

Median barriers were considered to be effective in preventing head-on crashes. Crashes in which the motorcyclist lost control and collided with oncoming traffic were excluded, since it is highly unlikely that a conventional median barrier would have mitigated the injury outcome. A Swedish study [6] has shown that serious and fatal motorcycle crashes have been substantially reduced on newly built roads with cable median barriers. However, the possible effect based on analysis of in-depth studies was considered to be somewhat uncertain, since it was impossible to exclude the possibility that the fatal crash would still have occurred if a median barrier had been present. While the type of barrier and its position are also important for the crash outcome, this aspect could not be taken into account.

Improved sight distance in the road environment had the potential for preventing crashes in which limited visibility due to obstacles in the road environment was a decisive factor. However, the potential was somewhat uncertain, since sight distance does not necessarily improve the driver's attention, although this would most probably improve the chances of detecting the motorcycles.

Intersections in urban areas: rebuilding ordinary intersections into roundabouts was considered to be effective in preventing all fatal crashes that occurred in an intersection in urban areas, excluding those crashes involving excessive speeding. In certain cases, it was difficult to assess the speed at which the crash could have been prevented, and the potential was therefore somewhat uncertain.

Safe roadsides: with this term it was meant that the area immediately adjacent to the road is cleared of any fixed object (such as poles, trees or rocks)

that could be dangerous in a collision. This intervention area was considered to be relevant in single crashes in which the motorcyclist was killed in a collision with some fixed object in the roadside. However, it was difficult to exclude that the motorcyclist could not have continued out into the terrain and collided with some other object if the roadside had been cleared. This potential was therefore uncertain.

Motorcycle-friendly side barriers were considered to be relevant in crashes in which a conventional barrier was the primary collision object. However, in crashes in which the impact speed was very high, the design of the barrier may be insignificant to the possibility of survival. The potential was somewhat uncertain, since it would be necessary to carry out a larger evaluation based on real-world crashes with conditions that comparable to Swedish ones.

A clean and regular road surface was expected to prevent crashes in which the poor condition of the road surface was a certain cause for the crash. This potential was considered certain.

Proper road repairs had the same criterion as clean and regular road surface. This potential was considered certain too.

Safe intersections on rural roads could have a great potential, since many crashes at intersections occurred on rural roads. However, crashes involving excessive speeding were not considered, for the same reason as for intersections in urban areas. The potential was uncertain, principally because there is no known specific road design that has been tested and evaluated with respect to motorcyclists.

The users

A number of countermeasures or intervention areas that related to the user have effect on the same crashes as countermeasures related to the vehicle. Their potentials were therefore assessed in the same manner.

Speed limit compliance had therefore the same potential as Intelligent Speed Adaptation (ISA).

Improved motorcycle rider conspicuity had the same potential as improved motorcycle conspicuity.

No drunk-driving was considered to be effective in the same crashes as alcohollocks on motorcycles. However, this potential was somewhat uncertain as the road traffic could still be accessed (see Figure 3).

Motorcycle riders' proper risk judgment or capability applied to crashes in which the rider's assessment of the traffic situation, risky behavior or poor riding knowledge (such as braking or cornering techniques) were considered to be critical factors in the crash. The potential was not certain, since it was difficult to determine to what extent a

crash could have been avoided or mitigated with, for instance, a less risky behavior.

Use of a helmet and full-body protective clothing were considered certain in those crashes in which a killed motorcyclist without helmet or full-body protective clothing would have survived with them, according to the forensic examinations.

No motorcycle lending: there are indications that riders who do not drive their own motorcycle are generally overrepresented in fatal crash involvement. No motorcycle lending was therefore considered to have an effect in preventing crashes, excluding those cases in which the motorcycle was stolen. However, this effect was uncertain, since it may sometimes be difficult to assess in in-depth studies when the motorcycle had been loaned or not. Moreover, in fatal crashes lending was often combined with alcohol and lack of helmet or other protective equipment. Consequently, the potential could be regarded as very uncertain.

More strict medical requirements for motorcycle driving were also difficult to assess. This countermeasure is not related to the actual motorcycle use, but rather to the access to the road traffic (see Figure 3). This assessment was based on cases in which serious illness could have caused the crash. Such assessment was also difficult to make and the potential of this intervention area was therefore considered to be uncertain.

Other road-users' proper risk judgment or capability had the same approach as for motorcyclists. The assessment in these cases was also relatively certain.

No use of unregistered motorcycles on the road was considered relevant in crashes in which an unregistered motorcycle was involved in the fatal crash. This potential was certain, as access to road traffic would be denied, although there is no known way to effectively achieve this.

Safe motorcycle riding in groups was considered relevant in those crashes in which the poor assessment of the traffic situation by one of the motorcycle rider of the group could have caused the crash. However, the potential was uncertain, since it was difficult to assess the extent to which safer group riding could have prevented these crashes.

Rested motorcycle riders: in general, an assessment of whether fatigue is the cause of a crash is difficult and particularly difficult in the case of motorcycle crashes. The potential of rested motorcycle riders was therefore somewhat uncertain, although every year in Sweden a number of crashes occur in which it is suspected that the rider could have fallen asleep on his motorcycle.

Motorcycle riders' appropriate driving license category was based on those crashes in which the motorcycle rider had no motorcycle driving license. Purely hypothetically, the crash could have been avoided if the rider had had the

right driving license category and thus better competence. However, the potential was uncertain or even very uncertain, since it is doubtful whether holding a motorcycle driving license by itself would have been sufficient to avoid the crash or not.

Improved motorcycle riders' attention was based on the number of crashes in which the rider's inattention was considered to be a cause of the crash. This assessment was considered to be fairly certain.

RESULTS

Analysis of in-depth studies of fatal motorcycle crashes in Sweden showed that all killed motorcyclists who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license (see Figure 4).

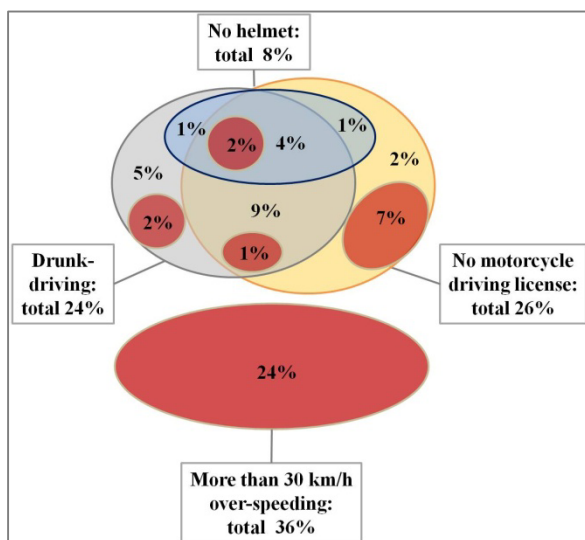


Figure 2. Relationship between influence of alcohol, use of helmet, motorcycle driving license, and estimated driving speed in fatal motorcycle crashes in Sweden 2005-2008.

As shown in Figure 4, it was found that 58% of all motorcyclists killed were either under the influence of alcohol, or did not use a helmet, or had no motorcycle driving license or drove more than 30 km/h over the speed limit. Besides, more than half of the killed motorcyclists killed who had no motorcycle driving license were under the influence of alcohol.

It was also found that in more than one third of the fatal crashes the motorcyclists' driving speed was judged to be at least 30 km/h over the speed limit. It was also shown that excessive speeding did not correlate with any other analyzed risk factor in two thirds of the crashes in which over-speeding by more than 30 km/h was present.

However, it was also found that that in only 2% of the cases all risk factors (rider under the influence of alcohol, not wearing a helmet, no motorcycle driving license and more than 30 km/h over-speeding) were present at the same time. In practical terms, this meant approximately one case per year in Sweden.

The results for the analysis of the potential of different countermeasures are presented depending on which element of the road system they related to: the vehicle (see Table 2), the infrastructure (see Table 3) and the user (see Table 4). The potentials are shown as number of lives per year that could have been saved in Sweden (in average, 53 motorcyclists were killed every year in Sweden during the period 2005-2008). The potentials were also grouped depending on the reliability of the assessment, as explained above.

Table 2. The potential of vehicle countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The vehicles	Certain potential (relationship is known or the assessment was certain)	Somewhat uncertain potential (relationship is missing or the assessment was somewhat uncertain)	Uncertain potential (further research is needed)
Antilock brake systems (ABS) on motorcycles	21 (40%)		
Improved motorcycle conspicuity			6 (11%)
Traction Control systems (TC) on motorcycles	5 (9%)		
Airbags on motorcycles			7 (13%)
Intelligent Speed Adaptation (ISA) on motorcycles			>15 (>28%)

Immobilizers on motorcycles	3 (6%)		
Alcolocks on motorcycles	8 (15%)		
E-call on motorcycles		4 (8%)	
Improved visibility in other vehicles (i.e. A-pillar etc.)		3 (6%)	
Approved motorcycle technical inspection	2 (4%)		

Table 3.
The potential of infrastructure countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The infrastructure	Certain potential (relationship is known or the assessment was certain)	Somewhat uncertain potential (relationship is missing or the assessment was somewhat uncertain)	Uncertain potential (further research is needed)
Median barriers		6 (11%)	
Improved sight distance in the road environment		6 (11%)	
Safe intersections in urban areas		4 (8%)	
Safe roadsides			6 (11%)
Motorcycle-friendly side barriers		5 (9%)	
Clean and regular road surface	2 (4%)		
Proper road repairs	<1 (<2%)		
Safe intersections on rural roads			8 (15%)

Table 4.
The potential of user countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The users	Certain potential (relationship is known or the assessment was certain)	Somewhat uncertain potential (relationship is missing or the assessment was somewhat uncertain)	Uncertain potential (further research is needed)
Motorcyclists' speed limit compliance			>15 (>28%)
Motorcycle riders' proper risk judgment or capability		16 (30%)	
Use of helmets	4 (8%)		
No drunk-driving		8 (15%)	
Use of full-body protective clothing	3 (6%)		
No motorcycle lending			9 (17%)
More strict medical requirements for motorcycle driving			7 (13%)
Other road-users' proper risk judgment	2 (4%)		
No use of unregistered motorcycles on the road	3 (6%)		
Safe motorcycle riding in groups			4 (8%)
Rested motorcycle riders		3 (6%)	
Motorcycle riders' appropriate driving license category			14 (26%)
Improved motorcycle rider conspicuity / other road-users' attention			6 (11%)
Improved motorcycle riders' attention	5 (9%)		

As shown in Tables 2, 3 and 4, the most promising countermeasures with a certain assessment were Antilock brakes (40%) and alcolocks (15%) on

motorcycles. Among those countermeasures or intervention areas with a somewhat uncertain assessment, motorcycle riders' proper risk judgment

or capability (30%), no drunk-driving (15%), median barriers (11%) and improved sight distance in the road environment (11%) were the most promising ones. Other countermeasures or intervention areas with great potential were speed limit compliance or ISA systems on motorcycles (at least 28%) and motorcycle riders' appropriate driving license category (26%). In these cases, however, the assessments were uncertain and further research is therefore needed.

DISCUSSION

This study analyzed motorcycle fatal crashes in Sweden and showed that some risk factors such as no helmet, drunk-driving, no motorcycle driving license and excessive speed may often occur in the same crash. For instance, it was found that all killed motorcyclists in Sweden during the period 2005-2008 who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license. This suggested that, in those crashes, the lack of a helmet could be related to a certain type of behavior, that is, this was likely to be a conscious violation rather than a simple error. It is therefore important to take this into account when planning campaigns or other countermeasures to address this issue.

In this study, assessments were made on whether certain countermeasures could have prevented motorcycle fatal crashes or mitigated the injury outcome. However, it is clear that the reliability of these assessments may vary depending on the problem area. While the STA's in-depth studies contain very comprehensive material, in some cases it was difficult to assess the potentials of certain countermeasures due to the lack of information.

In the present study, the possibility of preventing fatal crashes has been assessed in the first place, since the material was based on in-depth studies of fatal crashes. While countermeasures that are effective in reducing the number of fatalities among motorcyclists could also be appropriate for reducing the number of seriously injured, further research is needed to determine whether this is the case.

Among all analyzed countermeasures or intervention areas, Antilock brakes (ABS) on motorcycles were estimated to have the largest effect in terms of saved lives per year. Intelligent Speed Adaptation (ISA) on motorcycle could have also saved many lives, at least 28%. The same potential applied to speed limit compliance for motorcyclists. While ISA has shown promising results on passenger cars [7], no evaluations on motorcycles have been carried out yet. A recent Swedish survey [8] showed that approximately 10%

of the two-thousand participants were positive to implementing ISA on motorcycles. However, it should be noted that, while the potentials of ISA or motorcyclists' speed limit compliance were uncertain, this was most likely an underestimation as no effects on injury mitigation were taken into account.

The most promising infrastructure countermeasure was safe intersections on rural roads, although the potential was considered to be uncertain due to the lack of a specific road design. Median barriers and improved sight distance in the road environment were also found to have significant potentials in reducing motorcycle crashes (11% reduction), although these assessments were somewhat uncertain. Motorcycle-friendly barriers were found to have the same potential, even though the assessment was uncertain due to the lack of real-life evaluations.

Among user countermeasures, motorcycle riders' proper risk judgment or capability was found to be a promising intervention area with a large potential (30%). However, this potential was considered somewhat uncertain as it may be difficult to determine to what extent a crash could have been avoided or mitigated with, for instance, a less risky behavior.

Motorcycle riders' appropriate driving license category had a great potential as well, as 26% of the motorcycle riders involved in these fatal crashes did not have one. However, this potential was uncertain too as it was impossible to exclude that the crash would have occurred anyway, even if the rider had had a proper driving license, as riding without a motorcycle driving license was often associated with other risky behaviors (see Figure 4).

The potentials shown in Table 2, 3 and 4 were calculated separately and no interactions were taken into account. For instance, it could be argued that increased speed limit compliance would enhance the effectiveness of helmets, full-body protective clothing and motorcycle-friendly barriers. On the other hand, it could be expected that, with the implementation of Antilock brakes on a large scale, fewer motorcyclists would fall prior to collision, thus reducing the number of crashes in which motorcycle-friendly barriers may be effective. Besides, it should be noted that in many cases the potentials presented in this study may overlap. For instance, a motorcyclist under the influence of alcohol who was killed in a collision with a conventional side barrier could have been saved by both alcolocks and motorcycle-friendly barriers. At the same time, the potential of some countermeasures may be added to each other, for

instance ABS and Traction Control System, as they act on different types of critical situations.

This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. While certain intervention areas may already be included in other action plans (i.e. safe intersections on urban and rural roads, improved sight distance, median barriers and roundabouts), this study showed that those intervention areas may be effective in reducing fatal motorcycle crashes too.

However, it is also important to keep in mind that the potentials of the analyzed countermeasures or intervention areas shown in this study were based on Swedish crash data. While the material was fully representative for Swedish conditions, possibly for Scandinavian conditions at large, it should be noted that Sweden is a small country with particular weather conditions. The use of motorcycles and the infrastructure may therefore differ in other regions of the world. For instance, the calculated potential of use of helmets and fully-body protective clothing, approved motorcycle technical inspection, clean and regular road surface or proper road repairs was relatively low in Sweden due to the relatively limited number of relevant crashes. In the same way, median barriers and roundabouts are getting more and more frequent on the Swedish roads and it could therefore be argued that the potential of those intervention areas could be bigger elsewhere.

Furthermore, most of the motorcycles included in this study were heavier models (see Table 1) which may reflect the fact that motorcycling is a somewhat seasonal activity in Sweden. Clearly, lighter motorcycles (i.e. scooters) are rather uncommon in fatal crashes in Sweden, which may not be the case in other countries in which motorcycle are used as a mean of transportation as well. Further studies should therefore be carried out in other countries as well.

A possible limitation of this study is that the calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures or intervention areas. In most cases, the findings of this study could be seen as an assessment of the maximum benefit. While risk compensation would naturally affect the actual effectiveness of a certain countermeasure, further studies need to address this issue using real-world crash data after the implementation of a countermeasure. However, it should also be noted that no behavioral adaptation seems to have

occurred with the implementation of Antilock brakes (ABS) on motorcycles [3, 4, 5].

CONCLUSIONS AND RECOMMENDATIONS

- All killed motorcyclists in Sweden during the period 2005-2008 who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license.
- 58% of all motorcyclists killed were either under the influence of alcohol, or did not use a helmet, or had no motorcycle driving license or drove more than 30 km/h over the speed limit.
- Antilock brakes (ABS) on motorcycles were estimated to have the largest effect in terms of saved lives per year. Intelligent Speed Adaptation (ISA) on motorcycle could have also saved many lives, at least 28%. The same effect applied to speed limit compliance for motorcyclists.
- The most promising infrastructure countermeasure was safe intersections on rural roads, although the effect was considered to be uncertain due to the lack of a specific road design. Median barriers and improved sight distance in the road environment were also found to have significant effects in reducing motorcycle crashes (11% reduction).
- Among user countermeasures, motorcycle riders' proper risk judgment or capability was found to be a promising intervention area with a large potential (30%). However, this effect was somewhat uncertain. Motorcycle riders' appropriate driving license category had a great potential as well, as 26% of the motorcycle riders involved in these fatal crashes did not have one.
- This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. However, it is also important to note that Swedish conditions may differ from other countries. Furthermore, these calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures.

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