STATISTICAL DRIVER MODEL FOR ACCIDENT SIMULATION

Using a statistical driver model for benefit estimation of advanced safety systems with warning interfaces

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Abstract - The main focus of the benefit estimation of advanced safety systems with a warning interface by simulation is on the driver. The driver is the only link between the algorithm of the safety system and the vehicle, which makes the setup of a driver model for such simulations very important. This paper describes an approach for the use of a statistical driver model in simulation. It also gives an outlook on further work on this topic.
The build-up process of the model suffices with a distribution of reaction times and a distribution of reaction intensities. Both were combined in different scenarios for every driver. Each scenario has then a specific probability to occur.
To use the statistical driver model, every accident scene has to be simulated with each driver scenario (combinations of reaction times and intensities). The results of the simulations are then combined regarding the probabilities to occur, which leads to an overall estimated benefit of the specific system.
The model works with one or more equipped participants and deliver a range for the benefit of advanced safety systems with warning interfaces.

INTRODUCTION AND MOTIVATION

The benefit estimation of autonomous advanced safety systems is often executed by real world accident simulations [1]. Figure 1 shows the functional principle of such a simulation process.

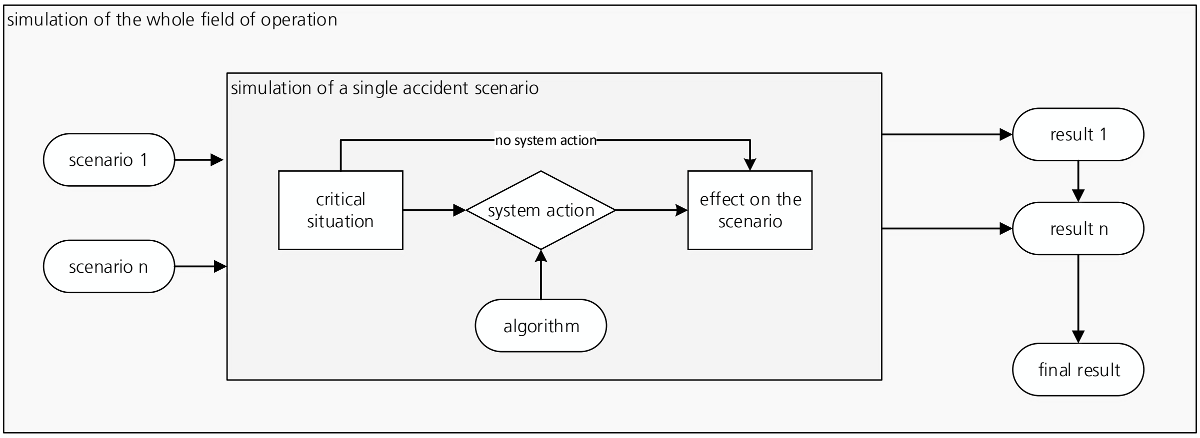

Figure 1: simulation process for autonomous advanced safety systems

A significant number of real world accident scenarios in the field of operation of the safety system is one requirement for the simulation process. These accident scenarios are then simulated one by one until the collision occurs. During the simulation of the accident scenarios, the participants of interest are equipped with the safety system sensor(s) and algorithm(s). Those algorithms are able to initiate a system interaction when a critical situation is detected. The system interaction (braking/steering) can have an effect to the whole accident scenario, leading to a mitigation or avoidance of the accident scenario. Based on the system complexities and functional safety requirements, most of the advanced safety systems on the market combine an autonomous interaction with a previous warning to initiate a driver reaction. A driver reaction after the warning can be used as a confirmation that a critical situation is imminent. For those warning systems, the driver requires an additional step within the simulation process, which leads to a more complex benefit estimation.

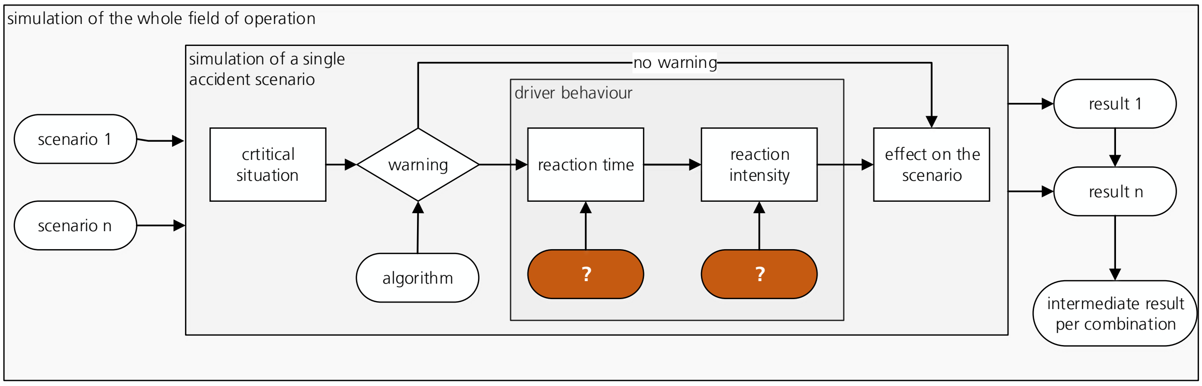

Figure 2: simulation process for warning safety systems

Figure 2 shows the functional principle of the simulation process including a warning system. The difference to Figure 1 is the driver behavior, which can be described with the reaction time and the reaction intensity. The warning safety system can only have an effect on the accident scenario if there is a specific response of the driver. The driver behavior model can have different complexities. The following paper will describe one method to define a driver model in a statistical way and gives some examples of results.

Main target

The aim of the statistical driver model is to define parameters for the driver reaction time and reaction intensity in a way that fit all possible scenarios regarding their single probabilities to occur. This driver model should then be used to execute a benefit estimation of a warning system.

APPROACH

In general, every driver shows an individual behavior and reaction based on a critical traffic situation. Based on different parameters such as age, driving experience, distraction, situation judgment, warning type, etc., the driver reaction will (or will not) occur with a specific intensity after a specific reaction time.

To reach the main target of the publication, the following three steps are required:

- Definition of the reaction intensity distribution
- Definition of the reaction time distribution
- Implementation into the simulation

Definition of the reaction intensity distribution

In this case, the driver reaction type “braking” is focused. It should be consensus that not every driver brakes with the same intensity after a critical situation occurs or after the warning of a safety system is given to the driver. This topic was also investigated by Felix Klanner in [2]. The following table of successful and unsuccessful reactions to the warning of advanced safety systems is one intermediate result of [2].

Table 1: intermediate results of Felix Klanner [2]

	successful reaction	unsuccessful reaction	Number
without warning	8%	92%	20
with warning	75%	25%	25

Table 1 shows the success of driver reactions on a system warning after a critical situation occurs. This means that 75% of the all drivers who did show a brake reaction related to the system warning avoided a potential collision. Within this study, different warning types were combined. This leads to the first assumptions for this paper:

If there is a reaction on the warning of a safety system:

- 75% of the drivers perform a brake maneuver with a high deceleration; → 100% brake pressure and
- 25% of the drivers perform a medium brake maneuver; → 50% brake pressure.

Definition of the reaction time distribution

After the intensity of the driver reaction was defined, the driver reaction time is mandatory for the estimated benefit. This distribution was already investigated by Wolfgang Hugemann [3].

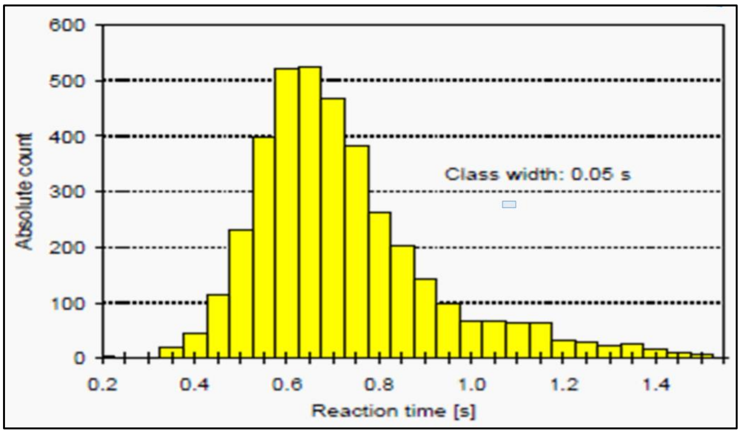

Figure 3: distribution of reaction times, W. Hugemann [3]

Figure 3 shows the distribution of the reaction times in 0.05s steps. Based on the different parameters mentioned above, the reaction times spread between 0.35s to 1.5s. To limit the calculation effort, the reaction times will be divided in three homogenous groups and a mean value of each group is calculated. The following table shows the mean reaction time of each group related to the probability.

Table 2: mean reaction times and probabilities

group	probability	mean reaction time
1	35%	0.48s
2	36%	0.70s
3	29%	1.08s

These reaction times (0.48s, 0.7s and 1.08s) will be used for the further calculations.

Implementation into the simulation

The last step of this approach is the implementation of the reaction times and intensities into the real world accident simulation. Figure 4 shows all possible combinations for one single driver which are the basis for the implementation into the simulation model.

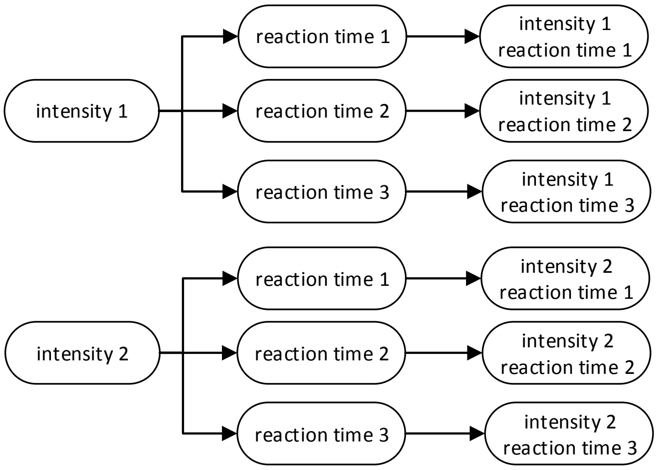

Figure 4: possible combinations for a single driver

Each accident scenario will be simulated with all possible combinations of reaction time and brake intensity. Figure 5 shows the functional principle of this procedure.

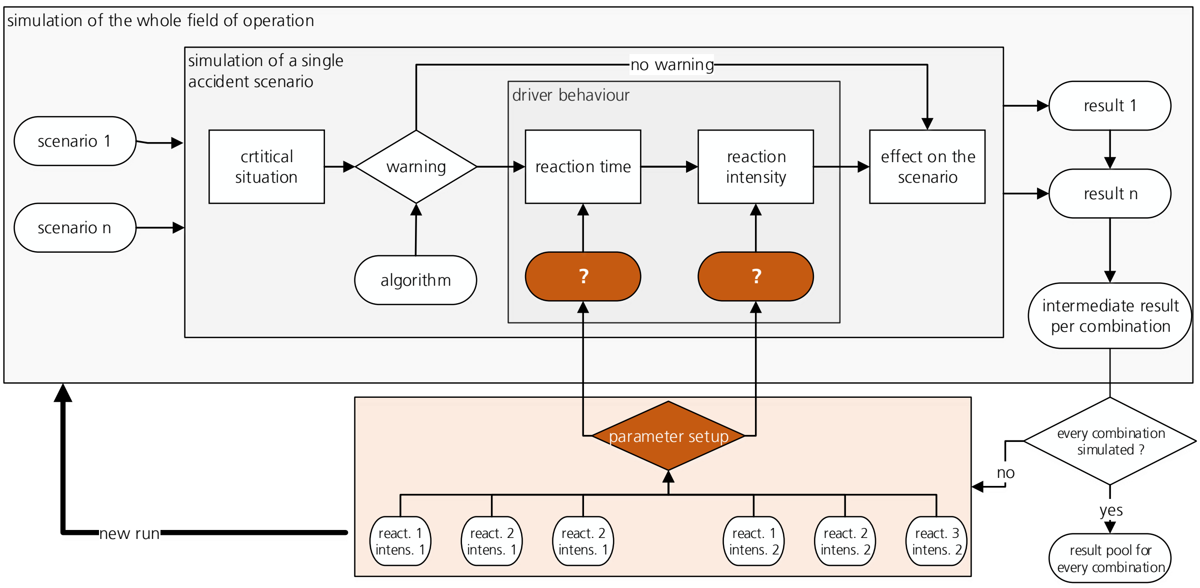

Figure 5: simulation process for warning systems with driver behaviour

The result of this extensive simulation process is a huge dataset of possible intermediate results. The size of this dataset depends on the number of accident scenarios in the field of operation and the number of possible driver behavior combinations. Figure 6 shows some possible result datasets for six combinations.

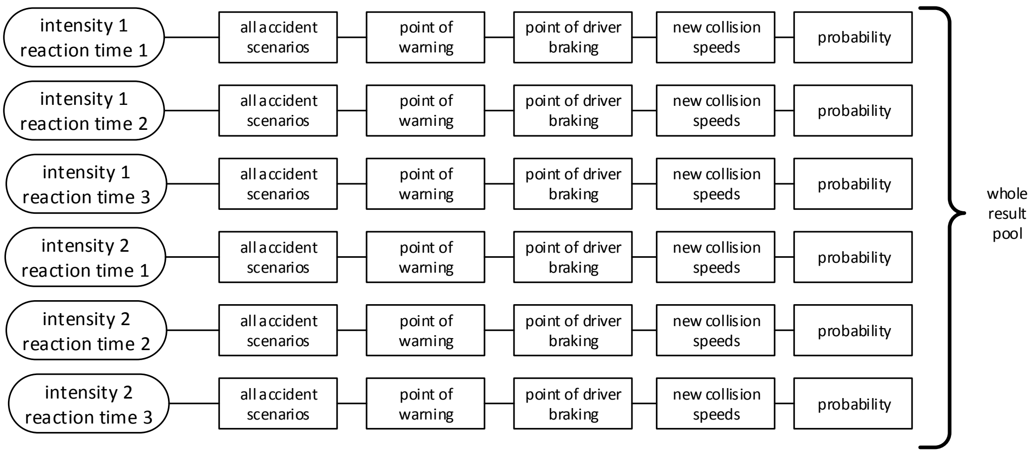

Figure 6: possible results for six combinations

Due to the fact that every accident scenario can be avoided or mitigated only once, a choice of the results of interest has to be made. This choice is made randomized led by the probability of every combination. The summation of all chosen single results produces one possible and plausible intermediate result. The random choice of the combinations lead to a variation of the intermediate results. To explain this variation, the following example is given:

If all fast reactions with high brake intensities are randomly addressed to accidents with a higher potential for avoidance or accident mitigation, a huge benefit of the investigated system will be the result. If all slow reactions with low brake intensities are addressed to this group, the benefit of the investigated system will be very low.

This results in an approach in which the benefit of the system is between a high and a low border. To define these borders, the random choice will be repeated until no significant change of the borders will appear. In a final step, the final result will give a tolerance band for all parameters of interest such as new collision speeds, points of driver braking or points of system warnings.

EXAMPLES

To give a deeper understanding for the usage of the statistical driver model, two examples will be shown in this chapter. One for a single driver and one for two drivers. The PCM [4] and some additional GIDAS [5] data is used as a basis for the simulations.

Single driver example

For the first example, pre-defined sensor systems and warning algorithms of the Adam Opel AG are used to simulate accident scenarios of a specific field of operation. The simulations were carried out using the simulation model of the Fraunhofer IVI.

Initially the probabilities for all possible combinations of the driver behaviour are calculated.

Table 3: possible combinations and dedicated probabilities (single driver)

single driver equipped			
combination	**reaction time [s]**	**brake intensity [%/100]**	**probability [%/100]**
1	0.48	0.50	0.0875
2	1.08	1.00	0.2625
3	0.70	0.50	0.0900
4	0.70	1.00	0.2700
5	1.08	0.50	0.0725
6	1.08	1.00	0.2175

Table 3 shows all possible combinations of reaction time and brake intensity of the statistical driver model of a single driver.

In this example, the field of operation of the specific warning system gives 3,172 accident scenarios in the PCM [4]. Every accident is then simulated with each combination of table 3. This gives a pool of simulation results of 19,032 scenarios. After the simulation, the result files have to be combined by the probability of each combination in a random way until there is no significant change of the whole result. This means for example that 27% of all accidents get the combination 4 (0.7s reaction time / 100% brake intensity). The choice of the 27% accidents is performed randomly.

Table 4: statistical variation of simulation results

configuration scenario	1	2	3	4	5	...	100
Accident number	combination	combination	combination	combination	combination	combination	
1	2	6	3	4	2	...	1-6
2	6	2	2	1	6	...	1-6
3	5	2	6	1	6	...	1-6
4	6	4	6	4	4	...	1-6
5	2	2	4	2	1	...	1-6
6	4	3	6	6	2	...	1-6
7	2	1	3	6	4	...	1-6
8	3	2	4	6	5	...	1-6
9	4	6	5	2	2	...	1-6
10	1	2	6	6	5	...	1-6
11	6	3	6	6	1	...	1-6
12	6	6	3	2	2	...	1-6
13	5	6	6	4	6	...	1-6
14	4	3	2	2	3	...	1-6
15	1	2	3	4	3	...	1-6
16	6	6	1	5	6	...	1-6
17	4	2	4	4	4	...	1-6
...							
3127							
	result 1	result 2	result 3	result 4	result 5	result ...	result 100
minimal effect of all results							
maximal effect of all results							

The comparison of the results after 100 different combinations delivers no further significant change in the overall result.

The following picture shows all 100 result files plotted in one single diagram.

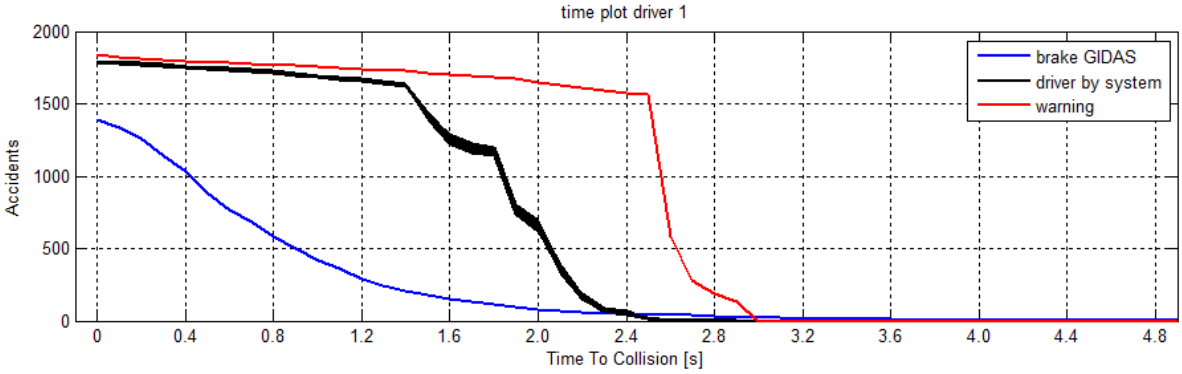

Figure 7: time plot for single driver example

Figure 7 shows the sum of all accidents where an original braking (GIDAS), a system warning and a warning-initiated braking (driver by system) related to the time to collision (TTC). The bold line of the 'driver by system' attracts attention and will be zoomed in in the next figure in the range of 1,000 to 1,400 accidents at the position of 1.6s to collision.

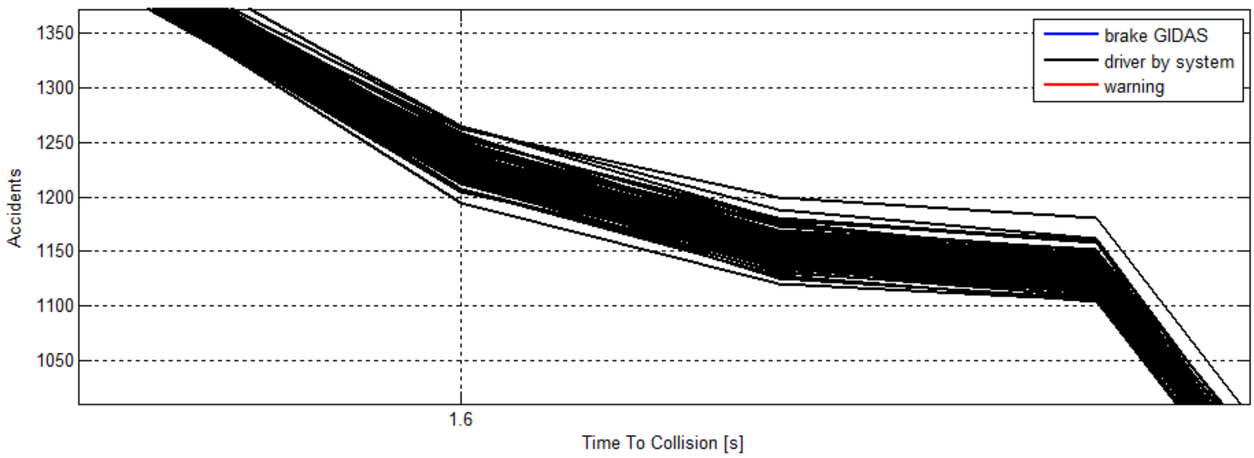

Figure 8: Enlargement of time plot (single driver example)

The enlargement in Figure 8 shows that the bold line in Figure 7 is based on the 100 different lines of the result dataset. These 100 lines are the result of the variation of the driver behaviour by their probability. It shows a spread of 80 accidents as a tolerance value at TTC= 1.6 s.

The next result parameters for this example are the collision speeds of the participant who was equipped with the warning system for the whole field of operation.

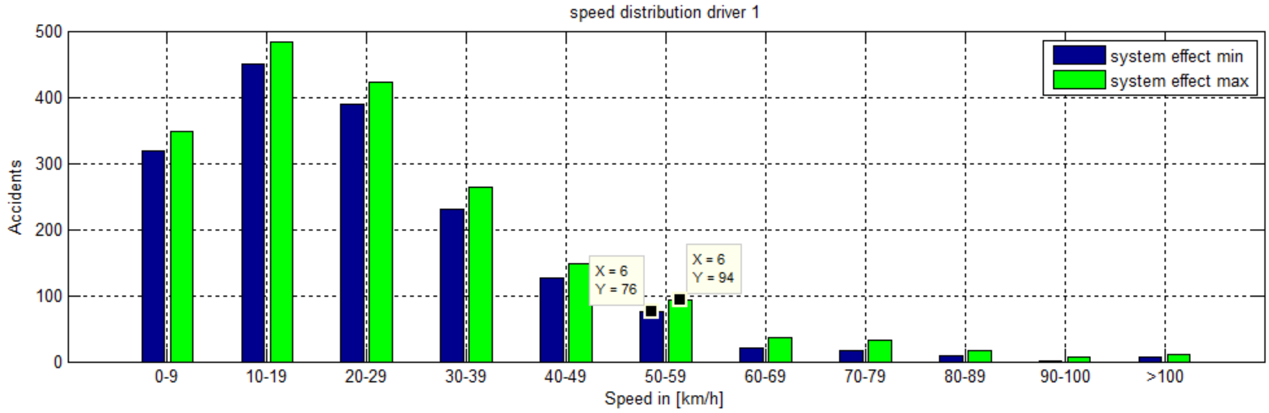

Figure 9: distribution of collision speeds of driver 1 (single driver example)

Figure 9 shows the number of accidents, divided by collision speed groups. Avoided accidents are not considered in this bar plot. This graphic shows also a tolerance band of results for each collision speed group. In group 6 (50-59 km/h), a spread of 18 accidents can be identified. This spread is the result of different driver behaviour by reacting on the same warning algorithm. The varying driver behaviour of driver 1 influence also the second accident participant (driver 2). The following bar plot shows this direct influence.

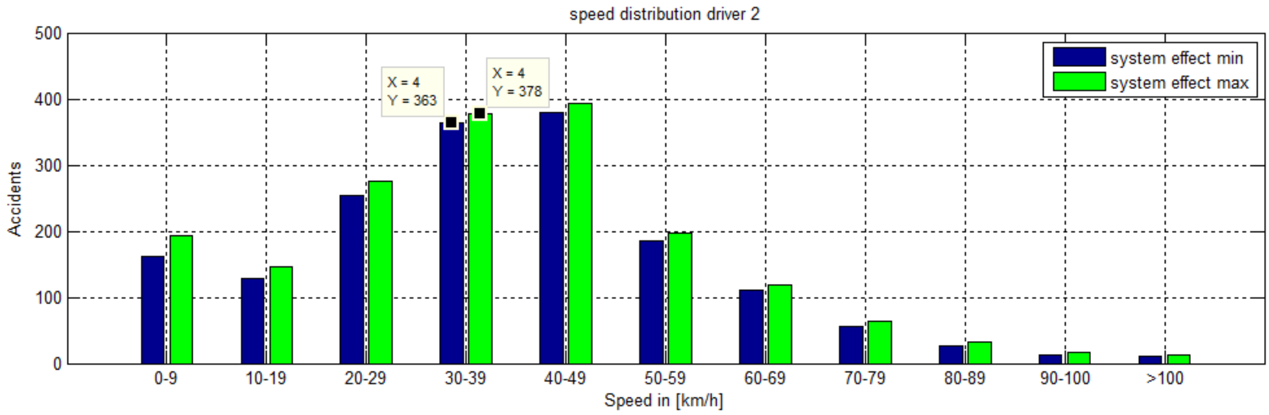

Figure 10: distribution of collision speeds of driver 2 in the single driver example

The differences in the collision speeds of the participant 2 are linked to the varying accident sequence caused by the varying driver behaviour of driver 1.

The variation of the driver behaviour related to the probability to occur produces different results depending on the assignment of the combinations to the different accident scenarios. Thus, the necessity arises to take into consideration the varying driver behaviour while estimating the benefit of warning safety systems using accident simulations.

Example for two drivers

The developed statistical driver model will be applied to two drivers. The basis for these simulations is the same field of operation and the same algorithm as in the first example. The simulations were carried out using the Fraunhofer IVI simulation model.

If two drivers are equipped with the algorithm and the statistical driver model, 36 configurations of the driver behaviour are possible if the initial values for reaction time and brake intensity are used.

Table 5: possible combinations and dedicated probabilities (double driver)

double driver equipped					
	driver 1		driver 2		
combination	**reaction time [s]**	**brake intensity [%/100]**	**reaction time [s]**	**brake intensity [%/100]**	**probability [%/100]**
1	0.48	0.5	0.48	0.5	0.0146
2	0.48	1.0	0.48	0.5	0.0292
3	0.48	0.5	0.48	1.0	0.0292
4	0.48	1.0	0.48	1.0	0.0438
5	0.48	0.5	0.7	0.5	0.0148
6	0.48	1.0	0.7	0.5	0.0294
7	0.48	0.5	0.7	1.0	0.0298
8	0.48	1.0	0.7	1.0	0.0444
9	0.48	0.5	1.08	0.5	0.0133
10	0,48	1.0	1.08	0.5	0.0279
...	...	...	...	...	...
33	1.08	0.5	1.08	0.5	0.0121
34	1.08	1.0	1.08	0.5	0.0242
35	1.08	0.5	1.08	1.0	0.0242
36	1.08	1.0	1.08	1.0	0.0363
					1

Table 5 shows a cut-out from the whole table for the 36 combinations. Each accident scenario was simulated with all of the 36 combinations to generate the intermediate result. This makes up a resulting dataset of 114,192 possible result files. After these simulations, the statistical variation of the results regarding their probability to occur is carried out in a similar way as in the single driver example. Table 6 shows a cut-out of the basis variation table.

Table 6: statistical variation of simulation results (double driver)

configuration scenario	**1**	**2**	**3**	**4**	**5**	...	**100**
Accident number	combination	combination	combination	combination	combination	combination	
1	34	12	26	35	15	...	1-36
2	6	36	28	22	22	...	1-36
3	1	35	24	8	23	...	1-36
4	32	8	12	4	36	...	1-36
5	6	34	34	15	11	...	1-36
6	9	2	35	16	8	...	1-36
7	9	20	33	30	28	...	1-36
8	3	31	34	31	14	...	1-36
9	8	5	4	32	35	...	1-36
10	14	18	23	17	27	...	1-36
11	30	36	18	10	32	...	1-36
12	7	16	18	26	16	...	1-36
13	15	24	26	30	18	...	1-36
14	18	16	23	28	36	...	1-36
15	35	3	4	7	36	...	1-36
16	22	12	35	28	28	...	1-36
17	6	21	19	19	24	...	1-36
...							
3127							
	result 1	**result 2**	**result 3**	**result 4**	**result 5**	**result ...**	**result 100**
minimal effect of all results							
maximal effect of all results							

Once there are no more significant changes in the overall result borders, the final results can be analysed in a similar way to the first example. This analysis is carried out for the collision speeds and then compared to the first results.

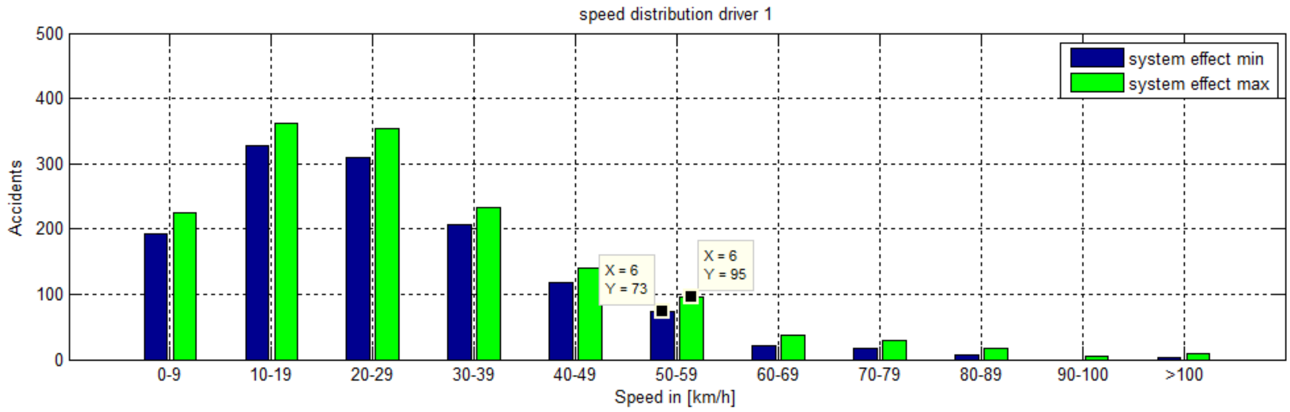

Figure 11: distribution of collision speeds of driver 1 (double driver example)

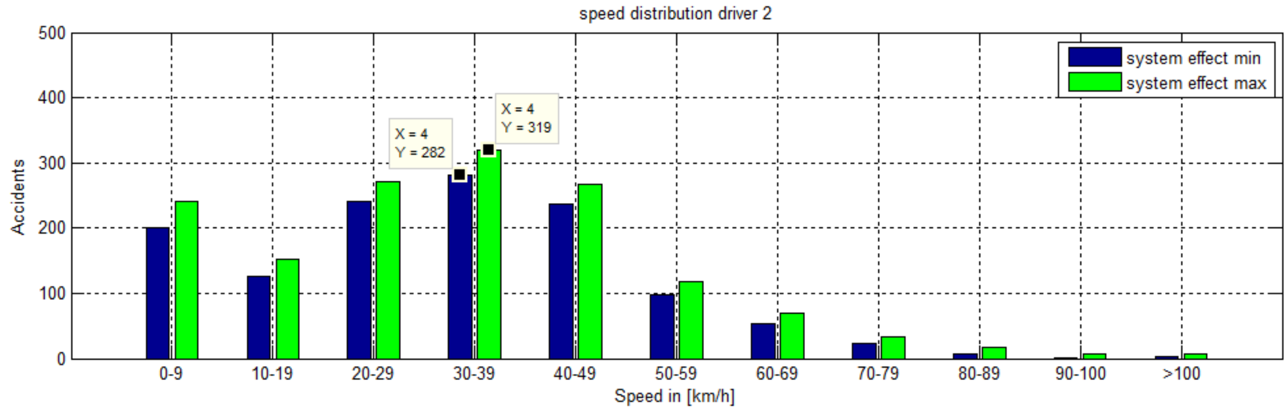

Figure 12: distribution of collision speeds of driver 2 (double driver example)

Figure 11 and 12 show that, in general, the number of accidents can be reduced significantly if both drivers are equipped with the warning system. The comparison with Figure 9 and 10 is shown in Table 7.

Table 7: comparison of single and double driver equipped

	single driver example			double driver example		
	min	**max**	**spread**	**min**	**max**	**spread**
Group 6 (50-59 km/h) driver 1	76	94	**18**	73	95	**22**
Group 4 (30-39 km/h) driver 2	363	378	**15**	282	319	**37**

The comparison in Table 7 shows that the spread of the min and max values is much higher when both drivers are equipped with the statistical driver model, even if the total numbers of accidents is lower. This underlines the necessity of the usage of this statistical driver model to point out the spread or tolerance of the estimated benefit of a warning system.

CONCLUSION

This paper presented a novel method to estimate the benefit of advanced safety systems with a warning functionality. It states important reasons for the necessity of driver models in the benefit estimation by simulation of real world accidents. The paper shows how to create a statistical driver model and its application in accident simulations for one and more drivers which are equipped with warning safety systems. Some representative results are given to underline the importance of tolerances in benefit estimation and accident simulation.

LIST OF REFERENCES

[1] Christian Erbsmehl: "Simulation of real crashes as a method for estimation the potential benefits of advanced safety technologies", ESV Conference; “21st International Technical Conference on the Enhanced Safety of Vehicles”, Stuttgart 2009

[2] Felix Klanner: „Entwicklung eines kommunikationsbasierten Querverkehrsassistenten im Fahrzeug“ ; Dissertation; Darmstadt 2008

[3] Wolfgang Hugemann: Driver reaction times in road traffic, EVU-Tagung, Portoroz 2002

[4] Christian Erbsmehl, Angela Schubert: “The GIDAS Pre-Crash-Matrix”, 5th ESAR-Conference „Expert Symposium on Accident Research”, Hannover 2012

[5] German-In-Depth-Accident-Study (GIDAS-Database): http://www.vufo.de/forschung-und-entwicklung/gidas/