Cost-benefit analysis for ABS of motorcycles

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Kurzfassung · Abstract

Nutzen-Kosten-Analyse für ABS bei Motorrädern

Anfang 2000 hat die Europäische Kommission sich als Ziel gesetzt, die Zahl der Unfallgetöteten bis zum Jahr 2010 um die Hälfte zu senken. Schwerpunkte sind dabei der Pkw- und der Lkw-Verkehr. Hier konnte eine beachtliche Senkung der Unfallzahlen erreicht werden. Ein wichtiger Bestandteil des Programms stellt die Förderung von aktiven Fahrzeugsicherheitssystemen dar.

Die Sicherheit im Motorradverkehr wurde allerdings bis jetzt vernachlässigt. Seit dem Jahr 1991 ist die Zahl der getöteten Motorradfahrer pro Jahr weitgehend konstant geblieben. Im selben Zeitraum hat sich die Zahl der getöteten Pkw-Insassen mehr als halbiert. Von daher sind Initiativen zur Steigerung der Motorradsicherheit begründet.

Der aktiven Sicherheitstechnik Antiblockiersystem (ABS) wird ein großes Sicherheitspotential zugesprochen. Die vorliegende Studie beleuchtet ABS für Motorräder aus der volkswirtschaftlichen Sicht. Eine Nutzen-Kosten-Analyse soll klären, ob die volkswirtschaftlichen Nutzen von ABS bei Motorrädern höher sind als die dazu notwendigen Ressourcenaufwendungen. Mittels einer Sensitivitätsanalyse werden gegebenenfalls die maximal vertretbaren Ressourcenaufwendungen berechnet, ab denen ABS volkswirtschaftlich sinnvoll ist. Anschließend wird in einer Break-even Analyse geklärt, ab welchem Preis bzw. ab welcher jährlichen Fahrleistung sich ABS für den Nutzer lohnt. Hierzu wird der faire Marktpreis berechnet, den der Nutzer bereit ist zu bezahlen. Für die angenommenen Marktpreise wird ebenfalls die jährliche Fahrleistung berechnet, ab der sich ABS für den Motorradfahrer lohnt.

Der Zeithorizont der Analyse erstreckt sich auf die Jahre 2015 und 2020. Für diese beiden Jahre werden die Unfallzahlen hochgerechnet. Hierbei wurde prognostiziert, dass die Unfallhäufigkeit pro Million registrierte Motorräder entsprechend dem derzeitigen Trend abnimmt. Motorradfahren wird also sicherer. Der Motorradbestand wird langsamer wachsen als die Unfallhäufigkeit pro Million registrierter Motorräder abnehmen wird. In Summe bedeutet dies, dass in den Jahren 2015 und 2020 die Unfallzahlen geringer sein werden als heute.

Die Nutzen-Kosten-Analyse wird pro Jahr für jeweils vier Szenarien durchgeführt. Zwei Szenarien legen die Marktdurchdringung fest. Hier wird zwischen Trendszenario und obligatorischer Einführung ab dem Jahr 2010 unterschieden. Die beiden anderen Szenarien beschreiben das Unfallvermeidungspotential von ABS.

Die Wirkpotentiale werden mittels einer Literaturrecherche bestimmt. Aufgrund der Datenlage können nur die Potentiale berechnet werden, die aus der Sturzvermeidung vor dem eigentlichen Unfall resultieren. Demnach geht die Anzahl der Unfälle um 2,4 % zurück. Die Zahl der Unfallgetöteten sinkt um 12,1 %, die Zahl der Schwerverletzten kann um 11,7 % gesenkt werden. Die Zahl der leicht Verletzten nimmt allerdings um 2,1 % zu.

Diese Potentiale beziehen sich auf die Szenarien mit der höheren Wirksamkeit. Da nur die vermiedenen Sturzunfälle betrachtet werden, unterschätzen diese Zahlen das reale Wirkpotential allerdings immer noch.

Die erforderlichen Ressourcenaufwendungen hängen von der produzierten Menge ab. Je mehr ABS Systeme hergestellt werden, desto geringer sind die Kosten pro System. Dies liegt an realisierten Skaleneffekten und Lernkurveneffekten. Die Systemkosten hängen somit von der Ausstattungsrate ab. Für das Trendszenario liegen die Kosten für ABS bei 120 Euro für das Jahr 2015 und bei 105 Euro für das Jahr 2020. Im Szenario mit obligatorischer Einführung werden die Kosten auf 115 Euro für das Jahr 2015 und auf 100 Euro für das Jahr 2020 geschätzt.

Die Nutzen-Kosten-Verhältnisse liegen alle über der kritischen Schwelle von 1,0. ABS ist somit volkswirtschaftlich sinnvoll. Für die Szenarien mit der höheren Wirksamkeit von ABS liegen die Werte in der Spanne zwischen 4,6 und 4,9 und damit sogar über der Schwelle von 3,0.

Die Break-even Analyse kommt zu dem Ergebnis, dass ABS für den Nutzer ebenfalls sinnvoll ist. Die angenommenen Marktpreise von 400 Euro im Jahr 2015 und von 300 Euro im Jahr 2020 liegen deutlich unter den berechneten fairen Marktpreisen in Höhe von 701 Euro für das Jahr 2015 und 622 Euro für das Jahr 2020. Damit ist ABS für Motorradfahrer wirtschaftlich sinnvoll, die mehr als 2.200 km pro Jahr (für das Jahr 2015) bzw. mehr als 1.900 km pro Jahr (für das Jahr 2020) zurücklegen. Ein Motorradfahrer legt im Durchschnitt jährlich 3.900 km zurück. Somit lohnt sich ABS für die meisten Motorradfahrer. Auch hier sind nur die Ergebnisse für die Szenarien mit dem höheren Wirkpotential angegeben.

Cost-benefit analysis for ABS of motorcycles

At the beginning of the year 2000 the European Commission set the goal to halve the number of road deaths till the year 2010. The main focus are passenger car and lorry traffic. A significant reduction of the accident data could be reached in these groups. The advancement of active vehicle safety systems is an important issue of the programme.

The safety of the motorcycle traffic has been disregarded till now. Since 1991 the number of killed motorcycle riders per year has been constant. The number of killed passenger car occupants has been more than halved in the same period. This is why initiatives are caused for the increase of the motorcycle safety.

A great safety potential is expected for the Antilock Brake System (ABS). ABS for motorcycles is considered from the economic view in this study. A cost-benefit analysis shall clarify whether the economic benefit of ABS for motorcycles is greater than the consumed resources. Moreover, a sensitivity analysis will determine the maximal justifiable consumption in resource for which ABS is worthwhile. After the sensitivity analysis is done a break-even analysis will determine the market price respectively the annual mileage from which on ABS is worthwhile on user level. For this the fair end consumer market price is calculated which the user is ready to pay. For the considered market prices the annual mileage is determined from which on ABS is worthwhile for the user.

The considered time horizon for this analysis are the years 2015 and 2020. For each of these years the accident data is forecasted. At this, it is assumed that the frequency of having an accident per million registered motorcycles decreases based on the present trend. Thus, riding motorcycle gets safer. Hence, the accident data in the years 2015 and 2020 is lower than the accident data today.

The cost-benefit analysis is done for each year for four scenarios. Two scenarios handle the market penetration. The first one is the trend scenario, the second one is the mandatory equipment from the year 2010 on. The other scenarios describe the effectiveness of ABS.

The effectiveness rates are determined by a literature review. The only potential which can be considered due to the available data is the potential due to an avoiding of the downfall just before the real accident happens. According to this the number of accidents will decrease by 2.4 %. The number of fatalities will decrease by 12.1 %. The number of severe injuries decreases by 11.7 %. However, the number of slight injuries increases by 2.1 %.

The mentioned effectiveness rates are valid for the scenarios with the high effectiveness. Even these figures underestimate the actual effectiveness because there are only considered the avoided accidents with downfall.

The necessary consumption in resources depends on the produced volume. The more ABS systems are produced, the lower are the costs per system. This is due to realised effects of scale and effects out of learning curves. The system costs depend on the penetration rate. In the trend scenario the system costs for ABS are 120 Euro for the year 2015 respectively 105 Euro for the year 2020. In the mandatory scenario the system costs are 115 Euro for the year 2015 respectively 100 Euro for the year 2020.

The benefit-cost ratios are all over the critical barrier of 1.0. Thus, ABS is worthwhile on economic level. In the scenarios with high effectiveness the benefit-cost ratios range between 4.6 and 4.9. Thus, the values are even above the barrier of 3.0.

The result of the break-even analysis is that ABS is worthwhile on user level. The considered market prices are 400 Euro in 2015 and 300 Euro in 2020. They are clearly below the determined fair end consumer market prices. The fair end consumer price for the year 2015 is 701 Euro respectively 622 Euro for the year 2020. Thus, ABS is worthwhile for motorcycle riders with an annual mileage higher than 2,200 km (year 2015) respectively 1,900 km (year 2020). The annual mileage of a motorcycle rider is 3,900 km on average. Thus, ABS is worthwhile for most of the motorcycle riders. The mentioned results are valid for the high effectiveness scenarios.

Contents

1 Problem definition

The political road safety goal of the European Union is halving the number of road deaths by 2010. This target for improving road safety was phrased in the year 2000. It is set in the White Paper (EUROPEAN COMMISSION, 2001). The development of fatalities within the European Union shows the right direction but the decline is not sufficient yet. The share of motorcycle fatalities based on all fatalities has even grown in the period 2001 till 2004 (EUROPEAN COMMISSION, 2006).

In Germany the number of killed passenger car occupants decreased by 58 % in the period 1991 till 2006. In the same period the number of killed motorcycle occupants remains even constant (see also Fig. 2). The share of killed motorcycle occupants in the road deaths increased from 8.5 % in 1991 to 15.5 % in 2006 (DIW 2006, STATISTISCHES BUNDESAMT 2006a).

There are efforts to make the roads safer. The scientific research of the economical effectiveness is advanced for intelligent vehicle safety systems (IVSS) for passenger cars. European or German projects are e.g. CHAUFFEUR (2003), SEiSS (2005), ROSEBUD (2005), Cost-benefit assessment and prioritisation of vehicle safety technologies (2006), and INVENT (2006). The issue of these projects was the economical effectiveness of IVSS in the passenger car market. An ongoing project which can be mentioned is eIMPACT. In this project the economical effectiveness of another twelve electronic safety systems for passenger cars is assessed.

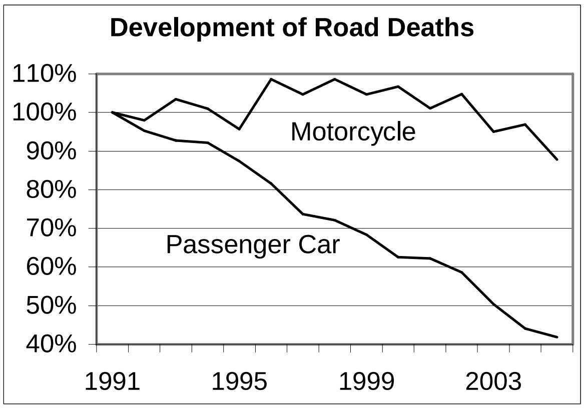

Fig. 2: Development of Road Deaths in Germany (1991 = 1)

The safety of motorcycle traffic has been disregarded in the last years. Thus, the topic traffic safety is still important – especially for motorcycles. The development of motorcycle fatalities shows that there is need for action. Motorcycles are part of the weaker traffic participants. They are vulnerable road users. The risk of being injured severely

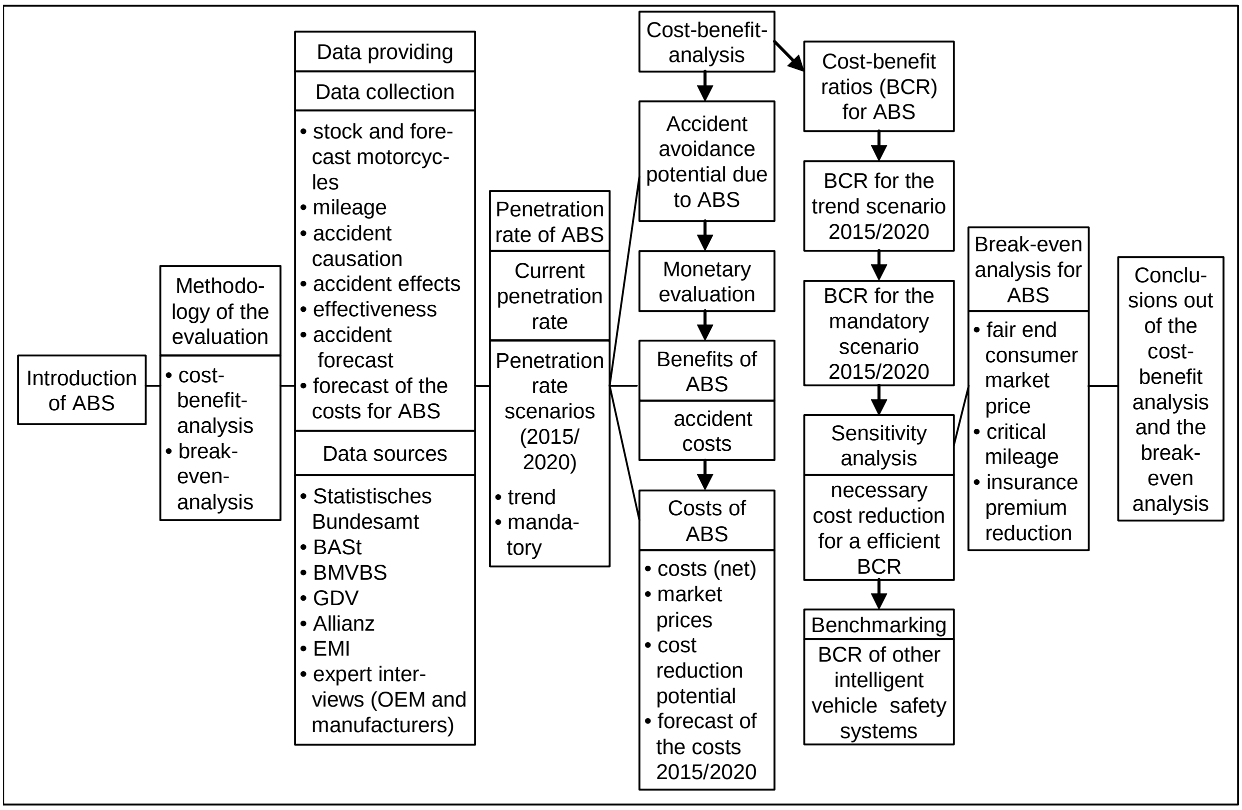

Fig. 1: Analytical framework for the cost-benefit analysis for ABS of motorcycles

is higher for motorcycle users than for vehicle occupants. Here, a good training and an improvement respectively an introduction of active safety systems is important to reduce the number of motorcycle fatalities.

For a while there is the awareness that the Antilock Brake System (ABS) can avoid accidents. It was introduced into the markets in the year 1988. There are demands out of the politics to make ABS mandatory for new motorcycles. For such a decision a cost-benefit analysis is necessary; on the other hand a break- even analysis will determine the effects on user level.

The purpose of this study is to assess the social profitability of ABS in motorcycles in Germany. The horizons for this analysis are the years 2015 and 2020.

At first an analytical framework is developed. With this framework the cost-benefit analysis will be performed. The conception of the analysis is displayed in Fig. 1. The focus is the providing of the data, the accident analysis, the derivation of the benefit-cost results, and the break-even analysis.

It is made a cost-benefit-analysis for the socio-economical assessment and a break-even-analysis on the user level. Four scenarios are handled for each year. There are two scenarios for different penetration rates and there are two scenarios for different effectiveness of ABS.

- The penetration rate of the first scenario, the trend scenario, adjusts the penetration rate of ABS for the status quo. Thus, there are no special incentives to promote ABS on the part of the politics in this scenario.
- The second scenario which considers the penetration rate is the mandatory scenario. In this scenario ABS has to be equipped in new motorcycles from the year 2010 on.

The other two scenarios handle the effectiveness of ABS.

- There is one scenario with a low effectiveness. Here it is considered that every avoided fatality is shifted to severe injury. The number of accidents and of slight injuries remains constant.
- The last scenario has a high effectiveness. In this scenario the number of accidents, of fatalities, of severe injuries, and of slight injuries changes.

The cost-benefit-analysis shall give an answer whether ABS is beneficial from society's point of view. This is the case for a benefit-cost ratio above 1. The system is excellent for a ratio above 3. If the ratio is lower than 3 respectively 1, the required cost-prices for ABS are determined. In the break-even-analysis the topic is the driver himself. In chapter 7.1 the critical price is determined for which ABS is worthwhile for the average user. Chapter 7.2 analyses the critical annual mileage for which ABS is worthwhile on user level.

2 Technology

In this chapter the used terms are defined, the historical ABS penetration rates are illustrated and a forecast of these parameters is performed.

2.1 Definitions

This subchapter handles the definitions of a motorcycle and of the considered vehicle safety system ABS.

2.1.1 Motorcycle

Finding the correct classification of a motorcycle is a bit difficult. There are a few problems to be solved. The first and the biggest one is the problem that ABS has not the same effectiveness in each motorcycle class. This is due to the different power, different brakes and of course different type of driver. The best would be to calculate a cost-benefit-analysis for each type of motorcycle – e.g. sport motorcycle, chopper or enduro. This is not possible because the accident data are on an aggregated level. That is why exact conclusions for each type of motorcycle are impossible.

Due to the accident data on an aggregated level scooters have to be considered as a motorcycle as well. That is not a real problem because ABS is also available for scooters.

In the next section the motorcycle which is considered in this study is defined exactly.

A motorcycle is a powered two wheeler (PTW) with or without a sidecar. The driving license which is needed for steering such a vehicle is the driving license of the class A. The class A contains motorcycles with cubic capacity from above 50 cm^3 or with a maximum speed higher than 45 km/h. The class A is subdivided in the subclasses A1 (light motorcycles), A restricted (max. power of 25 kW and unladen mass of 6.25 kg per kW) and A Full standard. (FEV, 2006)

2.1.2 Antilock Brake System (ABS)

The Antilock Brake System (ABS) is a system which prevents the wheels from locking while braking. The purpose of this is on the one hand to avoid a possible fall of the motorcycle rider and on the other hand to shorten braking distances. A front wheel which is locked leads to a fall of the driver. The risk of being injured seriously or even killed after a fall is twice as high as without a fall (ASSING, 2002; SPORNER, 2002).

There are four kinds of ABS in the market. In 1988 FTE automotive developed the first ABS for motorcycles (ORTH and SORG, 2005). This ABS is constructed for separate braking systems. The motorcycle has two separate brakes – one for the front and one for the rear wheel. Both brakes are activated separately – by pulling the brake lever or stepping on the brake pedal of the motorcycle. A scooter has two brake levers and no brake pedal. So the driver has to adjust the ideal brake force distribution on his own. This system is called (conventional) ABS.

The second form is called integral ABS (I-ABS). It was developed in 2001 by FTE automotive. Apart from the defined ABS control function, this system offers the usual combination of front and rear-wheel brake operation as found on passenger cars. Thus, the decision for the best brake force distribution is taken off from the driver. Other features are an electrohydraulic brake servo and an adaptive brake force distribution. This I-ABS has more comfort than the normal ABS and is more expensive. The advantages of the I-ABS are that the motorcycle rider brakes with the optimal brake force distribution. This is due to the fact that the motorcycle rider just has to pull the brake lever. The decision on the necessary brake force distribution is done by the system itself. The second advantage is that the brakes have the optimal brake pressure from the beginning on. Both advantages lead to a shorter brake distance.

The third form of ABS is called partial integral ABS and means that the rear brake system can be activated separately by stepping on the brake pedal. If the driver pulls the brake lever, he uses the integral ABS.

The fourth kind of ABS is for scooters. It is a single-channel ABS that means that there is only ABS for the front wheel. It is the cheapest kind of ABS.

For the further approach in this study it is not differed between the different types of ABS. This is due to the available accident data. Thus, the effectiveness of all the different systems is considered as identically. In this study it is assumed that the motorcycle user has got an instruction in the usage of ABS. The potential of ABS which is considered is the same for each ABS system provided that the system is used properly.

2.2 ABS data

ABS was introduced in the German motorcycle market in the year 1988 by BMW (ORTH and SORG, 2005). The first generation of motorcycle ABS was constructed for two separate braking systems. The driver has the choice to brake the front wheel or the rear wheel. The first ABS weighted 11.1 kg and was invented by FTE automotive. BOSCH entered the market in 1994 and presented the second generation of ABS. The weight was 4.5 kg. In the year 1998 the third generation of ABS was introduced. Its weight was only 2.6 kg (BOSCH 2006). The fourth generation of ABS was released in 2006. The weight is only about 1.5 kg. Another producer of motorcycle ABS is Nissin.

In 2006 Continental-Teves introduced its first ABS in the market. It is an I-ABS. The advantage of the second I-ABS generation is that there is no brake booster necessarily. Its weight could be reduced by 50 % so that it weighs about 2 kg (AUTO-GAZETTE, 2006).

In September 2002 Peugeot, Yamaha and Ducati presented first motorcycles with ABS on the occasion of the INTERMOT, which is the world biggest fair for motorcycles. In the earlier years BMW and Honda have been the only motorcycle producers which sold motorcycles with ABS (KOCH, 2002). BMW and Honda had a market share in total of 35.4 % in 2002 (IVM, 2003).

The number of motorcycle producers which have ABS or I-ABS in their motorcycles available has grown: Aprilia, Honda, Kawasaki, KTM, Moto Guzzi, Piaggio, Suzuki, Triumph, and so on. Out of the group of the big players, Motorradwerk Zschopau and Harley-Davidson (but for motorcycles for the police) are the only motorcycle producers, which have no ABS in their programme (HARLEY, 2007 and MZ, 2007).

The penetration rate of ABS is important to determine the number of avoidable accidents and casualties and to determine the system costs in the years 2015 and 2020. The higher the penetration rate within the complete motorcycle fleet the more accidents and casualties can be avoided. Thus the penetration rates for the year 2015 and the year 2020 have to be estimated.

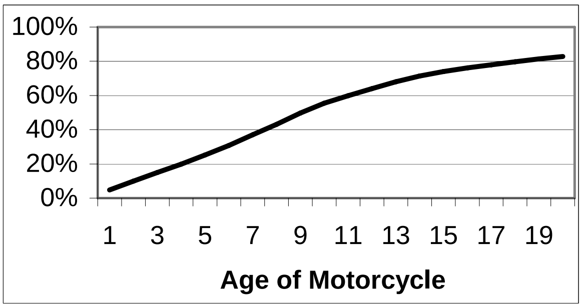

Fig. 3: Cumulated age distribution within the motorcycle fleet

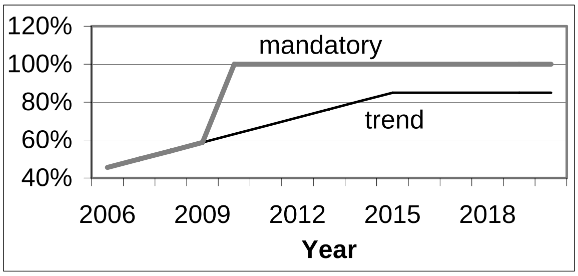

Fig. 4: Penetration rate of ABS for new motorcycles (PRNM)

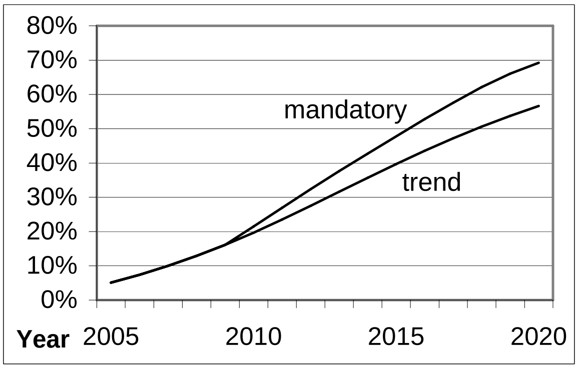

Fig. 5: Penetration rate within the complete motorcycle fleet

In the study there are considered two scenarios for the penetration rates:

- In the trend scenario there are no specific incentives to promote ABS.
- In the mandatory scenario ABS is mandatory from the year 2010 on. Thus, the penetration rate of the new motorcycles is 100 %. The penetration rate for the years before 2010 equals the penetration rates of the trend scenario.

The penetration rate of the complete fleet depends on the age distribution within the motorcycle fleet and the penetration rate of new motorcycles.

- Regarding the age distribution it can be seen that about 50 % of the motorcycles are younger than ten years. The share of motorcycles which is younger than twenty years is 81 % (KBA, 2006). Thus, it takes a long time to get a full penetration rate. Fig. 3 displays the cumulated age distribution. This cumulated age distribution can be used for forecasting the penetration rate of a system which is mandatory. Consider a system is introduced in the market and it is mandatory from the first year on. In this case the line displays the penetration rate within the complete fleet. ABS was introduced in 1988. Consider the hypothetical case that ABS had been mandatory from the first year on, the market penetration within the complete fleet would have been about 55 % in the year 1998. In the year 2007 the penetration rate would have been about 80 %.
- ABS was introduced in the year 1988, thus the year 1988 is the starting date. Till the year 2002 there had been only BMW and Honda who sold ABS. Hence, it can be assumed that the penetration rate before 2002 was very low. The penetration rate of ABS within the complete motorcycle fleet is considered as 5 % for the year 2005 (GWEHENBERGER ET AL., 2006). The penetration rate of ABS within the new sold motorcycles is estimated as 50 % in the year 2007. Further it is considered that a realistic upper limit of the penetration rate is about 85 % for new motorcycles (expert guess). This limit will be reached in the year 2015. The penetration rates of the new motorcycles are considered to follow a linear trend. Fig. 4 shows the considered penetration rate of ABS for new motorcycles for the scenarios trend and mandatory. The penetration rate is the same for both scenarios till the year 2009. Since 2010 the penetration rate for the scenario mandatory is fixed to 100 %. Hence, every new motorcycle is equipped with ABS since 2010. For the scenario trend the ABS penetration rate of new motorcycles follows a linear trend till the year 2015. In this year about 85 % of all new motorcycles are equipped with ABS. This penetration rate is considered as upper limit. Thus, the penetration rate of 85 % for new motorcycles is fixed for the following years.

For calculating the penetration rate of ABS within the complete fleet the share of motorcycles which are registered in year x and are equipped with ABS are summed up for all years. Thus, the following formula is used:

$$PRF_e = \sum_{t}^{e} SoM_{e,t} * PRNM_t$$

with

Year	trend	mandatory
2015	39.7%	47.8%
2020	56.7%	69.3%

Tab. 1: Fleet penetration rates for the considered scenarios

PRF Penetration rate of the complete fleet in the year e

e Year 2015 respectively year 2020

SoM Share of motorcycles registered in the year t within the complete fleet in the year e

PRNM Penetration rate of new motorcycles registered in the year t

The penetration rates for the complete fleet for the year 2015 respectively 2020 for both scenarios are the result of this formula. Fig. 5 displays the development of the penetration rate for the complete fleet for both scenarios for the period 2005 till 2020.

The penetration rates within the complete fleet for the trend scenario are 39.7 % for the year 2015 and 56.7 % for the year 2020. For the mandatory scenario the accordant values are 47.8 % for the year 2015 and 69.3 % for the year 2020 (see also Tab. 1).

3 Methodologies

This chapter gives an introduction in the used assessment tools – the cost-benefit analysis for the socio-economical assessment and the break-even analysis on the user level.

3.1 Cost-benefit analysis

Economic theory provides several methodologies for assessing and quantifying the specific values of (potential) socio-economic impacts. Besides the cost-effectiveness analysis (CEA), the cost-benefit analysis (CBA) is broadly-accepted as a sophisticated, objective evaluation instrument. In general, the CBA compares the potential economic benefits across a set of impacts with all relevant potential costs deriving from the implementation of a technology/measure. Since the CBA estimates benefits and costs in monetary terms by multiplying impact units by prices per unit, it can be used to assess the absolute efficiency of a technology/measure. Hence, the CBA aims at finding whether a proposed objective is economically efficient and how efficient it is. As a result of the analysis a quantitative relationship between benefits and costs is calculated. Although there are a number of indicators expressing the comparison between benefits and costs the most common is the benefit-cost-ratio.

The economic CBA originates from welfare economics. The increase of the overall economic production potential is used as a standard for evaluating a technology/measure (“resource-oriented approach”). The costs of the regarded measure are confronted with this overall economic effect. The benefits are defined in terms of productive resources saved within an economy (“cost-savings approach“). Given this definition, the implementation and deployment of technologies/measures should demonstrate profitability, which at least means in economic terms allocative efficiency.

In theory, the principle of allocative efficiency is determined by the situation that by introducing any kind of technology/measure at least one individual is made better off and no individual is made worse off (Pareto optimum). Since the consequent application of this criterion is impractical due to the impossibility of identifying all winners and losers, a potential Pareto optimum – the Kaldor-Hicks criterion – is generally applied. This criterion considers a measure as acceptable if the amount by which some individuals gain is greater than the amount that others lose for suffering higher costs. Hence, it is important to reach a net-benefit which allows – in principle – losers to be compensated by winners of the measure. No actual cash transfer is required. A measure may therefore be considered efficient even if some individuals lose, as long it generates net benefits (BOARDMAN ET AL., 1996). Consequently, social welfare may be enhanced by the redistribution of resources within society.

The Kaldor-Hicks criterion is commonly accepted and widely applied in welfare economics as well as in managerial economics. The criterion forms an underlying rationale for the cost-benefit analysis.

In the assessment of economic efficiency of road safety technologies/measures the evaluation of accident savings plays an important role, because these technologies/measures specifically aim to reduce the number and severity of current accidents. Avoiding accidents and achieving mitigation represent the direct benefits of road safety technologies/measures. In addition, the benefits encompass other savings of resources used within an economy, which also have to be taken into account. Due to avoided accidents the congestion is reduced. In the case of motorcycles this is different. As the motorcycle is an one-lane vehicle and most accidents occur on rural roads, there is only less congestion due to a motorcycle accident. Thus, time savings due to less congestion is considered as marginal. Linked to this issue there is no change in fuel consumption or emission exhausts and pollution. Hence, the only effect which is considered is the safety effect.

3.1.1 Cost-benefit analysis process

In general the CBA consists of a four step process. These four basic steps can be characterised as follows:

In the first step of the procedure the relevant alternatives that will be compared within the analysis have to be defined. For the CBA two cases are introduced:

- The “with-case“, which means that a road safety technology/measure like ABS will be introduced.
- The “without-case“, which assumes that there will be no implementation of the technology/measure to be evaluated.

Within the second step the potential safety impact has to be quantified. Conceptually, the main effect of road safety technologies/measures is the reduction of hazardous situations which affects the number and/or the severity of accidents. As a consequence, accident costs can be lowered.

Within the third step of the CBA process, the benefits are calculated in monetary terms by valuing the annual physical effects with standardised cost-unit rates. In addition to the monetarization of the physical benefits, the costs of the technology/measure have to be determined. The costs comprise the costs to be borne for implementation, operation and maintenance.

The result of the economic evaluation is obtained in the fourth step by comparing economic benefits with costs. For this comparison several measures can be calculated. The most common one is the benefit-cost-ratio (BCR) according to which a technology/measure is macro-economically profitable, if the calculated ratio is greater than one.

$$BCR_t = \frac{B_t}{C_t}$$

with

BCR	Benefit-cost ratio
t	Time horizon defined
B	Estimated value of benefits for t
C	Estimated value of costs for the year t

The value of the ratio indicates whether the implementation of ABS is favourable from a socio-economic point of view. A BCR of more than “1“ indicates that benefits exceed the costs. Thus, the introduction of ABS would be beneficial to society. Furthermore, the value of the BCR expresses the absolute profitability of ABS which can be interpreted as the socio-economic return for every monetary unit (e.g. Euro, US-$) invested in the implementation of ABS. For example, a BCR of “3.5” would show that 3.5 monetary units can be gained for society for every monetary unit provided for the investment evaluated. Setting absolute, monetised values of benefits and costs into relation, the BCR is a reliable indicator of efficient resource allocation.

In the cost-benefit analysis the costs and the benefits have to be determined. While the calculation of the physical benefits of ABS on basis of accident statistics and accident research is rather straightforward, the monetary valuation of accidents – that means the monetary valuation of injuries and human life – is a controversial matter. In this study the cost-of-damage approach is used to assess the value of the resource savings for the benefit categories.

The cost-of-damage approach is state of the art for cost-benefit analyses which are performed for Germany. The cost-of-damage approach is based on the total estimated amount of economic losses caused by any physical impact. Generally, the losses are quantified via the decline of gross product. For instance, the costs of an accident include the vehicle damage, medical and emergency costs and lost productivity of killed or disabled persons.

There are different benefits due to accident savings which have to assessed:

- Benefits due to the safety potential: The accident is avoided respectively the severity class of the accident is reduced. Thus, the number of casualties and the property damage can be reduced.
- Benefits due to avoided congestion: An accident implies congestion. If the accident is avoided or the severity class of the accident is reduced, there is no congestion respectively there are less time losses for the other traffic participants.

Benefit-category	relevant for this study
safety potential	yes
avoiding congestion	no
influence on the traffic-flow	no

Tab. 2: Relevant benefit categories

- Benefits due to reduced operating costs and emissions (pollutants and carbon dioxide): Linked to the point mentioned above there is less congestion. The fuel consumption and linked to this the emission is very high in congestion. If there is less congestion the fuel consumption and the emissions can be reduced.

In this study the first mentioned point is the most important one. Accidents with motorcycles mostly occur on roads with less traffic (ASSING, 2002; INFRAS/IWW, 2004). In addition to that there are fewer lanes affected due to motorcycle accidents. Thus, costs due to congestion are neglected.

ABS does not influence the traffic flow. Hence, there is no potential in saving operating costs or in saving emission outcast respectively pollution.

Tab. 2 displays the relevant benefit categories for this study.

3.1.2 Sensitivity analysis

The calculations of benefits and costs of ABS depend on a variety of factors. In particular, these influencing factors are:

- Data related to ABS (e.g. safety impact, costs and prices),
- Demand data (e.g. market penetration),
- Model Parameters (e.g. discount rate, cost unit rates).

Due to their nature of being input data for the CBA, these factors consequently determine the Benefit-Cost Ratio as the final result of the CBA calculation process. It therefore makes sense to perform the economic evaluation of ABS for more than one case, i.e. for various scenarios referring to different paths of the ABS implementation. With other words, different "with"-cases" have to be accounted for. For this, sensitivity analyses are performed.

The purpose of the sensitivity analyses is to select the "critical" variables and parameters of the socio-economic assessment. Critical variables are those whose variations, positive or negative, compared to the value used as the best estimate in the base case, have the greatest effect on the results of the CBA and consequently on the BCR.

The results of the CBA for ABS in terms of the BCR are most important for every kind of decision-maker interested in the evaluation of ABS before deciding on market introduction, deployment or promotion of the safety systems. Thus, the results should be presented in a way that is both comprehensive and coherent. As a consequence, ranges of BCR are given which illustrate the variance of evaluation results. In this context, classes for CBA results are introduced to expose a grading of the results. The following classes are used in the table (BAUM et al. 2006c):

- $0 < BCR < 1$: The BCR is rated "poor" showing that a socio-economic inefficiency of ABS is given,
- $1 \leq BCR < 3$: The BCR is rated "acceptable" meaning that the social benefits associated with the implementation of a safety system exceed the costs up to three-times which can be labelled as an acceptable absolute efficiency,
- $BCR \geq 3$: The BCR is higher than "3" indicating an "excellent" result of the socio-economic assessment. The system evaluated as "excellent" should be in first line for market deployment.

3.2 Break-even analysis

The break even analysis is a method of business administration used to determine from which production output an investment is getting profitable for the producer. Therefore, benefits and costs in dependence of output are put in contrast. Then the extent of output is being investigated which just brings benefits to the same level as costs. So the point is being determined where neither profits nor losses occur (=break even point). With lower output, costs are higher than benefits (=losses), with higher output, benefits are higher than costs (=profits).

The break even analysis is used in order to determine the benefits on user level and end consumer prices and to clarify if ABS is profitable for users and OEMs. Benefits and end consumer prices are being examined in dependence of the covered motorcycle mileage per year. It is assumed that benefits and end consumer prices are linear to the mileage. A low mileage means relatively high fixed end consumer prices and little benefit for ABS, so that a loss occurs. A high motorcycle mileage results in high benefits and low end consumer prices which is followed by a profit. In the break even point, benefits equal end consumer prices.

The private-individual benefits of the user accrue from the following cost savings:

- savings regarding avoided accident costs which are not covered by insurances,
- savings through rebates in insurance premiums due to smaller accident risks with IVSS,
- benefits of comfort for users.

In contrast to that, there are the investment costs for ABS on user level to be seen.

The benefit and cost components used in the break even analysis are partly also present in the cost-benefit analysis. The difference is that in the cost-benefit analysis only the actual benefits and costs are included, while the break even analysis considers the effective monetary savings and expenditures. This means in particular that in the break even analysis the flows of benefits and costs including taxes (value added tax) are calculated, while in the cost-benefit analysis taxes are treated as transfer payments and do not contribute to the parameters.

The result is expressed as motorcycle kilometres for which the costs are equal to the benefits. The cost-unit rates for the assessment of avoiding an accident are found with the willingness-to-pay approach. With this approach the calculation is based on an individual level. The value of the own life is individual for every person. The average value is higher than for the cost-of-damage approach which considers the economical losses. The willingness-to-pay approach displays a value on average which is generally accepted by the users. The ABS system is financed by credit taking.

Furthermore, the break even analysis provides information about the willingness-to-pay of ABS-users. The willingness-to-pay is limited by the prices for ABS charged by motorcycle manufacturers which may not be higher than the benefits for the users. A surcharge on benefits via benefits of comfort is allowed. In this study the comfort issue is not considered. In this respect, the price limit for ABS is defined by the break even analysis.

4 Data

The traffic and the accident data are topic of this chapter. The data is forecasted for the years 2015 and 2020. Because ABS is available on the market since 1988, the accident data has to be adjusted by the effects of the historical ABS-penetration rates. The adjusting process is also issue of this chapter.

4.1 Traffic data

In this chapter the vehicle mileage and the vehicle stock are handled. The vehicle mileage is important for the break-even-analysis while the vehicle stock is important for the cost-benefit-analysis. In the break-even analysis the mileage is determined for which ABS is worthwhile on user basis. Thus information about the vehicle mileage is important. The figure casualties per million motorcycle kilometre is an important figure in the break-even analysis. Another important figure within the break-even analysis is the figure annual mileage per user. For the cost-benefit analysis the vehicle mileage is not relevant. Here the costs of ABS depend on the motorcycle stock. In addition to that, there are done two important conclusions which are important for the study.

Motorcycles are used primarily for leisure trips. About 75 % of all motorcycle accidents with personal injuries are between April and September (SPORNER, 2002). The accident distribution during the day shows that the accident frequency in the afternoon between 3 and 10 pm is above average (ASSING, 2002).

Another characteristic for the use of motorcycles can be derived of the above described characteristic. In 13.3 % of all motorcycle accidents the road surface was wet. For accidents which were linked with a downfall of the motorcycle rider, the share is slightly higher – 16.7 % (SPORNER, 2002). Thus, the weather is important. In a year which has dry days above average, the motorcycle mileage is higher than for a year which has wet days above average. Linked to this, the number of accidents is higher in years with good weather than in years with bad weather.

4.1.1 Motorcycle mileage

The first parameter which has to be determined is the motorcycle mileage. As mentioned above, an exact forecasting for the future is nearly impossible. Thus, there is a need for a simple model. For this, the mileage for each motorcycle is considered as constant during the time. The mileage is 3,900 km on average per motorcycle (KALINOWSKA, 2005). Hence, the total motorcycle mileage is 14.9 million vehicle-km in the year 2005. Because of the growing motorcycle stock the trend is upwards. The advantage of this approach is that there has to be done just one forecasting, because the mileage is linked to the motorcycle stock.

The mileage per motorcycle is considered as constant.

The mileage will be forecasted because its value for the year 2015 can be taken from the integration scenario of the Bundesverkehrswegeplan 2003 (German masterplan for infrastructure development) (BMVBW, 2003). The prognosis for the motorcycle mileage in the year 2015 is 17.7 billion km (MANN, 2001). Hence, the only unknown value is the mileage in the year 2020.

In the Bundesverkehrswegeplan 2003 there is mentioned another scenario, the trend scenario. The differences between them are on the one hand different regulatory activities and on the other hand that every traffic mode shall play its advantages against each other. Hence, the trend scenario has a higher motorcycle mileage than the integration scenario. As mentioned above the motorcycle traffic is performed mostly in leisure and so driving motorcycle is a hobby for most bikers. This might lead to the assumption that the motorcycle mileage should be independent from the chosen scenario. The more realistic mileage would then be the one of the trend scenario. In this study the mileage out of the integration scenario is chosen. The reasons for this are: first the results of the integration scenario is a political goal and second using the values of the integration scenario leads to a conservative and more trustworthy result. This is linked with a likely underestimation of the accident data and the safety benefits.

The approach for forecasting the motorcycle mileage for the year 2020 is a regression model. The used data set is the mileage for the years 1991 till 2005. The linear regression approach with the time as independent fits best. The formula for the mileage in billion vehicle-kilometres equals:

$$\text{Mileage}(t) = 5.05 + 0.72 * t$$

with

t Considered year since 1991

With the linear regression model the value for the year 2015 is calculated. The value is higher than the value for the integration scenario. This is due to the characteristic of the described scenario. Thus, the forecasted value has to be scaled down to the given value. Therefore the ratio between forecasted absolute growth and given growth is used on the forecasted value for the year 2020. The result is the motorcycle mileage in the year 2020. It is 19.1 billion km.

4.1.2 Motorcycle stock

For the socio-economic assessment of ABS the motorcycle stock for the considered years – 2015 and 2020 – is important. To make a prognosis, the motorcycle stock since the year 1991 is analysed. For the years 1988 till 1990 there are problems with the data: the data is not available completely and there was the reunion in Germany. In 1991, there were nearly 1.5 million motorcycles reported for West Germany. Since 1993 the motorcycle stock is specified for Germany. In the year 2006 the number of motorcycles was about 4 Million (STATISTISCHES BUNDESAMT, 2007). Thus, there can be seen an upward trend. The number of motorcycles will grow even in the next years.

For the motorcycle stock the mileage for 2015 and 2020 has to be divided by the annual mileage per motorcycle. Thus, in the year 2015 there will be about 4.5 million motorcycles registered and about 4.9 million motorcycles in the year 2020. Hence, the motorcycle stock depends on the assumptions of the integration scenario of the Bundesverkehrswegeplan 2003.

All the values are presented in Tab. 3.

4.2 Accident data

In this chapter

- the number of accidents with personal injuries,
- the number of fatalities,
- the number of severe and
- the number of slight injuries are analysed.

The data is collected since 1991, this is the first year data is available for Germany after the reunion. The youngest data is available for 2006. With this dataset the situation in 2015 respectively 2020 is forecasted.

The data for motorcycle stock, accidents with personal injuries, severe injuries and slight injuries is based on the data from the Federal Statistical Office Germany (STATISTISCHES BUNDESAMT 2006a, STATISTISCHES BUNDESAMT 2006b).

4.2.1 Fatalities

The number of fatalities moves between 1,000 and 800. At first view there is no trend observable in the absolute numbers. For forecasting the number of fatalities for the year 2015 respectively 2020, a regression will be done. Thus, in a first step a figure has to be found for which a trend is observable. The figure fatalities per million motorcycles is decreasing during the time (Fig. 6). With this figure the number of fatalities can be determined by multiplying it with the motorcycle stock in million. The regression is done for the period from 1993 till 2006. This is because the motorcycle stock for the years 1991 and 1992 is specified for West Germany only (STATISTISCHES BUNDESAMT 2007). Another reason the considered period starts in the year 1993 is that the data from other sources is based on another reference date. For example, the DIW (German Institute for Economic Research) counted the motorcycle stock till the year 1997 at the end of February, the KBA (Federal Motor Transport Authority) counted the motorcycle stock till 2000 at the first of July while the Statistisches Bundesamt counts the motorcycle stock at the first of January (DIW 2006, KBA 2007, STATISTISCHES BUNDESAMT 2007). Thus, STATISTISCHES BUNDESAMT has the longest comparable time series. Its data is comparable for the period from the year 1993 on.

Thus, the figure fatalities per million motorcycles has to be forecasted. The best regression approach is the logarithmical regression with the time as independent. The formula is as follows:

$$FPMM(t) = 492 - 102 * \ln(t)$$

with

FPMM	Fatalities per million motorcycles
t	Considered year since 1993

This figure displays the number of fatalities per million motorcycles in the year t. Calculating the ratio for the year 2015, t is the considered year number 23. In 2015 there are about 171 fatalities per million motorcycles. This value has to be multiplied with the motorcycle stock in million to get the number of fatalities. In the year 2015 there are about 4.5 million motorcycles registered. Thus, there are about 777 fatalities in the year 2015 (171 fatalities per million motorcycles * 4.5 million motorcycles). In the year 2020 the number of fatalities is 746 (Tab. 3).

Eventually, the number of fatalities is determined by the integration scenario of the Bundesverkehrswegeplan 2003. This is due to the fact that the number of fatalities is calculated with the figure fatalities per million motorcycles. The motorcycle stock depends on the motorcycle mileage which is defined in the integration scenario of the Bundesverkehrswegeplan 2003. The model illustrates why

Year	Motorcycles in 1000	Mileage in bill. km	Accidents	Fatalities	Severe Injuries	Slight Injuries
1991	1,482*	5.8*	37,862	992	14,250	25,113
1992	1,618*	6.3*	34,881	903	12,623	23,740
1993	1,935	7.5	33,251	885	11,962	22,372
1994	2,121	8.3	36,210	934	12,885	24,518
1995	2,304	9.0	36,182	912	12,815	24,394
1996	2,534	9.9	35,350	864	12,148	23,830
1997	2,759	10.8	40,044	981	13,636	27,590
1998	3,007	11.7	37,833	945	12,726	25,985
1999	3,179	12.4	41,801	981	13,901	28,917
2000	3,410	13.3	39,809	945	12,835	27,332
2001	3,557	13.9	38,041	964	12,104	25,959
2002	3,657	14.3	37,620	913	11,859	25,507
2003	3,745	14.6	38,464	946	11,910	26,429
2004	3,828	14.9	34,889	858	10,969	23,484
2005	3,903	15.2	35,242	875	10,913	23,915
2006	3,969	15.5	33,573	793	10,589	22,689
2015	4,538	17.7	34,838	777	9,672	23,561
2020	4,939	19.1	34,487	746	9,058	23,275
* West Germany						

Tab. 3: Development of motorcycle stock and accident data

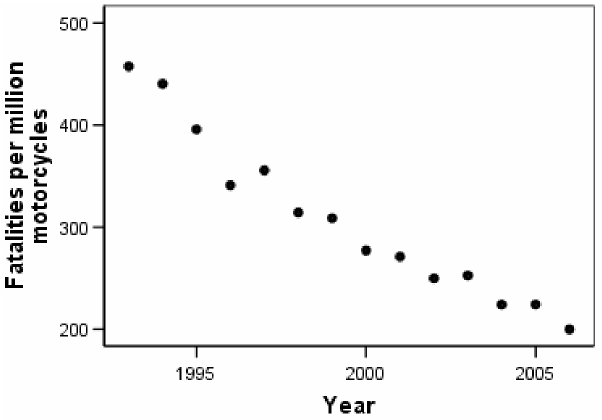

Fig. 6: Fatalities per million motorcycles

the number of fatalities has been constant in a wide range during the last twenty years.

ABS was introduced in the market in 1988, so it is likely that it has affected the number of fatalities yet. The risk for a motorcycle rider to be involved in an accident is higher for motorcycle riders without ABS. In other words, the accident data contains the respective ABS penetration rate for the motorcycle fleet in each year. This effect has to be considered in the further approach (see chapter 4.3).

4.2.2 Severe injuries

The first data for severe injuries is available for the year 1991. The years before, there was no differentiation between severe and slight injuries. There was only data for the category injuries.

The number of severe injuries lies between 10,600 and 14,250 for the considered period (see also Fig. 7). For the first twelve considered years there is no trend evident. Regarding the complete available data it can be seen that there is a slight downward trend which is dominating the curve. For the number of severe injuries as for all accident categories the weather is an important parameter.

The approach is similar as for the forecasting of the fatalities. Here also the figure severe injuries per million motorcycles is the most promising one. It is decreasing during the time. With this figure the number of severe injuries can be determined. At first the correlation matrix is analysed. The best correlation is for the time. The next step is a regression analysis. The best curve estimation is a logarithmical regression with the time as independent. The formula is as follows:

$$SePMM (t) = 6{,}865 – 1{,}510 * \ln(t)$$

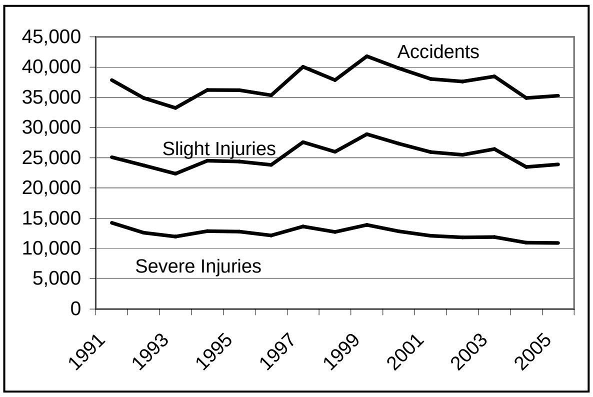

Fig. 7: Development of the number of accidents with personal injuries, severe injuries, and slight injuries

with

SePMM	Severe injuries per million motorcycles
t	Considered year since 1993

For the stock in the year 2015 the forecasted number of severe injuries is 9,672. The value for the year 2020 is 9,058 severe injuries (Tab. 3).

There is a comparable evolution within the number of severe injuries as for the number of fatalities. The motorcycle stock grows, the number of severe injuries remains nearly constant. For the time after 2006 the growth of the motorcycle stock will decline. Thus, the number of severe injuries has to decline. The motorcycle stock increases in the period from 2006 till 2015 from nearly 4 million motorcycles to about 4.5 million motorcycles. This equals an increase of 14.3 %. The number of severe injuries decreases in the same period. In the year 2006 there are about 2,700 severe injuries per one million motorcycles. This figure decreases to about 2,100 severe injuries per one million motorcycles. This decrease equals 20 %. Thus, the relative decrease of the figure severe injuries per one million motorcycles is higher than the relative increase of the motorcycle stock. Hence, the number of severe injuries has to decline also.

4.2.3 Slight injuries

The availability of the data is the same as for the data for severe injuries. So there is data available for the period 1991 till 2006.

Looking at the data there is also no superior trend evident. For the first ten years there is an upward trend. This upward trend got broken and was displaced by a downward trend (Fig. 7). Thus, it can not be said whether the superior trend is a downward trend or not.

For a regression the best figure is the number of slight injuries per million motorcycles. Analysing the correlation matrix the time is the best parameter for a regression model. Fitting the curve, the best regression function is also a logarithmical regression with the time as independent. The formula is as follows:

SlPMM (t) = 12,817 – 2,432 * ln(t)

with

SlPMM	Slight injuries per million motorcycles
t	Considered year since 1993

Thus, the number of slight injuries is also influenced by the integration scenario of the Bundesverkehrswegeplan 2003.

The forecasted value for the year 2015 is 23,561 slight injuries and 23,275 slight injuries for the year 2020 (Tab. 3).

4.2.4 Accidents with personal injuries

Also for this parameter the data availability is limited. The oldest data is for the year 1991, the youngest for 2006.

The number of accidents with personal injuries is moving between the upper limit of nearly 42,000 and the lower limit of circa 34,000 accidents. Regarding the chart (Fig. 7), it can be seen that there is an upward trend which is followed by a downwards trend. The chart is very similar to the chart of the slight injuries. Analysing the correlation matrix the interrelationship approves. The best curve estimation is a linear regression with the slight injuries as independent variable. The following formula shows this linkage:

Accidents (t) = 5,811 + 1.2 * (NSl (t))

with

NSl	Number of slight injuries
t	Considered year since 1993

Thus, the behaviour of the number of accidents with personal injuries is similar to the one of the number of slight injuries. The forecasted number of accidents is 34,838 in the year 2015 respectively 34,487 in the year 2020.

Hence, the complete accident data depends on the motorcycle stock which is determined by the integration scenario of the Bundesverkehrswegeplan 2003.

As mentioned in the traffic data chapter, the number of accidents is dependent from the weather condition. The nicer the weather, the more motorcycles are on the road, the more accidents happen. Thus, the forecasted values for the accident data are valid for a weather condition on average.

4.3 Adjusting the accident data

The forecasted accident data (see ch. 4.2) is valid for the trend scenario. ABS was introduced in the market in 1988. The penetration rate within the fleet is significantly greater than zero. So, ABS affects the accident data. This effect is greater for bigger penetration rates within the fleet. For calculating the ABS effect for the trend scenario, information about the accident data for the case no ABS in the market is necessary.

There are two possibilities for the consideration of the ABS penetration rate which is in the market.

- The first one is to adjust the historical accident data for the effects of ABS. This approach assumes that the penetration rate is known for every year since the market introduction of ABS. Hence, the accident data is adjusted for every year. The result are accident data for the hypothetical case that ABS has not been introduced in the motorcycle market before 2020. With this adjusted data the regression is done to get values for the years 2015 and 2020. Due to the fact that the historical penetration rates are not available completely this approach can not be done.
- The other way is to forecast the penetration rates of ABS for the years 2015 and 2020. The forecasted penetration rates are valid for the trend scenario. There is no special action from the politics to make ABS mandatory. Thus, the forecasted accident data are based on the assumption that the penetration rate of ABS for the years 2015 and 2020 equals the forecasted penetration rates. The forecasted accident data has to be adjusted by the forecasted penetration rate for 2015 re-

spectively 2020. The result is the accident data for the hypothetical case that ABS has not been introduced in the motorcycle market before 2020.

In this study the second approach is taken because of the incompleteness of the historical ABS penetration rates.

The forecasted accident data includes the effects of ABS for the trend scenario. In chapter 2.3 the penetration rate of ABS for the trend scenario is forecasted for the years 2015 and 2020. Thus, the effects of ABS have to be calculated. The adjusted accident data are the accident data for the case that there is no ABS in the market.

ABS avoids a certain share of the accident data. This share is called avoidance factor (BAUM and GRAWENHOFF, 2006a). This avoidance factor depends on

- the penetration rate of ABS within the complete fleet and
- the effectiveness which will be determined in chapter 5.3.

The avoidance factor equals the share of cases which can be avoided by ABS. If the effectiveness is greater than zero, the avoidance factor is also greater than zero. For an example, the avoidance factor is 5 %. Thus, 5 % of the accidents can be avoided by ABS. The forecasted accident data is too low because there would have been more accidents without ABS. The forecasted accident data equals in this case 95 % (1 – 5 %) of the accident data for the case without ABS. Hence, the adjusted number of accidents for the case no ABS is greater than the forecasted accident data.

A positive effectiveness leads to positive factors and therefore to higher adjusted accident data. Negative effectiveness would mean that the considered system causes accidents. Thus, the avoidance factor would be negative and the adjusted accident data would be less than the forecasted accident data.

The effectiveness rates of ABS are handled in chapter 5.3.

The formula for the avoidance factor is as follows:

$$af_{cat,t} = PR_t * EF_{cat}$$

with

af Avoidance Factor for the category in t

cat Accidents with personal injuries, fatalities, of severe injuries, or slight injuries

t Year 2015 or year 2020

PR Penetration rate of ABS in the year t

EF Effectiveness of ABS in the category

Penetration rate trend 2015	39.7%
Effectiveness for avoiding fatalities	12.1%
Avoidance factor af	39.7%*12.1% = 4.8%
Forecasted fatalities in 2015	777
The forecasted fatalities are the share which can not be avoided by ABS in the trend scenario	100%-4.8% = 95.2%
correction factor cf	1/95.2% = 1.05
Number of fatalities without ABS	777*1.05 = 816
Number of avoided fatalities in the trend scenario in the year 2015	816-777 = 39

Tab. 4: Example for avoidance and correction factor

In the year 2015 the penetration rate of the trend scenario is 39.7 %. The effectiveness of ABS for avoiding fatalities is 12.1 % (see chapter 5.3.2) for the scenario with high effectiveness. Thus, the avoidance factor af is 4.8 % (39.7 % * 12.1 %). Thus, in the year 2015 ABS avoids 4.8 % of all fatalities. As mentioned above the forecasted number of fatalities includes the effects of the trend penetration rate of ABS. In other words, the number of fatalities would be higher if the penetration rate of ABS would be zero in the year 2015. Based on this higher number 4.8 % of the fatalities can be avoided in the trend scenario. That means that 95.2 % (100 % - 4.8 %) of the fatalities can not be avoided by ABS in the trend scenario. This value equals the forecasted number of fatalities. The forecasted number of fatalities is 777 (chapter 4.2.1). For calculating the number of fatalities for the case that the penetration rate of ABS is zero, the forecasted number of fatalities has to be divided by the share of fatalities which can not be avoided by ABS. This is the difference of 1 and the avoidance factor af. In this example the difference is 95.2 % (1 – 4.8 %). Thus, the adjusted number of fatalities is 816 (777 / 0.952). The factor 1/0.952 is called correction factor cf (BAUM and GRAWENHOFF, 2006a). This factor is called correction factor because by multiplying the forecasted accident data with the correction factor cf the result is the adjusted accident data. The difference of the adjusted number of fatalities (816) and the forecasted number of fatalities (777) is the number of fatalities which can be avoided by ABS in the trend scenario in the year 2015. Hence, the potential is 39 avoided fatalities in the year 2015 for the trend scenario. The example calculation is displayed in Tab. 4.

Thus, for adjusting the accident data the forecasted accident data is multiplied with the correcting factor cf. This factor depends on the avoidance factor af and therefore it depends also on

- the penetration rate for the trend scenario and
- on the effectiveness.

The formula for the correction factor cf is as follows:

$$cf_{cat,t} = \frac{1}{1-\left(af_{cat,t}\right)} = \frac{1}{1-(PR_t * EF_{cat})}$$

with

af Avoidance factor for the trend scenario in the year t

cf Correcting factor for the category in t

For a positive effectiveness the avoidance factor af is positive as well.

For each year there are four avoidance factors and four correction factors for adjusting the accident data. This is due to the fact that four categories are considered which have different effectiveness rates:

- the number of accidents with personal injuries,
- the number of fatalities,
- the number of severe injuries, and
- the number of slight injuries.

The trend scenario is the only considered scenario within the adjusting process. To determine the correct accident data it is important to make a sufficient forecast of the ABS penetration rate within the fleet. The accident data for each category has to be adjusted with the accordant correction factor. The results are the accident data for each category for the hypothetical case that there is no ABS in the motorcycle market till the year 2020.

The adjusted accident data is the base for determining the number of avoided cases due to ABS. In the example above (Tab. 4) the approach for the trend scenario is shown. For determining the avoided cases for the mandatory scenario the avoidance factor af has to be calculated first. In the year 2015 the penetration rate of ABS is 47.8 % in the mandatory scenario. The effectiveness of ABS

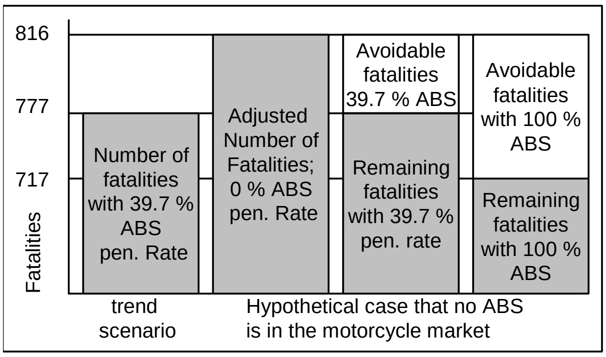

Fig. 8: Scheme of the adjusting process

in the category fatalities is 12.1 %. Thus, the avoidance factor af is 5.78 %. This avoidance factor af has to be multiplied with the adjusted number of fatalities in the year 2015. The result is the number of avoided fatalities in the mandatory scenario in the year 2015. Thus, the number of avoided fatalities is 47 (816 * 5.78 %). The number of fatalities in the mandatory scenario in the year 2015 is 769 (816 - 47).

The avoidance factor af for the hypothetical case that the penetration rate of ABS is 100 % in 2015 would be 12.1 % (12.1 % * 100 %). Thus, the number of avoided fatalities would be 99 (816 * 12.1 %) or in other words, the number of fatalities would be 717 (816 – 99) in the hypothetical case that the ABS penetration rate is 100 %.

In Fig. 8 the approach is displayed graphically:

- The first bar shows the forecasted number of fatalities for the year 2015. Because in this forecasting the number of fatalities includes ABS the forecasting is done for the trend scenario. Thus, the penetration rate of ABS is 39.7 %. The accordant number of fatalities is 777.
- The second bar displays the adjusted number of fatalities in the year 2015. The number of fatalities increases up to 816. This bar means that there is no ABS in the market. Thus, the positive effects of ABS can not be realised. The number of fatalities has to be higher than in the trend scenario with an ABS penetration rate of 39.7 %. The number of fatalities of the first bar is multiplied with the correcting factor cf to adjust the number of fatalities for the case that there is no ABS in the market.
- The third bar is divided into two areas. The grey area is the number of fatalities for the trend scenario. These are the fatalities which can not be avoided by the ABS penetration rate of the trend scenario. The white area displays the avoidable fatalities

due to the ABS penetration rate of the trend scenario. The number of avoided fatalities is the difference out of the number of adjusted fatalities and the number of forecasted fatalities. In this case the number of avoided fatalities is 39. The sum of both fatality numbers (777 + 39) is the number of fatalities for the case that there is no motorcycle equipped with ABS.

- The last bar displays the case for a full penetration rate. Every motorcycle is equipped with ABS. The grey area shows the number of fatalities which are not addressed by ABS. The white area is the avoidance potential of a full penetration. 717 fatalities can not be avoided by an ABS penetration rate of 100 %. The number of avoided fatalities is 99. The sum of both fatality numbers (717 + 99) is the number of fatalities for the case that there is no motorcycle equipped with ABS.

Thus, the first bar results out of the forecasting. The second bar is the result of multiplying the first bar with the correction factor cf. The white area of the third bar is the number of avoided fatalities due to the trend penetration rate of ABS. For the mandatory scenario the adjusted number of fatalities is multiplied with the avoidance factor af. The result is the number of avoided fatalities for the mandatory scenario (fourth bar). It displays the maximal potential of ABS in avoiding fatalities.

5 Accident effectiveness rates

ABS does not work in all situations, e.g. in curves with overspeeding or off-road. For this it is relevant to analyse the accident situations and possible effects of ABS. After this is done, the effectiveness rates of ABS can be deduced.

5.1 Accident causation

This chapter handles the accident situations. This is important for the effectiveness of ABS because ABS does work not in every accident situation.

The most relevant accident situations will be presented. Afterwards their relevance for ABS is considered.

There are five traffic situations in which accidents between a motorcycle and a passenger car occur very often. About 95 % of the collisions between motorcycles and passenger cars can be described with one of such categories (KRAMLICH, 2002).

- The first category is due to disobeying the right of way. The driver of the passenger car crosses or turns into a road which has right of way. A motorcycle is coming from right or left. The result is a side collision. The share of this category was about 45.3 % in the year 2002.
- The second category is due to disobeying the right of way as well. In this case both, the passenger car and the motorcycle, are on the same road, and they are driving in opposite direction. The passenger car wants to turn left in an intersection. The passenger car does not recognise the motorcycle. The result is a side collision as well. The share of this category was about 22.4 % in the year 2002.
- In the third category the passenger car performs a u-turn while the motorcycle comes from the back or the opposite. The share of this situation was about 6.3 % in 2002. Even in this case the result is a side collision.
- The fourth case is the last case which results in a side collision. In this situation the motorcycle overtakes the passenger car while the passenger car changes the track or turns off. The share of this situation is 9.8 % in 2002.
- The last situation is a head-on collision. A passenger car overtakes someone else or leaves its track in a curve. The motorcycle comes from the opposite. This situation represents 7.9 % in the year 2002.

In all these situations ABS would work.

Thus, the causation has to be analysed on a more concrete level. Important for ABS is the accident distribution. Another issue is the share of the accidents in which the motorcycle is the only participant. Important information is the distribution of the accidents on the different road types as well. A report from Assing provides an insight (ASSING, 2002):

- Analysing the accident distribution for the different road types, the highways have only a little share. This is due to the leisure traffic. About 2.2 % of all accidents with motorcycles are on highways. 46.5 % of all accidents occur on rural roads and 51.3 % of all accidents are in urban areas.

	Urban Roads	Rural Roads	Motor-ways	Sum
Fatalities	22.9	72.7	4.4	100
Severe Injuries	47.3	49.1	3.6	100
Slight Injuries	68.1	29.2	2.7	100
Accidents	51.3	46.5	2.2	100

Tab. 5: Distribution of injury classes for the different roads (in %)

- In 41 % of the highway accidents the motorcycle is the only participant. The share for rural roads is 36 % and for urban roads 12 %.
- 20 % of all accidents are accidents with the motorcycle as only participant. In another 25 % of the accidents the motorcycle is the main causer. In the remaining 55 % another road user is the main causer.
- Out of the accidents in which the motorcycle is the only participant the main reason is overspeeding. The share for a velocity which is too high for the multi-vehicle accidents is only 29 %.

5.2 Accident effects

In accidents motorcycle riders are more vulnerable than other vehicle passengers. The injury risk of a motorcycle rider is higher than for other vehicle drivers. When motorcycles are involved in fatal accidents, 90 % of the fatalities account for motorcyclists. The share for severe injuries is 90 %, while the share for slight injuries is 85 % (ASSING, 2002).

Analysing the distribution of the injury classes for the different road types (Tab. 5), accidents on highways are more severe than on other roads. About 2.2 % of all accidents are on highways, but the share of fatalities is 4.4 %, the share of severe injuries is 3.6 % and the share of slight injuries is 2.7 %. The accidents which occur on rural roads have more fatalities and severe injuries as on average, while the accidents which occur on urban roads have more slight injuries than on average.

29 % of all fatalities in motorcycle accidents are in accidents in which the motorcycle is the only participant. 25 % of all injuries account for single motorcycle accidents (STATISTISCHES BUNDESAMT, 2006). The share of downfalls[1] within accidents in which the motorcycle is the only participant is 20 % (CONTI-TEVES, 2004). The share of a downfall in the multi-vehicle accidents is about 10 % (SPORNER, 2002). The risk of being injured severely after a downfall is twice as high as without downfall (SPORNER and KRAMLICH, 2000). The risk of being killed after a downfall is twice as high for a motorcycle passenger than for without downfall before the accident. Tab. 6 displays these values.

[1] In this study a downfall stands for toppling in the early stage of the accident.

Distribution of the casualties		
Number of accident participants	share of fatalities	share of injuries
one	29%	25%
more than one	71%	75%
Sum	100%	100%
Share of downfall before the accident		
Downfall before accident	one participant	multi-vehicle accident
yes	20%	10%
no	80%	90%
Sum	100%	100%
Risk of being injured after downfall compared to the risk of being injured without downfall		
Risk of being …		Percentage
... killed after downfall		200%
... injured severely after downfall		200%

Tab. 6: Distribution of casualties, of downfalls and the risk of being injured after downfall

Most accidents occur under dry weather conditions. Nearly 80 % of the accidents are when the roads are dry. This value is independent whether the motorcycle rider falls down or not (SPORNER, 2002). This is due to the fact that driving motorcycle is done in the leisure time.

5.3 Accident effectiveness rates

In literature the following accident avoiding effects of ABS can be found: In every third accident the motorcycle did not braked. In about 65 % of all accidents the motorcycle rider could react (Fig. 9). In every second accident ABS would have worked. In about 20 % of these accidents the motorcycle drops down. ABS would have avoided at least 85 % of these dropdowns. In addition between 20 % and 30 % of the accidents with downfall ABS would have avoided completely (SPORNER, 2002).

Relevant accidents which might have been avoided by using ABS are 69 % of all accidents

Source	accidents	fatalities	severe injuries	slight injuries
Gwehenberger, 2001	9.9	8 - 17	8 - 17	-
Allianz, 2006	10	10 - 12	-	-
Kramlich and Sporner, 2000	-	8 - 10	8 - 10	-

Tab. 7: Avoidance potential (literature review) in %

which occur in rural regions and 83 % of all intersection accidents (GWEHENBERGER, 2001).

An overview of the findings of the literature review is presented in Tab. 7. The data out of the literature review is based on in-depth studies. The potential is as follows: The accident avoidance potential is estimated as 9.9 % (GWEHENBERGER, 2001) respectively 10 % (ALLIANZ, 2006). Even if not all of these accidents can be avoided, their accident severity can be reduced. The avoidance potential for the number of fatalities and the number of severe injuries is estimated as between 8 % and 10 % (KRAMLICH and SPORNER, 2000) and as between 8 % and 17 % (GWEHENBERGER, 2001). The avoidance potential for only fatalities is estimated as between 10 % and 12 % (ALLIANZ, 2006).

The big potential of ABS is that the motorcycle rider does not fall down (GWEHENBERGER, 2001). He is able to react – to brake or to sidestep or both. Thus, there is the assumption that ABS avoids only accidents with downfalls. This assumption is conservative, because it underestimates the possible benefit of ABS. However, due to the given data set it is only possible to calculate the potential of avoiding the downfall.

Based on the findings of the literature review the potential for ABS in motorcycles is determined. There are only assumptions about the avoidance potential. So, a possible shift within the severity classes is not considered. That means, that there are no shifts from fatality to severe injury or from severe injury to slight injury taken into account in literature.

Here two scenarios are considered:

- The first scenario is a scenario with a low effectiveness of ABS. In this scenario 85 % of the downfalls could have been avoided by the use of ABS. For these cases the risk structure of having an accident without downfall is applied. Because the risk of being killed in an accident with downfall is significantly higher than in an accident without a downfall, the number of fatalities decreases. The scenario with low

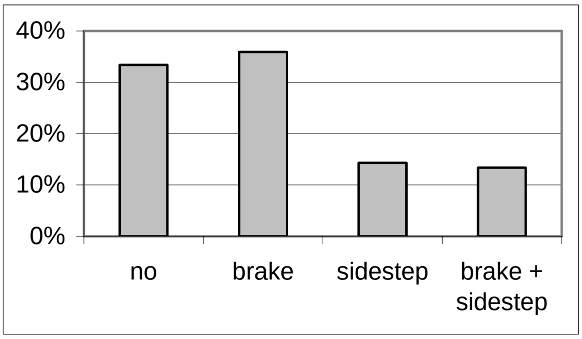

Fig. 9: Reaction of the motorcycle before the accident

effectiveness means in this case, that only fatalities are considered, whereas the number of slight injuries remains constant. Thus, it makes no difference for the number of slight injuries, whether the motorcycle topples down or not. A person who would have died in an accident with a downfall is in this scenario injured severely. That means, that the number of fatalities decreases, the number of severe injuries increases by the same amount, while the number of total accidents with personal injuries and the number of slight injuries remains constant. In addition the complete avoidance potential of ABS is not considered (ABS has also effects in accidents without downfall). The next issue which is not considered are other traffic participants. The considered potential of ABS is displayed in the lower part of Tab. 8.

- The second scenario is a scenario with a high effectiveness of ABS. This scenario underestimates the potential of ABS as well since there are other effects which can not be considered like shorter braking distances due to ABS and only are taken the lower limits from literature. The potential of ABS is avoiding 85 % of the downfalls. In addition to that, 20 % of the accidents with downfall can be avoided completely. There are no shifts from one severity class to another. Thus, a fatality can be avoided completely – that means the person is then uninjured – or stays a fatality. In this manner the scenario considers avoided accidents, avoided fatalities, avoided severe injuries and avoided slight injuries. The considered potential of ABS is displayed in the upper part of Tab. 8.

High effectiveness scenario				
Potential of ABS due to	Accidents	Fatalities	Severe Injuries	Slight Injuries
avoided downfalls	-	x	x	x
avoided accidents	x	x	x	x
other traffic participants	-	x	x	x
SUM	**x**	**x**	**x**	**x**
Low effectiveness scenario				
Potential of ABS due to	Accidents	Fatalities	Severe Injuries	Slight Injuries
avoided downfalls	-	shift from fatalities to severe injuries		-
avoided accidents	-	-	-	-
other traffic participants	-	-	-	-
SUM	**-**	shift from fatalities to severe injuries		-

Tab. 8: Considered potential of ABS for the effectiveness scenarios

5.3.1 Accidents

The first issue which has to be calculated is the avoidance potential differentiated for accidents in which the motorcycle is the only participant and for the other accidents.

This issue is only relevant for the scenario with a high effectiveness of ABS.

The share of accidents in which the motorcycle is the only participant is 20 % (ASSING, 2002). In 20 % of these cases the motorcycle drops down (CONTI-TEVES, 2004). That means based on the total accidents that 4 % (20 % * 20 %) of all accidents are accidents with motorcycles, which dropped down in an accident without other participants. For accidents with at least two participants 10 % of the motorcycles drop down (SPORNER, 2002). The share of multi-vehicle accidents is 80 % (1 – 20 %). So, based on the total accidents, 8 % of all accidents are multi-vehicle accidents with downfall (80 % * 10 %). In sum in 12 % of all accidents the motorcycle drops down (4 % + 8 %). One third of them are in accidents with only one participant, the other two thirds are in accidents with more than one participant. 85 % of these downfalls can be avoided by using ABS (SPORNER, 2002). In other words, the potential of ABS is a reduction of a downfall in 10.2 % based on the total amount of accidents: 3.4 % in accidents with only one participant and 6.8 % in the remaining accidents. In these accidents the severity class is reduced (see also Tab. 9).

Between 20 % and 30 % of the accidents with downfall (12 %) can be avoided completely. In the high effectiveness scenario the value is considered as 20 %. Hence, the total accident avoidance potential for the high effectiveness scenario is 2.4 % (12 % * 20 %) (see also Tab. 9).

share of single-vehicle accidents	20%
share of multi-vehicle accidents	80%
Sum	100%
share of downfalls in single-vehicle accidents	20%
share of no downfall in single-vehicle accidents	80%
Sum	100%
share of downfalls in multi-vehicle-accidents	10%
share of no downfall in multi-vehicle accidents	90%
Sum	100%
share of single-vehicle accidents without downfall	=20%*80% = 16%
share of multi-vehicle accidents without downfall	=80%*90% = 72%
sum of accidents without downfall based on all accidents	=16%+72% = 88%
share of downfalls in single-vehicle accidents based on all accidents	= 20%*20% = 4%
share of downfalls in multi-vehicle-accidents based on all accidents	= 80%*10% = 8%
accidents	= 12%
Sum all accidents	100%
20% of the accidents with downfall can be avoided by ABS completely	= 12%*20% = 2.4%
… thereof single-vehicle accidents	= 4%*20% = 0.8 %
… thereof multi-vehicle accidents	= 8%*20% = 1.6%

Tab. 9: Calculating the avoidance potential for accidents

The potential consists of 0.8 % avoided single-vehicle accidents and of 1.6 % avoided multi-vehicle accidents (see also Tab. 9).

5.3.2 Fatalities

This considered category is relevant for both scenarios.

For calculating the changes in the number of fatalities new parameters have to be designated. The parameters describe the distribution of fatalities within the accident categories and the risk factors for each accident category. There are four accident categories:

- single-vehicle accident, downfall,
- single-vehicle accident, no downfall,
- multi-vehicle accident, downfall, and
- multi-vehicle accident, no downfall.

The share of fatalities in accidents with only one participant is 29 % (STATISTISCHES BUNDES-AMT, 2006). The risk of being killed in an accident with downfall is twice as high as in accidents without downfall (SPORNER, 2002). With these two values the distribution of fatalities for the four accident categories can be determined. Therefore two calculation factors for accidents with one participant (calculation factor a) and for accidents with at least two participants (calculation factor b) are determined. The calculation factor for the single-vehicle accidents (a) is determined with the following formula:

$$SoS = a * RoDS * SoDS + a * (1 - SoDS)$$

with

SoS	Share of fatalities in single-vehicle accidents
a	Calculation factor
RoDS	Risk of being killed after a downfall compared to no downfall
SoDS	Share of downfall in single-vehicle accidents

This formula describes the composition of the share of fatalities in single-vehicle accidents. The first summand is the share of fatalities in single-vehicle accidents with downfall. The second summand is the share of fatalities in single-vehicle accidents without downfall. The formula has only one unknown variable: a. Thus, a has to be determined:

$$a = \frac{SoS}{RoDS * SoDS + (1 - SoDS)} =$$

$$= \frac{29\%}{200\% * 20\% + (1 - 20\%)} = 24.2\%$$

With this calculation factor a, the distribution can be calculated. The summand a*RoDS*SoDS displays the share of fatalities in single-vehicle accidents with downfall. The calculation factor a for single-vehicle accidents is 24.2 %, the risk of being killed after a downfall compared to no downfall is 200 %. The share of downfall in single-vehicle accidents is 20 %. Thus, the share of single-vehicle accidents with downfall is 9.7 % (24.2 % * 200 % * 20 %).

The summand a*(1-SoDS) displays the share of fatalities in single-vehicle accidents without downfall. The share is 19.3 % (24.2 % * 80 %).

After calculating the distribution of single-vehicle accidents, the distribution of multi-vehicle accidents has to be determined. The approach is analogue to the one before. Thus, the share of fatalities in multi-vehicle accidents depends on the risk of being killed after a downfall compared to no downfall and the share of downfall in multi-vehicle accidents. The share of fatalities in multi-vehicle accidents equals 100 % - 29 % (the share of fatalities in single-vehicle accidents) = 71 %. At first the calculation factor b for multi-vehicle accidents is determined. The formula for the distribution of the fatalities in multi-vehicle accidents is as follows:

$$SoM = b * RoDS * SoDM + b * (1 - SoDM)$$

with

SoM	Share of fatalities in multi-vehicle accidents
b	Calcualtion factor
RoDS	Risk of being killed after a downfall compared to no downfall
SoDM	Share of downfall in multi-vehicle accidents

This formula consists of two summands. The first one displays the share of fatalities in multi-vehicle accidents with downfall while the second summand displays the share of fatalities in multi-vehicle accidents without downfall. The formula contains one unknown: the calculation factor b. So, in a first step b has to be determined:

$$b = \frac{SoM}{RoDS * SoDM + (1 - SoDM)} =$$

$$= \frac{71\%}{200\% * 10\% + (1 - 10\%)} = 64.5\%$$

The calculation factor b is inserted in both summands. The first summand, b*RoDS*SoDM, describes the share of fatalities in multi-vehicle accidents with downfall. The share is 12.9 % (64.5 % * 200 % * 10 %). The second summand, b*(1-SoDM), displays the share of fatalities in multi-vehicle accidents without downfall. The share is 58.1 % (64.5 % * 90 %).

Tab. 10 shows the distribution of fatalities for the categories:

- single-vehicle accident, downfall,
- single-vehicle accident, no downfall,
- multi-vehicle accident, downfall, and
- multi-vehicle accident, no downfall.

The results are sorted first according to the number of accident participants and then according to downfall or no downfall. The rest of Tab 10 displays the risk factors of being killed.

The risk factor tells the likelihood of being killed in a special accident category. To determine the risk factor for a category the share of fatalities for the category has to be divided by the share of the accidents in this category. The distribution of the fatalities is taken from Tab. 10 and the distribution of the accidents is taken from Tab. 9. The following formula displays the risk factor:

$$rf_{cat} = \frac{SoF_{cat}}{SoA_{cat}}$$

with

rf Risk factor of being killed in an accident of the category

cat Single-vehicle accident with downfall, single-vehicle accident without downfall, multi-vehicle accident with downfall or multi-vehicle accident without downfall

SoF Share of fatalities in the category

SoA Share of accidents in the category

Accident Category (Fatality)	Percentage
One participant, downfall	9.7%
One participant, no downfall	19.3%
Sum one participant	29.0%
At least two participants, downfall	12.9%
At least two participants, no downfall	58.1%
Sum at least two participants	71.0%
Sum all fatalities	100%
One participant, downfall	9.7%
At least two participants, downfall	12.9%
Sum, downfall	22.6%
One participant, no downfall	19.3%
At least two participants, no downfall	58.1%
Sum, no downfall	77.4%
Sum all fatalities	100%
Risk Factor for Fatalities by	
One participant, downfall	2.4
One participant, no downfall	1.2
At least two participants, downfall	1.6
At least two participants, no downfall	0.8

Tab. 10: Distribution of fatalities for the accident categories and risk factors

The risk factor for the category single-vehicle accident with downfall can be assessed as follows: The share of fatalities within this category is 9.7 %. This value has to be divided by the share of accidents in this category. The share is 4 %. Thus, the division 9.7 % / 4 % displays the risk factor for being killed in a single-vehicle accident with downfall. The result is 2.4. The risk factor for being killed in a single-vehicle accident without downfall is 1.2 (19.3 % / 16 %). The risk factor for being killed in a single-vehicle accident with downfall is twice as high as in a single-vehicle accident without downfall (SPORNER, 2002).

The risk factors for the multi-vehicle accidents are 1.6 (12.9 % / 8 %) for downfall and 0.8 (58.1 % / 72 %) for no downfall. The risk factor for downfall is twice as high as without downfall.

The risk factors are displayed in Tab. 10.

If the share of fatalities is bigger than the share of accidents for the same category the risk factor is greater than one. Thus, having an accident in this category the likelihood of being killed is higher than on average. In the other case, if the share of fatalities is lower than the share of accidents the risk factor is lower than one. Hence, the likelihood of being killed in such an accident is lower than on average.

risk of being killed after downfall compared to no downfall	200%
risk of being killed without downfall compared to downfall	=1/200% = 50%
avoidable fatalities due to avoiding the downfall	=1-50% = 50%
potential due to ABS	85%
share of fatalities after downfall	22.60%
avoidance potential due to avoided downfall	=50%*85%* *22.6% = 9.59%

Tab. 11: Potential due to avoided downfalls

After determining the distribution of the fatalities and the risk factors for the categories, the potential of ABS has to be calculated.

About 85 % of the downfalls can be avoided by using ABS (SPORNER, 2002). The risk of being killed after a downfall is twice as high as for the case of no downfall. Avoiding every downfall would mean, that the number of fatalities after a downfall can be halved.

For calculating the potential of avoiding fatalities due to avoiding downfalls, the share of unavoidable accidents has to be subtracted from 1. The share of unavoidable accidents is the reciproke of RoDS (the risk of being killed after downfall compared to no downfall). The result is the share of avoidable fatalities. As mentioned above, ABS avoids 85 % of the downfalls. Thus, the share of the avoidable fatalities has to be multiplied with 85 %. To calculate the potential due to the avoided downfall, the result has to be multiplied with the share of fatalities after downfalls (SoFD). The formula for the potential due to avoided downfalls is as follows:

$$pav = (1 - \frac{1}{RoDS}) * 85\% * SoFD$$

with

pav	Potential due to avoided downfalls
RoDS	Risk of being killed after downfall compared to no downfall
SoFD	Share of fatalities after downfall

The risk of being killed after downfall compared to no downfall is 200 % (SPORNER, 2002). The share of fatalities after a downfall (SoFD) is 22.6 % (see also Tab. 10). Thus, the potential due to avoided downfalls is 9.6 % ((1-1/2)*85%*22.6%). For the calculation see also Tab. 11.

avoidable single-vehicle accidents	0.80%
avoidable multi-vehicle accidents	1.60%
risk factor for being killed in a single-vehicle accident	1.2
risk factor for being killed in a multi-vehicle accident	0.8
avoidance potential in single-vehicle accidents	=0.8%*1.2 = 0.97%
avoidance potential in multi-vehicle accidents	=1.6%*0.8 = 1.29%
avoidance potential all accidents	0.97%+1.29% =2.26%

Tab. 12: Potential due to avoided accidents, motorcycle riders only

The potential of ABS due to avoiding a downfall is a reduction of the fatalities by 9.6 %. This is the effectiveness of the low effectiveness scenario. In the low effectiveness scenario it is considered that there are only avoided fatalities due to the avoided downfalls. The avoided fatalities are shifted to severe injuries.

The scenario with high effectiveness considers additionally the potential due to avoided accidents and the potential due to avoided fatalities of other traffic participants.

As mentioned in chapter 5.3 about 2.4 % of all accidents can be avoided by using ABS. These avoided accidents influence also the number of fatalities.

The avoided accidents are part of the accidents in which ABS can work. ABS can avoid 85 % of all downfalls (SPORNER, 2002), for which the potential for avoiding fatalities was calculated above. But there the accident is not avoided. Thus, the additional potential out of avoided accidents has to be determined.

In chapter 5.3 the distribution of the avoided accidents is determined. The share of avoided single-vehicle accidents is 0.8 % and the share of avoided multi-vehicle accidents is 1.6 %. These values have to be multiplied with the risk factors for the categories without downfall. The result is the number of fatalities which can be avoided additionally:

The additional potential for single-vehicle accidents is 0.97 % (0.8 % * 1.2). The additional potential for multi-vehicle accidents is 1.29 % (1.6 % * 0.8). The sum of both values is the total additional potential due to avoided accidents: 2.26 % (0.97 % + 1.29 %). For the calculation see also Tab. 12.

share of motorcycle rider among fatalities	90%
share of other traffic participants among fatalities	=1-90% = 10%
Sum	100%
killed other traffic participants per killed motorcycle rider	=10%/90% = 0.11
share of fatalities in single-vehicle accidents	29%
share of fatalities in multi-vehicle accidents	=1-29% = 71%
killed other traffic participants per killed motorcycle rider in multi-vehicle accidents	=0.11/71% = 0.156
share of avoided fatalities in multi -vehicle accidents	1.29%
share of avoided other traffic participants due to avoided accidents	=0.156*1.3% = 0.2%

Tab. 13: Potential due to avoided accidents, other traffic participants

The last group of avoidable fatalities which is considered are other traffic participants. Avoiding a multi-vehicle accident means that there are other traffic participants who have a benefit due to ABS. This effect will be determined here.

The share of motorcycle riders among the fatalities is about 90 % (ASSING, 2002). Thus, for determining the number of killed other traffic participants per killed motorcycle rider (Tab. 13), the share of killed other traffic participants (10 %) has to be divided by the share of killed motorcycle rider (90 %). The result is 0.11 (10 % / 90 %). This value has still to be adjusted. The value which is interesting is the number of killed other traffic participants per killed motorcycle rider of a multi-vehicle accident. Therefore the above calculated share has to be divided by the share of killed motorcycle riders in multi-vehicle accidents. This share is the difference of 1 and the share of fatalities in single-vehicle accidents (29 %). Thus, the share of fatalities in multi-vehicle accidents is 71 %. The formula is as follows:

$$KpR = \frac{(1 - SoRF)}{(SoRF)} * \frac{1}{(1 - SoFS)}$$

with

KpR Killed other traffic participants per killed motorcycle rider

SoRF Share of motorcycle riders among fatalities

SoFS Share of fatalities in single-vehicle accidents

High effectiveness scenario	
avoided downfalls	9.59%
avoided accidents	2.26%
other traffic participants	0.20%
SUM	**12.05%**
Low effectiveness scenario	
avoided downfalls	9.59%
avoided accidents	-
other traffic participants	-
SUM	**9.59%**

Tab. 14: Effectiveness for fatalities and scenario

The number of killed other traffic participants per killed motorcycle riders is 0.156 (0.11 / 71 %).

This ratio has to be multiplied with the share of avoided fatalities in multi-vehicle accidents due to avoided accidents. The result is an additional decrease by 0.2 % (1.29 % * 0.156) (see also Tab. 13).

Together with the potential due to avoided downfalls (9.59 %), the potential among the motorcycle riders due to avoided accidents (2.26 %), and the potential among other traffic participants (0.2 %) the complete potential in avoiding fatalities of ABS in motorcycles is 12.05 %. This potential is the effectiveness for the high effectiveness scenario.

The effectiveness for the low effectiveness scenario is 9.59 % (see also Tab. 14).

5.3.3 Severe injuries

This category is only considered in the high effectiveness scenario.

The share of injuries in accidents with only one participant is about 25 % (STATISTISCHES BUNDESAMT, 2006). The risk of being injured severely in an accident with downfall is twice as high as in accidents without downfall (KRAMLICH and SPORNER, 2000). With these two values the distribution of severe injuries for the four accident categories can be determined. The approach is analogue to the approach described for the fatalities. Thus, in a first step, both calculation factors a and b are calculated. The formulas have to be adjusted for the category severe injuries. The share of severe injuries in single-vehicle accidents is used instead of the share of fatalities in single-vehicle accidents. The risk of being killed after downfall is displaced by the risk of being injured severely after downfall. Thus, the formula for the calculation factor for single-vehicle accidents (a) is as follows:

$$SoSS = a * RoSD * SoDS + a * (1 - SoDS)$$

$$a = \frac{SoSS}{RoSD * SoDS + (1 - SoDS)} =$$

$$= \frac{25\%}{200\% * 20\% + (1 - 20\%)} = 20.8\%$$

with

- a Calculation factor for single-vehicle accidents
- SoSS Share of severe injuries in single-vehicle accidents
- RoSD Risk of being injured severely after downfall compared to no downfall
- SoDS Share of downfalls in single-vehicle accidents

With the calculation factor a, the distribution of severe injuries can be calculated. The summand a*RoSD*SoDS displays the share of severe injuries in single-vehicle accidents with downfall. The calculation factor a for single-vehicle accidents is 20.8 %, the risk of being injured severely after a downfall compared to no downfall is 200 %. The share of downfall in single-vehicle accidents is 20 %. Thus, the share of severe injuries in single-vehicle accidents with downfall is 8.3 % (20.8 % * 200 % * 20 %).

The summand a*(1-SoDS) displays the share of severe injuries in single-vehicle accidents without downfall. The share is 16.7 % (20.8 % * 80 %). In sum the result has to be the share of casualties in single-vehicle accidents. This value is 25 % (STATISTISCHES BUNDESAMT, 2006).

In the next step the distribution for the correction factor for multi-vehicle accidents (b) is calculated. The formula is analogue to the one in the chapter for the fatalities. The share of severe injuries in multi-vehicle accidents (SoSM) is 75 % (100 % - 25 %). The formula is as follows:

$$SoSM = b * RoSD * SoDM + b * (1 - SoDM)$$

$$b = \frac{SoSM}{RoSD * SoDM + (1 - SoDM)} =$$

Accident Category (Severe Inj.)	Percentage
One participant, downfall	8.3%
One participant, no downfall	16.7%
Sum one participant	25.0%
At least two participants, downfall	13.6%
At least two participants, no downfall	61.4%
Sum at least two participants	75.0%
Sum all severe injuries	100%
One participant, downfall	8.3%
At least two participants, downfall	13.6%
Sum, downfall	21.9%
One participant, no downfall	16.7%
At least two participants, no downfall	61.4%
Sum, no downfall	78.1%
Sum all severe injuries	100%
Risk Factor for Severe Injuries by	
One participant, downfall	2.08
One participant, no downfall	1.04
At least two participants, downfall	1.70
At least two participants, no downfall	0.85

Tab. 15: Distribution of severe injuries for the accident categories and risk factors

$$= \frac{75\%}{200\% * 10\% + (1 - 10\%)} = 68.2\%$$

with

- SoSM Share of severe injuries in multi-vehicle accidents
- b Calculation factor for multi-vehicle accidents
- RoSD Risk of being injured severely after downfall compared to no downfall
- SoDM Share of downfalls in multi-vehicle accidents

The calculation factor b is inserted in both summands. The first summand, b*RoSD*SoDM, describes the share of severe injuries in multi-vehicle accidents with downfall. The share is 13.6 % (68.2 % * 200 % * 10 %). The second summand, b*(1-SoDM), displays the share of severe injuries in multi-vehicle accidents without downfall. The share is 61.4 % (68.2 % * 90 %). The sum of both shares is 75 % (13.6 % + 61.4 %), which equals the share of severe injuries in multi-vehicle accidents.

The distribution of the severe injuries is displayed in Tab. 15.

risk of being injured severely after downfall compared to no downfall	200%
risk of being injured severely without downfall compared to downfall	=1/200% = 50%
avoidable severe injuries due to avoiding the downfall	=1-50% = 50%
potential due to ABS	85%
share of severe inj. after downfall	21.90%
avoidance potential due to avoided downfall	=50%*85%* *21.9% = 9.31%

Tab. 16: Potential due to avoided downfalls

The next step is determining the risk factors. The approach is analogue to the one in chapter 5.3.2. The risk factor for the category single-vehicle accident with downfall can be assessed as follows: The share of severe injuries within this category is 8.3 %. This value has to be divided by the share of accidents in this category. The share is 4 %. Thus, the division 8.3 % / 4 % displays the risk factor for being injured severely in a single-vehicle accident with downfall. The result is 2.1. The risk factor for being injured severely in a single-vehicle accident without downfall is 1.0 (16.7 % / 16 %).

The risk factors for the multi-vehicle accidents are 1.7 (13.6 % / 8 %) for downfall and 0.9 (61.4 % / 72 %) for no downfall. The risk factor for downfall is twice as high as for no downfall.

The risk factors are displayed in Tab. 15.

After determining the distribution of the categories and the risk factors, the potential of ABS has to be determined. The approach is analogue to the one for fatalities. About 85 % of the downfalls can be avoided due to ABS. The risk of being injured severely after downfall is 200 % compared to no downfall. Thus, by avoiding 100 % of the downfalls the number of severe injuries can be halved within the categories with downfall.

Hence, about 50 % of the severe injuries are addressed by ABS. This share has to be multiplied with the potential of ABS, 85 %. This result has to be multiplied with the share of severe injuries after downfall. This share equals 21.9 % (Tab. 15). The result of the multiplication of all mentioned factors is the potential of ABS due to avoided downfalls. The potential is 9.31 % (50 % * 85 % * 21.9 %). The calculation is displayed in Tab. 16.

For a more detailed description see also chapter 5.3.2.

avoidable single-vehicle accidents	0.80%
avoidable multi-vehicle accidents	1.60%
risk factor for being injured severely in a single-vehicle accident	1.04
risk factor for being injured severely in a multi-vehicle accident	0.85
avoidance potential in single-vehicle accidents	=0.8%*1.04 = 0.83%
avoidance potential in multi-vehicle accidents	=1.6%*0.85 = 1.36%
avoidance potential all accidents	=0.8%+1.4% =2.19%

Tab. 17: Potential due to avoided accidents, motorcycle riders only

2.4 % of all accidents can be avoided completely by using ABS (chapter 5.3). Due to avoiding these accidents the number of severe injuries is reduced also. The avoided downfall is considered in the calculations above. Thus, the avoided accident which is considered here is now an avoided accident without downfall.

The share of avoidable single-vehicle accidents has to be multiplied with the risk factor for being injured severely in an accident without downfall. This multiplication is done also for the multi-vehicle accidents. Both results are summed up. The sum is the potential due to avoided accidents.

The potential for single-vehicle accidents is 0.83 % (0.8 % * 1.04) and the potential for multi-vehicle accidents is 1.36 % (1.6 % * 0.85). The complete potential is 2.19 % (0.83 % + 1.36 %). The calculation is displayed in Tab. 17. For a more detailed description see also chapter 5.3.2.

The last group of avoidable severe injuries which is considered are other traffic participants. The approach is analogue to the one for fatalities (chapter 5.3.2).

The share of motorcycle riders among the severe injuries is 90 % (ASSING, 2002). Thus, the number of severe injuries among other traffic participants is 0.11 per injured severely motorcycle rider. This value has still to be adjusted. The share of injuries in single-vehicle accidents is 25 % (STATISTISCHES BUNDESAMT, 2006). Hence, the share of severe injuries in multi-vehicle accidents is 75 % (1 – 25 %). The number of severe injuries of other traffic participants per injured severely motorcycle rider has to be divided by the share of severe injuries in multi-vehicle accidents. The result is the number of severe injuries of other traffic participants per injured severely motorcycle rider in

share of motorcycle rider among severe injuries	90%
share of other traffic participants among severe injuries	=1-90% = 10%
Sum	100%
injured severely other traffic participants per injured severely motorcycle rider	=10%/90% = 0.11
share of severe injuries in single-vehicle accidents	25%
share of severe injuries in multi-vehicle accidents	=1-25% = 75%
injured severely other traffic participants per injured severely motorcycle rider in multi-vehicle accidents	=0.11/75% = 0.147
share of avoided severe injuries in multi-vehicle accidents	1.36%
share of avoided severe injuries of other traffic participants due to avoided accidents	=0.147*1.4% = 0.2%

Tab. 18: Potential due to avoided accidents, other traffic participants

multi-vehicle accidents. This number is 0.147 (0.11 / 75 %). This value has to be multiplied with the avoidable severe injuries in multi-vehicle accidents (1.36 %). The result is an additional decrease in the number of severe injuries by 0.2 %. The calculation is displayed in Tab. 18.

Together with the potential due to avoided downfalls (9.31 %), the potential among the motorcycle riders due to avoided accidents (2.19 %), and the potential among other traffic participants (0.2 %) the complete potential in avoiding severe injuries is 11.70 %. This potential is the effectiveness for the high effectiveness scenario (see also Tab. 19).

The effect for the low effectiveness scenario is not considered here. There the effect is a shift from fatalities to severe injuries. The number of severe injuries increases by the amount the number of fatalities decreases. Thus, the effect is handled in chapter 5.3.2.

5.3.4 Slight injuries

This category is only considered in the high effectiveness scenario.

The share of injuries in accidents with only one participant is about 25 % (STATISTISCHES BUNDESAMT, 2006). The risk of being injured slightly in an accident with downfall is 54.6 % compared to accidents without downfall (KRAMLICH and SPORNER, 2000). With these two values the distribution of slight injuries for the four accident categories can be determined. The approach is analogue to the approach described for the fatalities. Thus, in a first step, both calculation factors a and b are calculated. The formulas have to be adjusted for the category slight injuries. The share of slight injuries in single-vehicle accidents is used instead of the share of fatalities in single-vehicle accidents. The risk of being killed after downfall is displaced by the risk of being injured slightly after downfall. Thus, the formula for the calculation factor for single-vehicle accidents (a) is as follows:

High effectiveness scenario	
avoided downfalls	9.31%
avoided accidents	2.19%
other traffic participants	0.20%
SUM	**11.70%**
Low effectiveness scenario	
shift 9.59 % of fatalities to severe injuries	

Tab. 19: Effectiveness for severe injuries and scenario

$$SoSlS = a * RoSlD * SoDS + a * (1 - SoDS)$$

$$a = \frac{SoSlS}{RoSlD * SoDS + (1 - SoDS)} =$$

$$= \frac{25\%}{54.6\% * 20\% + (1 - 20\%)} = 27.5\%$$

with

- SoSlS — Share of slight injuries in single-vehicle accidents
- a — Calculation factor for single-vehicle accidents
- RoSlD — Risk of being injured slightly after downfall
- SoDS — Share of downfalls in single-vehicle accidents

With this calculation factor a, the distribution can be calculated. The summand a*RoSlD*SoDS displays the share of slight injuries in single-vehicle accidents with downfall. The calculation factor a for single-vehicle accidents is 27.5 %, the risk of being injured slightly after a downfall compared to no downfall is 54.6 %. The share of downfall in single-vehicle accidents is 20 %. Thus, the share of single-vehicle accidents with downfall is 3.0 % (27.5 % * 54.6 % * 20 %).

The summand a*(1-SoDS) displays the share of slight injuries in single-vehicle accidents without downfall. The share is 22.0 % (27.5 % * 80 %). In sum the result has to be the casualties in single-vehicle accidents. This value is 25 % (STATISTISCHES BUNDESAMT, 2006).

In the next step the distribution for the correction factor for multi-vehicle accidents (b) is calculated. The formula is analogue to the one in the chapter for the fatalities. The share of casualties in multi-vehicle accidents (SoSlM) is 75 % (100 % - 25 %). The formula is as follows:

$$SoSlM = b * RoSlD * SoDM + b * (1 - SoDM)$$

$$b = \frac{SoSlM}{RoSlD * SoDM + (1 - SoDM)} =$$

$$= \frac{75\%}{54.6\% * 10\% + (1 - 10\%)} = 78.6\%$$

with

SoSlM	Share of slight injuries in multi-vehicle accidents
b	Calculation factor for multi-vehicle accidents
RoSlD	Risk of being injured slightly after downfall
SoDM	Share of downfalls in multi-vehicle accidents

The calculation factor b is inserted in both summands. The first summand, b*RoSlD*SoDM, describes the share of slight injuries in multi-vehicle accidents with downfall. The share is 4.3 % (78.6 % * 54.6 % * 10 %). The second summand, b*(1-SoDM) displays the share of slight injuries in multi-vehicle accidents without downfall. The share is 70.7 % (78.6 % * 90 %). The sum of both shares is 75 % (4.3 % + 70.7 %), which equals the share of slight injuries in multi-vehicle accidents.

The distribution of the slight injuries is displayed in Tab. 20.

The next step is determining the risk factors. The approach is analogue to the one in chapter 5.3.2. The risk factor for the category single-vehicle accident with downfall can be assessed as follows:

Accident Category (Slight Inj.)	Percentage
One participant, downfall	3.0%
One participant, no downfall	22.0%
Sum one participant	25.0%
At least two participants, downfall	4.3%
At least two participants, no downfall	70.7%
Sum at least two participants	75.0%
Sum all slight injuries	100%
One participant, downfall	3.0%
At least two participants, downfall	4.3%
Sum, downfall	7.3%
One participant, no downfall	22.0%
At least two participants, no downfall	70.7%
Sum, no downfall	92.7%
Sum all slight injuries	100%
Risk Factor for Slight Injuries by	
One participant, downfall	0.75
One participant, no downfall	1.38
At least two participants, downfall	0.54
At least two participants, no downfall	0.98

Tab. 20: Distribution of slight injuries for the accident categories and risk factors

The share of slight injuries within this category is 3.0 %. This value has to be divided by the share of accidents in this category. The share is 4 %. Thus, the division 3 % / 4 % displays the risk factor for being injured slightly in a single-vehicle accident with downfall. The result is 0.75. The risk factor for being injured slightly in a single-vehicle accident without downfall is 1.38 (22 % / 16 %).

The risk factors for the multi-vehicle accidents are 0.54 (4.3 % / 8 %) for downfall and 0.98 (70.7 % / 72 %) for no downfall.

The risk factors are displayed in Tab. 20.

After determining the distribution of the categories and the risk factors, the potential of ABS has to be determined. The approach is analogue to the one for fatalities. About 85 % of the downfalls can be avoided due to ABS. The risk of being injured slightly after downfall is 54.6 % compared to no downfall. Thus, by avoiding 100 % of the downfalls the number of slight injuries is nearly doubled within the categories with downfall.

For the case that every motorcycle is equipped with ABS, the share of slight injuries after downfall has to be divided by the risk of being injured slightly after downfall (Tab. 20). The result is the new share of slight injuries due to the avoided downfall. The result is 13.37 % (7.3 % / 54.6 %). Thus, it is an increase by 83 % (13.37 % / 7.3 %). This increase has to be multiplied with the potential of ABS, 85 % and with the share of slight injuries in accidents with downfall. The result of the multipli-

risk of being injured slightly after downfall compared to no downfall	54.6%
risk of being injured slightly without downfall compared to downfall	=1/54.6% = 183%
avoidable slight injuries due to avoiding the downfall	=1-183% = -83%
potential due to ABS	85%
share of slight inj. after downfall	7.3%
avoidance potential due to avoided downfall	=-83%*85%* *7.3% = -5.16%

Tab. 21: Potential due to avoided downfalls

avoidable single-vehicle accidents	0.80%
avoidable multi-vehicle accidents	1.60%
risk factor for being injured slightly in a single-vehicle accident	1.38
risk factor for being injured slightly in a multi-vehicle accident	0.98
avoidance potential in single-vehicle accidents	=0.8%*1.38 = 1.1%
avoidance potential in multi-vehicle accidents	=1.6%*0.98 = 1.57%
avoidance potential all accidents	=1.1%+1.57% =2.67%

Tab. 22: Potential due to avoided accidents, motorcycle riders only

cation is the potential of ABS due to avoided downfalls. The result is an increase in the number of slight injuries by 5.16 % (83 % * 85 % * 7.3 %). The calculation is displayed in Tab. 21.

2.4 % of all accidents can be avoided completely by using ABS (chapter 5.3). Due to avoiding these accidents the number of slight injuries is reduced as well. The avoided downfalls are considered in the calculation above. Thus, the avoided accidents which are considered here are now avoided accidents without downfall.

The share of avoidable single-vehicle accidents has to be multiplied with the risk factor for being injured slightly in an accident without downfall. This multiplication is done also for the multi-vehicle accidents. Both results are summed up. The sum is the potential due to avoided accidents.

The potential for single-vehicle accidents is 1.1 % (0.8 % * 1.38) and the potential for multi-vehicle accidents is 1.57 % (1.6 % * 0.98). The complete potential is 2.67 % (1.1 % + 1.57 %). The calculation is displayed in Tab. 22. For a more detailed description see also chapter 5.3.2.

share of motorcycle rider among slight injuries	85%
share of other traffic participants among slight injuries	=1-85% = 15%
Sum	100%
injured slightly other traffic participants per injured slightly motorcycle rider	=15%/85% = 0.18
share of casualties in single-vehicle accidents	25%
share of casualties in multi-vehicle accidents	=1-25% = 75%
injured slightly other traffic participants per injured slightly motorcycle rider in multi-vehicle accidents	=0.18/75% = 0.24
share of avoided slight injuries in multi-vehicle accidents	1.57%
share of avoided slight injuries of other traffic participants due to avoided accidents	=0.24*1.57% = 0.37%

Tab. 23: Potential due to avoided accidents, other traffic participants

The last group of avoidable slight injuries which is considered are other traffic participants. The approach is analogue to the one for fatalities (chapter 5.3.2).

The share of motorcycle riders among the slight injuries is 85 % (ASSING, 2002). Thus, the number of slight injuries among other traffic participants is 0.18 per injured slightly motorcycle rider. This value has still to be adjusted. The share of injuries in single-vehicle accidents is 25 % (STATISTISCHES BUNDESAMT, 2006). Hence, the share of slight injuries in multi-vehicle accidents is 75 % (1 – 25 %). The number of slight injuries of other traffic participants per injured slightly motorcycle rider has to be divided by the share of slight injuries in multi-vehicle accidents. The result is the number of slight injuries of other traffic participants per injured slightly motorcycle rider in multi-vehicle accidents. This number is 0.24 (0.18 / 75 %). This value has to be multiplied with the number of avoidable slight injuries in multi-vehicle accidents (1.57 %). The result is an additional decrease in the number of slight injuries by 0.37 %. The calculation is displayed in Tab. 23.

Together with the potential due to avoided downfalls (-5.16 %), the potential among the motorcycle riders due to avoided accidents (2.67 %), and the potential among other traffic participants (0.37 %) the complete potential in avoiding severe injuries is -2.12 %. Thus, the number of slight injuries will in-

High effectiveness scenario	
avoided downfalls	-5.16%
avoided accidents	2.67%
other traffic participants	0.37%
SUM	**-2.12%**
Low effectiveness scenario	
avoided downfalls	-
avoided accidents	-
other traffic participants	-
SUM	**-**
Annotation: minus sign means increase of cases	

Tab. 24: Effectiveness for slight injuries and scenario

crease due to ABS. This potential is the effectiveness for the high effectiveness scenario (see also Tab. 24).

The effect for the low effectiveness scenario is not considered here.

5.3.5 Synopsis

Although ABS has effects in various accidents, in this study the only accidents relevant for ABS were limited to accidents with a downfall. It is assumed, that in 85 % of all accidents with downfall the downfall can be avoided by ABS. An additional potential due to shorter braking distances is not considered. This is due to the fact that there is no data available for this issue. Thus, the effect of ABS is underestimated.

The effectiveness rates are calculated for two scenarios. The first scenario is the low effectiveness scenario. In this scenario there are only considered avoided fatalities due to avoided downfalls. A motorcycle passenger who would have been killed without ABS is then injured severely with ABS. In this scenario there are also only considered motorcycle passengers. Another limit in this scenario is that there is no reduction in the number of accidents taken into account.

The potential of the low effectiveness scenario is a reduction of fatalities by 9.6 %. In contrast, the number of severe injuries increases by the same amount as the number of fatalities decreases.

The second scenario is called high effectiveness scenario. It considers avoided accidents, avoided fatalities, avoided severe injuries, and avoided slight injuries. The potential of ABS is based on the potential due to accidents with downfall which are avoided completely, the potential of avoiding the downfall in the accident and the potential of avoiding casualties of other traffic participants in these situations. The results are displayed in Tab. 25.

Both, the low effectiveness scenario and the high effectiveness scenario are underestimating. In both scenarios there are no effects due to reducing the impact speed. The high effectiveness scenario considers more effects than the low effectiveness scenario. Thus, it is the more realistic one.

6 Cost-benefit analysis

This chapter handles the socio-economical assessment of ABS. After calculating the benefit-cost ratio (BCR) a sensitivity analysis is done for the scenarios in which the BCR is below 3 or even below 1. The final issue of this chapter is a benchmark in which the BCR of ABS is compared to other intelligent vehicle safety systems.

High effectiveness scenario				
Potential of ABS due to	Accidents	Fatalities	Severe Injuries	Slight Injuries
avoided downfalls	-	9.59%	9.31%	-5.16%
avoided accidents	2.4%	2.26%	2.19%	2.67%
effectiveness for other traffic participants	-	0.20%	0.20%	0.37%
SUM	**2.4%**	**12.05%**	**11.70%**	**-2.12%**
Low effectiveness scenario				
Potential of ABS due to	Accidents	Fatalities	Severe Injuries	Slight Injuries
avoided downfalls	-	shift 9.59 % to severe injuries		-
avoided accidents	-	-	-	-
effectiveness for other traffic participants	-	-	-	-
SUM	**-**	shift 9.59 % to severe injuries		-
Annotation: minus sign means increase of cases				

Tab. 25: Considered potential of ABS for the effectiveness scenarios

Benefit-category	relevant for this study
safety potential	yes
avoiding congestion	no
influence on the traffic-flow	no

Tab. 26: Relevant benefit categories

6.1 Assumptions

51.3 % of the motorcycle accidents occur in urban areas. About 2 % of all accidents are on motorways. The rest of them occur on rural roads (ASSING, 2002). Regarding the distribution of congestion in Germany (INFRAS/IWW, 2004) the likelihood of congestion due to a motorcycle accident is low. Most congestion occurs on motorways. The share of motorcycle accidents occuring on motorways is very low. In addition to this fewer lanes are affected due to motorcycle accidents. Thus, costs due to congestion can be neglected. These are time gains, avoided operating costs, and avoided emission outcast respectively pollution.

ABS does not influence the traffic flow. Hence, there is no potential in saving operating costs or in saving emission outcast respectively pollution.

Tab. 26 provides an overview over the considered benefit categories (see also chapter 3.1.1).

6.2 Scenarios

The assessment of ABS for motorcycles is done for two years: the year 2015 and 2020. For each year two scenarios are considered for the penetration rates.

- The first one is the trend scenario. In this scenario ABS is not mandatory.
- The other one is the mandatory scenario. In this scenario ABS is mandatory. It is considered that ABS is equipped mandatory for every new produced motorcycle from the year 2010 on.

Another two scenarios are for different effectiveness rates of ABS.

- In the scenario low effectiveness the avoided fatalities are shifted to the severity class severe injuries. The number of slight injuries and the number of accidents remain constant.
- The scenario high effectiveness considers avoided fatalities, avoided severe injuries, avoided slight injuries, and avoided accidents separately.

Year	Penetration rate	Effectiveness
2015	trend	low
2015	trend	high
2015	mandatory	low
2015	mandatory	high
2020	trend	low
2020	trend	high
2020	mandatory	low
2020	mandatory	high

Tab. 27: Overview of the considered scenarios

Penetration	trend	mandatory
2015	39.7%	47.8%
2020	56.7%	69.3%
System costs	trend	mandatory
2015	120.00 €	115.00 €
2020	105.00 €	100.00 €
Effectiveness	low	trend
accidents	-	2.40%
fatalities	9.59 % shift to severe injuries	12.05%
severe injuries		11.70%
slight injuries	-	-2.12%
Annotation: minus sign means increase of cases		

Tab. 28: Assumptions for each scenario

Thus, eight scenarios are considered in sum (Tab. 27). Four scenarios are considered for each year.

The accordant figures for the penetration rates (see also chapter 2.3), the effectiveness (chapter 5.3), and the system costs (chapter 6.4) are displayed in Tab. 28.

6.3 Benefits

The relevant benefits are due to the safety potential of ABS. ABS avoids accidents, fatalities, severe and slight injuries. The avoidance potential depends on the chosen effectiveness scenario (see also Tab. 28). The scenarios with a low effectiveness mean that the avoided fatalities due to ABS are shifted to severe injuries.

In the first step the accident data has to be corrected by the effect of ABS. There are already motorcycles in the market equipped with ABS. Thus, the measured accident data is underestimating. The numbers of accidents and casualties have to be calculated which are avoided by the ABS-systems which are in the market already. This is done by using the correcting factor $cf_{cat,t}$ (see also chapter 4.3). The effectiveness of ABS in the considered category is taken out of Tab. 28. The share of motorcycle stock equipped with ABS is taken from the trend scenario. The correcting factor is

Fatalities	2015	2020
forecasted values	777	746
trend penetration rate	39.7%	56.7%
effectiveness low	9.59%	9.59%
avoidance factor af =pen. Rate * effectiveness	39.7%*9.59% = 3.8%	56.7%*9.59% = 5.4%
correction factor cf =1/(1-af)	1/(1-3.8%) = 1.04	1/(1-5.4%) = 1.057
adjusted accident data	777*1.04 = 808	746*1.057 = 789
shift to severe injuries	808-777 = 31	789-746 = 53

Tab. 29: Avoidance potential of the trend penetration rate, low effectiveness

greater than 1 for a positive effectiveness. The difference between the corrected data and the measured data is the effect of ABS. The result are the accident data for the hypothetical case that there is no ABS in the motorcycle market. Because two effectiveness scenarios are considered there are two scenarios for the hypothetical case that there is no ABS. The first scenario is the low effectiveness scenario. In this scenario the number of accidents and the number of slight injuries are not influenced by ABS. The second scenario is the high effectiveness scenario. In this scenario all accident categories are influenced by ABS.

In the low effectiveness scenario the category fatalities is the only one with an effectiveness rate. The avoidance factor (af) is determined by multiplying the trend penetration rate (39.7 %) for the year 2015 with the effectiveness (9.59 %). With the result (3.8 %) the correction factor cf is calculated (1.04). This is done by dividing 1 with the difference between 1 and af. The adjusted number of fatalities for 2015 is determined by multiplying the forecasted number of fatalities with the correcting factor. The adjusted number of fatalities for the low effectiveness scenario in the year 2015 is 808. The difference between the adjusted and the forecasted value is the potential of the low effectiveness scenario for avoiding fatalities. The difference is 31. Thus, in the low effectiveness scenario 31 fatalities can be avoided. They are shifted to severe injuries. For the year 2020 the calculation is similar to the one for the year 2015. The only difference is that the trend penetration rate for the year 2020 is used. The result is a shift of 53 fatalities to severe injuries. The calculation is displayed in Tab. 29.

In a second step the potential of the mandatory scenario is determined. Therefore the adjusted accident data is used. In the mandatory scenario every new sold motorcycle is equipped with ABS from the year 2010 on. Thus, the penetration rates of ABS are higher for the mandatory scenario. The

Fatalities	2015	2020
adjusted values	808	789
mandatory pen. rate	47.8%	69.3%
effectiveness low	9.59%	9.59%
avoidance factor af	4.6%	6.6%
shift to severe injuries = adjusted value * af	808*4.6% = 37	789*6.6% = 52

Tab. 30: Avoidance potential for the mandatory penetration rate, low effectiveness

avoidance factor af is the product of the penetration rate and the effectiveness of ABS. The avoidance factor is greater for higher penetration rates. The new avoidance factor af has to be multiplied with the adjusted number of fatalities. The result is the number of avoided fatalities. In the low effectiveness scenario the avoided fatalities are shifted to severe injuries. In the year 2015 the penetration rate of the mandatory scenario is 47.8 %. The effectiveness is independent of the penetration scenario. It is 9.59 %. These two values have to be multiplied to get the avoidance factor af. The result is 4.6 % (47.8 % * 9.59 %). The avoidance factor af has to be multiplied with the adjusted number of fatalities of the year 2015. The product is the number of avoided fatalities. The result is 37 avoided fatalities (808 * 4.6 %). These 37 avoided fatalities are shifted to severe injuries. The number of avoided fatalities for the low effectiveness scenario with mandatory penetration rate for the year 2020 is 52. The calculations are displayed in Tab. 30.

These shift movements have to be assessed economically to determine the benefit. This is done later.

After considering the low effectiveness scenario the high effectiveness scenario is now in the focus. The approach is similar to the one for the low effectiveness scenario. The difference is that the high effectiveness scenario has other effectiveness rates and that all accident categories are considered.

In a first step the accident data has to be adjusted (Tab. 31). This is done by calculating the avoidance factor af by multiplying the trend penetration rate with the effectiveness. With the avoidance factor af the correction factor cf is calculated. This is done by dividing 1 with the difference between 1 and af. The correction factor cf is then multiplied with the forecasted accident data. The result is the adjusted accident data. The difference between the adjusted and the forecasted accident data is the safety effect of ABS in the trend scenario. This safety effect is reached by the motorcycles in the motorcycle market which are already equipped

High effectiveness scenario				
2015	Accidents	Fatalities	Severe Injuries	Slight Injuries
forecasted values	34,838	777	9,672	23,561
trend penetration rate	39.7%	39.7%	39.7%	39.7%
effectiveness high	2.40%	12.05%	11.70%	-2.12%
avoidance factor af	1.0%	4.8%	4.6%	-0.8%
correction factor cf	1.01	1.05	1.05	0.99
adjusted accident data	35,173	816	10,143	23,364
potential trend scenario =adjusted - forecasted data	35,173-34,838 = 335	816-777 = 39	10,143-9,672 = 471	23,364-23,561 = -197
2020	Accidents	Fatalities	Severe Injuries	Slight Injuries
forecasted values	34,487	746	9,058	23,275
trend penetration rate	56.7%	56.7%	56.7%	56.7%
effectiveness high	2.40%	12.05%	11.70%	-2.12%
avoidance factor af	1.4%	6.8%	6.6%	-1.2%
correction factor cf	1.01	1.07	1.07	0.99
adjusted accident data	34,962	801	9,701	22,999
potential trend scenario	475	55	643	-276
Annotation: minus sign means increase of cases				

Tab. 31: Avoidance potential for the trend scenarios, high effectiveness

High effectiveness scenario				
2015	Accidents	Fatalities	Severe Injuries	Slight Injuries
adjusted accident data	35,173	816	10,143	23,364
penetration rate mandatory	47.8%	47.8%	47.8%	47.8%
effectiveness	2.40%	12.05%	11.70%	-2.12%
avoidance factor af	1.1%	5.8%	5.6%	-1.0%
potential =adjusted accident data * af	403	47	567	-237
2020	Accidents	Fatalities	Severe Injuries	Slight Injuries
adjusted accident data	34,962	801	9,701	22,999
penetration rate mandatory	69.3%	69.3%	69.3%	69.3%
effectiveness	2.40%	12.05%	11.70%	-2.12%
avoidance factor af	1.7%	8.3%	8.1%	-1.5%
potential	581	67	786	-338
Annotation: minus sign means increase of cases				

Tab. 32: Avoidance potential for the mandatory scenarios, high effectiveness

with ABS. Tab. 31 displays the calculation and the results for the trend scenario. In the year 2015 about 335 accidents, 39 fatalities, and 471 severe injuries could have been avoided by ABS. The number of slight injuries increases by 197 due to ABS. The adjusted number of accidents for the year 2015 is 35,173, the adjusted number of fatalities is 816, the adjusted number of severe injuries is 10,143, and the adjusted number of slight injuries is 23,364. The adjusted accident data is valid for the hypothetical case that there is no ABS in the motorcycle market.

For the year 2020 the adjusted number of accidents is 34,962, the adjusted number of fatalities is 801, the adjusted number of severe injuries is 9,701, and the adjusted number of slight injuries is 22,999. The ABS systems which are on the motorcycle market in the year 2020 avoid 475 accidents, 55 fatalities, and 643 severe injuries. The number of slight injuries increases by 276 due to ABS.

The next step is calculating the potential of the mandatory scenario. The difference to the trend scenario is the higher penetration rate. Thus, the avoidance factor af is higher. These new avoidance factors have to be multiplied with the adjusted accident data. The result is the avoidance potential of ABS in the mandatory scenario.

The avoidance potential is determined as described above for all accident categories for the years 2015 and 2020. The results and the calculations are displayed in Tab. 32.

In a third step the complete avoidance potential for avoiding fatalities by means of ABS is determined. The complete avoidance potential means the hypothetical case that every motorcycle is equipped with ABS. Thus, the penetration rate is 100 %. The avoidance factor af is the product of the penetration rate and the effectiveness. Because the penetration rate is 100 % the avoidance factor af equals the effectiveness (100 % * effectiveness). The effectiveness for avoiding fatalities is 12.05 % (Tab. 28). So, the avoidance potential for the hypothetical case full penetration rate is the product of the avoidance factor af and the adjusted number of fatalities. In the year 2015 the number of avoided fatalities is 98 (816 * 12.05 %). In the year 2020 the value is 97 avoided fatalities. The number of avoidable fatalities in the year 2015 is higher because the adjusted number of fatalities is higher in 2015.

The potential of ABS in avoiding fatalities is about 100 avoided fatalities per year for a penetration rate of 100 %.

After calculating the safety potential of ABS for all scenarios for the years 2015 and 2020, the safety potential has to be assessed economically.

The numbers of avoided accidents and casualties are multiplied with the accordant cost-unit rates. The cost-unit rates are determined by the cost-of-damage approach (see also 3.1.1). Thus, only the economic losses are considered.

The cost-unit rates are taken from the Federal Highway Research Institute (BASt). The BASt determines the costs of road accidents on an annual basis. The cost-unit rates depend also on the economic growth. The latest available data is for the year 2004 (BAST, 2006). These values are applied for the year 2007. The values for the year 2007 are used in the further calculations. This is due to the fact, that the estimations for the system prices are based on the year 2007.

The cost-unit rates are divided into cost-unit rates for personal injuries and for property damage only. Both cost-unit rates are relevant for this study. Thus, they are summed up. The results are displayed in Tab. 33. These cost-unit rates are valid for the case that the accident can be avoided completely.

Accident severity	Cost-unit rate (Euro)
Fatality	1,190,335.00
Severe injury	101,077.00
Slight injury	13,923.00
Damage to property	5,813.00

Tab. 33: Cost-unit rates

In the scenarios with low effectiveness the avoided fatalities are shifted to severe injuries. Thus, the number of avoided fatalities has to be multiplied with the cost-unit rate for fatalities. Afterwards, the number of new severe injuries has to be multiplied with the cost-unit rate for severe injuries. The benefit for the scenarios with low effectiveness is the difference between the benefit due to avoided fatalities and the benefit due to new severe injuries. For an example, the trend scenario for the year 2015 is considered. The number of avoided fatalities is 31 (Tab. 29). This number has to be multiplied with the cost-unit rate for fatalities (1,190,335 Euro). The result is the benefit due to avoided fatalities: 36.9 million Euro. On the other hand the avoided fatalities are shifted to severe injuries. Thus, the number of severe injuries increases by the number of avoided fatalities: 31. This number has to be multiplied with the cost-unit rate for severe injuries: 101,077 Euro. The result is the negative benefit due to new severe injuries: 3.1 million Euro. The benefit of ABS in the low effectiveness scenario is the difference between the benefit due to avoided fatalities and the benefit due to new severe injuries: 33.8 million Euro. This calculation is also done for the mandatory scenario and for the year 2020. The results are a benefit of 40.3 million Euro for the mandatory scenario in 2015, 46.8 million Euro for the trend scenario in 2020, and 56.6 million Euro for the mandatory scenario in 2020. The results are displayed in Tab. 34.

In the scenarios with high effectiveness all accident categories are influenced by ABS. The number of avoided accidents has to be multiplied with the cost-unit rate for damage to property. The number of fatalities has to be multiplied with the cost-unit rate for fatalities. The cost-unit rate for fatalities implies that the fatality and the accident is avoided completely. The accidents which are completely avoided are handled separately (as mentioned above). Thus, the cost-unit rate for avoiding fatalities has to be reduced for the cost-unit rate for damage to property. Otherwise avoided accidents are considered twice. This means that the accident with former fatality is now an accident with property damage only. This procedure has to be performed also for the categories severe injuries and for slight injuries.

Year 2015		
Effectiveness low	trend	mandatory
fatalities	36.90	44.04
severe injuries	- 3.13	- 3.74
sum	**33.77**	**40.30**
Effectiveness high	trend	mandatory
accidents	1.95	2.34
fatalities	46.20	55.67
severe injuries	44.87	54.01
slight injuries	- 1.60	- 1.92
sum	**91.42**	**110.11**
Year 2020		
Effectiveness low	trend	mandatory
fatalities	51.18	61.90
severe injuries	- 4.35	- 5.26
sum	**46.84**	**56.64**
Effectiveness high	trend	mandatory
accidents	2.76	3.38
fatalities	65.15	79.36
severe injuries	61.25	74.88
slight injuries	- 2.24	- 2.74
sum	**126.93**	**154.88**

Tab. 34: Benefits for the different scenarios in mill. Euro

For an example the benefit for the trend scenario in the year 2015 for avoiding fatalities is handled. 39 fatalities can be avoided. The cost-unit rate for fatalities is 1,190,335 Euro. The cost-unit rate for damage to property is 5,813 Euro. The difference of both cost-unit rates is 1,184,522 Euro. Thus, the benefit is the product of the number of avoided fatalities and the difference of the cost-unit rates. The result is 46.2 million Euro (39 * 1.185 million Euro). This calculation is done for all casualty categories for the trend and for the mandatory scenario for the years 2015 and 2020. The number of avoided accidents is multiplied with the cost-unit rate for damage to property. The results are displayed in Tab. 34.

In the low effectiveness scenario the benefits are

- 33.8 million Euro for the year 2015 in the trend scenario,
- 40.3 million Euro for the year 2015 in the mandatory scenario,
- 46.8 million Euro for the year 2020 in the trend scenario, and
- 56.6 million Euro for the year 2020 in the mandatory scenario.

In the high effectiveness scenario the benefits of all accident categories have to be summed up. Till now the benefit due to avoided accidents, avoided fatalities, avoided severe injuries, and avoided slight injuries are accounted separately. The sum of them is the total benefit for the considered scenario:

- 91.4 million Euro for the year 2015 in the trend scenario,
- 110.1 million Euro for the year 2015 in the mandatory scenario,
- 126.9 million Euro for the year 2020 in the trend scenario, and
- 154.9 million Euro for the year 2020 in the mandatory scenario.

6.4 Costs

The costs have been determined by interviewing the three most important OEMs. The system costs for an ABS are 150 Euro per system in the year 2007.

The system costs per unit will decrease significantly till the year 2020. The decrease depends on the produced volume. The higher the produced volume the lower are the system costs. This is due to economies of scale and effects of learning curves.

The produced volume of the mandatory scenario is higher than in the trend scenario. This means that the system costs are lower for the mandatory scenario.

The system costs for the year 2015 are assumed as 120 Euro for the trend scenario and as 115 Euro for the mandatory scenario.

The figures for the year 2020 are 105 Euro for the trend scenario and 100 Euro for the mandatory scenario.

The system is used over the complete lifetime of the motorcycle. The average economic lifetime of a motorcycle in Germany is estimated with 13.2 years. Thus, the yearly costs have to be determined. Therefore the annuity rate is calculated. The annuity rate equals the yearly costs. The annuity rate depends on the economical lifetime and on the discount rate. The discount rate is estimated as 3 %.

The system costs have to be multiplied with the annuity rate. The annuity rate can be determined with the following formula:

2015	trend	mandatory
system costs per unit	120	115
annuity rate	0.0929	0.0929
system costs per unit per year (Euro)	120*0.0929 = 11.15	115*0.0929 = 10.68
motorcycle stock (mill.)	4.54	4.54
penetration rate	39.7%	47.8%
equipped motorcycle stock (mill.)	4.54*39.7% = 1.80	4.54*47.8% = 2.17
system costs per year (mill. Euro)	11.15*1.80 = 20.08	10.68*2.17 = 23.17
2020	trend	mandatory
system costs per unit	105	100
annuity rate	0.0929	0.0929
system costs per unit per year (Euro)	105*0.0929 = 9.75	100*0.0929 = 9.29
motorcycle stock (mill.)	4.94	4.94
penetration rate	56.7%	69.3%
equipped motorcycle stock (mill.)	4.94*56.7% = 2.80	4.94*69.3% = 3.42
system costs per year (mill. Euro)	9.75*2.80 = 27.29	9.29*3.42 = 31.78

Tab. 35: System costs per year

$$AR = \frac{d*(1+d)^n}{(1+d)^n - 1} = \frac{0.03*(1.03)^{13.2}}{1.03^{13.2} - 1} = 0.0929$$

with

AR Annuity rate

d Discount rate (3 %)

n Economic lifetime of a motorcycle (13.2 years)

Thus, the yearly system costs per system are 11.14 Euro for the trend scenario in the year 2015 (120 Euro * 0.0929). For the mandatory scenario it is 10.68 Euro. The yearly system costs per system for the year 2020 are 9.75 Euro respectively 9.29 Euro.

These yearly costs per system have to be multiplied with the equipped stock. The equipped motorcycle stock is the product of the penetration rate and the motorcycle stock. In the year 2015 the system costs are 20.1 million Euro for the trend scenario and 23.2 million Euro for the mandatory scenario. The values for the year 2020 are 27.3 million Euro respectively 31.8 million Euro.

Tab. 35 displays the calculations and the results.

6.5 Benefit-cost results

After calculating the benefits and the costs of ABS, the benefit-cost ratio can be determined. The benefit-cost ratio is calculated by dividing the benefits with the costs. At first the scenarios with a low effectiveness of ABS are considered. The benefit-cost ratio is 1.7 for the trend scenario (33.8 million Euro / 20.1 million Euro) and 1.7 for the mandatory scenario for the year 2015. In the year 2020 the benefit-cost ratios for the scenarios with low effectiveness are 1.7 for the trend scenario and 1.8 for the mandatory scenario. The results and the calculation are displayed in Tab. 36.

The results for the high effectiveness scenarios are better. The benefit-cost ratio is 4.6 for the trend scenario and 4.8 for the mandatory scenario for the year 2015. The benefit-cost ratios are 4.7 for the trend scenario and 4.9 for the mandatory scenario for the year 2020.

The benefit-cost ratios are higher in the year 2020. This is due to the fact, that the reduction in the system costs is higher than the reduction in the adjusted accident data.

The benefit-cost ratio above 1 illustrates that market deployment would be beneficial from society's point of view.

In the scenario with a high effectiveness of ABS the benefit-cost ratios are above 3.0. A benefit-cost ratio above 3 is evaluated as “excellent” (see chapter 3.1.2).

Another figure in the cost-benefit analysis is the net benefit. The costs have to be subtracted from the benefits. The result is the net benefit. It displays the society's benefit in absolute numbers. The results and the calculation are displayed in Tab. 36.

The net benefit of the scenario with low effectiveness of ABS is between 14 million Euro in the trend scenario for the year 2015 and 17 million Euro in the mandatory scenario. For the year 2020 the net benefit is between 20 million Euro in the trend scenario and 25 million Euro in the mandatory scenario.

The net benefit of the scenario with a high effectiveness is for the year 2015 between 71 million Euro for the trend scenario and about 87 million Euro for the mandatory scenario. The values for the year 2020 are 100 million Euro for the trend scenario and the net benefit is 123 million Euro in the mandatory scenario.

Low effectiveness scenario		
2015	trend	mandatory
benefit (mill. Euro)	33.8	40.3
costs (mill. Euro)	20.1	23.2
benefit-cost ratio benefit/costs	33.77/20.08 = 1.7	40.30/23.17 = 1.7
net benefit (mill. Euro) benefit-costs	33.77-20.08 = 13.7	40.30-23.17 = 17.1
2020	trend	mandatory
benefit (mill. Euro)	46.8	56.6
costs (mill. Euro)	27.3	31.8
benefit-cost ratio	1.7	1.8
net benefit (mill. Euro)	19.6	24.9
High effectiveness scenario		
2015	trend	mandatory
benefit (mill. Euro)	91.4	110.1
costs (mill. Euro)	20.1	23.2
benefit-cost ratio	4.6	4.8
net benefit (mill. Euro)	71.3	86.9
2020	trend	mandatory
benefit (mill. Euro)	126.9	154.9
costs (mill. Euro)	27.3	31.8
benefit-cost ratio	4.7	4.9
net benefit (mill. Euro)	99.6	123.0

Tab. 36: Benefit-cost ratio and net benefit

6.6 Sensitivity analysis

In this chapter the necessary potential is determined to reduce the system costs on a level that the benefit-cost ratio is equal to 1 respectively 3. The benefit-cost ratio for each scenario is above 1. Thus, the considered target value is a benefit-cost ratio of 3.

In the scenario with a high effectiveness the lowest benefit-cost ratio is above 3.0. Thus, for this scenario the sensitivity analysis is not relevant.

In the scenario with a low effectiveness the benefit-cost ratios are all below 3. The necessary system costs are determined to achieve a benefit-cost ratio of 3. The benefits for the trend scenario in the year 2015 are 34 million Euro. Dividing this value by a cost-benefit ratio of 3, the accordant system costs are about 11 million Euro. This value has to be divided by the equipped motorcycle stock. The equipped motorcycle stock is about 1.8 million (the penetration rate within the complete fleet equals 39.7 %, this value has to be multiplied with 4.5 million motorcycles). The result are the yearly system costs per unit. The overall system costs per unit are the focus of interest. Thus, the yearly system costs per unit have to be divided by the annuity rate (0.0929) (see also chapter 6.4). The formula for the system costs per unit is as follows:

$$SC_t = \left(\frac{benefits_t}{3} \Big/ \left(PR_t * MS_t\right) \right) \Big/ 0.0929$$

with

SC	System costs per unit in the year t
3	Favoured benefit-cost ratio
benefits	Benefits in the year t
PR	Penetration rate in t
MS	Motorcycle stock in t
0.0929	Annuity factor

Exemplary the system costs are determined for the year 2015, trend scenario:

$$SC_{2015} = \left(\frac{34}{3} \Big/ (39.7\% * 4.5) \right) \Big/ 0.0929 = 67$$

The system costs for a benefit-cost ratio of 3 have to be 67 Euro in the year 2015 in the trend scenario. For the year 2015 the system costs were estimated with 120 Euro for the trend scenario. This means that the system costs would have to be reduced by 53 Euro per system (120 Euro – 67 Euro).

The same calculation is done for the mandatory scenario for the year 2015 and for both scenarios for the year 2020. In the mandatory scenario of the year 2015 the system costs have to be 67 Euro to reach a benefit-cost ratio of 3.0. The system costs are considered with 115 Euro. Thus, the system costs have to be reduced by 48 Euro.

The system costs for a benefit-cost ratio of 3.0 in the year 2020 have to be 60 Euro (trend scenario) respectively 59 Euro (mandatory). Linked to these values the system costs have to be reduced by 45 Euro (trend) respectively by 41 Euro (mandatory). All the values and the calculations are displayed in Tab. 37.

To reach a benefit-cost ratio of 3 means a reduction of costs between 41 % and 44 %. Such a reduction is unlikely.

2015	trend	mandatory
benefits (mill. Euro)	33.8	40.3
favoured bcr	3	3
system costs (mill. Euro)	33.8/3 = 11.3	40.3/3 = 13.4
motorcycle stock (mill.)	4.54	4.54
penetration rate	39.7%	47.8%
equipped motorcycle stock (mill.)	4.54*39.7% =1.8	4.54*47.8% =2.1
system costs per unit per year (Euro)	11.3/1.8 =6.25	13.4/2.2 =6.19
annuity rate	0.0929	0.0929
system costs per unit (Euro)	6.25/0.0929 = 67	6.19/0.0929 = 67
2020	**trend**	**mandatory**
benefits (mill. Euro)	46.8	56.6
favoured bcr	3	3
system costs (mill. Euro)	15.6	18.9
motorcycle stock (mill.)	4.94	4.94
penetration rate	56.70%	69.30%
equipped motorcycle stock (mill.)	4.94*56.7% = 2.8	3.4
system costs per unit per year (Euro)	15.6/2.8 = 5.57	5.55
annuity	0.0929	0.0929
system costs per unit (Euro)	5.57/0.0929 = 60	59

Tab. 37: Required system costs for bcr of 3.0

6.7 Benchmarking of the results

Comparing the benefit-cost ratio of the considered system (ABS for motorcycles) to the ones of other intelligent vehicle safety systems (IVSS) is the aim of a benchmarking. Thus, a benchmarking can display the socio-economical effectiveness of ABS in relation to other realised or planned safety systems.

The scientific research of the effects and of the economic effectiveness is advanced for IVSS of passenger cars. However the economical assessment of IVSS for motorcycles is so far underdeveloped.

Because of this the benefit-cost ratio of the considered safety system ABS for motorcycles is compared to the ones for IVSS of passenger cars.

There are several groups of IVSS:

- The first group are systems warning the driver. If the driver does not react the system will intervene. Systems out of this group are for example seat belt reminder, congestion assistant, lane change assistant, lane keeping assistant, and adaptive cruise control (ACC).
- Another group are the intervening systems. They do not warn the driver before they react. Systems out of this group are ABS and the electronic stability control (ESC). ESC stabilises the vehicle if it starts to slide.
- The last considered group are systems which are activated after the accident occurred. Such a system is for example the event or accident data recorder, which stores the driving data before the accident happened.

Intelligent vehicle safety system	Benefit-cost
seat belt reminder *	8.2
event or accident data recorder *	7.1
ABS for motorcycles **	**4.6 - 4.9**
ESC - electronic stability control *	3.8
congestion assistant **	3.6 - 4.5
lane change assistant **	2.0 - 2.1
lane keeping assistant **	2.0 - 2.1
ACC - adaptive cruise control *	0.4
* year 2025, EU 25 ** year 2020, Germany	

Tab. 38: Overview of the BCR's of selected IVSS

The benefit-cost ratios for the IVSS are based on several studies (BAUM and GRAWENHOFF, 2006b; ECORYS and COWI, 2005).

As mentioned above even the scenarios with high effectiveness for conventional motorcycle ABS are underestimating. Thus, the scenarios with low effectiveness are not considered in the benchmarking. Tab. 38 gives an overview about the benefit-cost ratios of the different IVSS. ABS is one of the systems with the highest benefit-cost ratios.

Here the different time horizons have to be regarded. For the congestion assistant, ABS, lane change assistant, and lane keeping assistant the time horizon is 2020. For all other systems the year 2025 is the time horizon. Another issue which has to be regarded is the considered region. The systems which are assessed for the year 2020 are determined for Germany. All the other systems are assessed for EU 25. Thus the comparability of both groups is limited. Nevertheless conclusions about the tendency can be done. Thus, it is likely that a system which has a good CBR for the year 2020 in Germany has also a good CBR for the year 2025 in EU 25.

7 Break-even analysis

In this chapter ABS is assessed on the user level. The aim of the break-even analysis is to calculate the price (chapter 7.1) respectively the annual mileage from which on ABS is worthwhile for the user (chapter 7.2). For this approach personal injuries are considered only. Hence, the risk of being in an accident is determined for the two groups, motorcycles without ABS and motorcycles with ABS. This is one for the high effectiveness and the low effectiveness scenario. The adjusted number of casualties is divided by the motorcycle stock. The result is the risk of being in an accident for the group without ABS. For example the risk of being killed in an accident in the year 2015 is 0.00018 (808 / 4.5 million) in the low effectiveness scenario. The calculation is displayed in Tab. 39.

In the other group all motorcycles are equipped with ABS. Thus, the penetration rate is 100 %. The avoidance factor af equals the effectiveness. Thus, the safety effect is the product of the risk for the group without ABS and the effectiveness. In Tab. 39 this approach is displayed.

The safety effect for every casualty category has to be multiplied with the accordant cost-unit rate. The result is the willingness to pay for ABS per casualty category and year on user level. Thus, these values have to summed up over the casualty categories. The sum is the fair end consumer price per year. This is done in chapter 7.1. In chapter 7.2 the annual mileage is assessed for which ABS is worthwhile on user level.

Two classes of evaluation methods are possible for determining the cost-unit rates (LITMAN, 2005).

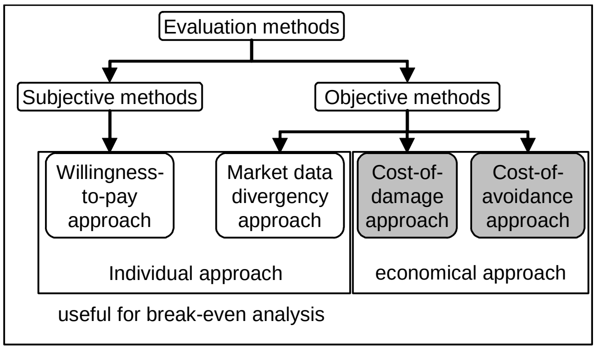

Fig. 10: Overview over the evaluation methods

The first one is the class of subjective methods, the second one is the class of objective methods. The first kind is based upon varying individual preferences about the valuation of non-market goods. Contrary to this approach, the objective methods rely on more objective criteria, as market prices of other goods, which are examined as calculation substitutes. The objective methods are separated into market data divergence analysis, cost-of-damage approach and cost-of-avoidance approach. The cost-of-damage and the cost-of-avoidance approach can be neglected for the break-even analysis since in the break-even analysis the individual is in the focus. The individual is not interested in the value of his life for the economy. Neither he is interested in the cost-unit rate the therapy will cost to recover his injury. The individual is only interested in avoiding the accident completely! Fig. 10 displays the evaluation methods.

The willingness-to-pay approach is useful for the break-even analysis. This is due to the fact, that this approach considers the individual valuation of avoiding an accident. People are asked about their valuation of the particular non-market good. Thus, individual preferences determine the amount,

Effectiveness Scenario	low	high		
2015	fatalities	fatalities	severe	slight
adjusted number of	808	816	10143	23364
motorcycle stock (1,000)	4,538	4,538	4,538	4,538
risk of being in an accident per 1,000 motorcycles	808/4,538 = 0.18	816/4,538 = 0.18	10,143/4,538 = 2.23	23,364/4,538 = 5.15
effectiveness	9.59%	12.05%	11.70%	-2.12%
safety effect per 1,000 motorcycles	0.18*9.6%	0.18*12.1%	2.23*11.7%	5.15*-2.1%
2020	fatalities	fatalities	severe injuries	slight injuries
adjusted number of	789	801	9701	22999
motorcycle stock (1,000)	4,939	4,939	4,939	4,939
risk of being in an accident	0.16	0.16	1.96	4.66
effectiveness	9.59%	12.05%	11.70%	-2.12%
safety effect per 1,000 motorcycles	0.015	0.020	0.230	-0.099

Tab. 39: Safety effect in reducing the risk of being in an accident per 1,000 motorcycles

which people are willing to pay to avoid an accident or to adopt the crash consequences. The disadvantage of this approach is that the results of such surveys depend heavily on the way the questionnaire is designed and conducted. The cost-unit rates which are determined with the willingness-to-pay approach are the highest ones within all evaluation methods. The cost-unit rates of the willingness-to-pay approach include values of non-market costs, such as grief and pain. The problem is as follows: Asking an individual about the cost-unit rate of his own life, the answer will be a very high value. But if the same individual has the real chance to pay his cost-unit rate or to die, the question is if he is able to pay the cost-unit rates he mentioned before. Thus, it is doubtful whether the cost-unit rates are reliable.

The market data divergence analysis can solve the disadvantages of the willingness-to-pay approach. In this approach it is possible to calculate the cost-unit rates with effects on market prices or related goods. For example, the wages of employees who are exposed a higher risk are higher than the wages of employees with low risks. The different wages of employees for different risks are analysed for Germany in a study (SPENGLER, 2004). The result of this study was that the cost-unit rate for a life in Germany is 1.65 million Euro for the year 2004. The disadvantages of this study are as follows:

- there are no cost-unit rates determined for severe injury or slight injury, and
- those who are considered are included in social insurance.

Thus, it is doubtful whether the value for the life is trustworthy for the motorcycle rider in general. It may be that the people, who are not in social insurance, have another cost-unit rate for their life. Not included in social insurances are students, self-employed, and pensioners. Thus, it is likely that this value is overestimating.

Because there is only the cost-unit rate for fatalities available for the most promising approach, the market data divergence analysis, here the second best approach, the willingness-to-pay approach is considered. The willingness-to-pay approach is used inter alia in Finland, France, the Netherlands, Sweden and UK. For the year 2005 the willingness-to-pay approach delivers cost-unit rates for fatalities between 1.36 million Euro and 1.57 million Euro for the mentioned countries (BICKEL et al., 2005). Compared to the value of the market divergence approach for the year 2004, 1.65 million Euro, the values are in a similar range. The level of

Cost-unit rate	Fatality	Severe injury	Slight injury
lowest value 2005	1,362,770	175,940	13,567
highest value 2005	1,565,720	243,430	39,277
mean 2005	1,439,484	206,681	24,116
interest rate	3%	3%	3%
cost-unit rate (2007)	1,527,149	219,268	25,584

Tab. 40: Cost-unit rates for break-even analysis in Euro

living in the mentioned European countries is comparable to the one in Germany. Thus, the mean of these countries is taken. These mean values are compounded to the year 2007. The interest rate for compounding is considered as 3 %. The cost-unit rates are displayed in Tab. 40. The values for the year 2005 are taken from (BICKEL et al., 2005).

All calculations are done with cost-unit rates for 2007. This is due to the fact that assumptions for possible end consumer prices are based on 2007.

In the next step the annual costs have to be determined. The user has to pay the end consumer price for ABS. On average, the motorcycle is 13.2 years in use. It is assumed that the motorcycle owner finances the ABS by a credit. The duration of the credit is considered as 13.2 years. The interest rate is considered as 8 % per year. The motorcycle owner pays over 13.2 years the same rate (annuity) to the bank. Within this rate there is a share for pay off and a share for the interest. During the time the share for interest decreases while the share for pay off increases. The total rate is calculated by multiplying the end consumer price with the annuity rate. The annuity rate for a duration of 13.2 years and an interest rate of 8 % is 0.125. In other words: for every 100 Euro of the end consumer price the user has to pay 12.54 Euro per year.

The end consumer price is about 600 Euro in 2007. In dependence of the manufacturer the delivered ABS for this price is even an I-ABS. Thus, the realistic end consumer price for a conventional ABS is below 600 Euro nowadays. The prices follow a downward trend or at least the quality of the sold system is improved due to economies of scales and effects out of learning curves. This means, that the conventional ABS gets cheaper during the time. Based on the system costs per unit (chapter 6.4) the end consumer prices are estimated. The system costs are multiplied with a factor about 3. This factor is an empirical value, which describes the difference between system costs (usage of resources for the motorcycle manufacturer) and end consumer prices. The factor 3 can be used as a rule of thumb. For the year 2015 the end consumer price is estimated with 400 Euro and with 300 Euro in the year 2020. The corresponding annuity rates are 50.16 Euro for 2015 respectively 37.62 Euro for 2020.

One of the German insurance companies allows a discount for the motor liability insurance. The only precondition is that the motorcycle is equipped with ABS. The discount is 10 % (ALLIANZ, 2005). This offer is considered in chapter 7.3. In the chapter 7.1 and 7.2 the discount is not considered. By considering the discount in chapter 7.3 the effect of the discount can be shown. Thus, in chapter 7.3 the discount expressed in Euro has to be summed up to the fair price which is calculated in the next subchapter. Due to the discount the fair end consumer prices will increase. For a given market price the discount leads to a decrease in the critical mileage.

7.1 Assessment for the critical end consumer prices

The critical end consumer price is the marginal price. For higher end consumer prices as the critical price the system is not worthwhile for the user. For lower end consumer prices as the critical price, the system is accepted by the user. In this chapter the price will be assessed, for which the benefit on user level of the system is as high as the end consumer price. This is the maximum price the user is ready to pay for the system.

At first the critical system costs are determined for the scenario with a high effectiveness. Afterwards the low effectiveness scenario is considered.

In chapter 7 the safety effects of ABS have been determined for the categories fatalities, severe injuries and slight injuries (Tab. 39). These safety effects have to be multiplied with the accordant cost-unit rates. The cost-unit rates are determined with the willingness-to-pay approach. They are displayed in Tab. 40. After multiplying the safety effects with the accordant cost-unit rates the results have to be summed up. The sum is the willingness to pay of the average motorcycle rider for using ABS for one year. Thus, to determine the fair end consumer price, the annual willingness to pay has to be divided by the annuity rate.

For an example the fair end consumer price for the year 2015 for the low effectiveness scenario is calculated. The safety effect per 1,000 motorcycles is 0.017 for avoiding fatalities. The cost-unit rate for a life is 1.5 million Euro (based on the year 2007). These values have to be multiplied. The result is the annual willingness to pay of 1,000 motorcycle riders for using ABS over one year for avoiding fatalities. The result is 26,074 Euro. Thus, this value has to be divided by 1,000 to get the willingness to pay per user: 26 Euro. In the low effectiveness scenario avoided fatalities are shifted to severe injuries. Thus, this shift has to be subtracted from the willingness to pay. The safety effect is for that purpose multiplied with -1, because the number of severe injuries increases, and with the cost-unit rate for severe injuries (219,268 Euro). The result is the willingness to pay per 1,000 motorcycle riders: -3,744 Euro. After dividing this value by 1,000 to get the willingness to pay per user (4 Euro), both willingness to pay values have to summed up. The result is the willingness to pay for the use of ABS for one year: 22 Euro (26 Euro – 4 Euro). To determine the fair end consumer price, this willingness to pay has to be divided by the annuity. The result is a fair end consumer price of 178 Euro for the low effectiveness scenario for the year 2015. In Tab. 41 the calculation and the results are displayed.

Year 2015, low effectiveness			
category	safety effect per 1,000 motorcycles	cost-unit rate (1,000 Euro)	willingness to pay (Euro)
fatality	0.017	1,527	0.02*1,527 = 26
shift to severe injuries		-219	0.02*-219 = -4
sum (Euro)			26-4 = 22
annuity			0.125
fair end consumer price (Euro)			22/0.13 = 178
Year 2020, low effectiveness			
category	safety effect per 1,000 motorcycles	cost-unit rate (1,000 Euro)	willingness to pay (Euro)
fatality	0.015	1,527	23
shift to severe injuries		-219	-3
sum (Euro)			20
annuity			0.125
fair end consumer price (Euro)			160

Tab. 41: Calculation of the fair end consumer price, low effectiveness scenario

The fair end consumer price is 178 Euro, whereas the estimated market price is about 400 Euro in the year 2015. Thus, ABS in the low effectiveness scenario is not worthwhile for the motorcycle rider on average. The critical mileage from which on ABS is worthwhile is calculated in chapter 7.2.

The fair end consumer price for the low effectiveness scenario for the year 2020 is 160 Euro (Tab. 41). This value is also below the estimated market price of ABS in the year 2020. This value is 300 Euro. Thus, also in 2020 ABS in the low effectiveness scenario is not worthwhile for the motorcycle rider on average. The critical mileage is determined in chapter 7.2.

The decrease of the fair end consumer prices is due to the decrease in the figure adjusted accident data per motorcycle in the period from 2015 till 2020.

The determining of the fair end consumer prices for the high effectiveness scenario is similar. In the high effectiveness scenario the numbers of fatalities, severe injuries, and slight injuries are influenced. For every category a safety effect is calculated in chapter 7 (Tab. 39). These safety effects are given per 1,000 motorcycles. In Tab. 42 the cost-unit rates are displayed in 1,000 Euro. Thus, the product of the safety effect per 1,000 motorcycles and the cost-unit rate in 1,000 Euro is the willingness to pay for ABS due to avoiding a casualty of the accordant category (fatality, severe injury or slight injury). Thus, for each year three willingness to pay values are calculated. These three values are summed up. The sum displays the annual willingness to pay for ABS. This value has to be divided by the annuity to get the fair end consumer price.

The safety effect per 1,000 motorcycles for fatalities in 2015 is 0.022. The cost-unit rate for fatalities is 1,527 thousand Euro. The product equals 33 Euro. This is the annual fair value of ABS due to its avoiding potential for fatalities. The same is done for severe injuries. The safety effect is 0.261, the cost-unit rate is 219 thousand Euro. The product equals 58 Euro. The same is also done for slight injuries. The product of the safety effect (-0.109) and the cost-unit rate (26 thousand Euro) is -3 Euro. The three products are summed up. The result is 88 Euro (33 Euro + 58 Euro – 3 Euro). This value equals the annual fair price for ABS. The annual fair price for ABS has to be divided by the annuity (0.125) to get the fair end consumer price. The fair end consumer price is 701 Euro for the high effectiveness scenario for the year 2015 respectively 622 Euro for the year 2020. The calculation is displayed in Tab. 42.

The market price in the year 2015 is estimated with 400 Euro and 300 Euro for 2020. Thus, the fair end consumer prices are higher than the estimated market prices. ABS is worthwhile for the user on average. In chapter 7.2 the critical mileage is determined for which ABS is worthwhile on user level.

The decrease of the fair end consumer prices is due to the decrease in the figure adjusted accident

Year 2015, high effectiveness			
category	safety effect per 1,000 motorcycles	cost-unit rate (1,000 Euro)	willingness to pay (Euro)
fatality	0.022	1,527	33.0
severe inj.	0.261	219	58.0
slight inj.	-0.109	26	-3.0
sum (Euro)			88.0
annuity			0.125
fair end consumer price (Euro)			701

Year 2015, high effectiveness			
category	safety effect per 1,000 motorcycles	cost-unit rate (1,000 Euro)	willingness to pay (Euro)
fatality	0.020	1,527	30.0
severe inj.	0.230	219	51.0
slight inj.	-0.099	26	-3.0
sum (Euro)			78
annuity			0.125
fair end consumer price (Euro)			622

Tab. 42: Calculation of the fair end consumer price, high effectiveness scenario

data per motorcycle in the period from 2015 till 2020.

7.2 Assessment for the annual mileage

In this chapter the costs for ABS are kept constant. The motorcycle’s mileage is about 3,900 km on average per year. The higher the individual mileage the sooner ABS amortises. Thus the fair prices per year which are calculated above have to be divided by 3,900. The result is the fair price per motorcycle-km per year. Given a market price the mileage per year can be assessed from which on buying ABS makes sense on user level. Is the individual mileage higher, ABS is a worthwhile system.

The market price for the year 2015 is estimated with 400 Euro and the market price for the year 2020 is 300 Euro.

In the low effectiveness scenario the fair end consumer price is 178 Euro for the year 2015 respectively 160 Euro for the year 2020 (Tab. 41). The fair prices are below the market prices. Thus, the critical mileage will be higher than the mileage on average. A high penetration rate of ABS is unlikely because ABS is just worthwhile for the minority group.

The annual fair price for 2015 is 22 Euro (Tab. 41). The annual mileage on average is 3,900 km. Thus,

low effectiveness	2015	2020
annual fair price (Euro)	22	20
mileage on average (km/year)	3,900	3,900
fair price per km (Euro)	22/3,900 = 0.006	20/3,900 = 0.005
market price (Euro)	400	300
annuity	0.125	0.125
annual market price (Euro/year)	400*0.125 = 50.16	300*0.125 = 37.62
critical mileage (km/year)	50.16/0.006 = 8,800	37.62/0.005 = 7,300
high effectiveness	2015	2020
annual fair price (Euro)	88	78
mileage on average (km/year)	3,900	3,900
fair price per km (Euro)	0.02	0.02
market price (Euro)	400	300
annuity	0.125	0.125
annual market price (Euro/year)	50.16	37.62
critical mileage (km/year)	2,200	1,900

Tab. 43: Calculation of the critical mileage

the fair price per km is 0.6 ct/km (22 Euro / 3,900 km). The annuity of the market price equals 50.16 Euro (400 Euro * 0.125). The annuity of the market price has to be divided by the fair price per km. The result is the critical mileage: 8,800 km per year (50.16 / 0.6 ct/km). The calculation is displayed in Tab. 43. The critical mileage is more than twice as high as the mileage on average. Thus, ABS is worthwhile for all motorcycle riders with a higher mileage than 8,800 km.

The critical mileage for the low effectiveness scenario for the year 2020 is calculated analogue. The result is 7,300 km.

The critical mileage is decreasing during the time because the market price decreases stronger than the fair end consumer price. The market price decreases by 25 % (from 400 Euro to 300 Euro) while the fair end consumer price decreases by 10 % (from 178 Euro to 160 Euro).

In the high effectiveness scenario the fair consumer end prices are higher than the market prices. Thus, the critical mileage will be lower than the mileage on average. The fair consumer end price for the year 2015 is 701 Euro respectively 622 Euro for the year 2020. The calculation is displayed in Tab. 43. The annual fair price for the year 2015 is 88 Euro. Thus, the fair price per km is 0.2 ct/km (88 Euro / 3,900 km). The annuity of the market price is 50.16 Euro. Thus, the critical mileage is 2,200 km (50.16 Euro / 0.2 ct/km). This mileage is less than the mileage on average. Thus, ABS is worthwhile for all users with an annual mileage higher than 2,200 km.

The critical mileage for the year 2020 is 1,900 km. This mileage is even less than halve of the mileage on average. Thus, ABS is worthwhile for all users with an annual mileage higher than 1,900 km.

The critical mileage is decreasing due the time because the market price decreases stronger than the fair end consumer price. The market price decreases by 25 % (from 400 Euro to 300 Euro) while the fair end consumer price decreases by 11 % (from 701 Euro to 622 Euro).

7.3 Insurance premium reduction

One of the German insurance companies allows a discount for the motor liability insurance. The only precondition is that the motorcycle is equipped with ABS. The discount is 10 % (ALLIANZ, 2005). According to information from Allianz, this discount equals a reduction between 15 and 20 Euro per year. For the further approach the lower value (15 Euro) is considered.

The discount has to be summed with the annual fair price.

In the low effectiveness scenario the annual fair price is 22 Euro for 2015 respectively 20 Euro for 2020. Thus, the new annual fair prices are 37 Euro (22 Euro + 15 Euro) for 2015 and 35 Euro for 2020.

The annual fair price has to be divided by the annuity. The annuity is 0.125. Thus, the fair end consumer price for the low effectiveness scenario is 298 Euro for the year 2015 respectively 279 Euro for the year 2020.

The market price for the year 2015 is estimated with 400 Euro respectively with 300 Euro for the year 2020. Thus, ABS is not worthwhile even when the insurance premium reduction is included for the user on average in the low effectiveness scenario.

The calculation and results are displayed in Tab. 44.

In the high effectiveness scenario the annual fair prices are 88 Euro for 2015 respectively 78 Euro for 2020. The discount is 15 Euro. Thus, the sum of the annual fair price and the discount is the new

low effectiveness	2015	2020
annual fair price (Euro)	22	20
discount (Euro)	15	15
new annual fair price (Euro)	22+15 =37	35
annual mileage on average (km)	3,900	3,900
fair price per km (Euro)	37/3,900 = 0.01	0.01
annuity	0.125	0.125
fair end consumer price (Euro)	37/0.125 = 298	279
market price (Euro)	400	300
annual market price (Euro)	400*0.125 = 50	38
critical mileage (km)	50/0.01 = 5,200	4,200
high effectiveness	2015	2020
annual fair price (Euro)	88	78
discount (Euro)	15	15
new annual fair price (Euro)	103	93
annual mileage on average (km)	3,900	3,900
fair price per km (Euro)	0.03	0.02
annuity	0.125	0.125
fair end consumer price (Euro)	818	739
market price (Euro)	400	300
annual market price (Euro)	50	37
critical mileage (km)	1,900	1,600

Tab. 44: Fair end consumer prices and critical mileages with discount from insurance companies

annual fair price. It is 103 Euro for 2015 respectively 93 Euro for 2020. The new fair end consumer price for ABS is 818 Euro for 2015 respectively 739 Euro for the year 2020 (see also Tab. 44). The fair end consumer prices are above the market prices. Thus, ABS is worthwhile for most of the motorcycle users.

The new critical mileage for the low effectiveness scenario for the year 2015 respectively 2020 is calculated analogue. The result is 5,200 km respectively 4,200 km. Even in the year 2020 ABS is still not worthwhile for most of motorcycle riders (Tab. 44).

The critical mileage for the high effectiveness scenario for the year 2015 is 1,900 km with discount (1,600 km for 2020).

The new critical mileages far are below the mileage on average. Thus, more users will equip their motorcycle with ABS due to the discount.

7.4 Consequences

In chapter 7.1 the fair end consumer prices are handled. These are the prices, the user is willing to pay. The benefits on user level are as high as the fair end consumer price. The fair end consumer prices are compared with the market prices for 2015 (400 Euro) respectively for 2020 (300 Euro).

In the low effectiveness scenario the fair end consumer prices are below the accordant market prices. Thus, ABS is only interesting for users with an annual mileage which is higher than the average. The fair end consumer price is 178 Euro for the year 2015 and 160 Euro for the year 2020. Thus, in the low effectiveness scenario ABS will be too expensive for the most motorcycle riders.

ABS is even too expensive if the discount from the insurance companies is considered.

In the high effectiveness scenario the fair end consumer prices are higher than the accordant market prices. For the year 2015 the fair end consumer price is 701 Euro respectively 622 Euro for the year 2020. Thus, ABS is worthwhile for the most motorcycle users.

In chapter 7.2 the critical mileage is determined for both years and both scenarios.

In the low effectiveness scenario the critical mileage is 8,800 km for 2015 respectively 7,300 km for the year 2020. The mileage on average is 3,900. ABS is only worthwhile for users with higher annual mileages than 8,800 km for 2015 respectively 7,300 km for 2020.

Considering the discount of the insurance companies the critical mileages of the low effectiveness scenario decrease to 5,200 km for 2015 respectively 4,200 km for 2020. Compared with the annual mileage on average, the critical mileages are still higher. Nevertheless, the critical mileage for 2020 is near to the annual mileage on average.

In the high effectiveness scenario the critical mileages are 2,200 km for 2015 and 1,900 km for 2020. These mileages are below the mileage on average. ABS is worthwhile for most users.

In this scenario it is likely that the well informed user will equip his motorcycle with ABS. However a full penetration rate is implausible. This is due to the fact that there are users with a low annual mileage. Another reason for this is that there are users who are confident that they do not need ABS.

8 Conclusion

There are four ABS scenarios considered for each year:

- penetration rate for ABS: trend; low effectiveness of ABS
- penetration rate for ABS: trend; high effectiveness of ABS
- penetration rate for ABS: mandatory for new motorcycles; low effectiveness of ABS
- penetration rate for ABS: mandatory for new motorcycles; high effectiveness of ABS

The penetration rate is differentiated into a trend scenario and a mandatory scenario. Trend scenario means that there are no special incentives to promote ABS on the part of the politics. In opposition to that the mandatory scenario means that ABS is equipped in every new motorcycle from the year 2010 on.

The system costs depend on the produced volume. The more systems are produced the lower are the system costs. Hence, the system costs of the mandatory scenario will be lower than the ones of the trend scenario. For the year 2015 the system costs are estimated as 120 Euro for the trend scenario and as 115 Euro for the mandatory scenario. For the year 2020 the figures are 105 Euro respectively 100 Euro (see also Tab. 45). Economies of scale and effects of learning curves are included.

The other two mentioned scenarios handle different effectiveness of ABS. In the scenario with a low effectiveness only the number of fatalities is considered. An avoided fatality is shifted to severe injury. Thus, the total number of fatalities decreases by the same quantity as the number of severe injuries increases. In the other scenario with high effectiveness it is considered that ABS influences the total number of accidents, of fatalities, of severe injuries, and of slight injuries. Both scenarios have in common that they only consider accidents in which the motorcycle rider falls down before the real accident happens. The downfall is usually caused by blocking wheels due to false braking manoeuvres which can be avoided by ABS. Additional effects due to shorter braking distances with ABS are neglected. This is due to the lack of data. Hence, both scenarios are underestimating. The scenario with high effectiveness is more significant and realistic than the scenario with low effectiveness. Thus, the subsequent conclusions are given for the (conventional) ABS with a high effectiveness.

In the scenario with high effectiveness the avoidance potential of ABS is as follows (see also Tab. 45):

- the number of accidents decreases by 2.4 %,
- the number of fatalities decreases by 12.1 %,
- the number of severe injuries decreases by 11.7 % and
- the number of slight injuries increases by 2.1 %.

Based on the estimated accident data about 98 fatalities could be avoided in the year 2015 and about 97 fatalities in the year 2020 due to ABS in motorcycles. This is the potential of ABS for the case of a 100 % equipment rate for ABS. Nevertheless this scenario is unrealistic. ABS is a system which can not be retrofitted. Thus, the chosen trend and mandatory scenario display a more realistic situation.

The benefit-cost ratios of the scenarios with high effectiveness are between 4.6 and 4.9. These ratios depend on the penetration rate and on the considered year. For the trend scenario the ratios are 4.6 for the year 2015 and 4.7 for the year 2020. The values for the mandatory scenario are 4.8 for the year 2015 and 4.9 for the year 2020.

Since the benefits are underestimated, the realistic benefit-cost ratios are significantly above the mentioned values. Hence, the benefit-cost ratios are significantly above 3.0. These figures argue for making ABS mandatory (see also Tab. 45).

In order to be complete the benefit-cost ratio for the scenarios with low effectiveness are between 1.7 and 1.8. Thus, even in this scenario the socio-economical benefits of ABS are higher than the costs.

For the break-even analysis the end consumer market prices for a conventional ABS were estimated. For the year 2015 the end consumer market price is considered as 400 Euro. For the year 2020 the figure is estimated as 300 Euro. The break-even analysis shows that most of the motorcycle riders are in favour to equip their next motorcycle with ABS. The end consumer market prices are below the fair prices, the average motorcycle rider is ready to pay. These fair prices are 701 Euro for the year 2015 and 622 Euro for the year 2020. The critical mileage, above which the ABS is

Cost-benefit analysis for the scenarios with high effectiveness		
Assumptions		
Penetration	trend	mandatory
2015	40%	48%
2020	57%	69%
System costs	trend	mandatory
2015	120 €	115 €
2020	105 €	100 €
Effectiveness		
accidents	decrease by	2.4%
fatalities	decrease by	12.1%
severe injuries	decrease by	11.7%
slight injuries	increase by	2.1%
Cost-benefit ratio	trend	mandatory
2015	4.6	4.8
2020	4.7	4.9
Break-even analysis		
Scenario high effectiveness	fair end consumer price	critical mileage
2015	701 €	2,200 km
2020	622 €	1,900 km
	market price	annual mileage on average
2015	400 €	3,900 km
2020	300 €	3,900 km

Tab. 45: Synopsis of the results

worthwhile for the motorcycle rider, is about 2,200 km for the year 2015 and about 1,900 km for the year 2020. The annual mileage on average is 3,900 km. Thus, most of the motorcycle riders should be expected to equip their motorcycle with ABS.

To conclude, the benefit-cost analysis shows clearly that ABS for motorcycles is economically reasonable. The full potential of ABS can only be achieved by making ABS mandatory.

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