



TECHNISCHE
UNIVERSITÄT
DARMSTADT



Adaptive Lichttechnische Systeme
und Visuelle Verarbeitung

PRINCIPLES OF SYMBOL DESIGN AND BRIGHTNESS CONFIGURATION FOR DISPLAY AND SIGNALLING UNITS IN THE CONTEXT OF AV- COMMUNICATION

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GG MQ 131

MARKET POTENTIAL AV

2019 - 2032

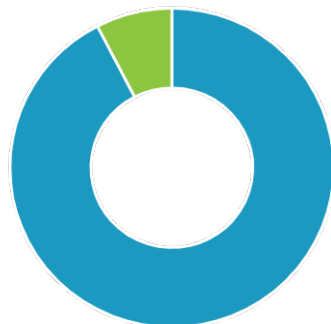
GLOBAL MARKET OVERVIEW FOR **AUTONOMOUS CARS**

- 2023 Value: 1.88 billion USD
- 2024 Value: 2.30 billion USD
- 2032 Value: 38.78 billion USD



Factor of 17 between
2024 and 2032

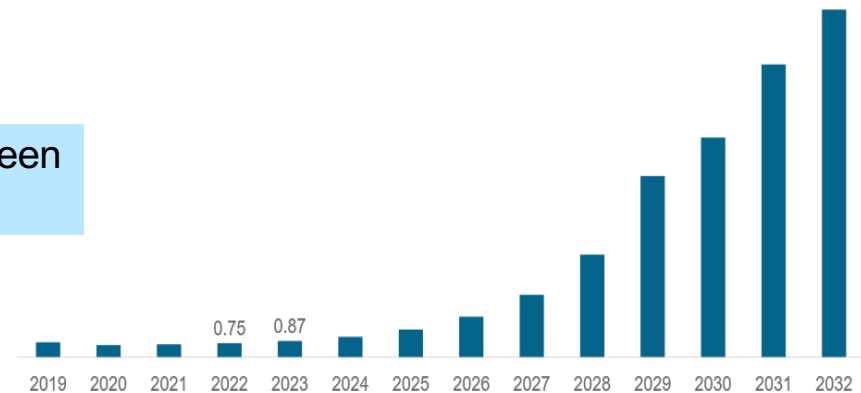
Global Autonomous Cars Market Share, By Vehicle Type, 2023



Passenger Cars
Commercial Vehicles

www.fortunebusinessinsights.com

Asia Pacific Autonomous Cars Market Size, 2019-2032 (USD Billion)



www.fortunebusinessinsights.com

→ „... Autonomous cars are equipped with communication technologies that enable them to interact with other vehicles (V2V communication) and infrastructure (V2I communication), improving safety and efficiency on the road. ...“

LIGHT SIGNALLING AND LIGHTING REQUIREMENTS FOR ADS VEHICLES

Motivation:

→ National authorities recognize the need for automated driving systems in traffic situation

- Federal Ministry of Transport and Digital Infrastructure (Germany)
 - "...so that **critical situations do not arise** in the first place...the entire spectrum of technical possibilities...**signals for vulnerable persons**...should be used and continuously further developed..."
 - "...it must be **clearly distinguishable whether a driverless system is being used or whether a driver retains responsibility** and has the ability to ..."
- SAEC (Society of Automotive Engineers of China)
 - "...to establish technical standards, including a **common language for communication** between vehicles and regulatory guidelines."
- US National Highway Traffic Safety Administration
 - "...the **surroundings of the vehicle**, including pedestrians, cyclists and other vehicles, signaling their intentions..."



AGENDA

AV communication

Symbol design:

- ISO 23049 – 2018
- ISO 23735 – 2025
- ISO 2575 – 2021
- PhD thesis M. Baumann
- PhD thesis J. Reschke
- Paper Peier



Brightness configuration:

- Paper Rosenhahn

ISO 23049 - 2018

PRINCIPLES OF SYMBOL DESIGN



1 Introduction

- **ADS must clearly communicate intentions and behavior**
 - Visual signals are preferred, as interactions with vehicles are predominantly perceived visually
 - **Standardization and comprehensibility are required:**
 - industry-wide, cross-vehicle designs to avoid confusion.
 - **Design recommendations:**
 - A small number of clearly distinguishable visual signals
 - Conspicuous, but not distracting
- **Goal:** increased safety and acceptance through consistent visual communication

ISO 23049 - 2018

PRINCIPLES OF SYMBOL DESIGN

2 potential AV communication

1. Vehicle state

- Indicates physical parameters (e.g., speed, braking).
- The benefit of additional explicit displays has not yet been sufficiently investigated

2. Driving mode

- Indicates whether the vehicle is manually driven (MV) or automated (AV) → important for other road users.

3. Perception & detection

- Displays what the vehicle “sees” or has detected (e.g., pedestrians, cyclists).
- **Addressability** – who is the signal intended for? → risk of misinterpretation.

4. Instructions

- Signals such as “safe to cross now” are **not recommended**:
 - risk of incorrect interpretation
 - violation of traffic regulations, as vehicles are not permitted to give instructions

6. Intention

- Central approach: communicating planned actions (“I am stopping,” “I yield”).
- Implementation via light patterns, symbols, or text.

ISO 23049 - 2018

PRINCIPLES OF SYMBOL DESIGN



3 Format of the AV communication

- **Distance and speed perception are crucial for pedestrian decision-making (especially for children)**
- Visual displays on AVs are evaluated as *helpful and desirable*
→ visual systems facilitate pedestrians' understanding of vehicle intent and driving behavior
- **Communication modalities**
 - **Visual signals:** suitable for frequent communication → high specificity and clarity, but require attention
- **Design principles for AV interfaces**
 - No confusion with conventional vehicle displays
 - Signals should be unambiguous, clear, and not overwhelming
 - Pedestrians require **clear and intuitive visual cues** - consistent and not overloaded
 - **Standardized designs** prevent confusion and increase road safety

ISO 23735 - 2025

PRINCIPLES OF SYMBOL DESIGN

4 Development of a communication language

Initial situation & communication problem of automated vehicles

Objective:

- A shared situational understanding between AVs and VRUs
→ safe and smooth interaction in mixed traffic.
- **Key challenges**
 - Loss of human non-verbal communication (eye contact, gestures)
 - Diverging perceptions → misinterpretations and conflicts
 - Misunderstandings are among the most common causes of pedestrian accidents
- **Role of non-verbal communication**
 - Particularly relevant at **low speeds** and in **ambiguous situations**
 - At higher speeds, vehicle motion becomes the dominant cue
 - Standardized driving behavior alone is insufficient
- **Consequence**
→ Need for **new, explicit forms of communication (eHMI)**

ISO 23735 - 2025

PRINCIPLES OF SYMBOL DESIGN

4 Development of a communication language

Communication channels & effects on other road users

- **Implicit communication (primary form in road traffic)**
 - Information transfer through driving behavior rather than symbols
 - speed, distance, acceleration.
 - **Advantages:** intuitive, safety-relevant, algorithmically implementable.
 - **Risk:** inconsistency between vehicle motion and light signals → confusion.
- **Explicit communication**
 - eHMIs to clarify vehicle **state and intention**.
 - Effective only **in combination with implicit signals**.
 - **Goal:** intuitive and culturally independent understanding.
- **Acceptance & perception**
 - Acceptance depends on: perceived safety, trust, and social norms.
 - Signals must be **conspicuous but not overstimulating**.
 - Display location, lighting conditions, and gaze direction are critical.
 - Overly complex signals → slower reactions; overtrust must be avoided.

ISO 23735 - 2025

PRINCIPLES OF SYMBOL DESIGN

4 Development of a communication language

Development of a communication language for AV

Typical interaction situations

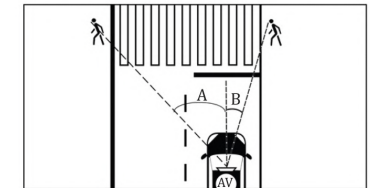
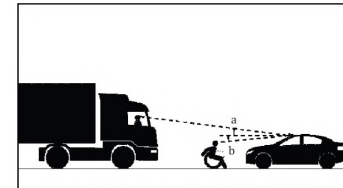
- **Driving:** AV is recognizable as automated.
- **Decelerating:** desire for safety confirmation.
- **Stopping:** replacement for eye contact as a trust signal.

Potential communication building blocks

- **Driving mode:** AV state is recognizable (e.g., marker light).
- **“I see you”:** position-based detection without granting right of way.
- **Intent to stop & yield:** early, clear communication of intent (40–60 m).
- **Stop & intend to yield:** vehicle at standstill with yielding intention.
- **Wait:** patient waiting as a substitute for eye contact.
- **Intent to drive:** short, clear departure announcement.

Core message

- A **multimodal, clearly structured communication language** is required.
- Combination of **vehicle motion, system state, and explicit signals**.
- **Safety consistency** between eHMI and driving behavior is critical.



Communication aims

ISO 2575 - 2021

PRINCIPLES OF SYMBOL DESIGN

1

Symbols for automotive

Symbol No.	Annex ^a																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
01								P										OFF
02								R										AUTO
03								N										ON
04								D										START
05																		STOP
06																		ECO
07																		READY
08																		MAX
09																		MIN

Example symbol design

PHD-THESIS M. BAUMANN

PRINCIPLES OF SYMBOL DESIGN

1

Methodology

Development of the eHMI system

- Construction of an RGB LED display for the presentation of **dynamic symbols**.
- **Objective:** flexible representation of communication signals using light and motion.

Variations of:

- Light color and symbol types (e.g., arrows, hands, pictograms)
- **Goal:** investigation of perception and effects under controlled conditions.

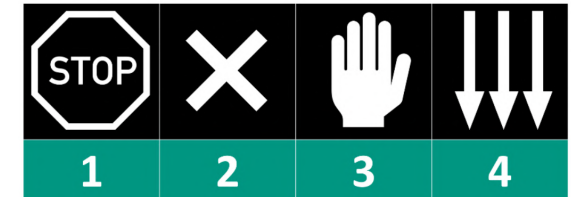
Research focus of the eHMI system

Symbol projection:

- 26 symbols tested, categorized into **STOP**, **GO**, and **Random**
(n = 64 participants, including children)

Results

- **STOP symbols** were recognized very reliably
- Symbols with a **clear motion context** (e.g., arrows, hands) were particularly well understood
- **Children** were also able to interpret light signals accurately
- Recognizability depends on **symbol size and ambient lighting**
→ optimal symbol size is context-dependent



final symbols

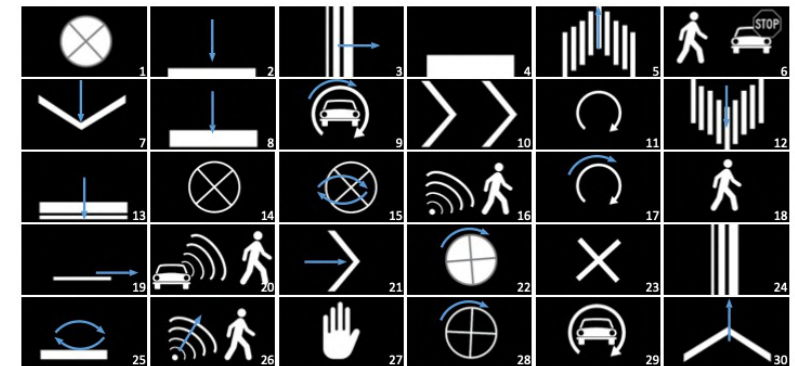
PHD THESIS J. RESCHKE

PRINCIPLES OF SYMBOL DESIGN

1

Light-based vehicle-pedestrian communication

- Study evaluation:
 - Objective: Investigation of symbols/dynamics for comprehensibility
- Structure
 - White on dark
 - Static & dynamic
- Implementation (two front displays (30 cm x 23 cm))
 - Part 1: 10 m distance; free interpretation; 10 sec.
 - Part 2: 10 m distance; specifications
 - Part 3: Intuitiveness, recognizability, communication
 - Part 4: Yes/no assignment of meaning (10 m distance)



Predefined symbols

PHD THESIS J. RESCHKE

PRINCIPLES OF SYMBOL DESIGN

1

Light-based vehicle-pedestrian communication

- Study: Intuitiveness, symbols, and dynamics
 - According to ISO 9186-1989: min. 67% correct interpretation = understandable and intuitive
 - Only one symbol (stop hand fulfills value)
- Results:
 - Intuitive design and learning are decisive
 - Only three symbols for further investigation



Symbols for further
investigation

ISAL - PAPER – PEIER

PRINCIPLES OF SYMBOL DESIGN

1 Symbol study ALSVV

- Background:
 - VR is limited in brightness, contrast, and realism (previous ALSVV studies)
 - Objective: How can the results of previous studies be translated into reality?
- Technical implementation:
 - Opel Grandland with RGBW display in radiator grille → display of various symbols
 - Not all symbols are always visible from different angles



ISAL Showacar 2023

ISAL - PAPER – PEIER

PRINCIPLES OF SYMBOL DESIGN

1

Symbol study ALSVV

Study concept:

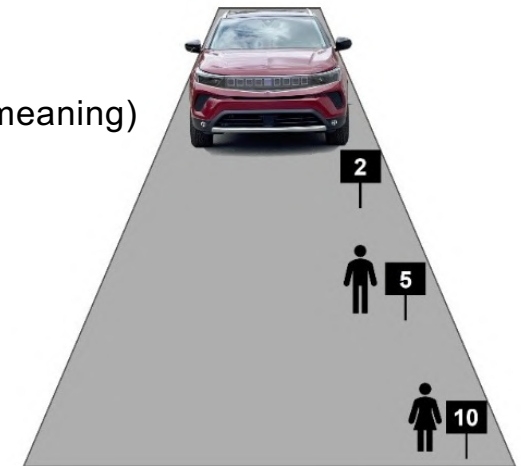
- Investigation of legibility and comprehensibility (2m - 20m)
- **Test** subjects evaluate (recognizability, symbol brightness & understanding of meaning)

Study:

- Symbols from studies by Singer et al. (stop hand, P, or filled square)
- **Positive** Positive and negative contrast
- **Randomized** symbol sizes in 5 test steps (distances)
 - Symbol sizes: 4 cm to 11.5 cm
 - Test steps: 2 m, 5 m, 7.5 m, 10 m, and 20 m

Questions:

- „Which symbol can be seen?” or “The symbol is...” (bright, dark, correct)
- „How well can the symbol be recognized?” or “What is the meaning of the symbol?”



Study symbol size ALSVV

ISAL - PAPER – PEIER

PRINCIPLES OF SYMBOL DESIGN

1

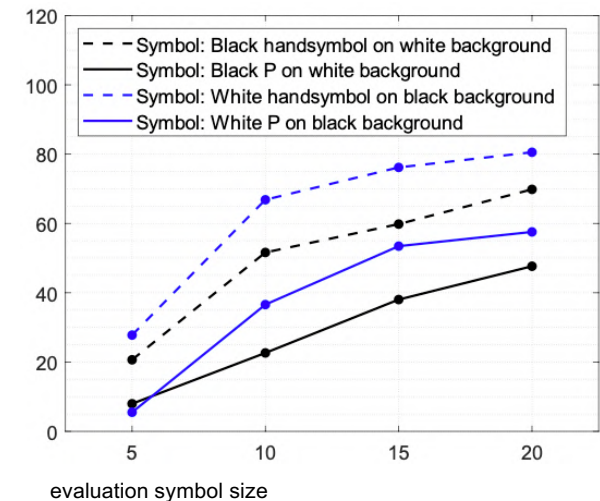
Symbol study ALSVV

Conclusion:

- Questions:
 - **Define minimum symbol size**
 - Check comprehensibility of symbols

Results:

- Symbol size increases with distance
- Min. 48 mm symbol size
- White on black preferred (positive contrast)
- Symbol comprehensibility:
 - P was correctly recognized as a symbol
 - Stop hand was correctly interpreted by all
- Symbols not visible from every angle



ISAL - PAPER – ROSENHAHN

BRIGHTNESS CONFIGURATION FOR DISPLAY

1 Brightness study Rosenhahn

Study design:

- Two physical display prototypes
- **Measurements** in real-world environments:
 - **Night** (low beam)
 - **Day** (direct sunlight)
- **Test distance:** 5 m, 10 m, and 30 m
- **Test subjects** (n = 6) subjectively evaluated the brightness and readability of content (rating: optimal, too bright, too dark)



Display 1: L = 2254 cd/m²



Display 2: L = 9864 cd/m²

ISAL - PAPER – ROSENHAHN

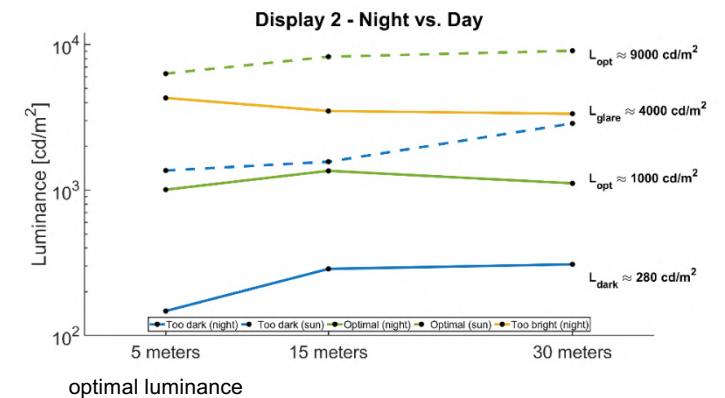
BRIGHTNESS CONFIGURATION FOR DISPLAY

1 Brightness study Rosenhahn

Results:

- Luminance:
- **At night:**
 - **Optimal:** approx. 1,000 cd/m²
 - **“Too dark“:** approx. 280 cd/m²
 - **„Too bright“:** approx. 4,000 cd/m²
- **During the day:**
 - **Optimal:** 9000 cd/m²

→ **Adaptive display with day/night settings**



CONCLUSION

PRINCIPLES OF SYMBOL DESIGN & BRIGHTNESS CONFIGURATION



Symbol design:

- ISO standards provide recommendations on what future communication could look like.
- No clear symbols defined.
 - **Research questions:**
 - **RQ1:** Which symbols are unambiguous?
 - **RQ2:** What could future communication look like in concrete terms?
 - **RQ3:** What could be the optimum symbol size for the different distances?

Brightness configuration:

- Adaptive system – different conditions
 - **Research questions:**
 - **RQ1:** Which brightness for which condition?
 - **RQ2:** Do we need different brightness or resolution level for different distances?

SHOWCAR STELLANTIS

PRINCIPLES OF SYMBOL DESIGN & BRIGHTNESS CONFIGURATION

exampe use-case: default



exampe use-case: car will stop



exampe use-case: car will go



exampe use-case: warning



**THANK YOU VERY MUCH FOR
YOUR ATTENTION!**