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PRELIMINARY ASSESSMENT OF THE ADVANCED DRIVER ASSISTANCE SYSTEMS EFFICIENCY FROM THE SAFETY POINT OF VIEW

The paper presents benefits of Advanced Driver Assistance Systems ("ADAS") application from the safety point of view. Statistical data on accidents on Polish roads in 2015 was used as the basis for preliminary risk assessment. Potential reduction of the number of accidents due to ADAS equipment per each of accidents' type was estimated using an expert method. Knowing the participation of individual types and causes in the total number of accidents, assessment of the influence of systems to improve road safety was possible. Estimates carried out for the following systems: the Advanced Emergency Braking System ("AEBS"), the Adaptive Cruise Control ("ACC") and the Lane Departure Warning ("LDW"). The results show that the most effective is AEBS - reduction of the number of accidents by 33%. If ACC was considered – 27%, LDW – 4%. For all three driver assistance systems are active, the road safety can increase by almost 47%.

INTRODUCTION

Nowadays, more and more often the cars are equipped with systems that assistant the driver. These systems called Advanced Driver Assistance Systems ("ADAS") aim to raise road safety. ADAS warn the driver to avoid car accidents and other road threats or take control over a human. The issues related to ADAS are widely studied and developed by researchers in terms of safety [1][2][3][4][5][6] and other issues [7][8][9].

It is obvious, that safety analysis is one of the priorities of science in the world. Engineers use many methods and tools for risk and reliability assessment. Development of safety engineering is revealed by the ability to better identify possible hazards, considering safety issues at the design stage of technical equipment and progress in the field of hazard prevention through the extension of existing methods of risk and reliability analysis and proposing new ones [10].

Risk analysis of such systems in this article is different from the classical approach. It is shown as reduction of the number of accidents compared to cars without additional equipment. In this case, such an approach seems to be more effective in view of the fact that it shows improvement of security and benefits of such systems. Moreover, there is little data on the Polish conditions on the number of cars and accidents for vehicles equipped with ADAS.

In this article mainly the following subsystems were considered:

- Advanced Emergency Braking System ("AEBS")
- Adaptive Cruise Control ("ACC")
- Lane Departure Warning ("LDW")

1. STATISTICAL DATA ON ROAD ACCIDENTS IN POLAND

Statistical data on road accidents are available through annual reports called "Wypadki drogowe w Polsce w 2015 roku" (*Road accidents in Poland in 2015*) [11] prepared by the Police. These reports do not show whether a car was equipped with ADAS. Driver Assistance Systems are introduced in new models of cars and only 10% of all cars in Poland are less than 5 years old. Cars equipped with ADAS are therefore a substantial minority.

Statistical data relevant for further analysis (road accidents by types and causes) are provided in this chapter.

1.1. Types of accidents in Poland in 2015

The most common accidents on Polish roads in 2015 are: side impact (29.6%), hitting a pedestrian (25.6%), rear impact (12.1%), frontal impact (9.2%), rollover (8%) and hitting a tree (5.4%). It is shown in ***Fig. 1.***

Fig. 1. *Types of accidents in 2015 in Poland [11]*

1.2. Causes of accidents in Poland in 2015

The driver (82.8%) and pedestrian (7.9%) caused the most common accidents on Polish roads in 2015. The data is shown in ***Fig. 2***.

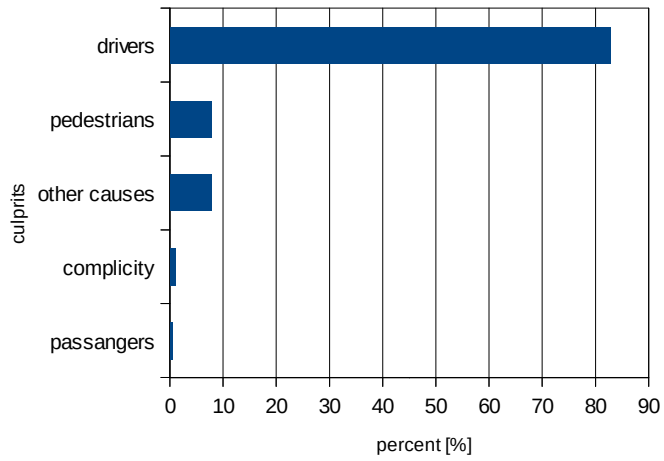

Fig. 2. Road accident culprits in 2015 in Poland[11]

The most common causes of accidents due to driver fault were: non-compliance with the right way (26.5%), inappropriate speed for the driving conditions (24.9%), incorrect behaviour towards pedestrians (15.2%), lack of safe distance (8.7%), incorrect overtaking (5.4%), incorrect turning (3%), incorrect lane change (2.5%) and tiredness, falling asleep (2%). It is shown in ***Fig. 3.***

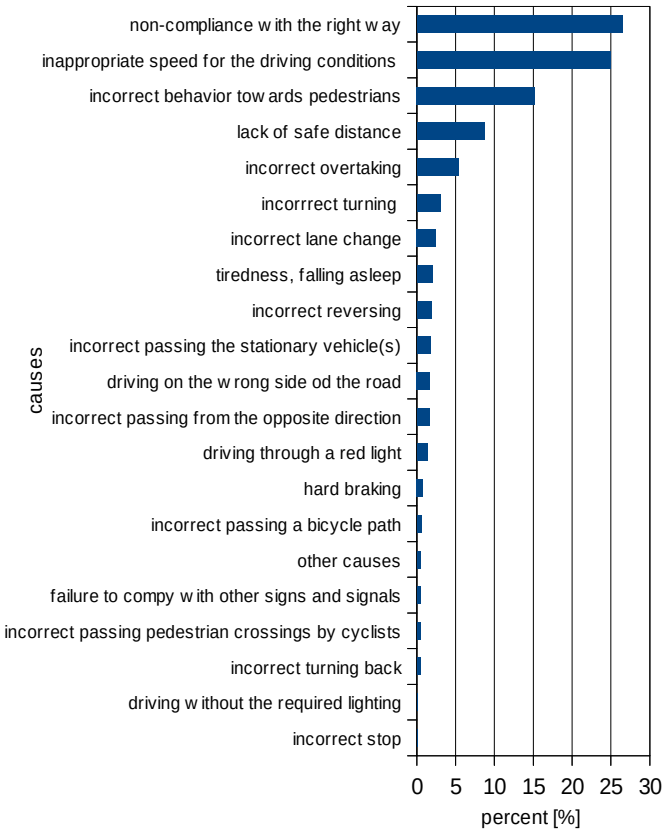

Fig. 3. Causes of accidents due to the driver fault in 2015 in Poland[11]

The most common causes of accidents due to pedestrian fault were: careless in front of a moving vehicle (55.9%) crossing a roadway in a prohibited place (11.2%), careless crossing a roadway behind the vehicle/obstacles (10.3%), crossing a roadway through a red light (8.2%), standing on the road, lying (7%), and walking the wrong side of the road (5.5%). It is shown in ***Fig. 4.***

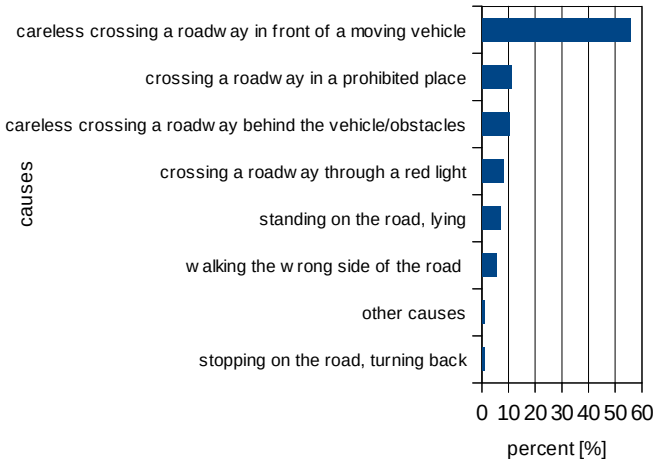

Fig. 4. Causes of accidents due to the pedestrian fault in 2015 in Poland[11]

2. DESCRIPTION OF THE ANALYZED ADVANCED DRIVER ASSISTANCE SYSTEMS

2.1. Advanced Emergency Braking Systems

Main functionality of AEBS is to initiate the emergency braking procedure if an obstacle, which the driver did not notice, is detected. Sensors monitor the proximity of other objects and detect situations that could cause a collision. In such cases, the system will automatically activate brakes to avoid an accident.

2.2. Adaptive Cruise Control

Main function of this system is to maintain the established speed and detect other vehicles moving on the same lane in front of the car [12]. In case of the system detects a vehicle, the speed of the vehicle equipped with ACC is reduced to compensate the distance between cars.

2.3. Lane Departure Warning

The focus of this system is to help the driver keep the vehicle in the lane on highways and highway-like roads. Accordingly, a warning is issued to alert the driver in case of lane departure caused by, for example, inattention. Moreover, LDW are not intended to issue warnings with respect to collisions with other vehicles or to control vehicle motions [13].

3. PRELIMINARY RISK ASSESSMENT

3.1. Description of the methodology

This analysis is not substantially risk analysis but assessment of improving safety (decrease of the accident rate). Considerations were performed using the expert estimates. Data from police reports for 2015 connected with causes and types of accidents [2] (which were presented in the previous chapter) were also used. Safety improvement was determined using the reduction of accidents coefficient specifying the percentage of accidents that could have been avoided if ADAS have been applied. It was performed using the expert method both for assessment concerning causes as well as types of accidents.

The tables ***(Tab. 1, Tab. 2, Tab. 3)*** shows the conducted analyses. The expert method was based on the assessment per-

formed by the authors of this article. It was assessed which systems would reduce the accident rate and to what extent. If it was considered that few systems could reduce the accident rate, first, coefficient for all active systems was estimated, and then (in parentheses) for each individual. In the analysis the causes and types of accidents with the highest frequency were taken into account. The rest of them were qualified for the category called "other".

3.2. Expert estimation

For each cause or type of accident co-authors estimated which systems can reduce the accident rate and to what extent. The reduction of accident coefficient was specified for all systems and individually for each one.

The scale used for the expert assessment of the reduction of accidents coefficient was as following:

90% - very big influence to reduce the number of accidents
70% - big influence to reduce the number of accidents
50% - medium influence to reduce the number of accidents
30% - small influence to reduce the number of accidents
10% - very small influence to reduce the number of accidents
0% - lack of influence to reduce the number of accidents

The expert could give also indirect assessments which were multiples of 5% (0, 5, 10, 15, 20, …)

The results of expert estimation are presented in ***Tab. 1, Tab.2*** and ***Tab. 3***.

Tab. 1. *Expert estimation. Types of accidents*

Type of accident	Frequency of accidents [%]	Which systems can reduce the accident rate?	To what extent? (the reduction of accidents coefficient)
1. side impact	29.6	AEBS, ACC	30% (25%, 15%)
2. hitting a pedestrian	25.6	AEBS, ACC	45% (40%, 20%)
3. rear impact	12.1	ACC, AEBS	80% (70%, 60%)
4. frontal impact	9.2	AEBS, LDW, ACC	30% (20%, 20%, 20%)
5. flipping over	8	ACC, LDW	80% (75%, 15%)
6. hitting a tree	5.4	AEBS, LDW, ACC	80% (70%, 40%,40%)
7. other	10.1	AEBS, ACC, LDW	30% (20%, 15%, 5%)

Tab. 2 *Expert estimation. Causes of accidents due to the driver fault*

Cause of accident: due to the fault of driver	Frequency of accidents [%]	Which systems can reduce the accident rate?	To what extent? (the reduction of accidents coefficient)
1. non-compliance with the right way	26.5	AEBS	20%
2. inappropriate speed for the driving conditions	24.9	ACC, AEBS	85% (70%, 50%)
3. incorrect behavior towards pedestrians	15.2	AEBS	50%
4. lack of safe distance	8.7	ACC, AEBS	85% (70%, 50%)
5. incorrect overtaking	5.4	LDW, AEBS	30% (20%, 20%)
6. incorrrect turning	3	LDW, AEBS	30% (20%, 20%)
7. Incorrect changing lanes	2.5	LDW, AEBS	30% (25%, 15%)
8. tiredness, falling asleep	2	none of them	0%
9. other	11.8	AEBS, ACC, LDW	30% (20%, 15%, 5%)

Tab. 3. *Expert estimation. Causes of accidents due to the pedestrian fault*

Cause of accident: due to the fault of pedestrian	Frequency of accidents [%]	Which systems can reduce the accident rate?	To what extent? (the reduction of accidents coefficient)
1. careless crossing a roadway in front of a moving vehicle	55.9	AEBS	15%
2. crossing a roadway in a prohibited place	11.2	AEBS	50%
3. careless crossing a roadway behind the vehicle/obstacles	10.3	AEBS	15%
4. crossing a roadway through a red light	8.2	AEBS	70%
5. standing on the road, lying	7	AEBS	50%
6. walking the wrong side of the road	5.5	AEBS	50%
7. other	1.9	AEBS	50%

3.3. Calculations

In calculations the following abbreviations were used:

– *FOA* – Frequency of accidents (in percentages)
– *RAC* – reduction of accidents coefficient

"Types of accidents" method

The calculations and results for "types of accidents" are shown in ***Tab. 5.*** The effectiveness of the systems is as following: AEBS – 32%, ACC – 30%, LDW – 6%, all systems – 47%.

Tab. 4. *Preliminary risk assessment. Results of "types of accidents" method*

TYPES of accidents									
type	FOA	all systems		AEBS		ACC		LDW	
		RAC	RAC* FOA	RAC	RAC* FOA	RAC	RAC* FOA	RAC	RAC* FOA
1	29.6	30	8.88	25	7.4	15	4.44	0	0
2	25.6	45	11.52	40	10.24	20	5.12	0	0
3	12.1	80	9.68	60	7.26	70	8.47	0	0
4	9.2	30	2.76	20	1.84	20	1.84	20	1.84
5	8	80	6.4	0	0	75	6	15	1.2
6	5.4	80	4.32	60	3.24	40	2.16	40	2.16
7	10.1	30	3.03	20	2.02	15	1.515	5	0.505
RAC for all types			46.59		32.00		29.55		5.71

"Causes of accidents" method

The reduction of accidents coefficient was calculated taking into account causes both due to the fault of drivers and pedestrians. Others were omitted.

The appropriate proportions should be used:

– percent of accidents due to the fault of the driver:

$$\%DRIVGUILTY = \frac{82.8}{82.8+7.9}\% = 91.29\%$$

– percent of accidents due to the fault of the pedestrian:

$$\%PEDGUILTY = \frac{7.9}{82.8+7.9}\% = 8.71\%$$

The calculations and results are shown in ***Tab. 5***. The most effective is AEBS (reduction of the number of accidents by 34%. If ACC was considered – 27%, LDW – 3%. For all three driver assis-

tance systems were active, the road safety could increase by almost 47%.

"Mixed" method

The previous methods were two ways to estimate the reduction of accidents taking into account types and causes of road accidents in Poland in 2015. In order to increase the expert estimation accuracy, it was decided to calculate average values. The results obtained by mixed method were arithmetic averages from "causes of accidents" and "types of accidents" methods. It is shown in ***Tab. 6 and Fig. 5.*** Eventually, the effectiveness of the systems is as following: AEBS – 33%, ACC – 27%, LDW – 4%, all systems – 47%.

Tab. 6. *Reduction of accidents coefficient. "Mixed" method*

method	all systems	AEBS	ACC	LDW
causes	46.5	33.6	24.2	2.6
types	46.6	32	29.6	5.7
average	**46.6**	**32.8**	**26.9**	**4.2**

It should be also emphasized that these results are rough estimates of decrease of the accident rate (the reduction of accidents coefficient) but are consistent with those obtained in other papers, for example in the report from research conducted in Germany [1][3]. Lack of reliable data does not allow to carry out more detailed analysis using statistical methods.

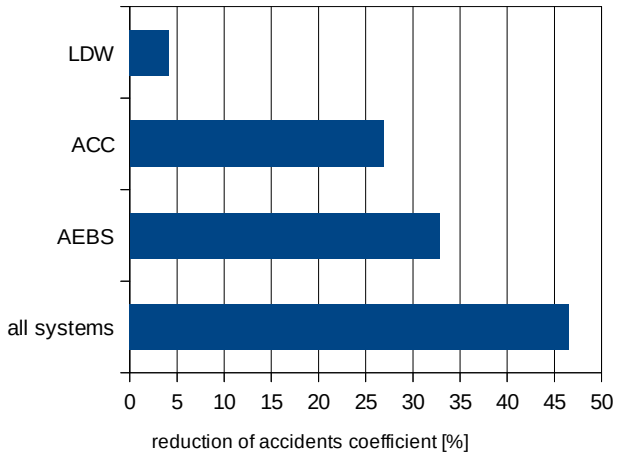

Fig. 5. *Reduction of accidents coefficient. "Mixed" method*

SUMMARY

The effectiveness of driver assistance systems on the example of AEBS, ACC and LDW was demonstrated with the use of quite simple method based on statistical reports and the expert assessments. The results are consistent with other studies. The applied method shows how to estimate the benefits of introducing such systems without data relating to crashes of cars equipped with AEBS (For Poland this data is missing or inaccurate).

Benefits of application of ADAS from the safety point of view are very high. The expert estimation showed that the effectiveness of these systems is 33% for AEBS, 27% for ACC, 4% for LDW and 47% for all systems active.

Tab. 5. *Preliminary risk assessment. Results of "causes of accidents" method*

ACCIDENTS due to the fault of the driver						%DRIV GULITY			0.9129
cause	FOA	all systems		AEBS		ACC		LDW	
		RAC	RAC*FOA	RAC	RAC*FOA	RAC	RAC*FOA	RAC	RAC*FOA
1	26.5	20	5.3	20	5.3	0	0	0	0
2	24.9	85	21.165	50	12.45	70	17.43	0	0
3	15.2	50	7.6	50	7.6	0	0	0	0
4	8.7	85	7.395	50	4.35	70	6.09	0	0
5	5.4	30	1.62	20	1.08	0	0	20	1,08
6	3	30	0.9	20	0.6	0	0	20	0,6
7	2.5	30	0.75	15	0.375	0	0	25	0,625
8	2	0	0	0	0	0	0	0	0
9	11.8	30	3.54	20	2.36	25	2.95	5	0,59
RAC for all causes (driver guilty)			**48.27**		**34.12**		**26.47**		**2.90**
RAC for all causes * %DRIV GUILTY			44.07		31.14		24.16		2.64
ACCIDENTS due to the fault of the pedestrian						%PED GULITY			0.0871
cause	FOA	all systems		AEBS		ACC		LDW	
		RAC	RAC*FOA	RAC	RAC*FOA	RAC	RAC*FOA	RAC	RAC*FOA
1	55.9	15	8.385	15	8.385	0	0	0	0
2	11.2	50	5.6	50	5.6	0	0	0	0
3	10.3	15	1.545	15	1.545	0	0	0	0
4	8.2	70	5.74	70	5.74	0	0	0	0
5	7	50	3.5	50	3.5	0	0	0	0
6	5.5	50	2.75	50	2.75	0	0	0	0
7	1.9	50	0.95	50	0.95	0	0	0	0
RAC for all causes (pedestrian guilty)			**28.47**		**28.47**		**0.00**		**0.00**
RAC for all causes * %PED GUILTY			2.48		2.48		0.00		0.00
RAC for all causes			**46.55**		**33.62**		**24.16**		**2.64**

The results are valuable because of the possibility to estimate the benefits of these systems that are not yet widespread and will be introduced in the near future. The application of ADAS together with a reduction in the number of accidents should significantly decrease the number of injured and killed in road accidents. Some of the accidents probably will not happen and the rest will take place at lower car speed. The development and implementation of driver assistance systems is well founded.

It is also planned to verify the results in the future. In the later stages of this project tools to assess risk more quantified will be developed. Moreover, the testing station is built, which will also help in research of safety analyses.

ACKNOWLEDGEMENTS

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Wstępna ocena skuteczności zaawansowanych systemów wspomagania kierowcy z punktu widzenia bezpieczeństwa

Tematem niniejszej publikacji jest przedstawienie korzyści z zastosowania zaawansowanych systemów wspomagania kierowcy (Advanced Driver Assistance Systems – „ADAS") z punktu widzenia bezpieczeństwa. Wstępna ocena ryzyka została wykonana z wykorzystaniem danych statystycznych dotyczących wypadków na polskich drogach w roku 2015 z podziałem na ich rodzaje i przyczyny. Dla poszczególnych rodzajów i przyczyn wypadków oszacowano, wykorzystując metody eksperckie, zmniejszenie liczby wypadków (zmniejszenie współczynnika wypadkowości) spowodowane wyposażeniem samochodu w systemy wspomagania kierowcy. Znając udział poszczególnych typów i rodzajów w ogóle wypadków możliwa była ocena wpływu omawianych systemów na poprawę bezpieczeństwa ruchu drogowego. Oszacowania przeprowadzono dla zawansowanego systemu hamowania awaryjnego („Advanced Emergency Braking Systems – „AEBS"), tempomatu adaptacyjnego (Adaptive Cruise Control - „ACC") oraz systemu ostrzegania przed niezamierzoną zmianą pasa ruchu (Lane Departure Warining - „LDW"). Wyniki pokazują, że najbardziej efektywny jest AEBS - redukcja liczby wypadków o około 33%. Natomiast dla ACC wyniesie ona 27%, dla LDW 4%. Jeśli aktywne są trzy systemy wspomagania kierowcy, bezpieczeństwo na drodze może wzrosnąć nawet o 47%.

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