SAKURA online seminar by Hans-Peter Schöner
March 29 (Mon) 15:00 to 16:30 (JST)

On the Relation between Fuzzy Safety Metrics and Tactical Safety for Autonomous Vehicles

SEMINAR CONTENTS

- Operational Driving Domains (ODD) can be divided into two regions: one with a traditional crisp safety approach, and one with a probabilistic safety approach for rare, but dangerous situations
- The importance of Tactical Safety for this probabilistic region
- Discussion of proposed fuzzy safety metrics in this probabilistic region

Dr. Schöner is an independent consultant (and CEO) of "Insight from Outside"- Consulting.

- Worked at Daimler AG for nearly 30 years.
- Former positions at Daimler include Senior Manager for "Driving Simulation and Testing Concepts" in Daimler's R&D Center "Assistance Systems, Active Safety and Testing", with responsibilities tied to the development and supply of methods for testing and validation for future chassis and assistance systems, including autonomous driving functions.

"Safety is no Accident !" Dr. Schöner played a key role in defining the German government-funded research project PEGASUS.

Agenda

- Short Review of previous work:
  - Risk Exposure and Prevention
  - Tactical Safety
  - Cooperative Sensing
  - Perception of Danger
- Why unbounded ODDs need Tactical Safety
- Comments on NHTSA ADS Safety Framework Proposal
- Comments on a recent paper on Fuzzy Safety Metrics by EU-JRC

Key message

Safety in traffic does not only depend on

- being able to react on given critical situations **C**

but also on

- behaviour in order to avoid critical situations **E**

$$R = E\,(1-C)\,S$$

- R: Risk contribution
- E: Exposure
- C: Controllability
- S: Severity

of a single risk-contributing scenario

Preventable Risks

Severe dangers can be prevented by either

- **controlling** emergency situations $C \rightarrow 1$

but also by

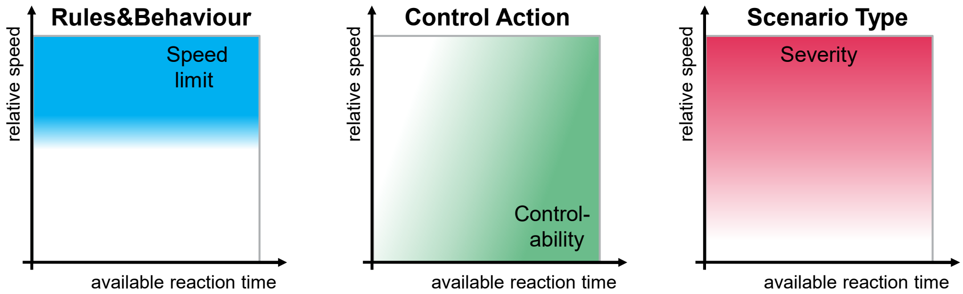
- **avoiding** exposure to (especially potentially uncontrollable) situations $E \rightarrow 0$

$$R = E\,(1-C)\,S$$

- R: Risk contribution
- E: Exposure
- C: Controllability
- S: Severity

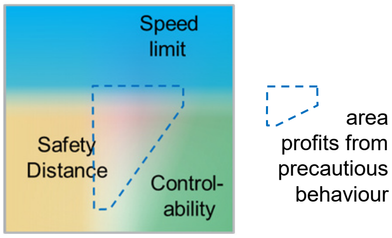
of a single risk-contributing scenario

Risk depends on three factors



$$R = E\,(1-C)\,S$$

Behaviour avoids exposure to uncontrollable situations !

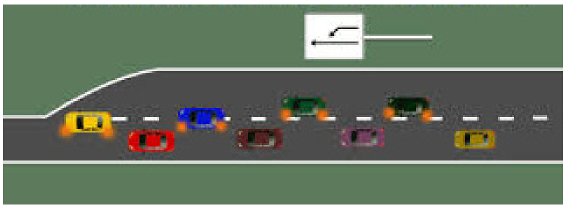


Challenging Scenario Set for Safety Assessment

- A set of testing scenarios is proposed, with the goal to cover the most important aspects of **precautious** and **cooperative** driving on highways.
- Four categories are included:

Category	Occurrence / Exposure (E)	Expected Severity (S)	Foreseeable	Preventable	Goal for Controllability (C)
Difficult traffic situations	~ every day	low - medium	yes	yes	**flawless behaviour**
Extraordinary traffic situations	~ once per week or month	high	yes	limited	**avoidance, no injury**
Worst foreseeable failure situations	rare or very rare	probably high	yes, but not in detail	no	**mitigation**
Long range sensing occluded situations	~ every day	possibly high	yes	largely by communication	**verify the basic function**

Schöner HP. 2020. Challenging Highway Scenarios Beyond Collision Avoidance for Autonomous Vehicle Certification. In: Research Gate, DOI: 10.13140/RG.2.2.29355.05926



1. Drive flawlessly in difficult every day situations

2. Know your limits in extraordinary situations

3. Cope with rare, surely dangerous failures

4. Cooperate in long range sensing

Tactical Safety

Change your behaviour <u>early</u> and <u>smoothly</u>

based on indicators for <u>possibly dangerous</u> situations

in order to avoid potentially uncontrollable situations

Human drivers take the risk of short safety distances because they **assume**, the highway is usually free of hazards.

AVs should **know**, that the highway is safe when they are designed to drive at even shorter distances.

Speed difference is the biggest hazard on highways

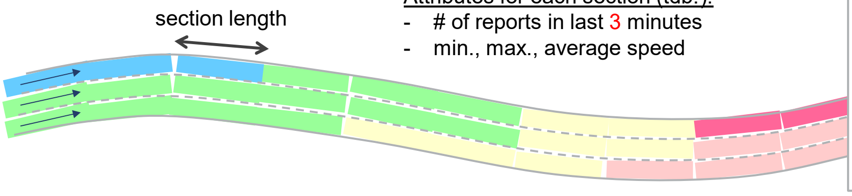
The **speed at which the cars are driving** is the simplest and readily available available indicator for road hazards.

An essential point is the step
- from reporting hazards „without any obligation“
- to a dependable information about road status
  with indicated actuality and known completeness

(at least) for high speed roads with ODD speed for AVs above 60km/h.

Example: 3-lane highway

Attributes for each section (tdb!):
- # of reports in last 3 minutes
- min., max., average speed



Legend: Minimal speed:
- 0 .. 20 km/h
- 20 .. 50 km/h
- 50 .. 80 km/h
- 80 .. 110 km/h
- >110km/h

Extended hazard warning

Report not only the speed of the own car, but also speed and location of other significant objects on and near the own lane.

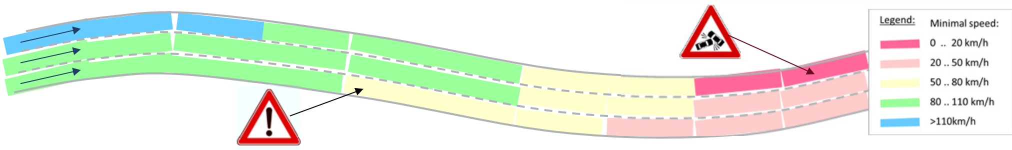
➔ Covers vehicles and objects without own communication (unequipped vehicles, lost objects, pedestrians, animals, environmental hazards, road problems, …)

Sensors needed / suited to provide this information: cameras, lidars, radars, …
Data could be provided by: **all trucks with ADAS**, all new vehicles with ADAS, stationary road sensors

Example: 3-lane highway

Additional attributes for each hazard (tdb!):
- # of reports in last 3 minutes
- location and category of hazard
- if moving object: measured speed / direction

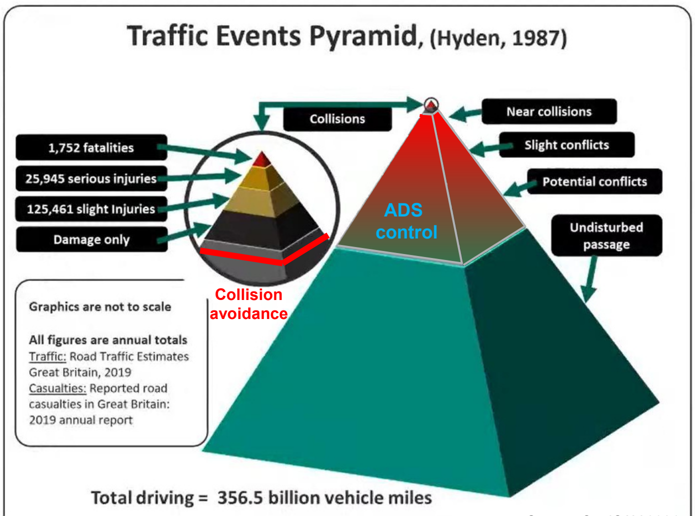
Categories (examples)



Behaviour change needs to start when danger increases, not only near collisions

Traditional binary safety metrics were developed to decide, whether an **ADAS collision avoidance** action should be initiated. A binary limit is OK.

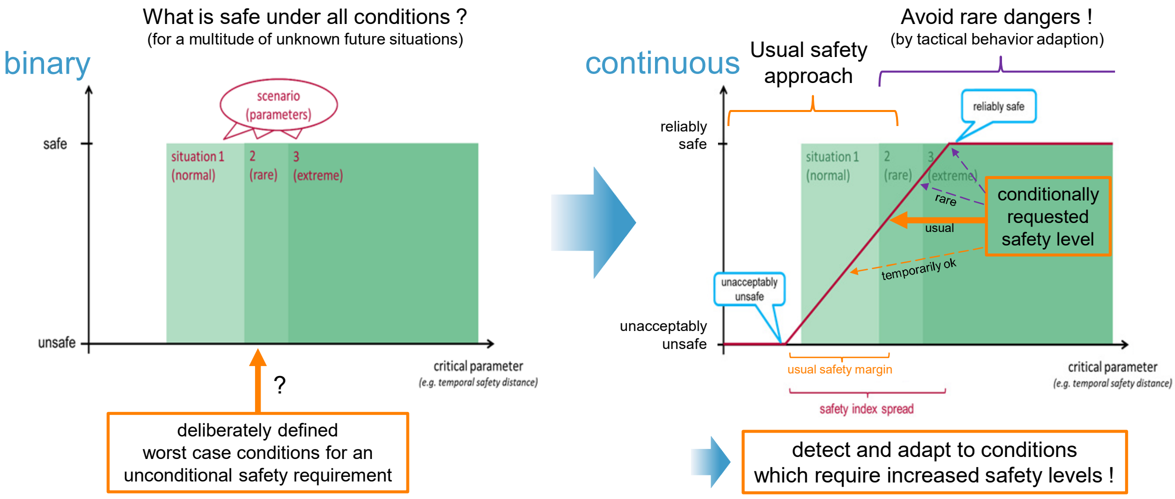
Autonomous driving system control needs different quantitative metrics in order to effectively avoid potentially unsafe situations. Control actions need to start already in the conflict zone.



Source: CertiCAV 2021

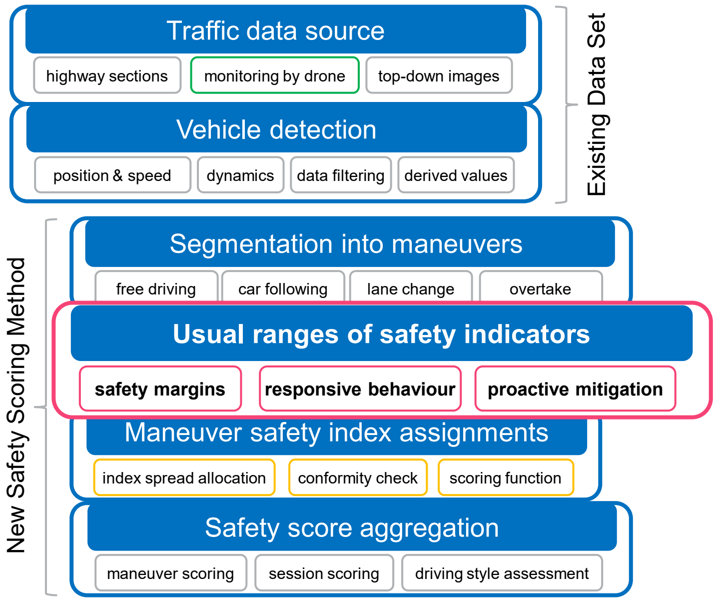
From binary to continuous safety metrics:

Safety metrics as basis for perception of danger and behaviour change



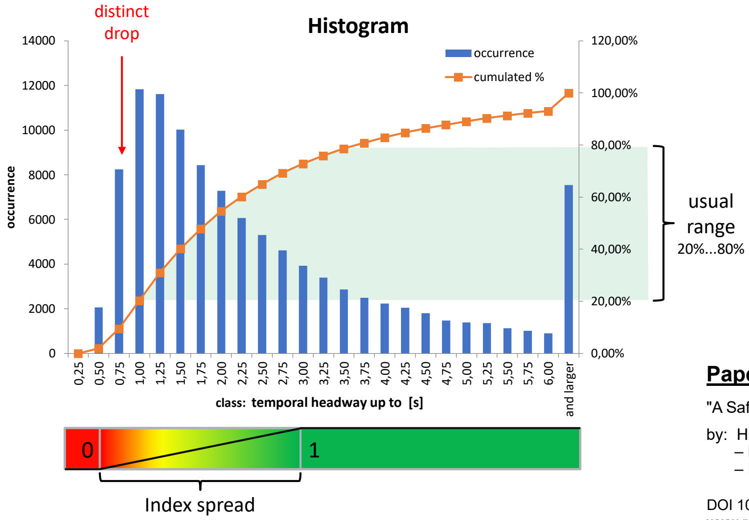
Safety Score
for Driving Style Assessment

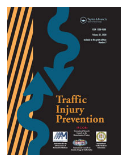
- Concept for a quantitative measurement of the level of cautious and careful driving.
- Derived from statistical data of human behaviour.
- It can serve for validation tests and as basis for an effective learning behaviour.



Result of a joint research project of

Safety score based on fuzzy metrics





Paper to be published in TIP Journal:

"A Safety Score for the Assessment of Driving Style"

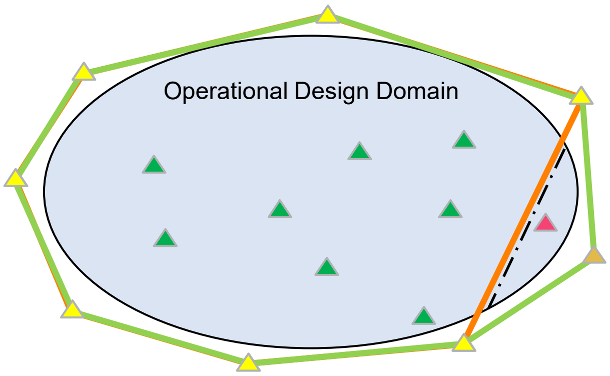
by: H.P. Schöner – P. Pretto – J. Sodnik
– B. Kaluza – M. Komavec – D. Varesanovic
– H. Chouchane – J. Antona-Makoshi

DOI 10.13140/RG.2.2.12438.98885,
www.researchgate.net/publication/344852118_A_Safety_Score_for_the_Assessment_of_Driving_Style

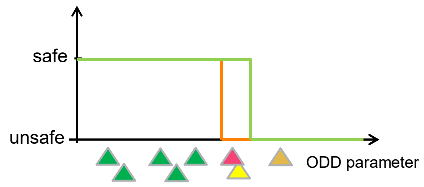
IFO Consulting

How safety works

for clear use cases in a well specified ODD



- Use cases
- Test cases, with safety margins
- Safety argument
- Critical case
- ODD restricted by operator
- Additional test and argument, covers also critical case



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Conditions for safe operation

for clear use cases in a well specified ODD

- **Complete set of rules which is free of conflicts within the ODD**
  - But: a large and complex ODD requires more restrictive behaviour rules to cover all use cases
- **Operational conditions stay always within the ODD**
  - But: it is the responsibility of the operator to continuously verify, that these conditions are consistent with the ODD

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Use cases and ODD for Autonomous Vehicles

- Creative human agents and traffic cultures:
  Traffic conditions will vary indefinitively
- Unpredictable environment:
  Extreme weather and road conditions have to be expected
- Huge number of participants and long-term operation:
  Whatever fault or mishap might happen, will happen !

Unusual use cases exist, which cannot be defined exactly, and the ODD cannot be tightly bounded just by definition

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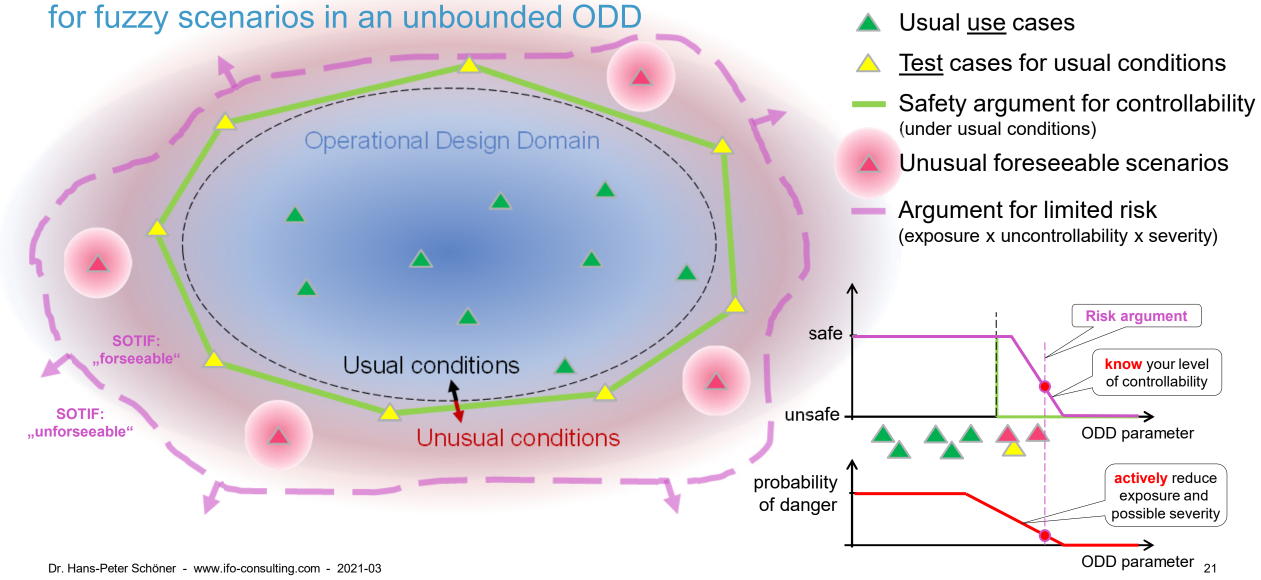
Tactical Safety reduces the probability of danger

for fuzzy scenarios in an unbounded ODD



Conditions for safe operation

for fuzzy scenarios in an unbounded ODD

- **Complete set of rules which is free of conflicts within the ODD under usual conditions**
- **ODD is continuously supervised and unusual conditions are recognized**
- **The levels of controllability of possible unusual conditions are understood**
- **Tactical Safety Actions are taken to return back into the ODD, or to reduce exposure to possibly severe and uncontrollable situations**

Test cases are needed for verification & validation of

- supervision of ODD conditions,
- knowledge about controllability in unusual situations,
- adequate *Tactical Safety Actions*

IFO Consulting

NHTSA ADS Safety Framework Proposal

published on Dec. 3, 2020 and requested comments by April 2, 2021

This document is scheduled to be published in the Federal Register on 12/03/2020 and available online at federalregister.gov/d/2020-25930, and on govinfo.gov

National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA-2020-0106]

RIN 2127-AM15

Framework for Automated Driving System Safety

The proposal was commented by IFO-Consulting.
The main topics dicussed are:

a) consideration of **implicit tasks** of a human driver;

b) consideration of risks which arise from traditional vehicle system specifications, which are **based on the assumption that a human driver exists**;

c) the **need for a quantitative measure for ‚safe driving‘** as a general guideline, best as an internationally harmonized regulation;

d) the proposal of a fith core element called **‚tactical behavior module‘**, as a **supervisor** of autonomous driving tasks, generating a tactical behavior guideline to the ADS;

e) a proposal of a regulation for a ‚**Real-time Traffic Safety Data Base**‘, as a prerequisite for autonomous high speed highway driving systems with specific properties;

f) a link to the attached document Schöner 2020: „Challenging Highway Scenarios Beyond Collision Avoidance for Autonomous Vehicle Certification“, with scenarios derived from a risk-based identification of **relevant highway scenarios**. These scenarios are proposed as essential scenarios for ADS certification.

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Core Elements of the NHTSA ADS Safety Framework

FEDERAL REGISTER Document Number: 2020-25930
Summary: NHTSA is requesting comment on the development of a framework for Automated Driving System (ADS) safety.

https://public-inspection.federalregister.gov/2020-25930.pdf?1606916719

This document is scheduled to be published in the Federal Register on 12/03/2020 and available online at federalregister.gov/d/2020-25930, and on govinfo.gov

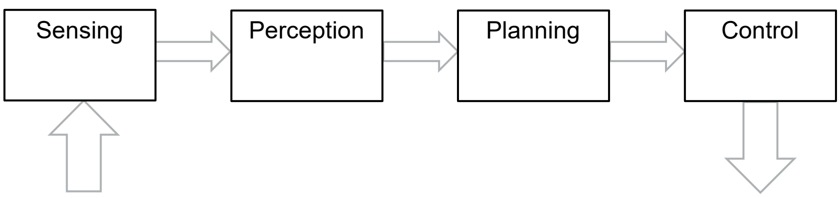
National Highway Traffic Safety Administration

49 CFR Part 571

[Docket No. NHTSA-2020-0106]

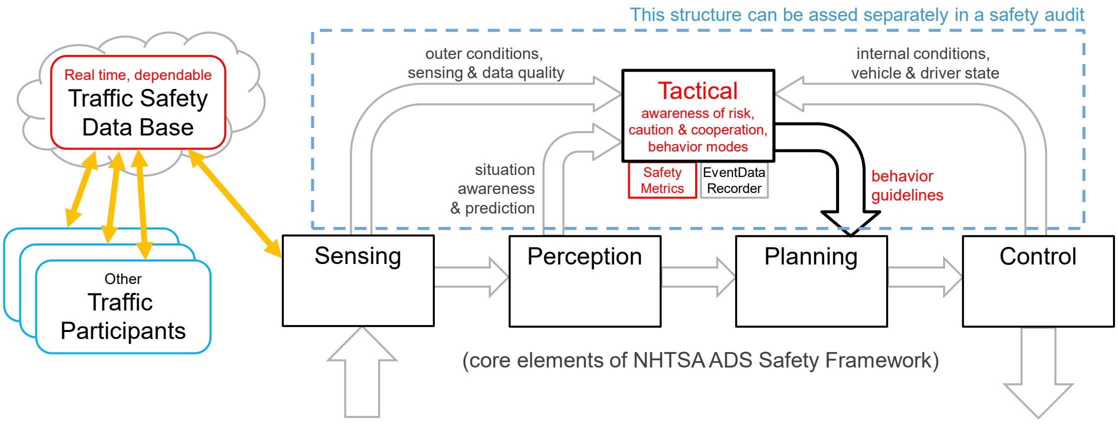
RIN 2127-AM15

Framework for Automated Driving System Safety



Structure for the implementation of Tactical Safety

Proposed new elements and new regulations of an ADS Safety Framework



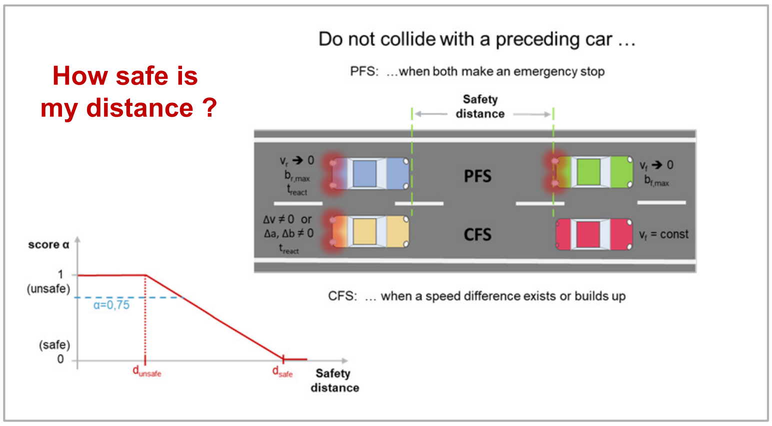
Summary

- The NHTSA ADS safety framework proposal was a good reference to verify whether the topics and discussions of the last 2 years can be integrated in the actual state of the art.

- IFO-Consulting is convinced that the developed core concepts
  - Consideration of risk exposure and risk prevention
  - Cooperative sensing, accumulated in a dependable traffic safety data base
  - Continuous metrics for the perception of level of danger
  - Behaviour adaption through tactical safety

  are important building blocks of an overall AV safety assurance.

- There is still a lot to accomplish before safe autonomous driving will be on our roads.



Insight from Outside

analyze – visualize – understand

Comments on a Paper by Mattas e.al.:

‚Fuzzy Surrogate Safety Metrics for real-time assessment of rear-end collision risk‘

by University of Thrace, AstaZero Test Track, European Commission – Joint Research Centre

Dr. Hans-Peter Schöner, Insight from Outside - Consulting

2021-03

IFO Consulting

The document under discussion

https://doi.org/10.1016/j.aap.2020.105794

Fuzzy Surrogate Safety Metrics for real-time assessment of rear-end collision risk. A study based on empirical observations

Konstantinos Mattas [a],*, Michail Makridis [c], George Botzoris [a], Akos Kriston [c], Fabrizio Minarini [c], Basil Papadopoulos [a], Fabrizio Re [c], Greger Rognelund [b], Biagio Ciuffo [c]

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Accident Analysis and Prevention 148 (2020) 105794

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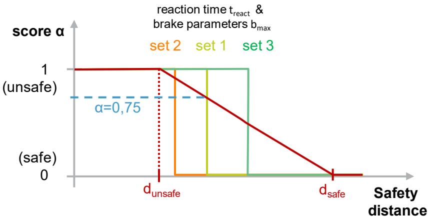
journal homepage: www.elsevier.com/locate/aap

Summary of the paper (Mattas e.al.)



- Comparison of several safety measures for rear collision scenarios
- All use **physical driving dynamics formulas** for stopping distances (similar to the RSS-model) with different parameters t_{react} and b_{max}
- Results show a strong influence of different brake parameters and a smaller influence of including a jerk term; hence, the **choice of suitable parameters** is paramount for a binary limit of ‚safe'
- **Proposal of ‚*Proactive Fuzzy Safety metric*' (PFS) and ‚Criticality Fuzzy Safety metric' (CFS),** both characterized by a continuous **score α** for ‚unsafety' which **varies linearly with distance between a**
  - **lower limit** with α=1 i.e. *just acceptable (‚minimum safe') distance* d_{unsafe} based on decel. e.g. **9m/s²**
  - **upper limit** with α=0 i.e. *reliably safe (‚maximum unsafe') distance* d_{safe} based on decel. e.g. **3m/s²**
- A continuous score α can serve as safety **control variable**, better than a binary safe/unsafe limit (like RSS)
- **A target score in the range** (e.g. α≈0,75 for normal conditions) **can provide a reference safety margin,** adaptable to road conditions, with the effective operational score staying safely below the unsafe limit of α=1

General comments

- The **above mentioned *general* result can be fully supported from an engineering point of view**
- **RSS** was primarily designed to be used as a *liability limit* – which explains the binary metric.
- The ***parameters* used in the article are not thoroughly investigated** and may <u>not</u> be taken as recommendations for a valid implementation of the concept.
- **Comparison of the different models is <u>not</u> a significant result of the article**; all physics based models do a very similar job for the prediction of principal braking performance.
- **A valid safety metrics is more a matter of choice of suitable parameters**: many different conditions may occur, one single set of parameters cannot do the job for all.
- **A ‚fuzzy' safety metrics**, adapted to the conditions **with a tunable parameter α, does a better job.** A high value of α may be acceptable for dry and normal conditions, with a lower value of α being necessary to use for less safe outer (road class, weather, visibility, traffic dynamics, …) and inner (vehicle and tire status, quality and completeness of information about the road ahead, …) conditions.
- **The observation, that the missing safety margin has a roughly linear relation to crash severity is an important finding of the article** (an analysis here shows the correct theoretical relation).

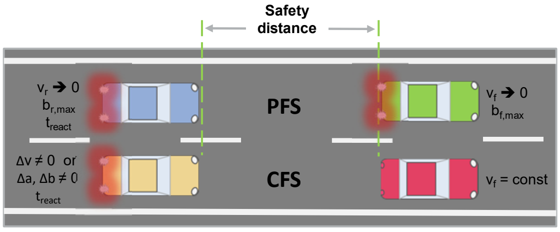
The two Fuzzy Safety Metrics use the same physical equations

PFS (proactive fuzzy) safety condition:
both vehicles shall come to a stop **without collision** in case of an (assumed) **emergency braking with max. deceleration** of the front vehicle down **to a full stop**. The vehicles might have different inital speeds and assumed decelerations. Since the emergency braking is just assumed, this metrics is called ‚proactive' metrics.

CFS (criticality fuzzy) safety condition:
any **accelerations or decelerations of the rear vehicle** from its inital speed **shall not cause a collision** when the rear vehicle initiates an emergency braking after its reaction time; the **front vehicle keeps its initial speed**. Since this conditon can be used to quantify the severity of an already critical situation, this metrics is called ‚criticality' metrics.

Do not collide with a preceding car …

PFS: …when both (would) make an emergency stop



CFS: … when a speed difference exists or builds up

PFS provides exactly the same results as CFS when **PFS is applied to a stopped front vehicle** with $v_{f,PFS}=0$ **and calculated with the initial speed difference for the rear vehicle**, $v_{r,PFS} = v_{r,CFS} - v_{f,CFS}$.

CFS allows for initial accelerations of the rear vehicle as an additional cause of an accident (which could be implemented easily in the PFS as well, using the same mathematics for considering the speed change during reaction time as in CFS).

Since CFS works with relative speed, while PFS is using ‚ground speed', **PFS typically results in larger safety distances.**

Comments on a Paper by Mattas e.al.

Comments on method and AEB performance

The method for experimental comparison is to use excitations of acc-controlled convois (consisting of several series production vehicles with ACC and AEB functions) which drive on a test field, the leading vehicle changes speed by modifications of the acc settings, and the authors monitor how the different safety measures assess the safety of every single vehicle reactions on those excitations. This method **does not use a representative set of real driving situations**, but just some examples with the goal to drive close to the limit of critical situations in quasi stationary operation. Especially **sudden events are not covered by the tests**.

The authors use parameters for the models which are extracted from **emergency braking experiments** with the same vehicles on the proving ground, braking onto standing brake targets. Their result was, that the implemented **AEB function managed to avoid a crash** (even in this ‚clean' proving ground setting) **only in 80% of all experiments**. Although this is an acceptable value for an *assistance* system which provides support for a driver who comes into a critical situation (so 8 out of 10 driver faults are ‚mended'), this value is not good enough for autonomous vehicles – if this is the only way of managing such critical situations.

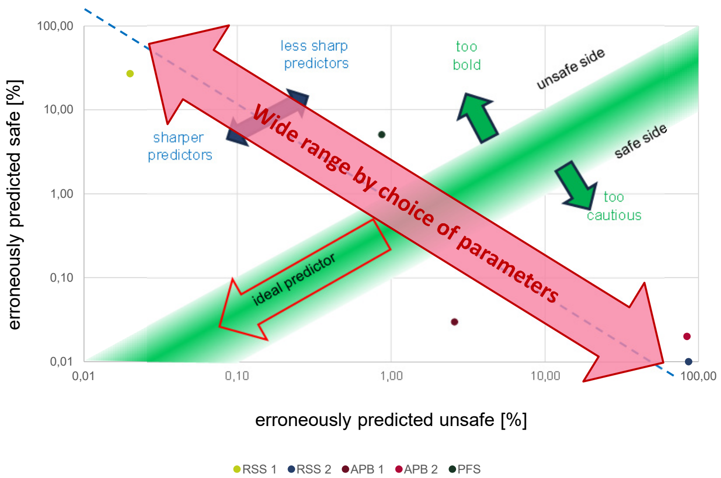
1. Scenario coverage is not complete for validation of parameters.
2. For AV design, larger safety margings have to be applied than in the actual implementations of AEB systems

Compared Models

- RSS Responsibility Sensitive Safety model
  with two different parameter sets, 9m/s² and 3m/s² (RSS1 and RSS2)
- APB Automatic Preventive Braking model (equivalent to RSS, but with jerk)
  with two different parameter sets, 9m/s² and 3m/s² (APB1 and APB2)
- PFS Proactive Fuzzy Safety model,
  based on 9m/s² and 3m/s² combined in the fuzzy model,
  with α = 95% as binary safety limit (for comparison purposes)

Trade-off of predictions

- Ground truth is a surrogate based on a reference model (with a certain parameter set)
- **The comparison only tells which other model comes closest to the reference model**
- All models use basically the same physical models of driving dynamics, the only difference is the use of jerk terms for APB models
- RSS 1 and 2 as well as APB 1 and 2 model only different brake performance



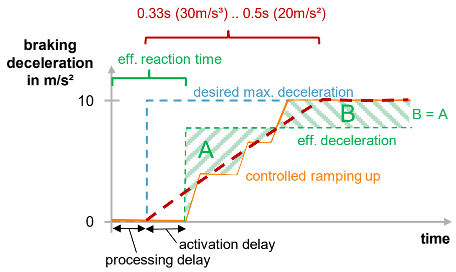
Parameter choice is paramount !

Emergency Braking: ‚Effective brake deceleration' vs. ‚Jerk'

Braking force has technical delays and deliberate speed control of ramping up (in order to give reaction time for the following car).

‚Effective brake deceleration' models brake delays and gradual ramping up of deceleration by brake control. It assumes the same average force (B=A) for the complete deceleration process.

The measured equivalent **<u>effective</u> decelerations are well in line with values in the literature**, which used <u>models without jerk</u>. For many safety models in literature, a reliably reachable *effective deceleration* value of **6m/s²** is used for automatic braking systems, with **400..500ms** *effective reaction* time.



‚Jerk' is a second order model, which is an alternative approximation for delays and active force ramping;
a reaction time of 200ms plus a jerk of 20m/s³ leads to similar results as 400ms effective reaction time

<u>Source:</u> H. Winner (2016) "Fundamentals of Collision Protection Systems". in: Winner e.al.: „Handbook of Driver Assistance Systems", Springer international Publishing, Cham

Parameter choice from measurements (as used in the paper)

9m/s² as *maximum achievable* <u>AEB</u> braking deceleration including a jerk of 20m/s³
(**equivalent to 6.5 ... 7 m/s²** ***effective*** deceleration calculated without jerk)

3m/s² as *comfortably manageable* deceleration of <u>human</u> and <u>ACC</u> drive controllers;

12m/s² as *maximum expectable* braking deceleration including a jerk of 30m/s³ as a worst case derived from <u>human</u> braking tests (**equivalent to 9 .. 10m/s²** ***effective*** decel. without jerk);

20m/s³ as jerk when ramping up to the constant deceleration in <u>AEB</u> systems

The authors **never measured real reaction time; they just assumed 200ms as a reasonable value.**
In Winner (2016) 0.4s to 0.5s is considered a realistic *effective* value to reach full braking power;
the difference of 0.2s to 0.3s is similar to modelling the brake force ramp with a jerk of 20m/s².

➔ This choice of design parameters represents an **unreachable limit performance**:
a reaction time of 200ms is *unrealistically* short in a model without jerk,
9m/s² as maximum *effective* braking deceleration is hardly achievable for an AEB.

Equivalence between fuzzy α-cut and binary safe/unsafe model

The fuzzy approach still **allows to deduct an equivalent binary safe/unsafe metric** (if needed at all), since any specific limit value α between 0 and 1 can be mapped to a stopping distance d(α)

$$d(\alpha) = d_{safe} - \alpha\,(d_{safe} - d_{unsafe})$$

which is (at given reaction time) attached to a corresponding deceleration value between $3m/s^2$ and $9m/s^2$. This can be calculated exactly even in this ‚fuzzy' concept. According to figure 3 of the article, an **α-value of 75% relates to a deceleration of around $6m/s^2$ for the speeds and reaction times used in the investigation**. This might be important, if existing experience about safe limits should be translated into the fuzzy approach, or vice versa.

➔ 1. Using RSS with variable parameters can achieve the same effect as using a fuzzy approach with a variable α-cut.
2. Existing models of human performance of weather influence can similarly be implemented with a variable α-cut.
(➔ a good chance for internationally harmonized agreements based on fuzzy metrics)

Fuzzy safety metrics and ‚Tactical Safety'

It has to be mentioned, that the assumption of $12m/s^2$ (or effectively $9..10m/s^2$ without jerk) as <u>maximum</u> braking deceleration is only applicable under the assumption that the leading vehicle <u>stops with its own brakes</u>. **If the leading vehicle is involved in a collision, all the discussed safety measures do not provide a valid safety assessment.** Any acc system <u>which only relies on the monitoring of the leading vehicle</u> and which uses safety distances close to d_{unsafe} will definitively have the same fate as the vehicle in front: **if the leading vehicle collides and comes to a sudden stop (deceleration >>$12m/s^2$), the following vehicle will collide as well.** And many other following vehicles will do the same. Such severe accidents might even happen more often with autonomous vehicles, because they consistently will use short following distances. A human driver might anticipate the situation and react ealier. Such Tactical Safety behaviour needs to be developed for autonomous vehicles, as discussed in *Schöner (2020) ‚Challenging Highway Scenarios Beyond Collision Avoidance…'*, DOI: 10.13140/RG.2.2.29355.05926 .

➔ ‚Tactical Safety' considerations need to complement the proposed safety metrics for collision avoidance under *unusual* conditions; a simple implementation is to activate a suitable target α-value in order to prevent an unusual, possibly uncontrollable situation

<u>Example:</u> if the road ahead is not guaranteed to be free of traffic jams, debris etc., increase the safety distance compared to normal

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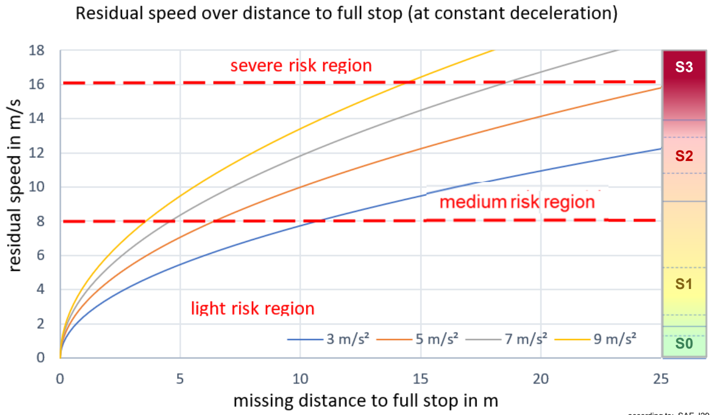
Crash severity in frontal collisions (rear vehicle has residual speed, when front vehicle comes to a stop)

a) More than 60km/h (16m/s) collision speed might **surpass the verified capabilities** of modern passive safety systems; the outcome is not predictable and may lead to severe injury or even death of the passengers.

b) Below 30km/h (8m/s) it can be expected an outcome **with minor injury** for the passenger (in most cases, and state of the art passive safety systems assumed).



Residual speed is a square root function of missing safety distance.
Hence, collision energy increases linearly with missing safety distance.

according to: SAE J2980

Collision Type	Range for	S0	S1	S2	S3
Front	Min. km/h		>4-10	>20-50	>40-65
	Max. km/h	<4-10	<20-50	<=40-65	
Back	Min. km/h		<4-10	>20-50	>40-60
	Max. km/h	<4-10	<20-50	<=40-60	
Side	Min. km/h		>2-10	>=8-30	>16-40
	Max. km/h	<2-3	<8-30	<16-40	

Connected Places Catapult

Sources for a) and b): Rules of thumb from crash analysis (personal information)

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Crash severity in frontal collisions

Crash severity caused by a missing safety distance d (front collision into a standing vehicle)			
Severity:	light	medium	severe
Deceleration:	v_{crash} < 30km/h	30km/h < v_{crash} < 60km/h	60km/h < v_{crash}
5 m/s²	d < 6.4 m	6.4 m < d < 25.6 m	25.6 m < d
7 m/s²	d < 4.5 m	4.5 m < d < 18.0 m	18.0 m < d
9 m/s²	d < 3.6 m	3.6 m < d < 14.4 m	14.4 m < d

Based on such arguments, the **effect of a wrong initial estimation** of safety distance can be developed, as well as an assessment of the **parameter sensitivity for the safety metrics**. This again might be used for an argument, **how large the safety margin (α-value) should be chosen** under different conditions. This is helpful for Tactical Safety behaviour guidelines.

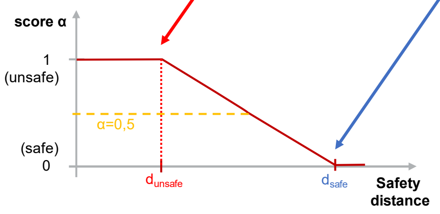
These implications could be further investigated in a separate research task.

Design with a larger deceleration leads to a higher sensitivity to wrong estimations.

Important values derived from parameters in the paper

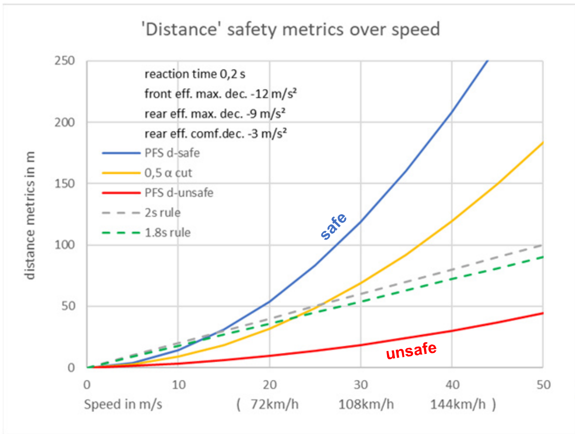
Speed	d-unsafe	Δt-unsafe	d-safe	Δt-safe
km/h	m	s	m	s
60	7,2	0,43	38,1	2,28
80	11,3	0,51	66,2	2,98
100	16,3	0,59	102,0	3,67
120	22,1	0,66	145,6	4,37
140	28,8	0,74	196,8	5,06

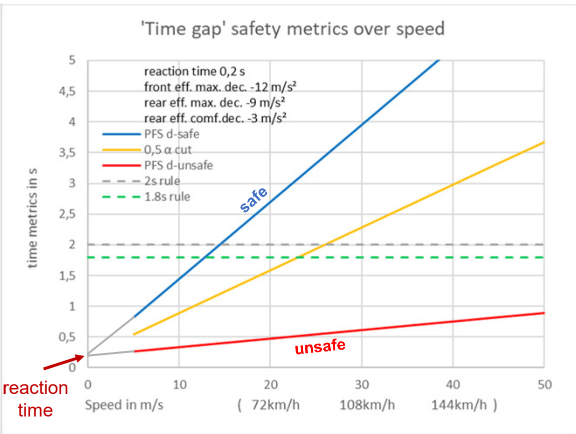
Parameters:		
reaction time	0,2	s
front vehicle:		
front eff. max. dec.	-12	m/s²
rear vehicle:		
rear eff. max. dec.	-9	m/s²
rear eff. comf.dec.	-3	m/s²



These values are shown in the following graphics for better overview and interpretation

Safe distances and time gap based on PFS (‚as in paper‘, ambitious)



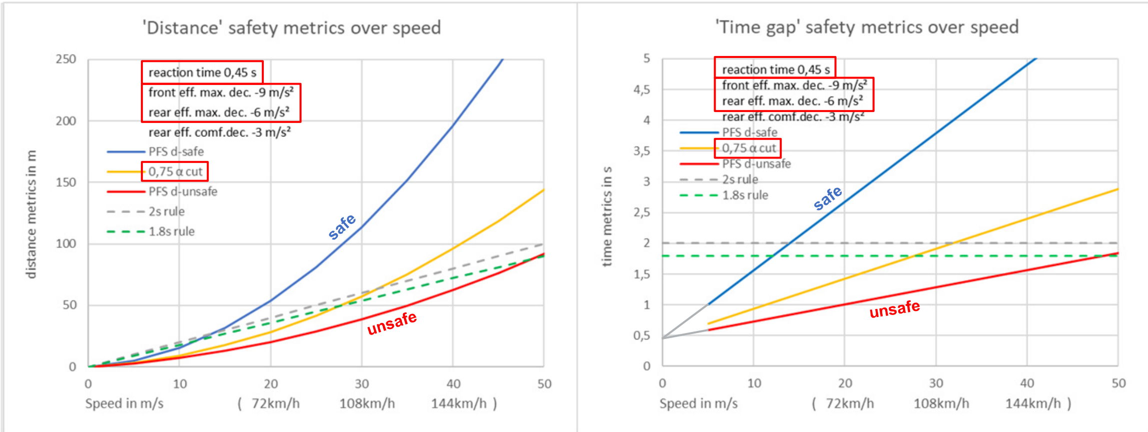


Time gap is a linear function of speed in PFS ➔ easy interpretation is possible:

Intersection point at zero speed is reaction time, slower reaction shifts the curves up;

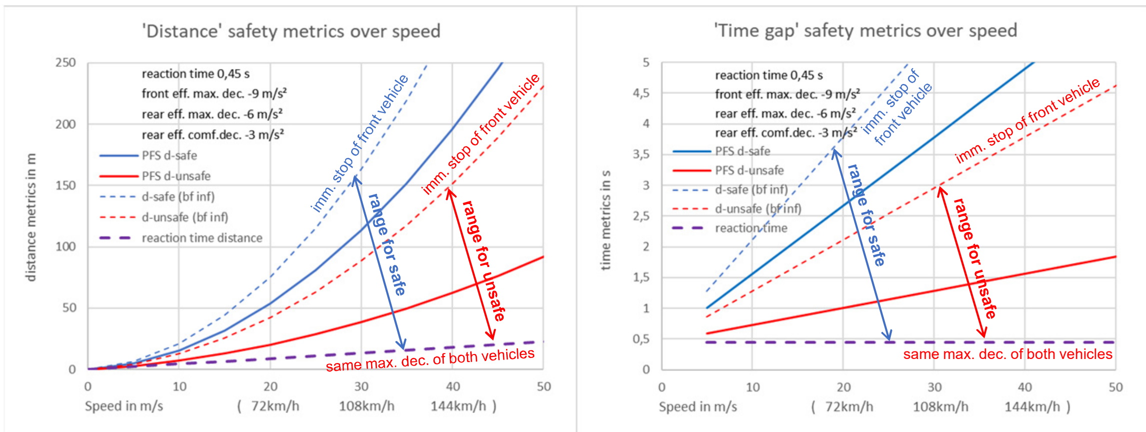
$Slope_{unsafe} = 0.5\ ((1/b_{r,max}) – (1/b_{f,max}))$ and $Slope_{safe} = 0.5\ ((1/b_{r,comf}) – (1/b_{f,max}))$

Safe distances and time gap based on PFS (‚safe automation' proposal)



The suitable choice of parameters is still open for discussion.
There is a fundamental speed dependance of safe distances, calling for different time gaps than the traditional „1.8s/2s rule of thumb" (under ‚normal' conditions).

Safe distances and time gap based on PFS (range of variations)



Assumptions of prevailing conditions have significant impact on parameters, hence on limit lines and on the span between.

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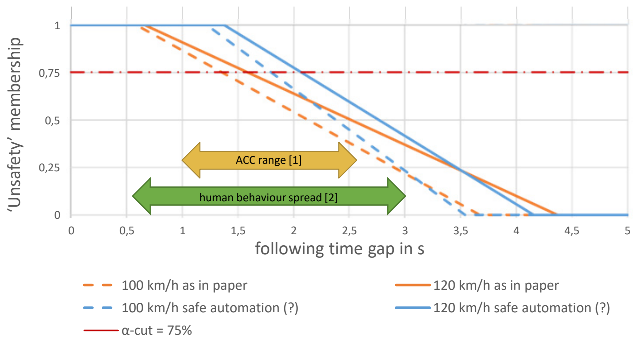
Fuzzy membership curves for different parameter sets

- The graph shows the effect of two different parameter sets (line colour), and the influence of speed (line type).
- 'Safe Automation' proposal for normal road conditions leads to ≈1,8s@100km/h and ≈2s@120km/h
- Existing ACC systems can be set to time gaps between 1.0s and 2.6s.
- From human behaviour on highways a range for scoring safety between 0.6s and 3.0s was deducted in [2].



PFS and [2] use very similar mathematics for the safety model (inverted membership curve).
In [2] it has been shown, how this approach can be used for a continuous scoring.

[1] ACC-range: H. Winner, M. Schopper (2016) "Adaptive Cruise Control". in: Winner e.al.: „Handbook of Driver Assistance Systems", Springer international Publishing, Cham
[2] Human behaviour spread: Schöner e.al. (2020). "A Safety Score for the Assessment of Driving Style". Paper submitted to TIP Journal. DOI: 10.13140/RG.2.2.12438.98885

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Summary

- Fuzzy safety metrics fit well to the variable safety conditions of traffic in order to consider the wide range of possible braking actions, traffic and weather conditions.
- A target safety level (α-cut) in the range of 75% of the realistically maximum braking performance might be a candidate for acceptable safety with suitable margin under <u>normal</u> conditions (needs to be validated !).
- (Unusual) conditions which require a ‚Tactical Safety' behaviour change can be implemented by changing the target safety level to the safer side; the quantitative change depends on conditions and should be investigated.

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Thank you !

- for the encouragement,
- the challenging topics,
- the good discussions,
- your personal feedback and support,

and for this great international cooperation within the last two years !

Good success to the further activities of JARI and JAMA in the challenging field of safety assurance of Autonomous Vehicles!

SAKURA
Safety Assurance KUdos for Reliable Autonomous Vehicles

Insight from Outside
analyze – visualize – understand

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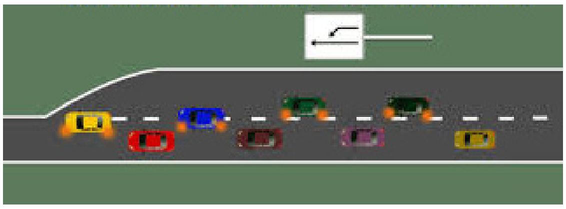
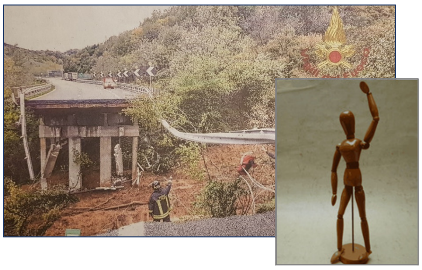


1. Drive flawlessly in difficult every day situations

2. Know your limits in extraordinary situations

3. Cope with rare, surely dangerous failures



4. Cooperate in long range sensing

Bye Bye !

Insight from Outside
analyze – visualize – understand