RCS-TUG STUDY: BENEFIT POTENTIAL INVESTIGATION OF TRAFFIC SAFETY SYSTEMS WITH RESPECT TO DIFFERENT VEHICLE CATEGORIES

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Paper Number 11-0155

ABSTRACT

The multiplicity of accident causation has led to development of various traffic safety systems for collision avoidance or reduction. Since the customer will not purchase all these systems, a question of prioritization of these systems for the manufacturers as well as authorities arises.

In previous papers a method was described which investigated the benefit potential of 43 different systems. The in-depth accident database ZEDATU which includes fatal accidents in Austria was used to select a sub-sample of accidents. For those, the pre-collision phase was reconstructed in detail with numerical accident reconstruction using PC-Crash. The efficiency of safety systems was calculated either by integration of intervening systems in the simulation (ESC, ABS, Brake Assist and Evasive Maneuver Assistant) or by subjective evaluation of the pre-collision situation. This study, called RCS-TUG study (Retrospective Case Study of the Graz University of Technology), exhibited the advantage that many different systems were analyzed in detail using the same sample with a comparatively high case number. This led to improved comparableness.

In another previous paper, the selected sample (n=217) of the database was weighted to achieve statistical representativeness, since single vehicle accidents were underrepresented. For each of the selected 43 systems, the potential for collision avoidance or reduction of severity was analyzed. The results were compared to findings in literature and the authors proposed a prioritization for traffic safety systems. The results indicated that especially systems effective in lateral vehicle dynamics (Evasive Maneuver Assistant, Lane Keeping Assist, ESC) offer significant potential to avoid fatal injuries, as well as autonomous Brake Assist, Collision Warning Systems and Driver Vigilance Monitoring.

The present study continues the analysis of the RCS-TUG study. The new analysis differentiates between the vehicle categories such as motorized two-wheelers, light trucks, passenger cars, trucks and busses with respect to the ego-vehicle. Additionally, the database was checked for errors.

The limitations of the study are the restriction to fatal accidents in the area of Austria. Additionally some systems are evaluated by subjective judgment of the authors.

INTRODUCTION

The variety of causations of traffic accidents [1, 2] has led and will lead to development of many different countermeasures for traffic accidents, [3, 4]. Countermeasures for traffic accidents can operate on the primary/active (collision avoidance and collision severity mitigation), secondary/passive (reduction of injury risk) or tertiary (post-crash treatment) safety level of the involved traffic element: human, vehicle or environment. In [3] a brief overview of 161 different systems is provided; detailed descriptions of these traffic safety systems can be found in the literature, e.g. [5-7]. Many different studies [7-20] have been conducted to evaluate the safety potential of traffic safety systems. In the author's opinion, many of these studies face one or more of the following problems, [21]:

- Level of detail in statistical accident databases;
- Number and representativeness of in-depth accident databases;
- Comparability of potentials on different systems;

Therefore, the present study investigates many different traffic safety systems with the same methodology and the same database. As described above, methodology and the accident database are described in detail in [4, 22-24].

METHODOLOGY

The RCS-TUG study is an ‘a priori’ benefit investigation method of the ‘case-by-case analysis within database’ type, see [25, 26]. It uses the ZEDATU database [27] which is an in-depth accident database with more than 950 cases and 763 database arrays per accident. It covers fatal traffic accidents of Austria. For the previous and the present evaluations 217 cases as a subsample of the year of 2003 were used. For these cases the pre-collision phase starting at the conflict point could be reconstructed in detail using numerical accident reconstruction software [28]. It was found that this subsample is statistically biased since single-vehicle accidents are underrepresented. The reason is that the examination of the accident scene was sometimes not sufficient for reconstruction of the pre-collision phase since the question of guilt was not always a primary target of the court. Therefore the subsample was weighted by comparing the proportion of the accident type of the subsample with all fatal accident of that year, [21]. With this corrected database, several conclusions for the benefit effectiveness could be drawn. The present paper extends these analyses.

RESULTS

Figure 1 recapitulates previous findings of the RCS-TUG study, [21]. The safety potential is ranked according to the ‘avoidance’ A_s of system *S*. Symbol A_s is the percentage of cases where the accident is prevented automatically by the system, thereby preventing the fatalities and reads

$$A_S = \frac{n_{A,S}}{n_S} \cdot 100\ [\%] \quad , \qquad (1).$$

with $n_{A,S}$ the number of avoided accidents by safety system *S* and n_S the number of evaluated cases of safety system *S*.

Additionally the ‘potential’ P_s was assessed, where a prevention of the fatality is possible but either the accident was not fully avoided or the potential depends on additional parameters such as a correct driver reaction upon warnings of the system. Potential P_s reads

$$P_S = \frac{n_{P,S}}{n_S} \cdot 100\ [\%] \quad , \qquad (2).$$

with $n_{P,S}$ representing the number of collisions with possibly prevented fatalities by safety system *S* and n_S the number of evaluated cases of safety system S.

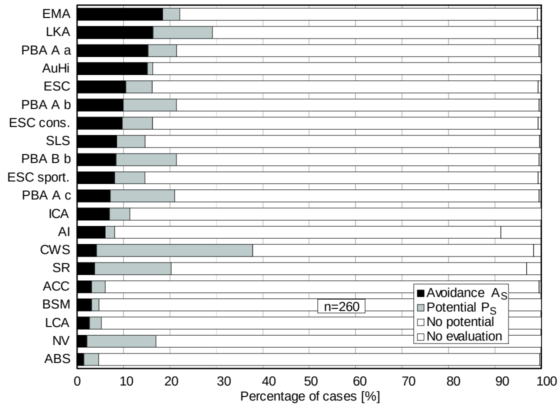

Figure 1. Safety potentials of safety systems in weighted RCS-TUG, [21]

For the meaning of the abbreviations in Figure 1 refer to Table 3 in the appendix. It can be seen that an Evasive Maneuver Assistant (EMA) provides the highest potential for system controlled accident avoidance, but the highest overall potential have Collision Warning Systems (CWS), when the driver reacts accordingly. The results of the first evaluation of the RCS-TUG study are explained in detail in [4, 21]. Especially the results are compared with other studies from literature. For the present evaluation, the database was reanalyzed.

Influence of the Vehicle Category

The database was prepared to define the vehicle category of the ego-vehicle, which was typically the accident causer.

Accordingly, the analysis separated the Vehicle group ID 1: motorized two-wheelers; 3: cars; 4: light trucks; 5 and 10: trucks and busses see Table 1., [29, 30].

The related number of cases for each vehicle category n_V can be seen in Table 2. Obviously, the quality of the analysis is highest for passenger cars (n_V=164), followed by the trucks/busses category (n_V =34) and motorized two-wheelers (n_V =30). For light trucks the number of cases is low (n_V=12). Although the case number is high only in passenger cars, trends are analyzed and discussed in the following.

Table 1.
Vehicle categories in the ZEDATU database

Body Style Code	Vehicle Group ID	BodyStyle
0	0	not applicable
1	1	Moped or Mofa under 50cc
2	1	Motorcycle under 125cc
3	1	Motorcycle over 125cc
4	1	Motorcycle with sidecar
5	1	Scooter
6	3	Hatchback
7	3	Saloon
8	3	Estate
9	3	Convertible
10	3	Sports car
11	3	Off-road
12	3	SUV
13	3	Derivative
14	3	Van - Multi-Purpose-Vehicle
15	4	Caravanette
16	4	Minibus
17	4	Microvan based pick-up
18	4	Dropside - large pick-up
19	4	Micro Van
20	4	Box Van
21	4	Crew cab
22	4	Dedicated
23	5	Rigid box
24	5	Rigid flat
25	5	Rigid tipper
26	5	Rigid curtain side
27	5	Rigid liquid - powder
28	5	Demountable
29	5	Dedicated truck
30	5	Articulated
31	5	Semitrailer
32	2	Trike
33	2	Three wheeled vehicle
34	6	Bicycle
35	11	Train
36	11	Tram
37	7	Tractor
38	10	Bus
88	8	other
99	99	Unknown

Table 2.
Number of cases n_V for each vehicle category

Vehicle type	Number of cases n_V
All	260
Two-wheelers	30
Cars	164
Light trucks	12
Trucks and busses	34
Others	54

Not surprisingly, the highest benefit of all safety systems system is ‘Autonomous Driving’. Because of the difficult realization, the results are not presented and discussed. The following presentation of the results is in the same order than presented in [21].

Evasive Maneuver Assistant (EMA)

EMA systems have not been introduced into the market for technological and legal reasons. Yet research dealing with this topic is ongoing and previous benefit analyses have showed significant potentials [21].

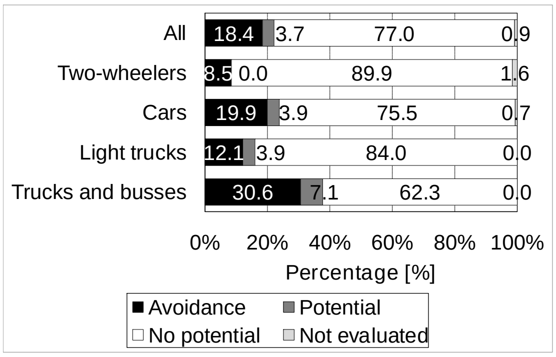

Figure 2. Influence of vehicle type on EMA

Figure 2 shows the influence of the vehicle category on the benefit of EMA. For trucks and busses, EMA tends to provide more potential than the other vehicle categories. The benefit for motorized two-wheelers is low. The same methodology as for doubled-tracked vehicles was applied [22], yet for two-wheelers such a system would be even more complicated than for double-tracked vehicles.

Lane Keeping Assist (LKA) Figure 3 shows the influence of the vehicle category on the safety benefit of Lane Keeping Assist. The benefit is significantly higher in cars than in trucks/busses, indicating the higher occurrence of lane departure of that vehicle category. Due to the system’s definition it is not feasible for two-wheelers.

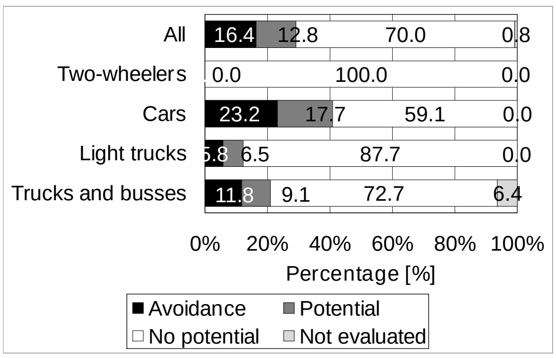

Figure 3. Influence of vehicle type on LKA

Predictive Brake Assist (PBA) Figure 4 shows the influence of the vehicle category on the safety benefit of PBA. For the analysis in the present paper the most efficient PBA system of the RCS-TUG analysis was chosen. This is a full braking action of the driver following a collision warning of the human-machine-interface with 0.8s reaction time; this equals an automated emergency braking 1.8s before an anticipated forward collision. In the RCS-Study this was system 'A' and driver behavior 'a', [4].

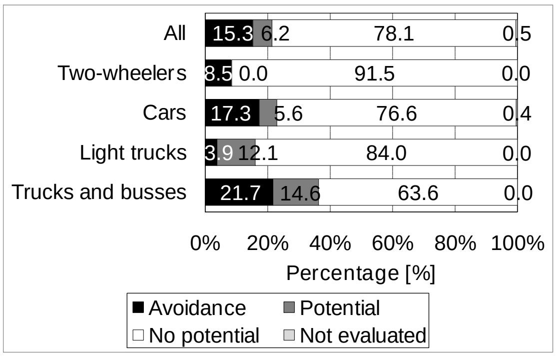

Figure 4. Influence of vehicle type on PBA (System 'A' and driver reaction 'a')

The potential of this considered PBA system is higher in trucks and busses than in the other categories. Note that even for two-wheelers some potential was found.

Automated Driving on Highways (AuHi) Figure 5 shows the influence of the vehicle category on the safety benefit of automated driving on highways. For trucks and busses this is significantly higher than in all other types of vehicles.

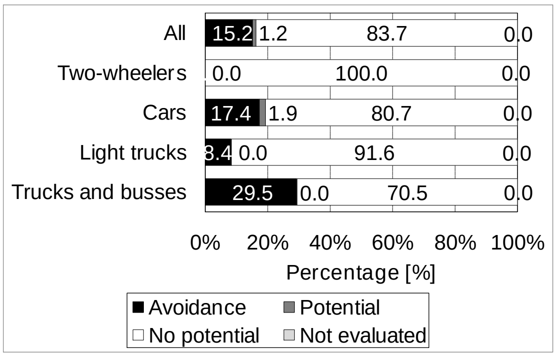

Figure 5. Influence of vehicle type on AuHi

Electronic Stability Control (ESC) Figure 6 shows the influence of the vehicle category on the safety benefit of ESC. In this evaluation only a standard set-up of the ESC was analyzed. The influence of different intervention strategies (sportive, standard, conservative) as analyzed in [21] was not evaluated.

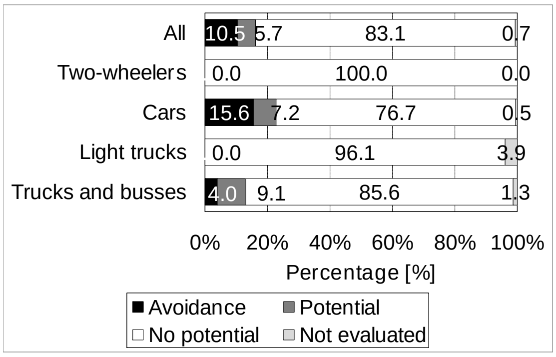

Figure 6. Influence of vehicle type on ESC

The benefit potential is significantly higher in passenger cars compared to trucks and busses, for two-wheelers this system is not feasible.

Speed Limiting System (SLS) Figure 7 shows the influence of the vehicle category on the safety benefit of speed limiting systems as analyzed in the RCS-TUG. Whereas for two-wheelers the system was not defined, a real benefit was only found in passenger cars.

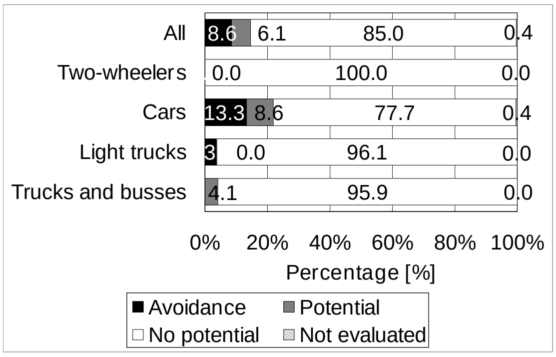

Figure 7. Influence of vehicle type on SLS

Intersection Collision Assistant (ICA) Figure 8 shows the influence of the vehicle category on the safety benefit of ICA systems.

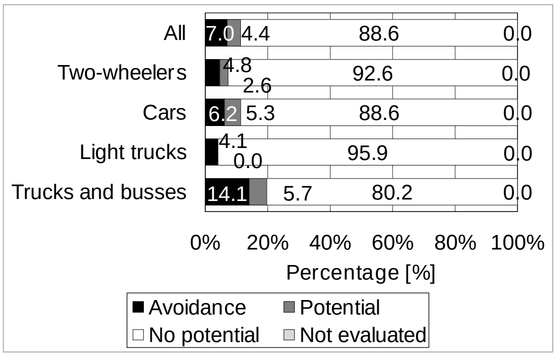

Figure 8. Influence of vehicle type on ICA

The potential is more evenly distributed among the different types of vehicles, where the highest potential is in trucks and busses.

<u>**Alcohol Interlock (AI)**</u> Figure 9 shows the influence of the vehicle category on the safety benefit of alcohol interlock systems.

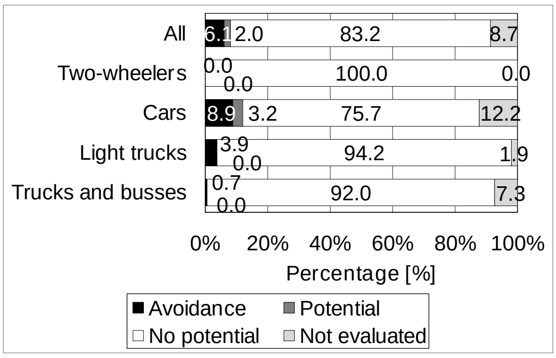

Figure 9. Influence of vehicle type on AI

The analysis reveals that in the used ZEDATU database drunk driving is mainly an issue of car drivers, whereas it could not be found in two wheelers and hardly in trucks and busses. For professional truck and bus drivers, the blood alcohol limit in Austria is zero, whereas for the others it is 0.5 %. However, note the comparably high number of not evaluated cases, where an expert statement on alcohol impairment of the driver was missing.

<u>**Collision Warning Systems (CWS)**</u> Figure 10 shows the influence of the vehicle category on the safety benefit of CWS systems.

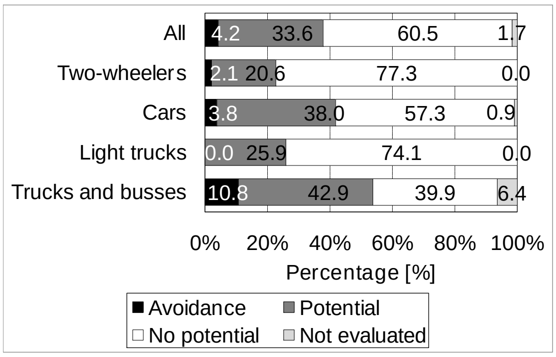

Figure 10. Influence of vehicle type on CWS

Here the distribution is a bit more evenly, with a slight trend for higher potential in trucks and busses. Note that the majority of the cases are rated 'potential' since the driver has to react in a proper way to the warning of the human-machine-interface. In PBA systems a partially automated braking of the systems reverses these results of CWS systems.

<u>**Driver Vigilance Monitoring (DVM)**</u> Figure 11 shows the influence of the vehicle category on the safety benefit of DVM systems.

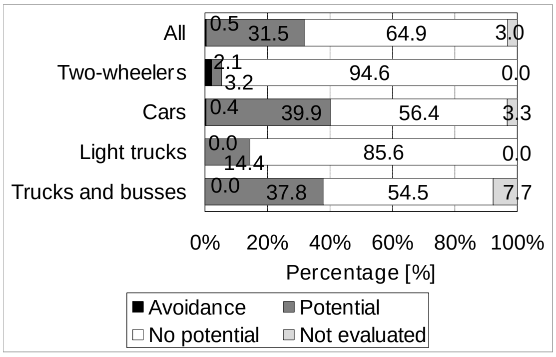

Figure 11. Influence of vehicle type on DVM

According to this study, vigilance is an issue which is same common for car and truck/bus drivers, while only small numbers in two-wheeler category were found.

<u>**Further systems**</u> Further systems with less potential can be found in the appendix where all investigated systems are presented, see Table 4.

Prioritization

Table 4 in the appendix shows the proposal of a system ranking with respect to benefit potential. To overcome the issue of separate rating of avoided $A_{S,V}$ and potentially $P_{S,V}$ prevented fatalities a weighting method was applied. For this purpose the weighting method given in (3) was applied:

$$W_{S,V} = \frac{A_{S,V} \cdot W_A + P_{S,V} \cdot W_P}{n_{S,V}} \cdot 100\ [\%] \quad , \qquad (3).$$

where $W_{S,V}$ is the weighted benefit potential of system *S* in vehicle category *V*; $A_{S,V}$ the number of avoided collisions by system *S* in vehicle category *V*; $P_{S,V}$ the number of possibly avoided fatalities by system *S* in vehicle category *V*; $n_{S,V}$ the number of all cases of vehicle category *V* investigated for system *S;* W_A=1.0 and W_P=0.5 weighting factors. Thereby the importance of definitely avoided collisions was rated double than compared to the possibly avoided fatalities. The choice of the weighting factor was done by judgment of the authors.

DISCUSSION

Although the number of cases for the motorized two-wheelers and truck/bus drivers are significantly lower than for passenger car drivers some observations and trends can be discussed for these categories. For drivers of light trucks the numbers are too small. For the following discussion it has to be emphasized that systems that require driver interaction had been analyzed by subjective evaluation of the pre-collision phase which is a possible source of error. Automated driving is not discussed because of the difficult technological implementation.

Two-wheelers

The beneficial potential of Advanced Driver Assistance Systems (ADAS) in two-wheelers is rather small compared to other vehicle categories. The most effective systems according to the present analysis are Collision Warning Systems, Evasive Maneuver Assistant, Predictive Brake Assist, Lane Change Assistant, Blind Spot Monitoring (see Table 4.) and Intersection Collision Assistant. The weighted potential $W_{S,V}$ drops below 5% for further systems. Since a 100% fleet penetration and a 100% working system without failures was anticipated, the potential of these further systems is considered small.

Cars

The most effective systems ranked by the weighted potential $W_{S,V}$ and with $W_{S,V}$>10% are: Lane Keeping Assist, Collision Warning Systems, Evasive Maneuver Assistant, Driver Vigilance Monitoring, Predictive Brake Assist, Electronic Stability Control, Automated Driving on Highways, Speed Limiting Systems, Seat Belt Reminder, Night Vision, Speed Recommendation and Alerts and Alcohol Interlock. The most effective systems are rather lateral vehicle control related, compared to trucks and busses.

Trucks and busses

For trucks a little bit different rating was observed. Ranked by the weighted potential $W_{S,V}$ and with $W_{S,V}$>10% they are: Evasive Maneuver Assistant, Collision Warning Systems, Automated Driving on Highways, Predictive Brake Assist, Driver Vigilance Monitoring, Automatic Cruise Control, Intersection Collision Assistant, Lane Keeping Assist and Blind Spot Monitoring. A more pronounced potential of longitudinal assistance compared to lateral assistance was observed, ESC is not present at the top ten systems for trucks.

Light trucks

For light trucks the small number of cases does not allow discussions for reasons of statistical significance.

SUMMARY

Previous researches on the benefit of traffic safety systems for prevention of fatalities in road accidents were continued using the RCS-TUG analysis approach. These studies are based on the ZEDATU database which covers fatal accidents in Austria. A total of 260 cases in the year of 2003 were analyzed for benefit of 43 different systems for prevention of fatalities. The special characteristics of the RCS-TUG study are the in-depth investigations of the pre-collision phase using a database with a comparatively high case number. The present investigation focused on differences on the benefit of traffic safety systems within the vehicle categories motorized two-wheelers, light trucks, passenger cars, trucks and busses. The investigation showed that a comparatively low benefit for two-wheelers is to be expected. For light trucks the number of cases was too small to draw conclusions. For cars, the analysis showed that a trend exists that Advanced Driver Assistance Systems for lateral vehicle control is more beneficial compared to trucks and busses where the benefit of systems of longitudinal vehicle control support is higher.

The authors emphasize that it is not intended to remove well established systems such as ABS from the vehicle because of less observed benefit, since this could increase cases that have been already prevented by penetration into the vehicle fleet. The study is intended to support decisions for introduction of systems especially in all vehicle segments and to prioritize systems in terms of introduction to the market.

OUTLOOK

Further investigations will deal with combinations of traffic safety systems, reflecting vehicles which are equipped with more than one system. Also the fatality risk will be investigated in more detail by application of injury risk functions to the cases where the ADAS have decreased collision severity but not prevented the fatality.

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APPENDIX

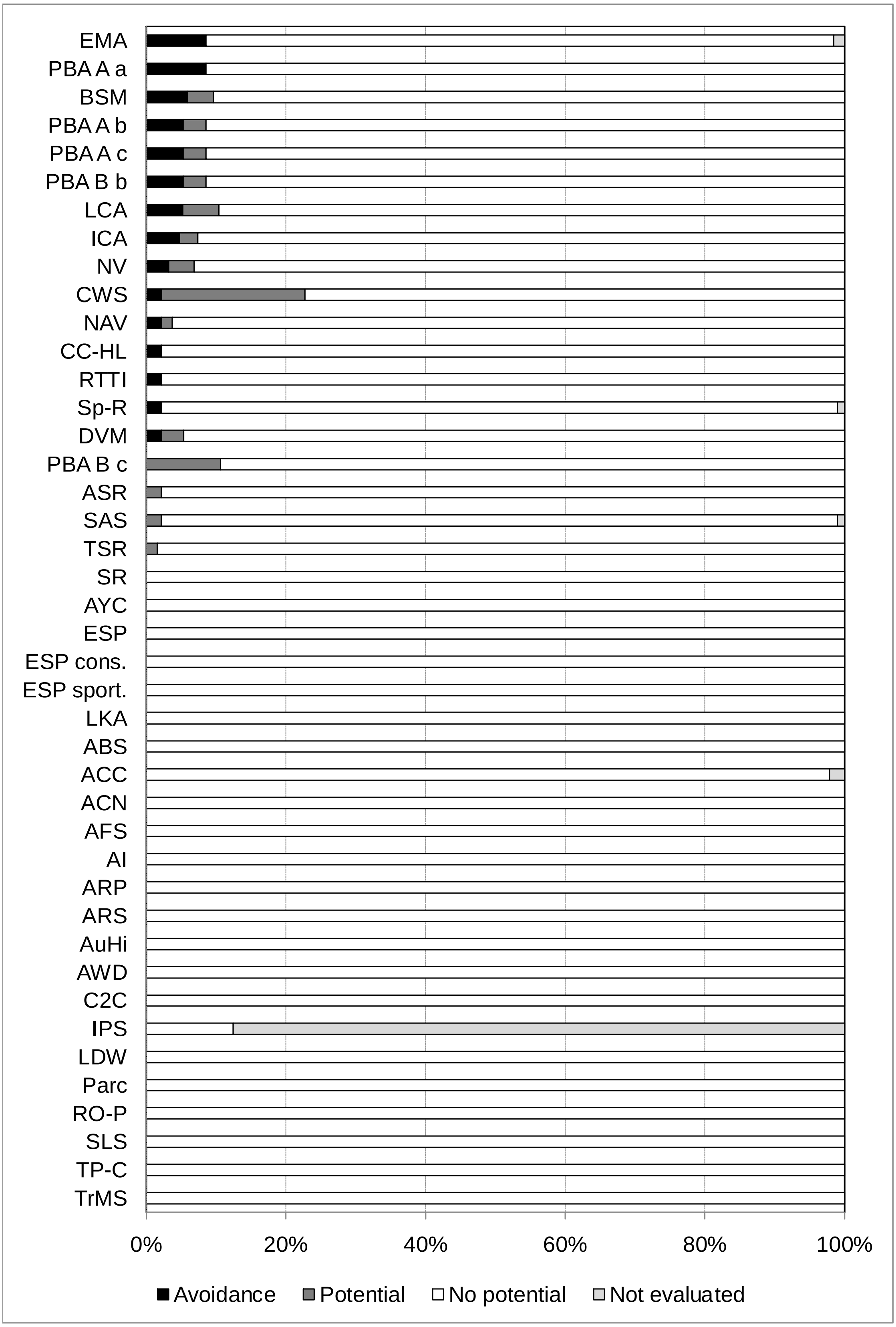

Figure 12: Percentage of Avoidance $A_{S,V}$ and Potential $P_{S,V}$ for vehicle category 'two-wheelers'

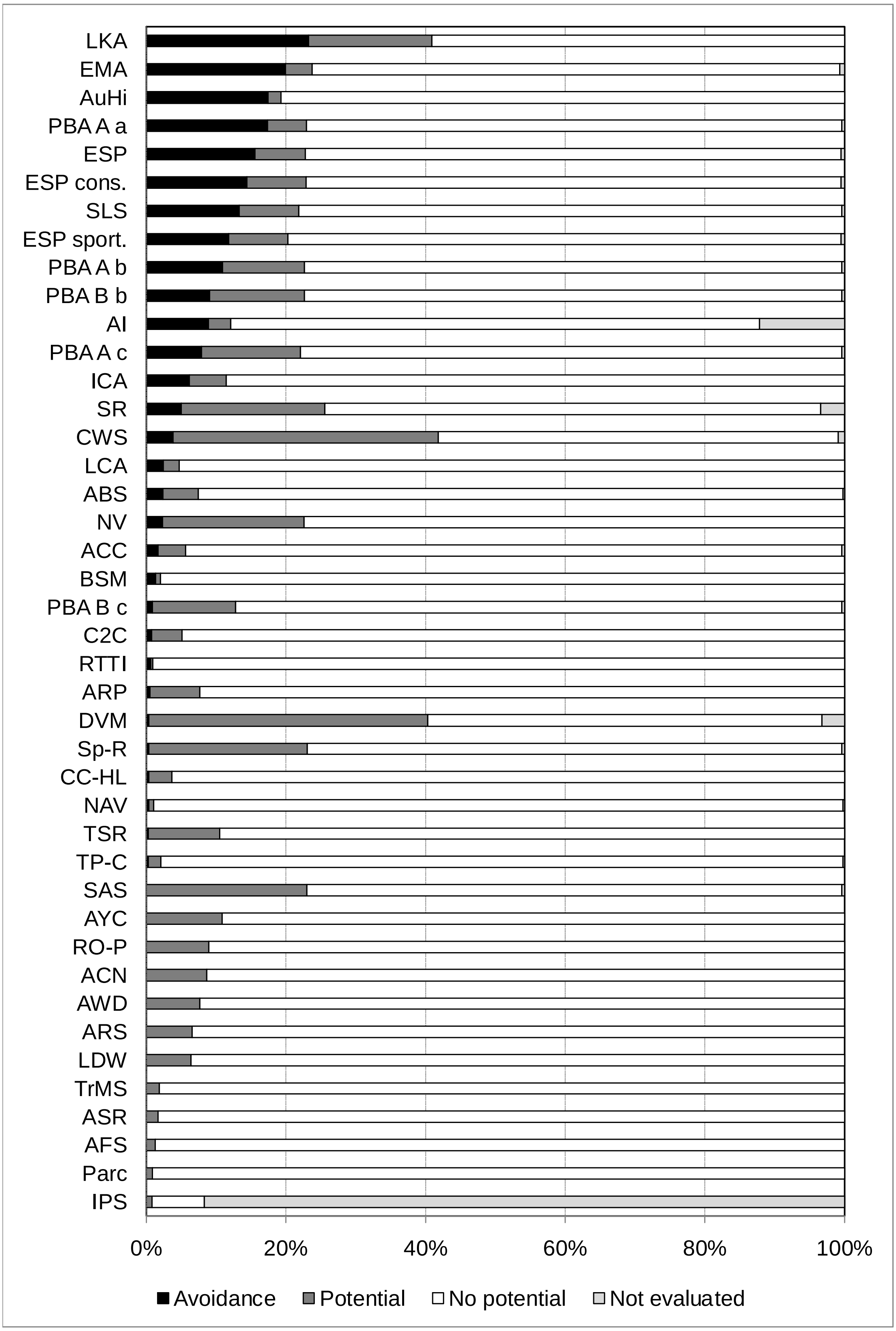

Figure 13: Percentage of Avoidance $A_{S,V}$ and Potential $P_{S,V}$ for vehicle category 'cars'

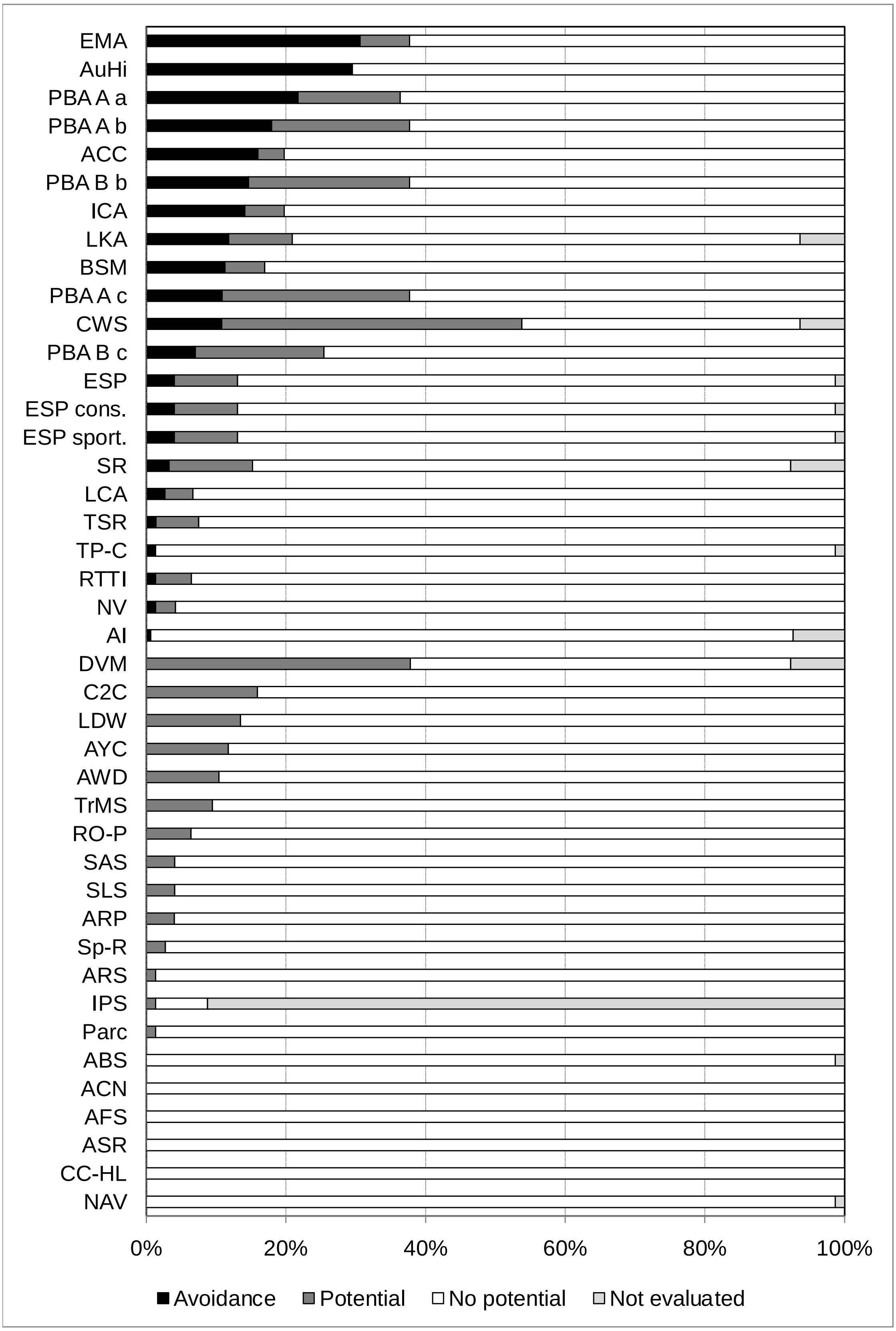

Figure 14: Percentage of Avoidance $A_{S,V}$ and Potential $P_{S,V}$ for vehicle category 'trucks and busses'

Table 3.
Investigated traffic safety systems in RCS-TUG

Abbr.	Description
ABS	Anti-Lock Braking System
ACC	Adaptive Cruise Control
ACN	Automatic Crash Notification
AFS	Active Front Steering
AI	Alcohol Detection and Interlock
ARP	Active Rollover Protection
ARS	Active Rear Steering
ASR	Anti-Slip Regulation
AuDr	Autonomous Driving
AuHi	Automated Highway
AWD	All Wheel Drive
AYC	Active Yaw Control
BSM	Blind Spot Monitoring
C2C	Inter-Vehicle Communication Systems
CC-HL	Cornering/Axis Controlled Headlights
CWS	Collision Warning
DVM	Driver Vigilance Monitoring
EMA	Evasive Maneuver Assistant
ESP	Electronic Stability Program
ESP cons.	ESP conservative
ESP sport.	ESP sportive
ICA	Intersection Collision Avoidance
IPS	Intelligent Crash Protection
LCA	Lane Changing Assistant
LDW	Local Danger Warning
LKA	Lane Keeping Assist
NAV	Navigation Systems
NV	Night Vision
Parc	Parctronic
PBA A a	Predictive Brake Assist, intervention strategy A, driver reaction a
PBA A b	Predictive Brake Assist, intervention strategy A, driver reaction b
PBA A c	Predictive Brake Assist, intervention strategy A, driver reaction c
PBA B b	Predictive Brake Assist, intervention strategy B, driver reaction b
PBA B c	Predictive Brake Assist, intervention strategy B, driver reaction c
RO-P	Rollover Protection
RTTI	Real Time Traffic Information
SAS	Speed Alerting System
SLS	Speed Limiting System
Sp-R	Speed Recommendation
SR	Seatbelt Reminder and Buckle Sensor
TP-C	Tire Pressure Control
TrMS	Traffic Management System
TSR	Traffic Sign Recognition and Alert

Table 4.
Weighted Potential $W_{S,V}$ for different vehicle categories

Ranking	All vehicles	Weighted potential [%]	Two-wheelers	Weighted potential [%]	Cars	Weighted potential [%]	Trucks and busses	Weighted potential [%]
1	LKA	23	CWS	12	LKA	32	EMA	34
2	CWS	21	EMA	9	CWS	23	CWS	32
3	EMA	20	PBA A a	9	EMA	22	AuHi	29
4	PBA A a	18	LCA	8	DVM	20	PBA A a	29
5	DVM	16	BSM	8	PBA A a	20	PBA A b	28
6	AuHi	16	PBA A b	7	ESP	19	PBA B b	26
7	PBA A b	16	PBA A c	7	ESP cons.	19	PBA A c	24
8	PBA B b	15	PBA B b	7	AuHi	18	DVM	19
9	PBA A c	14	ICA	6	SLS	18	ACC	18
10	ESP	13	PBA B c	5	PBA A b	17	ICA	17
11	ESP cons.	13	NV	5	ESP sport.	16	LKA	16
12	SR	12	DVM	4	PBA B b	16	PBA B c	16
13	SLS	12	NAV	3	SR	15	BSM	14
14	ESP sport.	11	CC-HL	2	PBA A c	15	SR	9
15	NV	10	RTTI	2	NV	12	ESP	9
16	ICA	9	Sp-R	2	Sp-R	12	ESP cons.	9
17	Sp-R	8	SR	2	SAS	12	ESP sport.	9
18	SAS	8	ESP	2	AI	10	C2C	8
19	PBA B c	7	ESP cons.	2	ICA	9	LDW	7
20	AI	7	ESP sport.	2	PBA B c	7	AYC	6
21	ACC	5	ASR	1	AYC	5	AWD	5
22	TSR	4	SAS	1	TSR	5	TrMS	5
23	AYC	4	TSR	1	ABS	5	LCA	5
24	LCA	4	AYC	1	RO-P	4	TSR	4
25	BSM	4	LKA	1	ACN	4	RTTI	4
26	RO-P	3	ABS	0	ARP	4	RO-P	3
27	C2C	3	ACC	0	AWD	4	NV	3
28	ABS	3	ACN	0	ACC	4	SAS	2
29	AWD	3	AFS	0	LCA	4	SLS	2
30	LDW	3	AI	0	ARS	3	ARP	2
31	ARP	3	ARP	0	LDW	3	Sp-R	1
32	ACN	3	ARS	0	C2C	3	TP-C	1
33	ARS	2	AuHi	0	CC-HL	2	AI	1
34	CC-HL	2	AWD	0	BSM	2	ARS	1
35	TrMS	1	C2C	0	TP-C	1	IPS	1
36	RTTI	1	IPS	0	TrMS	1	Parc	1
37	TP-C	1	LDW	0	ASR	1	ABS	0
38	NAV	1	Parc	0	RTTI	1	ACN	0
39	ASR	1	RO-P	0	NAV	1	AFS	0
40	AFS	0	SLS	0	AFS	1	ASR	0
41	Parc	0	TP-C	0	Parc	0	CC-HL	0
42	IPS	0	TrMS	0	IPS	0	NAV	0