Is there a broken trend in traffic safety in Germany?
Model based approach describing the relation between traffic fatalities in Germany and environmental conditions

Thomas Lich, Jörg Mönnich, Nora Reiter,
Alexander Skiera, Thomas Schlender, Andreas Georgi*

* Robert Bosch Corporation, Corporate Research and Advance Engineering, Vehicle Safety and Assistance Systems, CR/AEV, Accident Research, P.O. Box 300240, 70442 Stuttgart, Germany

Abstract

The declining trend since 1991 in the number of killed people was broken in 2011 when overall 4 009 people died in traffic accidents in Germany. The question arises if there is a stagnating trend of fatalities in Germany in future?
By breaking down the accidents with casualties towards a monthly view one can see a decreasing trend of fatalities in the warmer months especially since 2009. When comparing against winter months higher deviations are observed. In December 2011 an increase of 191 traffic deaths were registered (181 in 2010 compared to 372 in 2011). Further analyses of different accident influences were evaluated and their possibility of drastic change from one year to the other was determined. As seen weather- and environmental conditions are one of the major contributing factors and are one of the causes for the increased number of fatalities.
To support the underlying assumption a model had been created to calculate the number of traffic deaths on a daily basis approach. As an input, road conditions projected through weather parameters and also different driving behaviors on weekdays or holidays were used. As a result, estimates of daily fatality with up to 75% precision can be achieved out of the 2009, 2010 and 2011 data.
Further on it shows that weather and street conditions have a high influence on the overall resulting number of traffic accidents with casualties, and especially to the number of fatalities. Hence it is estimated that approximately 3 300 people were killed in traffic accidents in Germany in 2013 which would be again a reduction of another 13% compared to 2012. Therefore an answer to the question will be that the decreasing trend in traffic fatalities in Germany somehow is not broken when environmental conditions are included in national statistics. Their effects will become more visible in future accident statistics and it is estimated variances of 5% to 8% of the annual number of traffic fatalities in Germany will be seen.

Abbreviations

ABS	Antilock Braking System
AEB	Advanced Emergency Braking System
ESP®	Electronic Stability Program
DESTATIS	Federal Statistical Office Germany
FAT	Forschungsvereinigung Automobil Technik (Federal Automotive Organization)
GIDAS	German In-depth Accident Study
KBA	Kraftfahrtbundesamt (Federal Motor Transport Authority)

INTRODUCTION

Background

Traffic accident reporting in Germany goes back to the early 20th century and the impact to the society was collected almost continuously. In 1912 the total number of traffic fatalities was only 442 but the risk of being fatally injured in a traffic accident during this time was high. 631 people per 100 000 vehicles were killed; when there were only 70 000 registered vehicles. After 1953 there was an increasing trend in the number of traffic fatalities which reached its top in 1970 where 21 332 people were killed. Till then the number of registered vehicles in Germany had increased to 20.8 million but fatality risk was reduced to 102 fatalities per 100 000 vehicles.
Since then - except after the German reunification - the number of traffic fatalities followed a decreasing trend but stopped in 2011 suddenly. The number of killed people in traffic accidents

increased to 4 009 and additional +361 fatalities occurred in 2011 (+9.9%) compared to 2010. Will 2011 mark a challenge in the decreasing trend of traffic safety in Germany?

According to the latest statistics in 2012 and estimations for 2013 this assumption is not supported as Figure 1 shows. Moreover in total the number of killed people in traffic accidents reached another minimum of 3 600 people in 2012 [1].

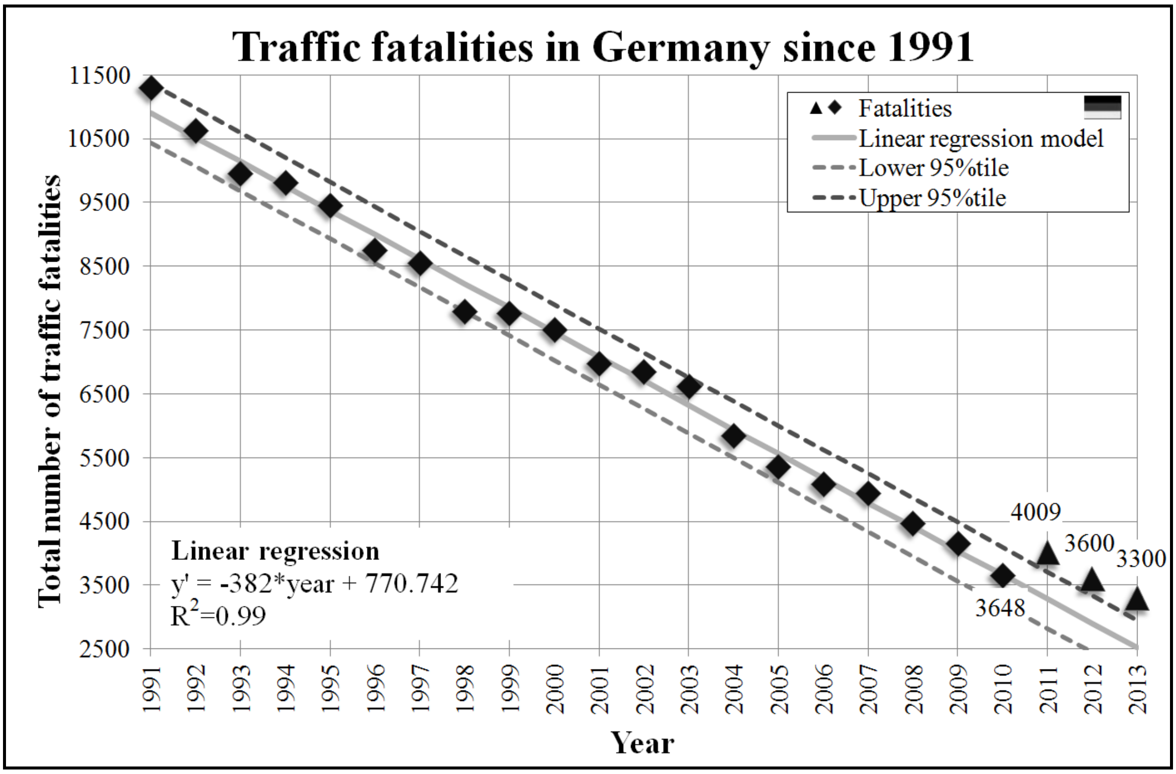


Figure 1. Number of traffic fatalities in Germany (Trend 1991-2010) [1]

Forecast for 2013 estimates a further reduction of approximately 300 fatalities to 3 300. If so then the target of the federal governmental traffic safety program (published in 2011) seems to be achievable in 2020. As claimed the total number of traffic fatalities shall be reduced to 2 188 fatalities in 2020 in Germany (-40%) using 2010 as a baseline. Following this trend, 2012 will not meet the goal but as of now it is not far from out of scope.

Hence the question arises are we back on track following the decreasing trend in future with a statistical outliner in 2011 or have we reached a certain limit in traffic safety in Germany in near future?

Scope and approach

Aim of the study is to identify the root cause for the increased number of fatalities in 2011 against 2010. Further scope is to determine the major contributing factors and their influences for each type of road user. To achieve this goal differences between 2009, 2010 and 2011 are evaluated and compared on a monthly level for the number of fatalities by road user type. A mathematical regression model is developed to estimate the number of fatalities on a daily base by using identified parameters. To understand their influence and to validate the model data from 2012 and 2013 are used. The output of the model – the estimated number of traffic fatalities - is compared against national statistics from Germany. Further on various literatures were analyzed to identify the root causing factors.

Accident contributing factors

The traffic accident situation of a country could be described in different ways – typically descriptive statistics is used by counting the number of accidents or the number of traffic fatalities within one year. By analyzing time series on monthly or annual level conclusions for the traffic safety are drawn and government or consumer organizations will use them to argue and to push their interests. More detailed analysis with such data is not done unfortunately hence root causes are not being identified. Effects from infrastructure, safety education or impacts from installed vehicle safety systems (active or passive safety) are typically not determinable using such statistics. There are several reasons for the evolution of traffic safety which could be categorized in two main contributing factors: direct and indirect impacts as seen in Figure 2 [1].

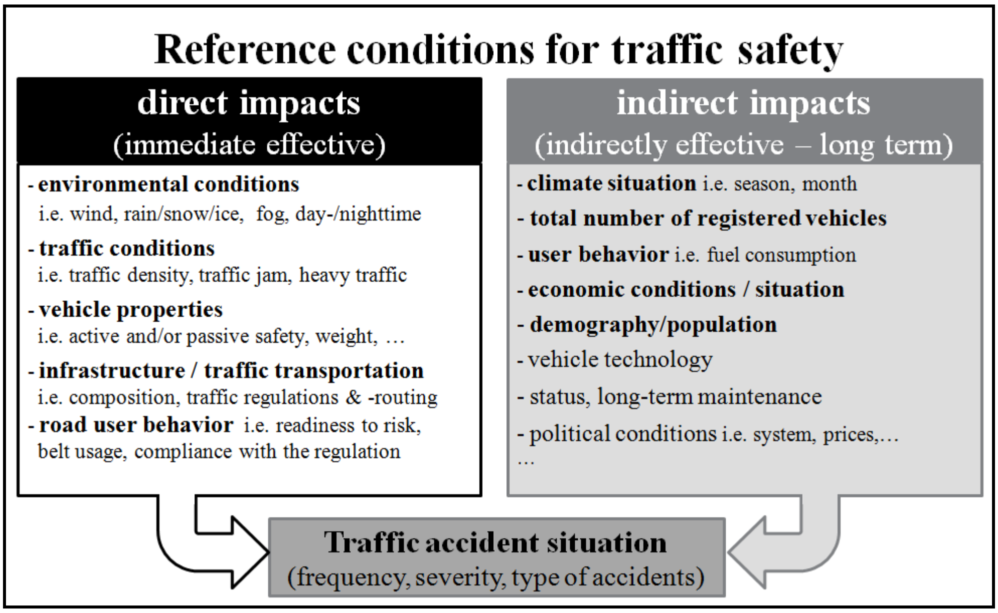


Figure 2. Examples for reference conditions for traffic safety [2]

Direct impacts typically are environmental- or traffic and transport conditions, properties of the vehicle and infrastructure or traffic regulations like helmet- and seatbelt use. Such factors are taken immediately effective and directly linked to the number of traffic accidents and therefore are statistically well reported. Indirect impacts such as demographic change, climate change and number of registered vehicles, safety education or the economic situation are seen on a long term base and will be visible after several years of their effectiveness. To identify the root cause for increased number of fatalities following aspects are considered within the study:

- Environmental conditions like wind, rain, snow, fog, day- or nighttime
- Traffic conditions e.g. weekday, holiday season
- Vehicle equipment and condition e.g. active or passive safety systems
- Annual climate and temperature situation
- Registered vehicles
- User behavior e.g. belt usage, alcohol
- Economic- and demographic situation

As far as data is available those aspects are taken into account and evaluated towards their contribution to influence the number of traffic fatalities.

MATERIAL AND METHOD

Literature survey

A detailed publication research is done by using various resources in the beginning of the study. In an official report from the Federal Statistical Office, more detailed accident data from 2011 and 2010 are compared using national statistics and are well documented [2].
In 1997 a similar situation occurred and this was analyzed in a study funded by the Federal Automotive Organization. A forecast model was developed using principal components out of weather related data but not on a daily base hence various root causes were not ideally identified [3].
In another study a model was developed to estimate the future traffic situation in Germany. Various conditions were evaluated and used in a more generic approach for the prediction of traffic accidents in Germany till 2020. This study aimed not to explain the root cause for traffic fatalities [4].
Apart from all studies, national accident data from the Federal Statistical Office are also used as well as detailed in-depth accident data out of the GIDAS database (2001-2012) [1;5].
Publicly available databases providing information about environmental conditions like weather, hours of daylight, rain- and snowfall in different cities from Germany are collected from official weather resources [6].
Furthermore on the number of registered vehicles is available from the Federal Motor Transport Authority and was also analyzed [7].

Methodology

By applying a linear regression model (*y'*= 770742-382·*year* with R^2=0.99) on the number of traffic fatalities in Germany from 1991 on the overall trend a reduction of ~382 fatalities p.a. (-3.5%) is given as shown in Figure 1. Taking this into account it is seen that the number of killed people does not follow this trend, since it increased to 4 009 (+9.9%) in 2011 compared to 2010. Reasons for that could be seen in a resolved statistic on a monthly base. Figure 3 shows respectively the total monthly number of traffic fatalities in Germany from 2009 till 2012.

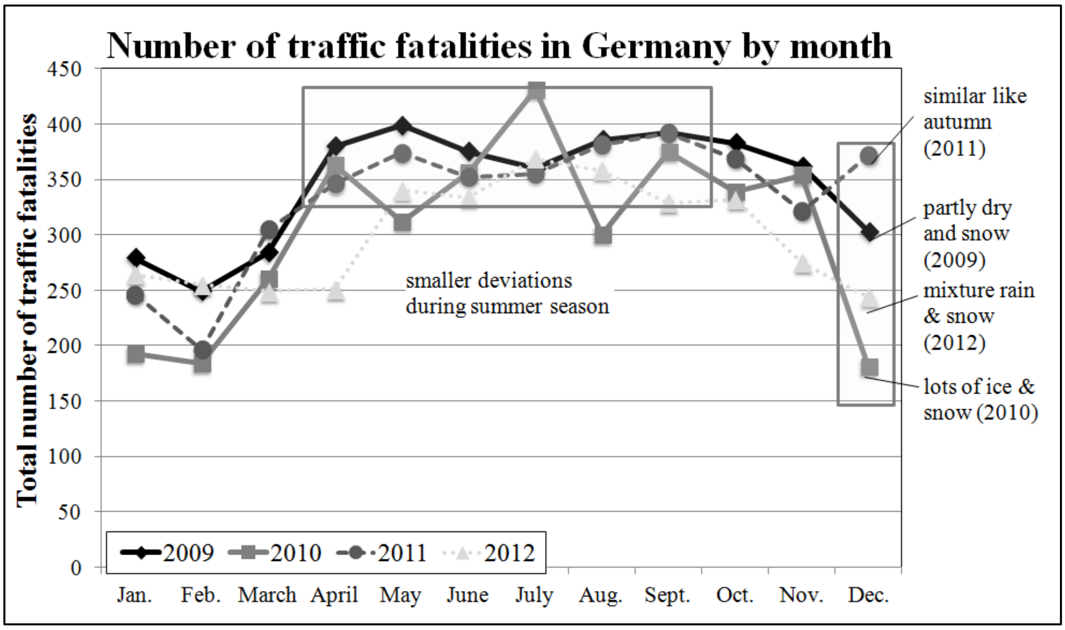


Figure 3. Number of traffic fatalities in Germany by month (2009-2012) [1]

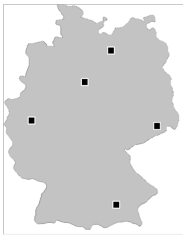
As seen in the statistics highest deviations occur during the winter season – especially in December. The difference of +191 killed people in 2011 (372 fatalities) and 2010 (181 fatalities) is the highest deviation between these years. Comparing against April/May and the summer season (June till August) smaller deviations are observed. It is evident that environmental conditions like the weather are one major root cause for such an increase. Cold temperatures results in different road user behavior and traffic involvement hence the probability being killed in a traffic accident is also different. This also supports Table 1 where the type of road user being killed in month December is compared for the three years 2009-2011.

Table 1. Traffic fatalities in December in Germany by year and type of road user

Fatalities by road user in December	Passenger car	Motorized two-wheeler	Cyclists	Pedestrian	all others	Total
2009	177	8	26	80	12	303
2010	113	4	3	40	21	181
2011	218	8	14	118	14	372

To further underline this assumption number of fatalities is compared against the weather condition averaged from five weather stations in Germany. The environment or moreover street conditions are estimated by counting the number of hours with dry, wet/rainy or snowy road conditions. Further on heavy rain storms, hurricanes and icy roads are collected as well as hours of sunshine and temperature. The weather stations are selected to represent the street conditions in Germany during a day [6].

- Schwerin
- Hannover
- Düsseldorf
- Dresden
- München



Unfortunately differences might occur if other weather stations would be selected but for being representative at least each region from North to South and East to West is considered. Figure 4 shows the number of traffic fatalities and the summarized and compressed results out of these weather stations on a daily base for the month December (2009-2011).

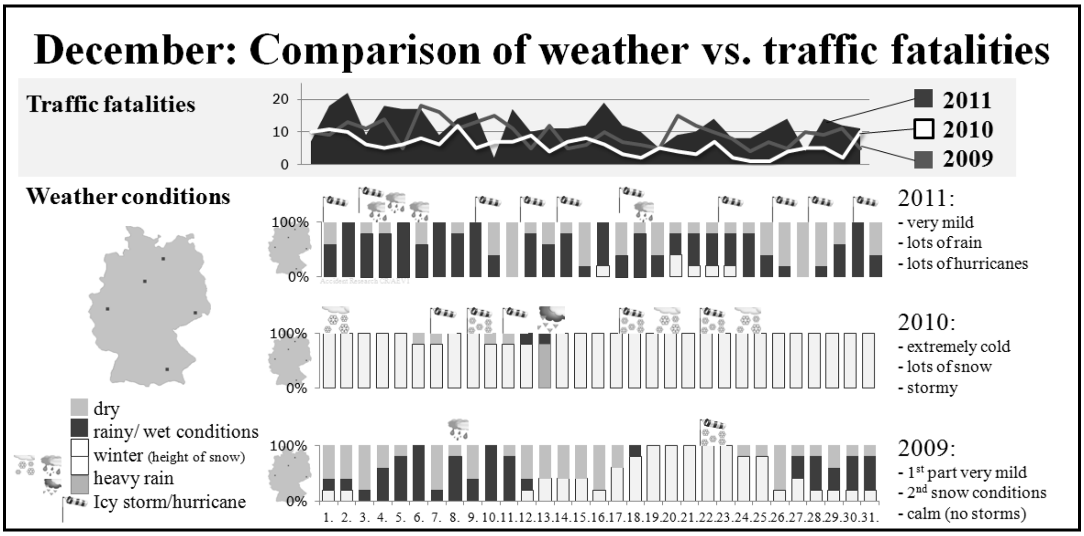


Figure 4. Comparison weather vs. traffic fatalities (December, Germany 2009-2011) [1;5]

Keeping in mind that 2009 was following the trend, it is seen that the first part of December 2009 was very mild and it ended with lots of snow and heavy rain but without storm. Overall a typical winter season resulting in a certain level of traffic fatalities (303 persons killed).
Having a closer look at December 2010 where the whole month was covered with lots of snow and heavy rain and extremely cold days. It was one of the coldest Decembers with -3.9°C since twenty years. In December 2010, 181 people died in traffic accidents (-40% against December 2009). As seen from Table 1 the number of killed VRU's is less than two times compared to 2009. Cold temperature and icy road result in less leisure activities outside and overall more sensitive driving e.g. reduced speed and therefore reduced probability being involved in an accident.
Taking this as reference +105% people were killed in traffic accidents in December 2011 (372 fatalities). Very mild weather conditions covered with lots of rain and hurricanes result in a situation similar to the autumn season e.g. as in October 2011 (369 fatalities). With a mean temperature of +3.7°C December 2011 was one of the warmest and stormiest since twenty years [8].
To quantify the correlation between environmental conditions and the number of traffic fatalities a model is built up to estimate the number of fatalities on a daily bases using various input parameters.

Model setup

To explain the influences in the number of traffic fatalities either statistical analysis can be done or a model based approach can be considered. Due to lack of information a statistical approach was not considered and a model was used. Target of the model is to map street conditions (throughout weather and temperature) to the number of traffic fatalities by considering different road user behavior. The estimation is done on a daily base resulting in an overall number of killed people in Germany. Following input parameters are used in the model (daily based):

- Daylight (Hours)
- Temperature
- Street condition (est.): counting hours of dry, rain and snow
- Single events: heavy rain storms, hurricanes, icy roads
- Day of week
- Holiday season or bank holiday

The length of daylight represents the month in a certain way due to the fact that during summer time the hours of sunshine averaged 7 hours (July) and 1.2 hours (December) in Germany [8]. Temperature impacts the road user behavior and gives minor indications to the street condition nevertheless it is obvious that even with cold temperatures the street condition could be dry. Hence other factors have to be taken into account such as counting of hours of dry weather, rain or snow. Single events like heavy rain, storms, hurricanes or icy roads are also considered. Daily traffic is limited represented by just taking weekdays or holiday seasons into account as it was also used in the FAT study [3]. Fog and frozen rain/snow are local and less frequent events hence not considered in the model.

The model setup is done according to Formula 1:

$$Fatalities\ (day) = b \cdot \sum_{j=1}^{3} a_j \cdot g_j \cdot \prod_i f_i(day) \qquad \text{with} \sum_j a_j = 1 \qquad [1]$$

with
$$b := \text{Bias representing a minimum number of fatalities per day/month}$$
$$a_j := \text{factor street condition (dry, rain, snow)}$$
$$g_j := \text{function representing street condition (dry, rain, snow)}$$
$$f_i := \text{function } i \text{ representing daily events (weekday, hurricanes', storms, ...)}$$

The bias *b* in the model represents the number of averaged traffic fatalities per day in a month. The value is estimated by the calculation of a mean value out of national statistics. For example in December 2010 and 2011 approximately 6 people and 10 people died in traffic accidents per day respectively.

The daily street condition is separated in three major factors – dry, wet and snow. Each condition is weighted by using multiplication factor *a* and function *g* respective. Each function *g* is realized by a simplified approach using the ratio between the numbers of fatalities occurring with the street condition in focus against all number of fatalities. This represents a mean value for the number of fatalities occurring under the street condition. For example the function *g(rain)* is estimated by the ratio of the number of fatalities during rain (558 in December 2009/10/11) to all number of fatalities without rain (436 in December 2009/10/11) respectively. This results in value of *g(rain)* = 1.3 or in other words being involved in a fatal accident is higher with a share of 30% in wet conditions compared to non wet conditions.

Individual events are represented by several functions *f* with a direct impact to the number of traffic accidents and fatalities. The following events are considered in the model – heavy rain storms, hurricanes and weekday. Each function is represented by a ratio considering every event as explained above. For example the function *f(Sunday)* for December 2009/10/11 is estimated by the ratio of the mean number of 6 fatalities at Sunday/Holiday and the mean value of 10 fatalities at all other days. This results in a value of *f(Sunday)* = 0.6 or in other words it is assumed that a lower frequency is given being killed in traffic accident on a Sunday with a share of -40% against all other days.

Such initial evaluation is done for various selected months in order to find very generic parameters for the model. The parameters listed in Table 2 are used for the estimations.

Table 2. Model parameters to estimate the number of traffic fatalities on a daily base

	Input parameters	Influence (Value)
Fatalities per day/months	*Bias b*	7.5
Street condition	*dry*	0% (1.0)
	rain	+30% (1.3)
	snow	-40% (0.6)
Extreme conditions (daily events)	*storm*	+50% (1.5)
	hurricane	+60% (1.6)
	heavy rainstorm	+60% (1.6)
Traffic participation	*Sat./holiday*	-20% (0.8)
	Sun./bank holiday	-60% (0.4)

The input parameters or time series are not preprocessed such that they are independent input vectors. Hence numerical dependency is not erased by e.g. calculation or the use of principal components. This somehow was considered in the study conducted by the FAT [3].

Further on this approach cannot cover multiple collisions or very severe accident events (accidents whereas a lot of people are killed). Such single events were identified throughout different research e.g. newspaper as it is shown in Figure 5 for some events in 2011.

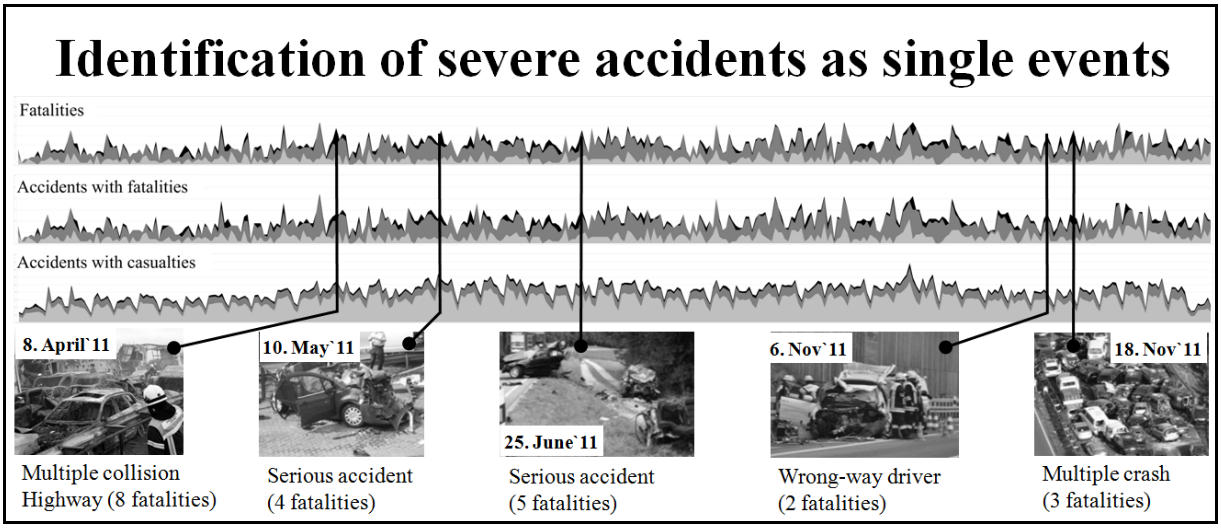


Figure 5. Examples for severe accidents occurred as single event (2011) [1]

As seen such single events causing a peak in the statistics and it is assumed that this approach is not able to project this by just using generic input data hence in such events a higher deviation in the estimation is expected.

RESULTS

Applying the parameters listed in Table 2 to the input information a daily based estimation for the number of traffic fatalities is given for each month. Exemplarily for the 17th of December the result of the estimation is shown in Table 3 for the years of reference 2009, 2010 and 2011. According to the number of registered fatalities in 2009, 10 people were killed on this day (6 fatalities in 2010, 18 fatalities in 2011). The model estimates 6 fatalities for the 17th of December 2009 (2010: 7 fatalities and 2011: 19 fatalities).

Table 3. Estimated traffic fatalities for 17th of December of 2009, 2010 and 2011

	Input parameters	Thursday 17th Dec. 2009	Friday 17th Dec. 2010	Saturday 17th Dec. 2011
Street condition	a_1 = *dry*	0.4	0.0	0.6
	a_2 = *rain*	0.0	0.0	0.4
	a_3 =*snow*	0.6	1.0	0.0
Extreme conditions (daily events)	*storm*	no = 1.0	yes =1.5	no =1.0
	hurricane	no = 1.0	no = 1.0	yes =1.6
	heavy rainstorm	no = 1.0	no = 1.0	yes =1.6
Traffic participation	*Sat./holiday*	no = 1.0	no = 1.0	yes =0.8
	Sun./bank holiday	no = 1.0	no = 1.0	no = 1.0
Estimated traffic fatalities		6	7	19
Police reported traffic fatalities		10	6	18

As seen in the example slight deviations occur unfortunately. Nevertheless the model is able to estimate the number of traffic fatalities just by taking environmental conditions into account. Typically this results in a parameter optimization problem using the smallest error between estimation and real value. As a matter of fact it was not aim of the study to have a parameter optimization for an estimation problem moreover it was the purpose to identify contributing factors to explain the increase of the number of fatalities in 2011. Hence the model was optimized in a way such that an explanation could be given for a certain level of traffic fatalities.

Therefore the model was also validated by using data out of 2012 which was not part of the parameter setup. Input data from December 2012 was collected and used for the estimation. The weather conditions during this month were similar like in 2009 with minor snow. Figure 6 shows summarized the contribution of each input data.

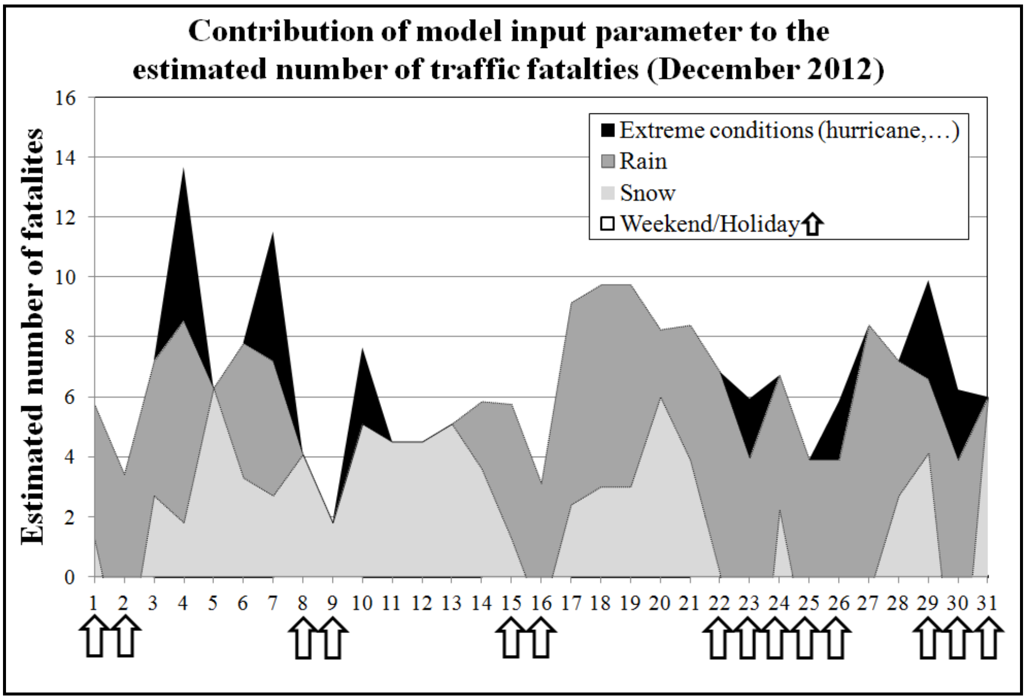


Figure 6. Impact of model input parameters for the estimated number of traffic fatalities (December 2012)

By considering a bias of 7.5 killed people per day each factor results in an increasing or decreasing trend of the estimation (Bias not shown).

Extreme weather situations e.g. hurricanes (black) resulted in an increase in the number of traffic fatalities. Similarly, it is given for the outcome if rainy weather (dark grey) is taken into account which also has an increasing contribution to higher fatalities.

Snow (light grey) was identified to reduce the number of accidents and therefore also the number of killed people. Further on Saturday/holiday or Sunday/bank holiday (arrows) reduces the frequency being killed in a traffic accident, hence also the predicted number of fatalities.

Overall these results in total estimated number of traffic fatalities for December 2012 of 210 killed people against 244 police reported fatalities. The daily prediction is compared against the real world values in Figure 7.

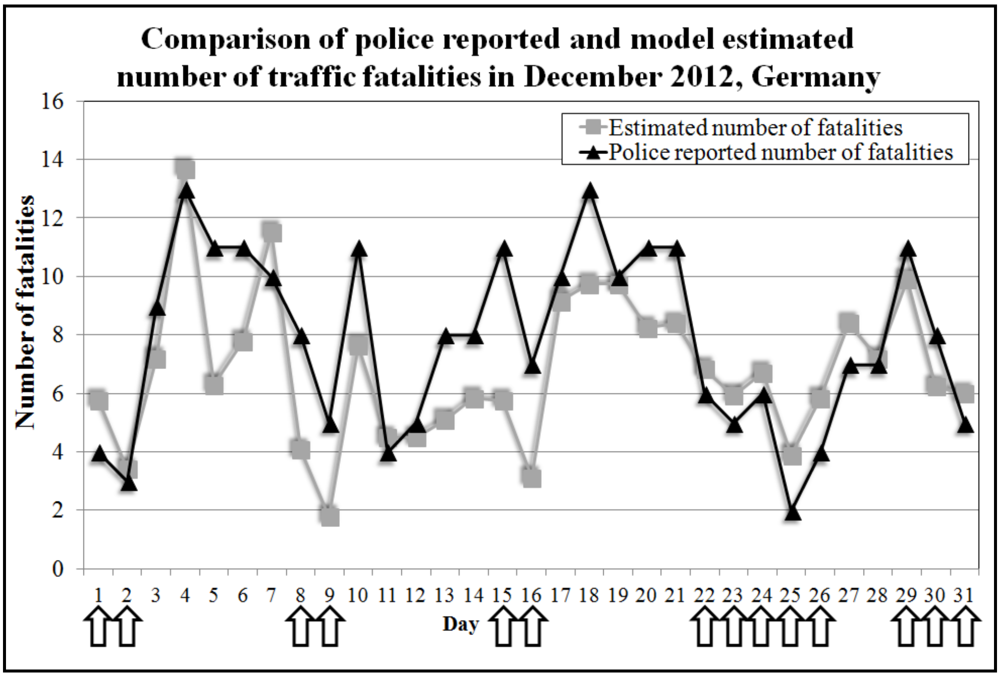


Figure 7. Comparison of police reported and model estimated number of traffic fatalities in December 2012 for Germany

Taking 244 traffic fatalities as reference then the model is able to estimate 75% of the traffic fatalities in this month by just using weather data on a daily base. Multiple collision events are not well predicted and results in more underestimated values.

Unfortunately, environmental conditions influence the traffic accident situation in warmer months (April till October) as well. In example the increase in the number of motorized two wheelers (+69 in 2011 against 2010) is assumed to be caused with a high probability due to nice and warm weather conditions in 2011. This results in more frequent traffic collision and the use of motorized two-wheelers e.g. +34 killed people in May 2011 during sunny weather compared May 2010 with lots of rain. Hence a verification of the model was also done by applying data from April till October and compared against official data - the result is seen in Figure 8 .

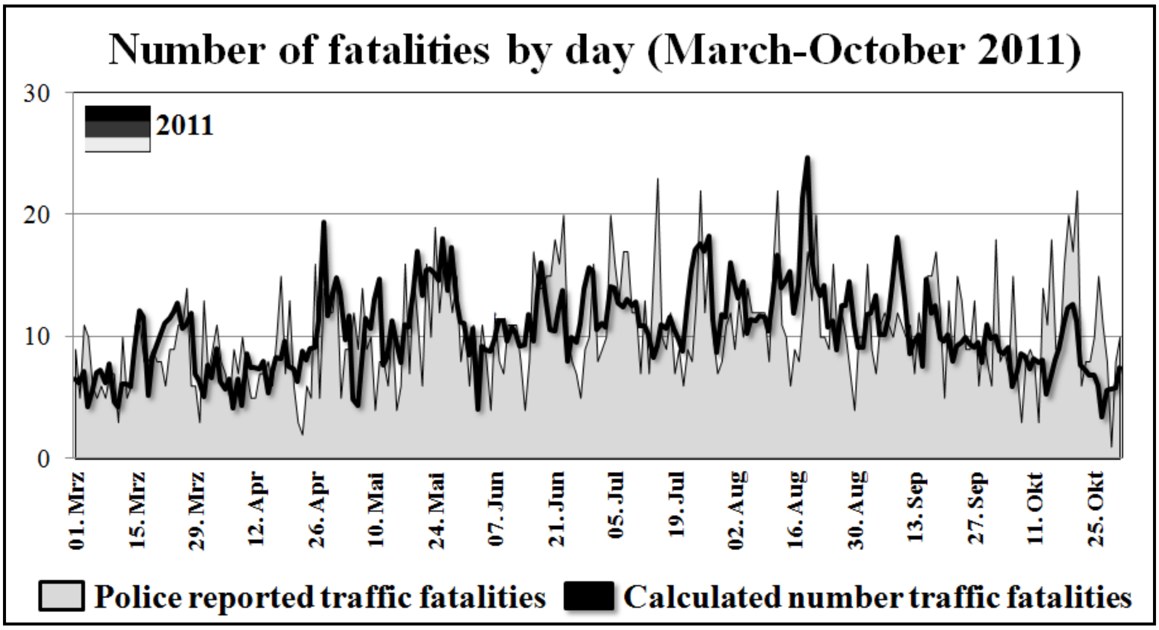


Figure 8. Police reported and model estimated number of traffic fatalities Germany 2012 (March-Oct.)

A monthly validation (especially in May) shows also that the increased number of fatalities could be described by temperature and weather conditions. In several months the model was able to explain the overall number of fatalities with up to 80% (as average per month not on a daily base). As it is clearly seen in Figure 7 and Figure 8 on several days higher deviations occur. It is obvious that such approach is not able to model single events quite well. A better solution would be given by modeling the number of accidents with casualties instead of the absolute number of fatalities. As a matter of fact in one accident more than one people could be killed hence estimating the accident will have some kind of filter effect on single events. This will be the next step in order to evaluate future trends more precisely.

Summarized environmental conditions are being identified as a major cause for the increased number of fatalities in 2011 especially during winter season. Up to 75% of this increase can be explained through weather conditions (annual comparison).
However, single local effects causing accidents with high severity are not clearly identified. As reported fog caused additional 45 fatalities throughout the year and especially in January 2011 approximately 25 additional fatalities occurred due to frozen rain [2].

Besides environmental conditions as a root cause for the increased number of traffic fatalities in 2011 additional factors were identified and analyzed to be responsible e.g. alcohol, road work accidents, technical defects etc.

Fatal accidents involving alcohol increased to a share of 17% to 400 fatalities (2010: 342 fatalities). However this increase in 2011 also follows the decreasing trend for the last few years involving alcohol. Physical or mental disability was registered in 83 accidents (2%) in 2011 and has only a minor impact in the overall number of fatalities with a decreasing trend since 2009. The number of road work accidents on German highways are less compared to 2010 and are assumed to be a result of the ending German economic support program II. However the number of 18 traffic fatalities is the same in 2010 and 2011. Technical defects were identified as a root cause in 31 fatal accidents in 2011 (2010: 71 fatal accidents) and significantly decreasing the last recent years.

Concluded, the main contributing factors are shown in Figure 9. As it is seen the majority of the root causes are through single events and environmental effects resulting in higher fatalities. This calculation takes a 75% explanation of the model (mainly in May and December) into account caused by different weather conditions in 2011 compared to 2010.

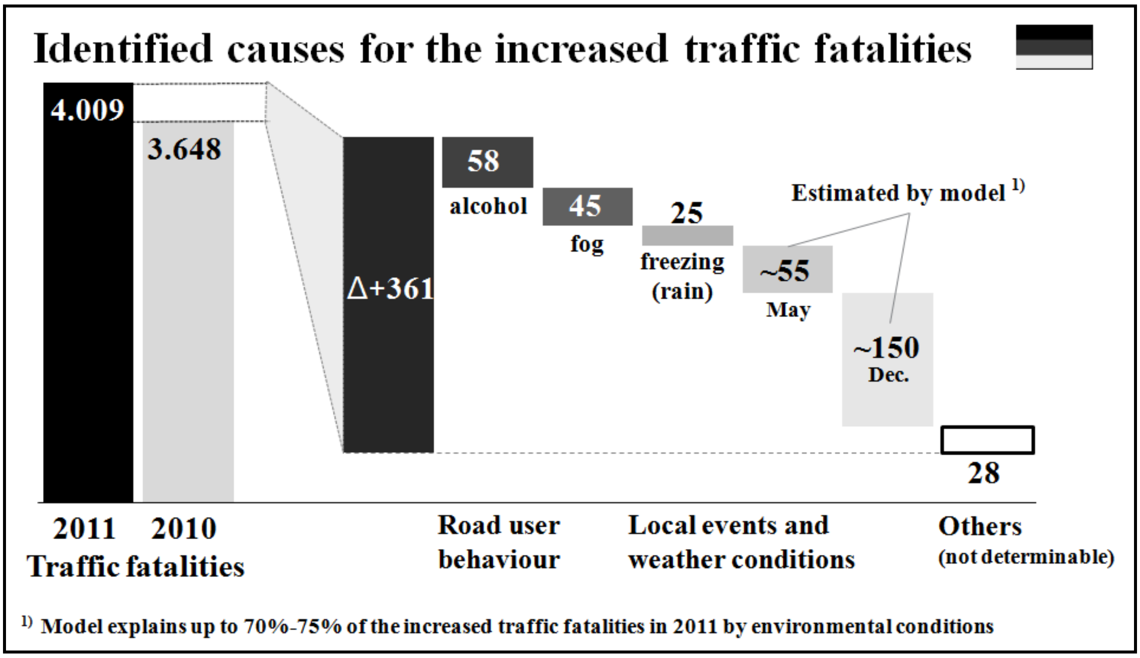


Figure 9. Contribution of several causes for the increased number of traffic fatalities in 2011 Germany

SUMMARY

The present study aimed to explain the root causes for the increased number of traffic fatalities in Germany in 2011. Various resources are used to identify the differences in the number of fatalities by type of road user. A model based approach was built up to estimate the number of fatalities on a daily basis and to show that weather conditions are the main root cause for the increased number of traffic fatalities. To summarize:

- In 2011, 4 009 people died in traffic accidents in Germany. Comparing against 2010 +361 fatalities occurred (+9.9%)
- The numbers of traffic fatalities in 2011 and 2012 in Germany are not in the long term trend since 1991 (about -382 fatalities p.a. with respect to 1991). Highest deviations seen during winter season at least in December 2011 over +191 people died in traffic accidents (+109% against December 2010). Thereof 107 car passengers and 78 pedestrians
- 2010 was one of the coldest Decembers with -3.9°C since twenty years. Compared to 2011 with +3.7°C as one of the warmest Decembers with heavy storms
- A model was developed mapping street and weather conditions as well as single events to the number of fatalities on a daily base. With the model an explanation of the number of traffic fatalities in a month is given in up to 75% throughout different street- and weather conditions
- Fog caused 45 traffic fatalities in 2011 (15 fatalities in 2010)
- Freezing (rain) in January 2011 is reported in additional 25 cases
- Alcohol caused 400 fatalities in 2011 (342 fatalities in 2010)

As one of the results it is seen that the number of traffic fatalities in Germany will be more influenced by environmental effects. Overall traffic safety in Germany is very high. As a matter of fact people were killed in only 1% of all accidents with casualty's; in particular the German highways are very safe (31% of the travelled mileage with a share of 11% of all fatal accidents only) [1].

CONCLUSION

Following conclusions are drawn from the study for the future of traffic safety in Germany:

1. A very early onset of winter (as in Dec. 2010) and long duration will influence the traffic in positive way. Moreover the total number of traffic fatalities in this season could be two times less.
2. Very mild and warm weather conditions (as in Dec. 2011) do increase the number of traffic fatalities. These conditions can result in a total fatality level similar like in the autumn season.
3. In future variances of 5% to 8% of the annual number of traffic fatalities in Germany are estimated as a result from environmental and weather conditions only.
4. Taking a full penetration of current state-of-the-art vehicle (car, motorcycle) safety systems into account it is assumed that a slight stagnating trend can be observed in future.
5. Additional measures on e.g. infrastructure, safety awareness (belt use) and new vehicle safety systems have to be taken into account in order to achieve the European target in 2020.

The question if there will be a broken trend in traffic safety in Germany is not clearly answered. Moreover it is assumed that a less decreasing trend will be seen superimposed with variances from environmental effects. Their influence will result in a higher impact to the number of traffic accidents with severe or fatal injuries hence also in the total number of traffic fatalities more and more in future.

REFERENCES

[1] Federal Statistical Office, Fachserie 8 Reihe 7, Annual traffic report 2012, published July 2013, www.destatis.de

[2] Vorndran I., „Unfallentwicklung auf deutschen Straßen 2011“, Federal Statistical Office, Wiesbaden, July 2012

[3] Wolff H., „Zusammenhang zwischen Wetterbedingungen und Verkehrsunfällen“, FAT Schriftenreihe Nr. 98, Frankfurt, 1998

[4] Maier et al., „Entwicklung der Verkehrssicherheit und ihrer Rahmenbedingungen bis 2015/2020”, BaSt Schriftenreihe, Mensch und Sicherheit, M224, Bergisch Gladbach, 2012

[5] GIDAS database (German-In-Depth-Accident Study), www.gidas.org

[6] Official WebPages for weather conditions: www.wetteronline.de and www.meteomedia.de

[7] Federal Motor Transport Authority (KBA – Kraftfahrt Bundesamt), Annual statistics 2012, published in January 2011, www.kba.de

[8] Federal Ministry of Transport and Infrastructure (DWD – Deutscher Wetter Dienst), “Weather in 2011: one of the five warmest years in Germany since 1881”, Archive 2011, www.dwd.de