Kollisionsvermeidung im Längsverkehr – die Vision vom unfallfreien Fahren rückt näher

M. Stämpfle[1], W. Branz[2]

In den letzten Jahren stehen Fahrerassistenzsysteme zunehmend im Fokus intensiver Forschungsaktivitäten im automobilen Bereich. Komfort- und Sicherheitssysteme sollen den Fahrer bei der Bewältigung seiner Fahraufgabe bei Routinevorgängen und in kritischen Situationen entlasten und unterstützen. Rund 60% der Auffahrunfälle und fast ein Drittel der Frontalzusammenstöße könnten vermieden werden, wenn der Fahrer nur eine halbe Sekunde früher reagieren würde. Bei fast 50% der Kollisionsunfälle bremst der Fahrer gar nicht und in weiteren etwa 20% zu zaghaft.

Einige aktive Systeme zur Kollisionsfolgenminderung sind bereits in Serie. Bosch führt schrittweise drei aufeinander aufbauende Entwicklungsstufen im Markt ein. Erkennt das System *Predictive Brake Assist* (PBA), dass ein Vollbremswunsch sehr wahrscheinlich ist, bereitet es den Bremsassistenten und die Bremskreise vor. Ergänzend zu diesen Maßnahmen warnt das System *Predictive Collision Warning* (PCW) durch ein optisches oder akustisches Signal, einen kurzen, spürbaren Bremsruck oder ein kurzes Anziehen des Sicherheitsgurts rechtzeitig vor kritischen Verkehrssituationen. Aufbauend auf diesen ersten beiden Entwicklungsstufen, die bereits in Serie sind, löst das System *Predictive Emergency Braking* (PEB) unabhängig von der Bremsbetätigung des Fahrers im Notfall eine Verzögerung aus um die Unfallfolgenschwere zumindern.

Dieser Beitrag schließt an die dritte Entwicklungsstufe an und adressiert den nächsten Meilenstein in der Systemevolution. Es werden Systeme zur *vollständigen Kollisionsvermeidung* für eine Vielzahl von Situationen im Längsverkehr untersucht. Derartige Systeme greifen also entsprechend früh ein, so dass nicht nur die Folgen eines möglichen Aufpralls sondern die Unfälle an sich gänzlich vermieden werden. Die Herausforderungen an eine adäquate Funktionsdefinition sind dabei vielschichtig. Durch eine funktionsbedingte zeitliche Vorverlegung des Warn- und Eingriffszeitpunkts wachsen die Anforderungen an eine sichere Situationsanalyse. Durch ein mehrstufiges Bremskonzept kann eine rechtzeitige Warnung an den Fahrer sowie an ein nachfolgendes Fahrzeug realisiert werden. Auch der Wunsch des Fahrers muss frühzeitig erkannt und berücksichtigt werden. So darf etwa ein Fahrer, der einen dynamischen Spurwechsel hinter einem langsameren Fahrzeug beabsichtigt, nicht durch einen Systemeingriff ausgebremst werden. Fehlauslösungen können durch verschiedene Maßnahmen auf ein akzeptiertes und absicherbares Minimum reduziert werden. Die Analyse des *Wirkfelds* basiert zum einen auf einer umfangreichen Datenauswertung des Verkehrs auf Autobahnen und zum anderen auf einer detaillierten Auswertung der GIDAS-Unfalldatenbank. Der *Wirkgrad* verschiedener Funktionsausprägungen wird durch Simulation evaluiert.

Die Robert Bosch GmbH ist an der Forschungsinitiative *Adaptive und kooperative Technologien für den intelligenten Verkehr* (AKTIV) des BMWi im Projekt *Aktive Sicherheit* beteiligt und arbeitet auch im Rahmen des Teilprojekts *Aktive Gefahrenbremsung* gemeinsam mit den Projektpartnern an zukunftsweisenden Assistenzsystemen zur aktiven Kollisionsvermeidung.

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Longitudinal Collision Avoidance – Approaching the Vision of Accident-Free Driving

M. Stämpfle[1], W. Branz[2]

In recent years driver assistance systems have moved into the focus of intensive research activities in the automotive sector. Convenience and safety systems shall disburden the driver from his driving tasks in both routine jobs and critical situations. About 60% of all rear-end crashes and nearly one third of all frontal crashes could be avoided if drivers would react only half a second earlier. In nearly 50% of all collision accidents the driver does not apply the brakes at all and in further 20% the driver brakes too unassertively.

Some active systems for collision mitigation are already in market. Bosch introduces three consecutive systems into the market. The system *Predictive Brake Assist* (PBA) detects if a hard braking wish is likely, and then prepares the brake assist and the brake circuits. In addition, the system *Predictive Collision Warning* (PCW) warns in time with a visible or audible signal, a short noticeable brake jerk, or a short tightening of the safety belt in critical traffic situations. In addition to these first two system specifications, the system *Predictive Emergency Braking* (PEB) performs a deceleration to mitigate an imminent collision independently of the driver's intention to press the bake pedal.

This contribution succeeds the third system evolution specification and addresses the next milestone. Systems for *complete collision avoidance* in a variety of longitudinal traffic scenarios are investigated. Such systems warn and intervene quite early to not only mitigate imminent collisions but avoid them at all. The challenges for an adequate function definition hereby are manifold. For a function inherent preponing of the point in time of system warning or intervention the requirements for a safe situation interpretation increase. Using a multi-phase braking concept a driver's warning as well as a warning to the following vehicle can be given in sufficient time. The driver's intention has to be determined early enough and has to be added to the overall situation evaluation as well. For example, a driver intending to perform a dynamic lane change behind a slower vehicle must not be disturbed by a system intervention. Applying various measures the system's false alarm rate can be decreased to an acceptable and safe minimum. The analysis of the systems's *field of benefit* is based on both a profound data analysis of highway traffic and a detailed investigation of the GIDAS accident database. The system's *rate of benefit* of different system variants is evaluated by simulation.

The Robert Bosch GmbH participates in the national research initiative *Adaptive und kooperative Technologien für den intelligenten Verkehr* (AKTIV) of the German government department BMWi within the project *Aktive Sicherheit* and works in the subproject *Aktive Gefahrenbremsung* on future assistance systems for active collision avoidance.

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Robert Bosch GmbH, Corporate Research, Stuttgart

* since March 2008: Hochschule Esslingen

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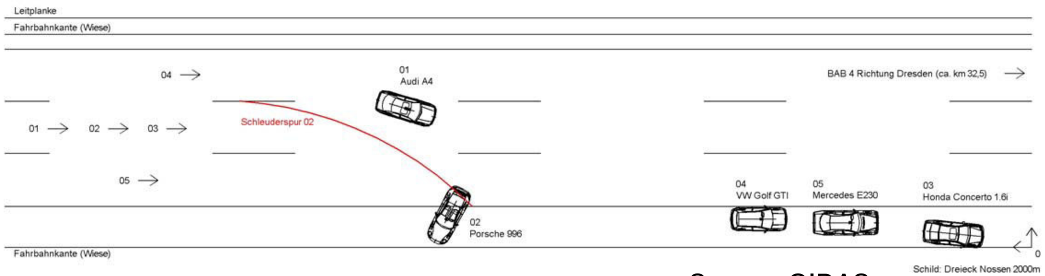
1. Motivation

A look into the Past

Source: Oil Company Promotional Postcard Picture 1912

1. Motivation

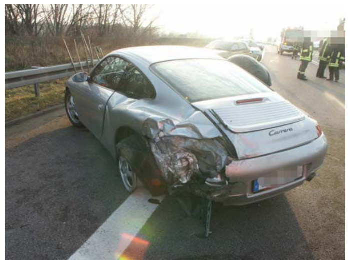
Example



Source: GIDAS

Most drivers react ...

- ➔ not at all
- ➔ unassertively
- ➔ too late
- ➔ in a wrong way



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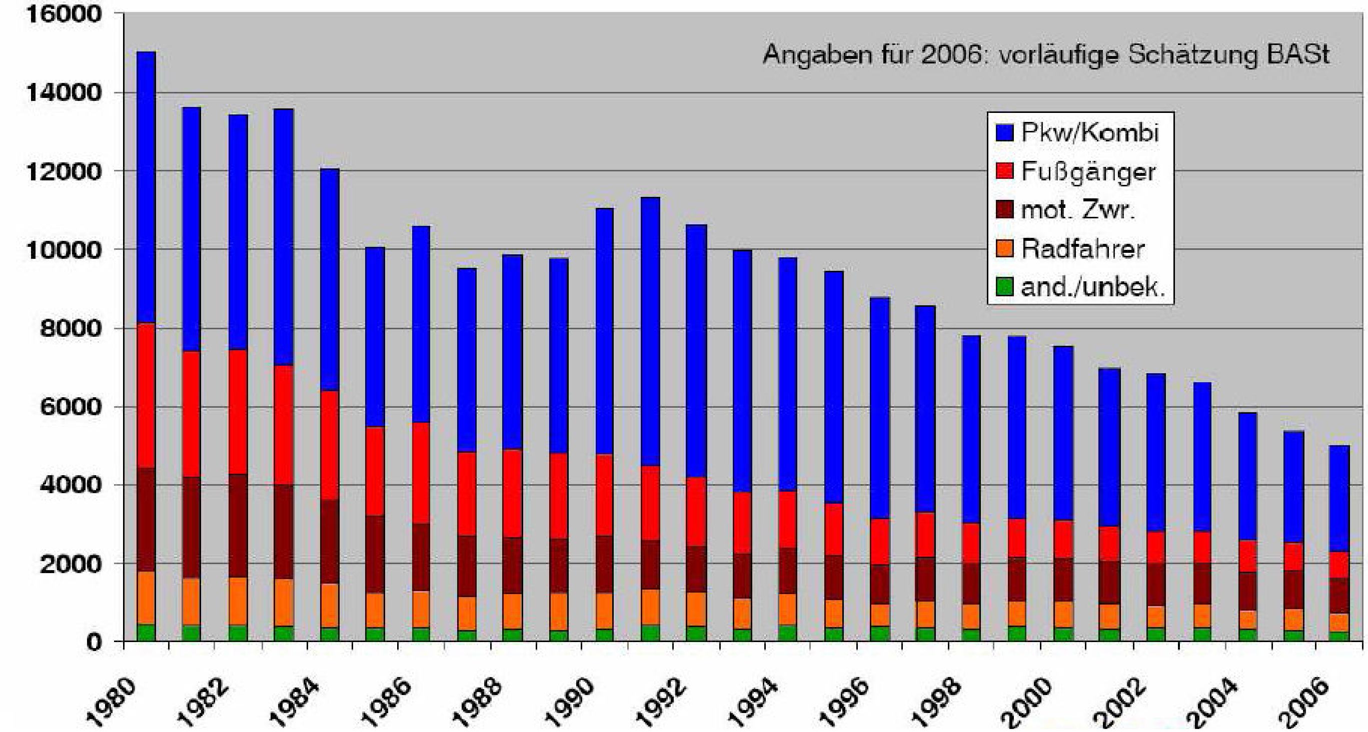
2. Accident Research: Statistics

Traffic Fatalities in Germany



Source: BASt

EU eSafety-Program: Halving the traffic fatalities from 2000 to 2010

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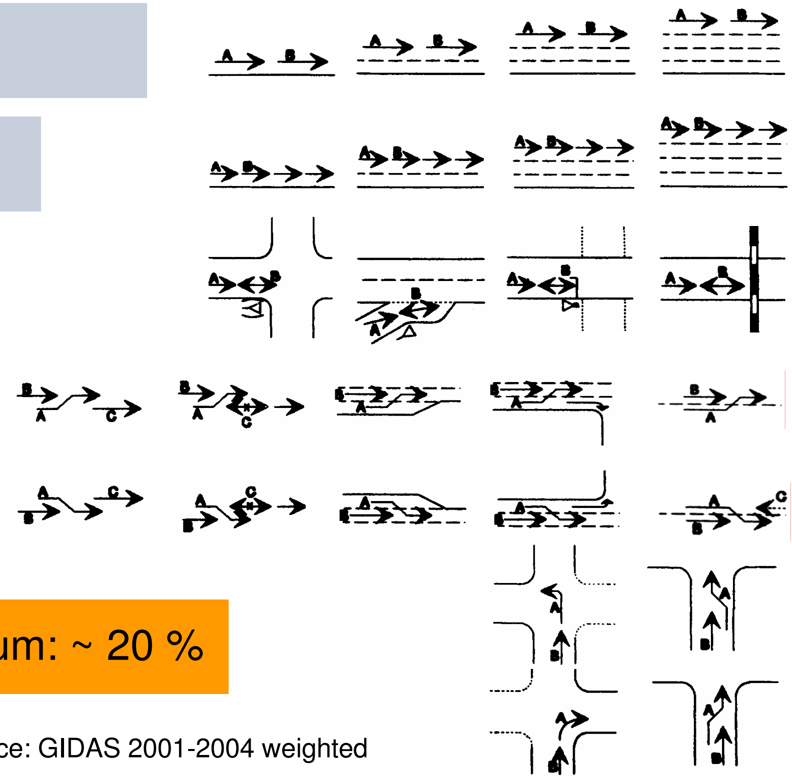
2. Accident Research: Field of Benefit

Longitudinal Collisions

5,2 %	Vehicle preceding
4,5 %	Vehicle in congestion
4,2 %	Vehicle waiting
2,6 %	Vehicle changing lanes to the left
1,4 %	Vehicle changing lanes to the right
1,4 %	Vehicle turning left
0,6 %	Vehicle turning right

GDV accident types



Sum: ~ 20 %

Source: GIDAS 2001-2004 weighted

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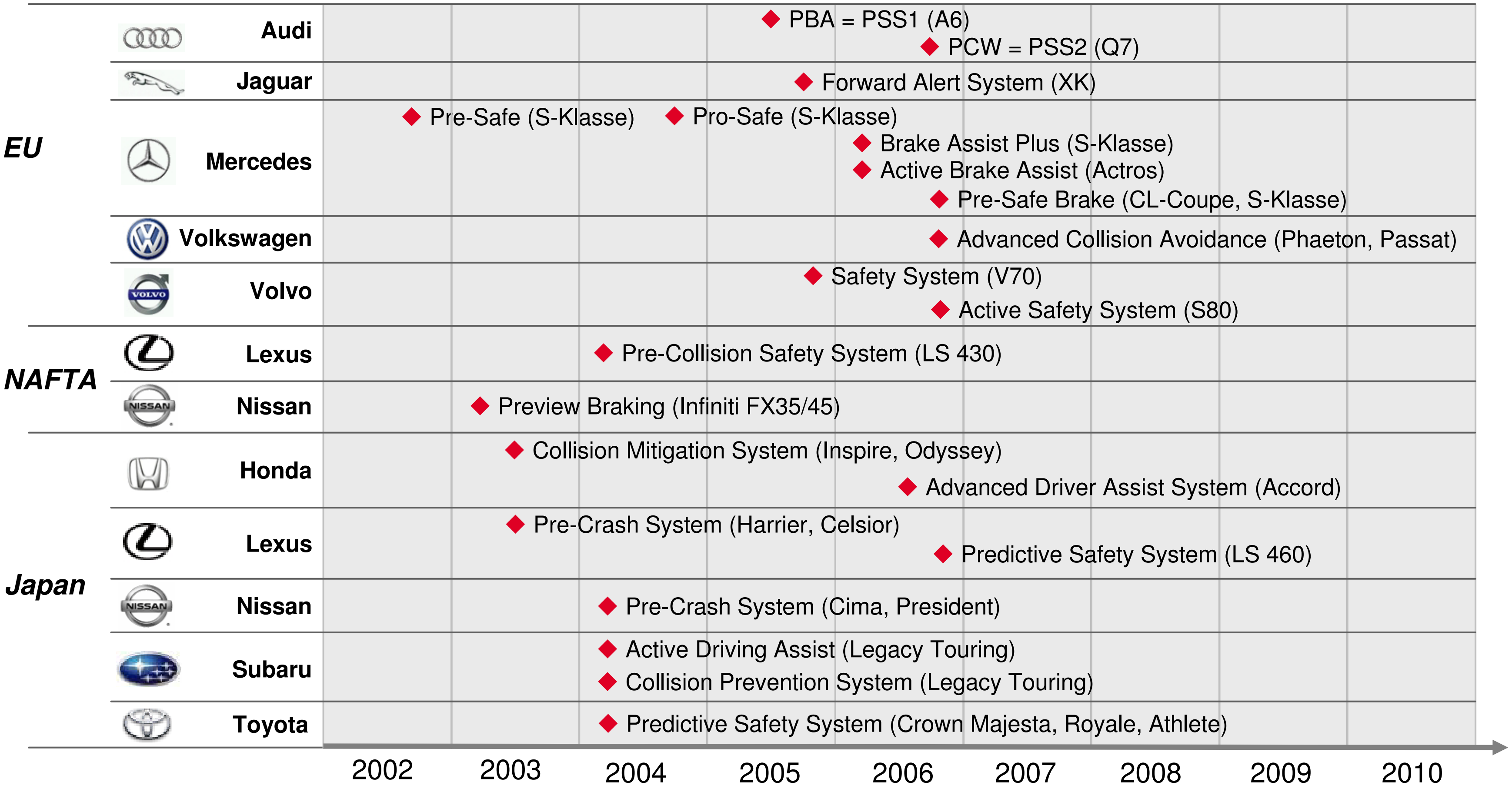
3. State of the Art: Active Safety Systems in Market



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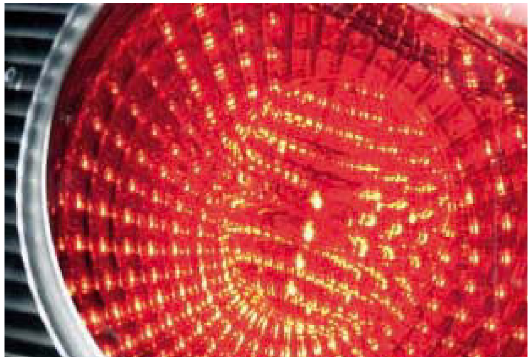
3. State of the Art: Bosch Predictive Safety Systems

- ***Predictive Brake Assist*** (PBA)
  detects if a braking request is likely and then prepares the brake assist and the brake circuits

- ***Predictive Collision Warning*** (PCW)
  warns with a brake jerk and a short tightening of the safety belt if a frontal crash is imminent



- ***Predictive Emergency Braking*** (PEB)
  performs an automatic braking in case of an emergency situation independent of any driver reaction

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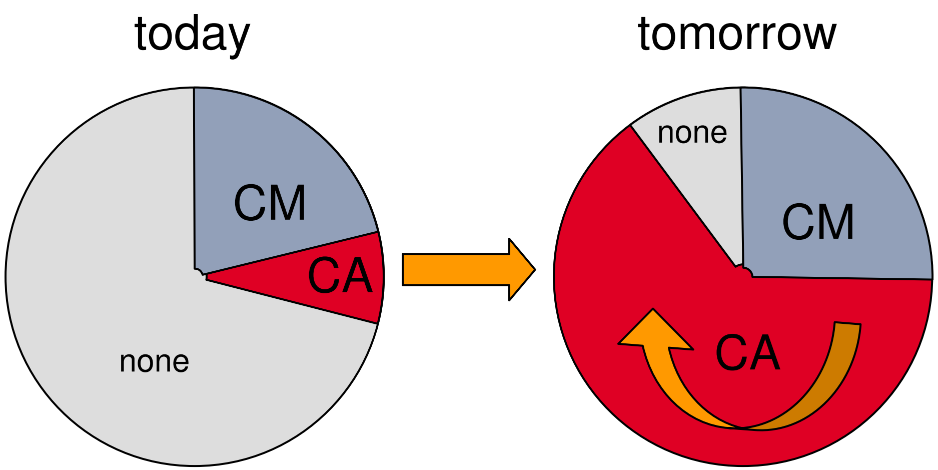
4. Collision Avoidance: The Next Milestone

System Performance and Field of Benefit



Problem: The Warning Dilemma

Collision Mitigation (CM)

- ➔ conservative
- ➔ low benefit
- ➔ late system action
- ➔ few false alarms

⇕

Collision Avoidance (CA)

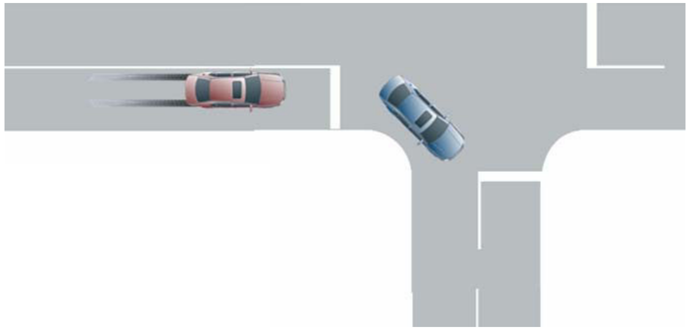
- ➔ progressive
- ➔ high benefit
- ➔ early system action
- ➔ risk of many false alarms

4. Collision Avoidance: Situation Criticality

Situation Criticality is NOT Equivalent to Time-to-Collision

- ***Example 1***
  highway, traffic jam end
  v_{rel} = 160 km/h, d_B = 99 m
  » ttc = 2.2 s but highly critical

- ***Example 2***
  urban area,
  preceding vehicle turning right
  v_{rel} = 20 km/h, d = 6 m
  » ttc = 1.1 s but uncritical



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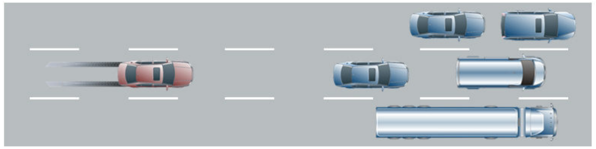
4. Collision Avoidance: Test Scenarios

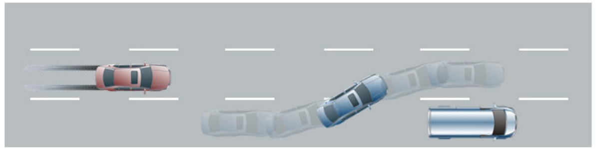
Positive and Negative Test Scenarios

- ***Scenario 1***
  Congestion end on multiple lanes
  » System is supposed to intervene



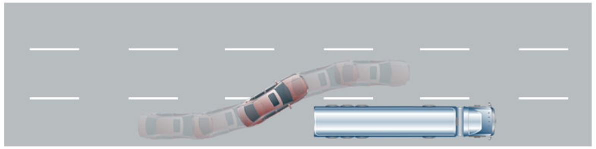
- ***Scenario 2***
  Slow vehicle cutting in
  » System is supposed to intervene

„Schweißperlen"



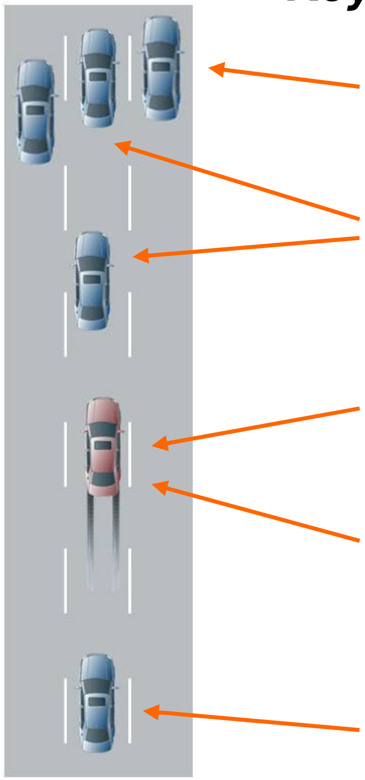
- ***Scenario 3***
  Dynamic lane change
  » System is supposed to remain silent

„Freude am dynamischen Spurwechsel"



4. Collision Avoidance: System Features

Key Features to Face the Collision Avoidance Challenge



- ➔ Use 2D multiple object situation interpretation
- ➔ Integrate information on preceding and pre-preceding vehicle (detection possible with Bosch LRR)
- ➔ Integrate driver intention
- ➔ Apply multi-phase information / warning / braking strategy
- ➔ Integrate information on following vehicle (to optimize between frontal and rear crash)

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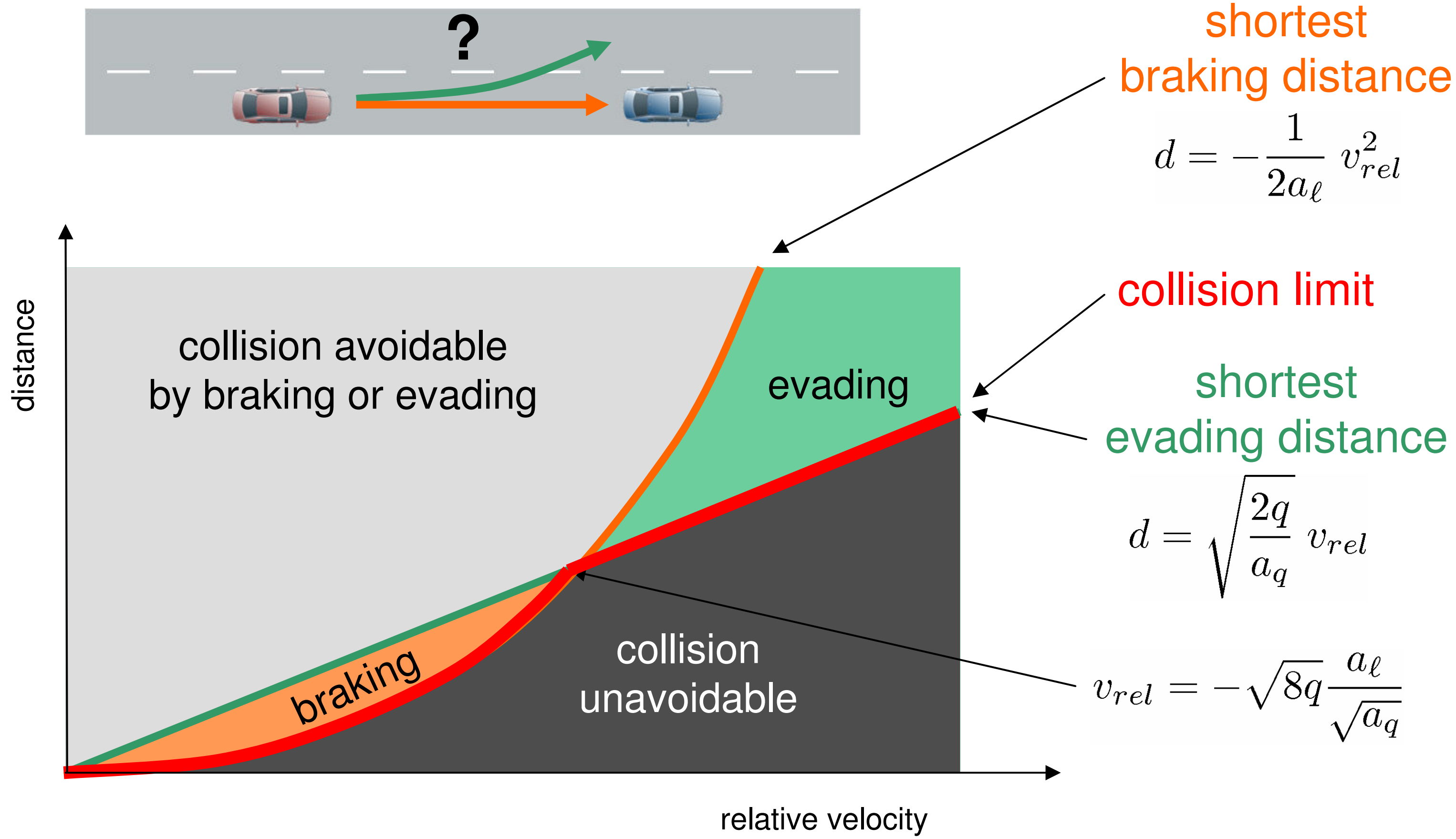
4. Collision Avoidance: Braking or Evading?



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4. Collision Avoidance: Situation Analysis

Situation Interpretation

➔ Model the objects‘ size and dynamics

➔ Integrate hypotheses based on surround information
- H1: *„Objects in standstill remain in standstill.“*
- H2: *„Objects changing lanes change into the own lane.“*
- H3: *„Crash barriers limit the evading space.“*

➔ Weight prediction trajectories

➔ Calculate criticality measure

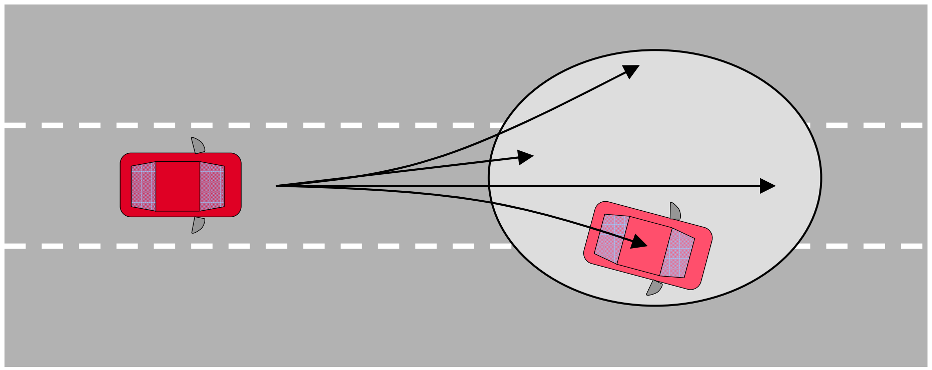
4. Collision Avoidance: Situation Prediction

Computation of All Possible Object Trajectories

Object's dynamics depend on ...

- ➔ vehicle size
- ➔ vehicle class
- ➔ interaction with other objects

A single prediction step Δt



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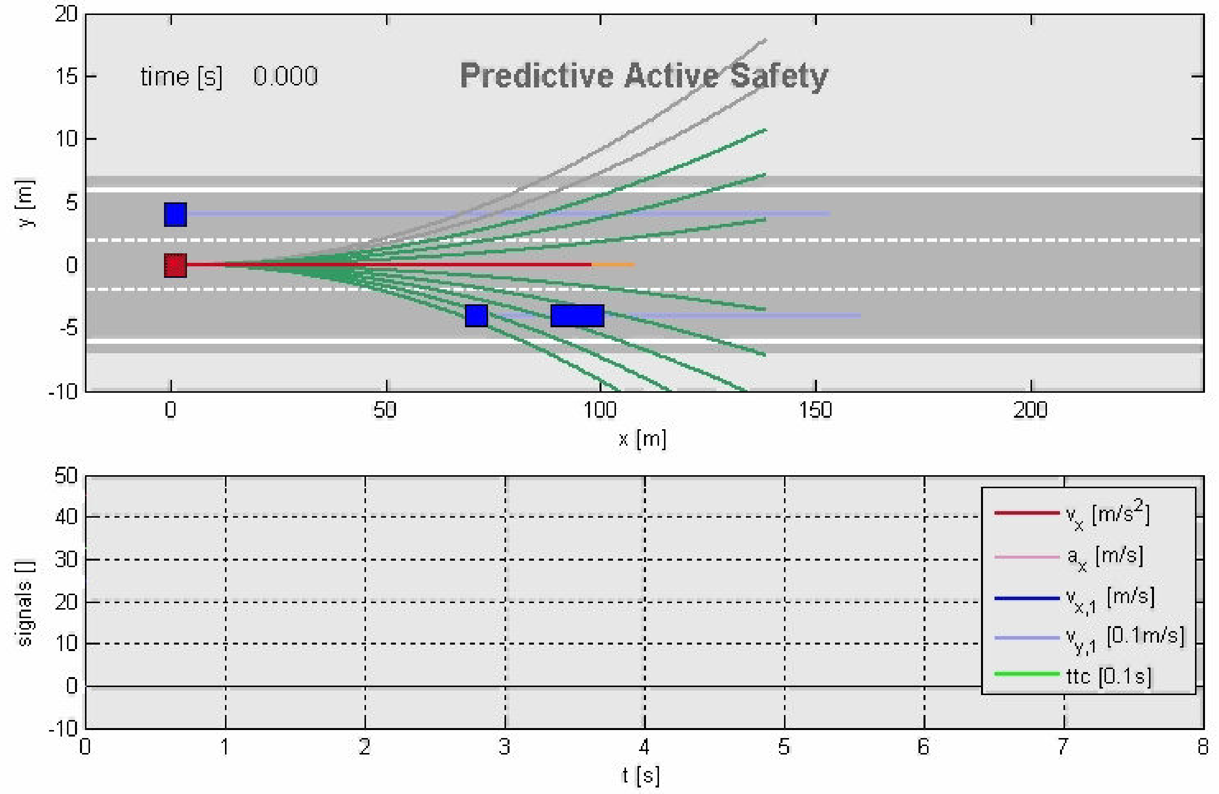
4. Collision Avoidance: Trajectory Method

Example



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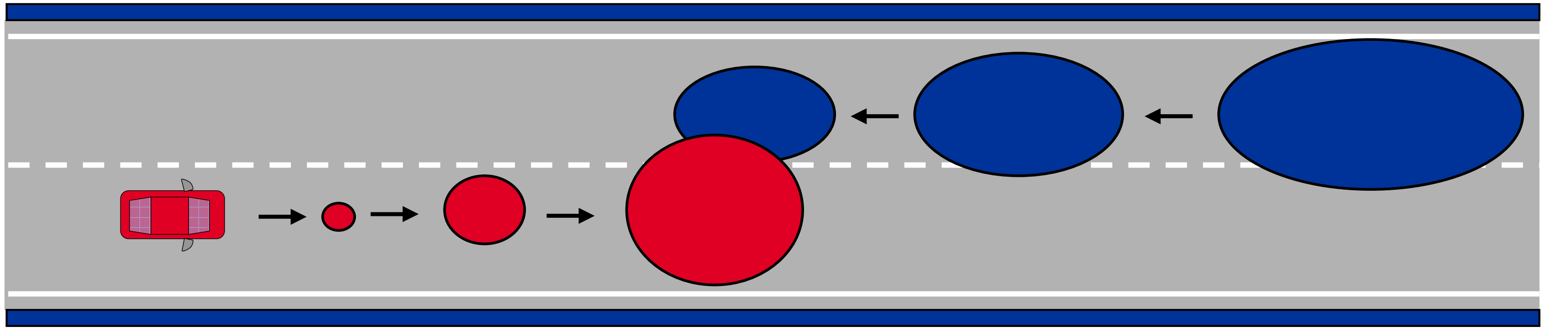
4. Collision Avoidance: Region Method

Sojourn Region G_A

Set of all points, where the vehicle‘s center of gravity can be located *without any collision*

Exclusion Region

Set of all points, where an expanded object is located *in any situation evolution case* (including its dimension and the subject‘s vehicle dimension)



Theorem

A collision is unavoidable

$$\iff \quad \forall f \in F \quad \exists O_k \quad \forall f_k \in F_k \quad \exists t \in I_P \; : \quad A(f(t)) \cap A_k(f_k(t)) \neq \emptyset$$

$$\iff \quad \exists t \in I_P \; : \quad G_A(t) = \emptyset$$

4. Collision Avoidance: Intervention Phases

➔ ***Phase 1***

Visual (!) information of the attentive driver about criticality

» Driver can disable system intervention

⬇ if situation still is evaluated as critical

➔ ***Phase 2***

Audible and haptic warning, partial braking (1 s)

» (Inattentive) driver and following vehicle are warned, collision velocity is reduced

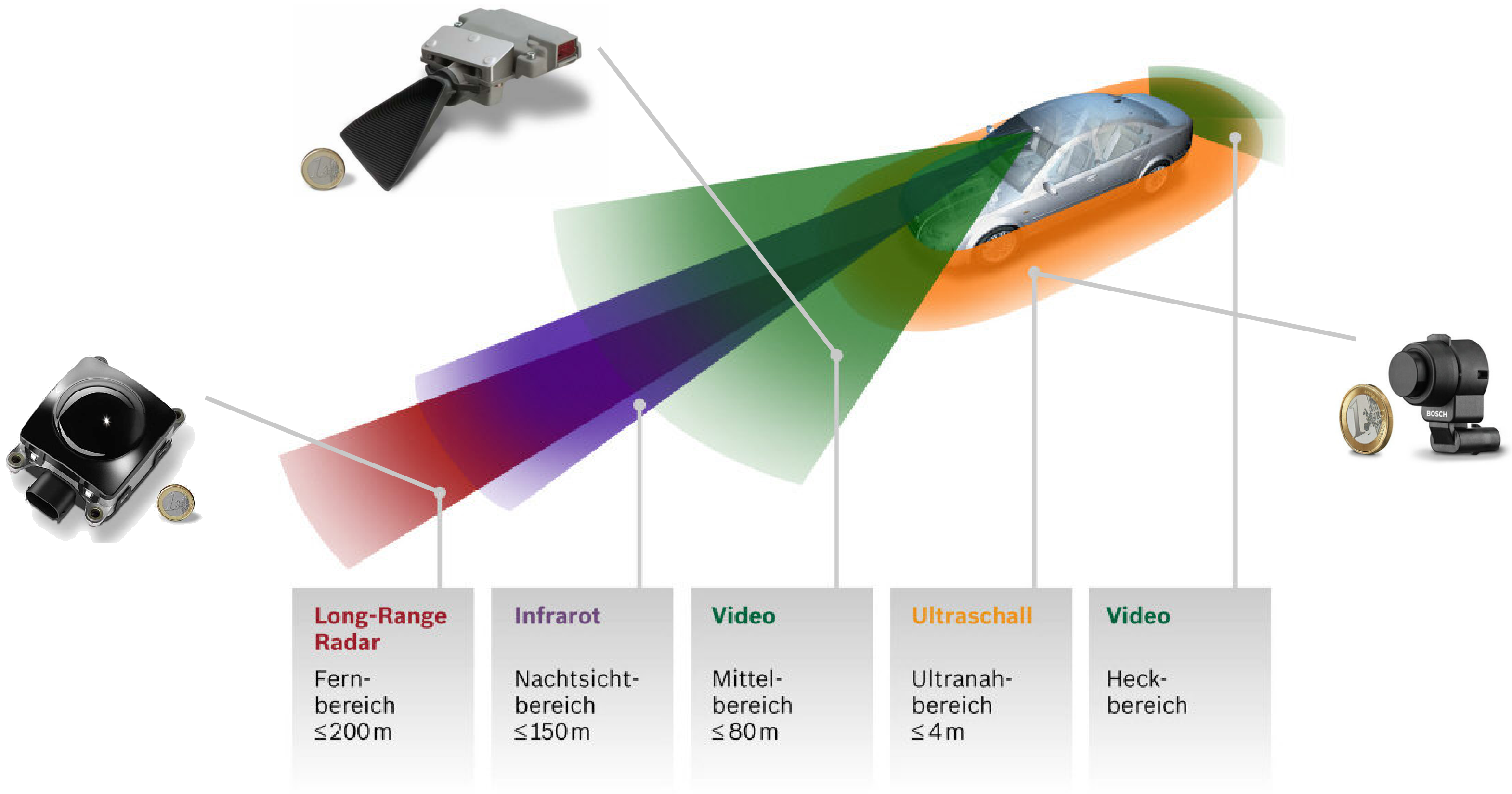
⬇ if situation still is evaluated as critical

➔ ***Phase 3***

Audible and haptic warning, full braking

» Driver is supported, collision velocity is reduced further

4. Collision Avoidance: Surround Sensing



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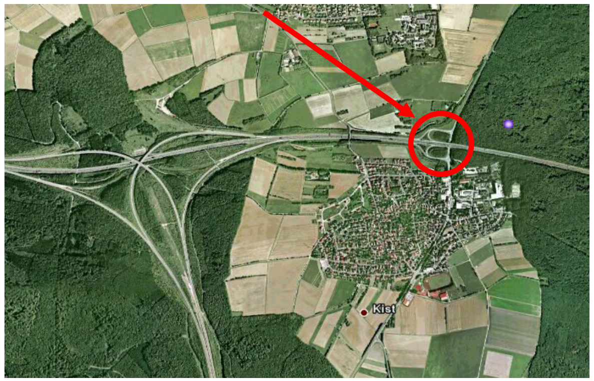
5. Results: Simulation with Induction Loop Data

Induction Loop Signals

- time, time gap
- lane
- vehicle velocity, length

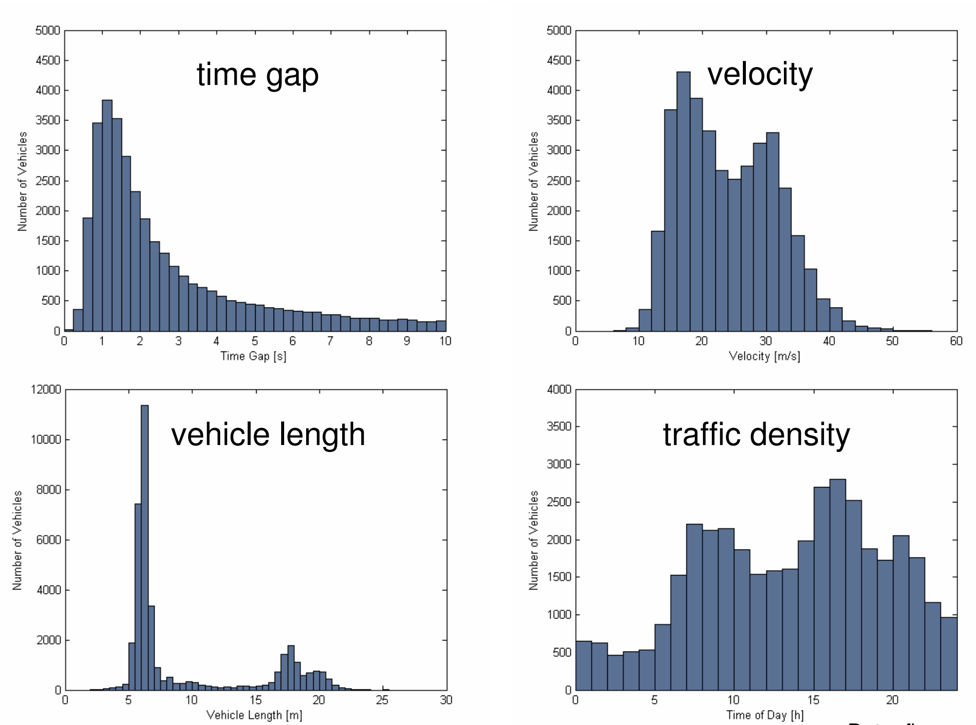
Example

A3, AS Würzburg/Kist



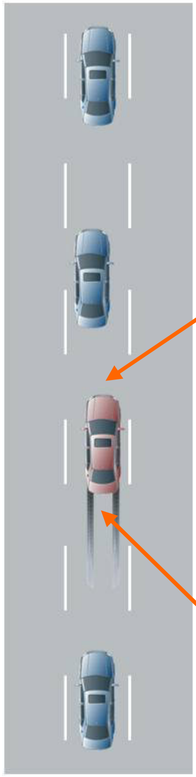
Source: Google Earth

Tue, 22.05.2001, 24h, 37806 vehicles, 2 lanes

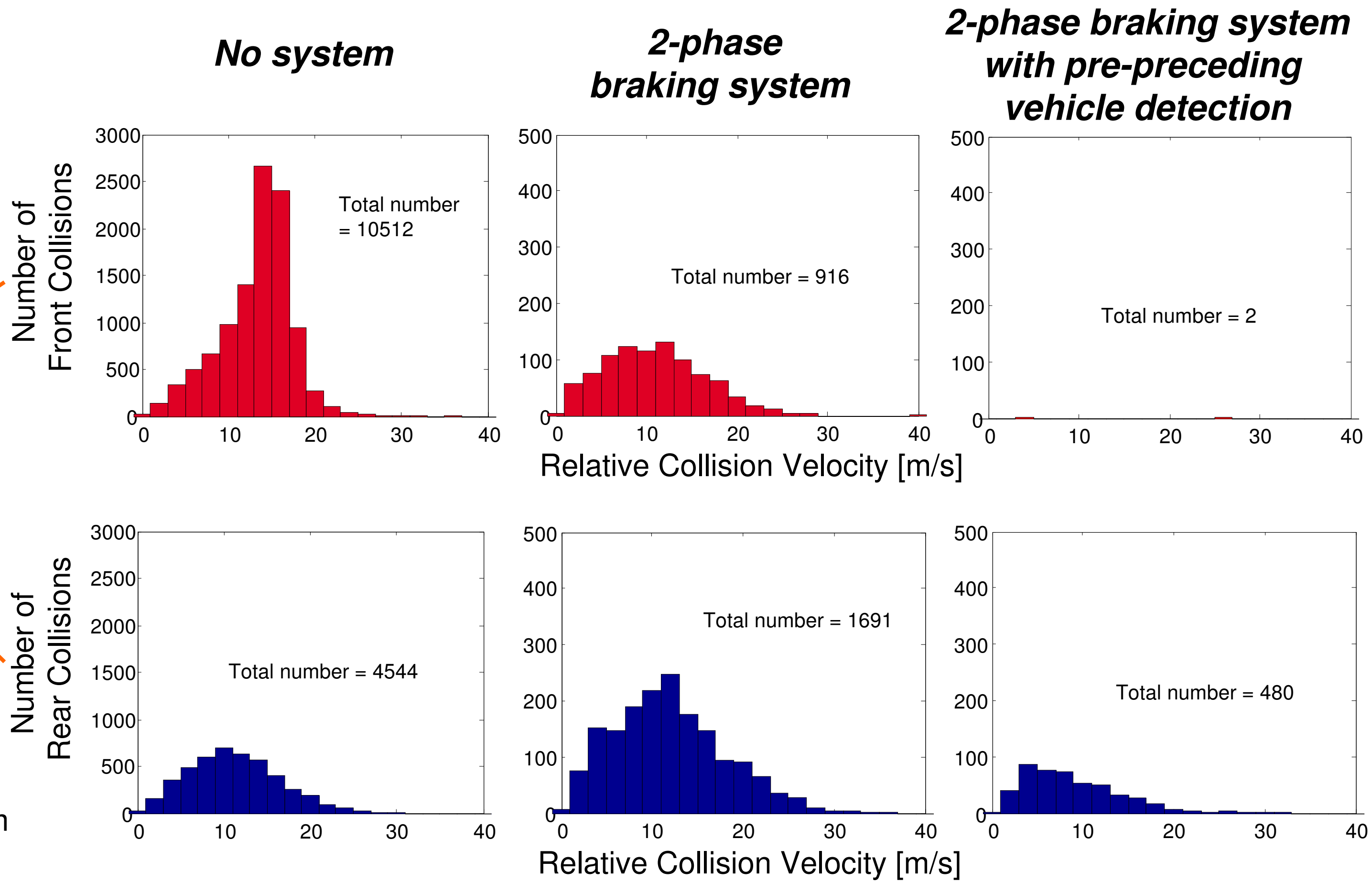


Data: fka

5. Results: Collision Simulation



Results based on 18477 scenarios from induction loop data



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6. Summary

- ➔ The warning dilemma is a key fact. Collision avoidance systems have to be tuned referring to this for maximum benefit
- ➔ The ratio between collision mitigation and collision avoidance can be improved only with multi-feature combined systems
- ➔ Situation analysis and interpretation plays a key role in the understanding of complex traffic scenarios
- ➔ Bosch
  - already offers systems (PBA,PCW) and improves them continuously
  - develops highly matured solutions for the near future (PEB)
  - works on the vision of totally accident-free longitudinal driving