Continental
The Future in Motion

Using STPA in Compliance with ISO26262

for developing a Safe Architecture for Fully Automated Vehicles

Automotive-Safety and Security 2017, Mai 31th 2017
Asim Abdulkhaleq, Daniel Lammering

University of Stuttgart
Germany

Using STPA in Compliance with ISO26262

Agenda

1 Motivation – Automated Driving

2 Operational Safety - Roadworthiness

3 HARA & ISO26262 Lifecycle

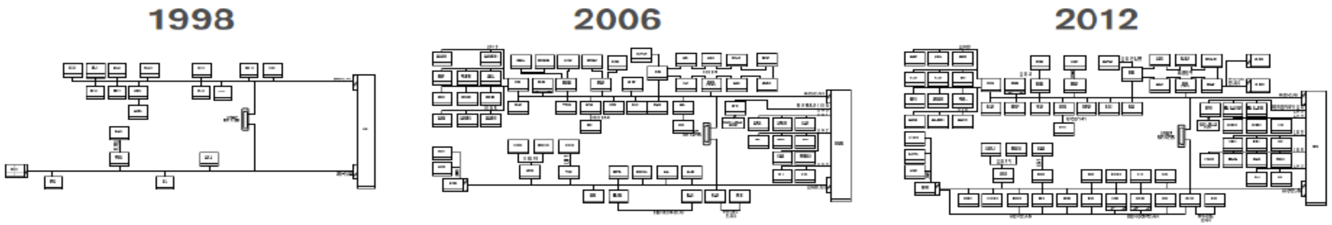
4 Introduction to STAMP/STPA

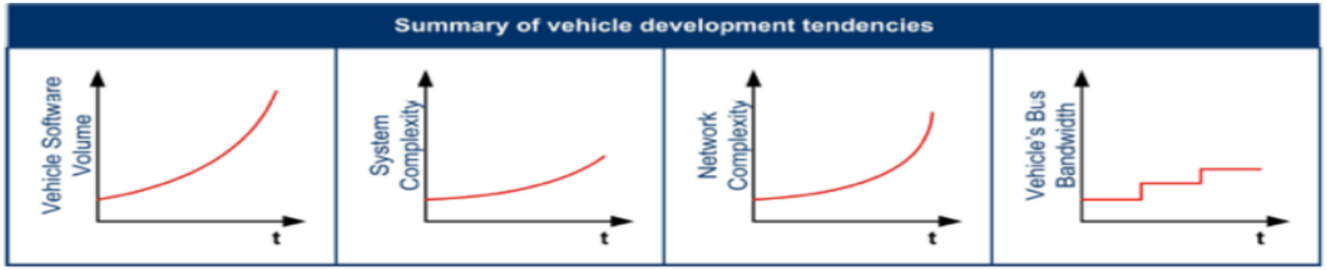
5 STPA in ISO 26262 & Results

6 Conclusion & Future Work

Motivation

Architecture trend analysis





Source: WRC Market Report E/E Architecture 2013

Continuously growing complexity, number of functions and networked ECUs results in:

- Requirements for new technologies and modules
- Major redesign of E/E architecture at most worldwide OEMs
- New design criteria required for future E/E architectures

Motivation

Safety-driven Design

Why paradigm change?

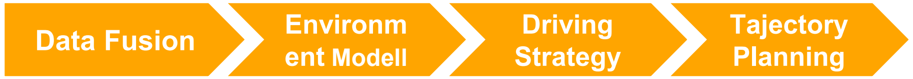
- Old approaches becoming less effective (FTA / FMEA focus on component failures)
- New causes of accidents not handled (interaction accidents / complex software errors)

Component reliability
(component failures)

Systems thinking (holistic View)

e.g. **Automated Driving**

- Many parallel interactions between components!



- Accidents happen with no component failures (Component Interaction Accidents)
- Complex, Software-intensive Systems
  (New Hazards: System functional **but** Process/Event is unsafe)

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Operational Safety in Automotive Domain
Architecture Challenges

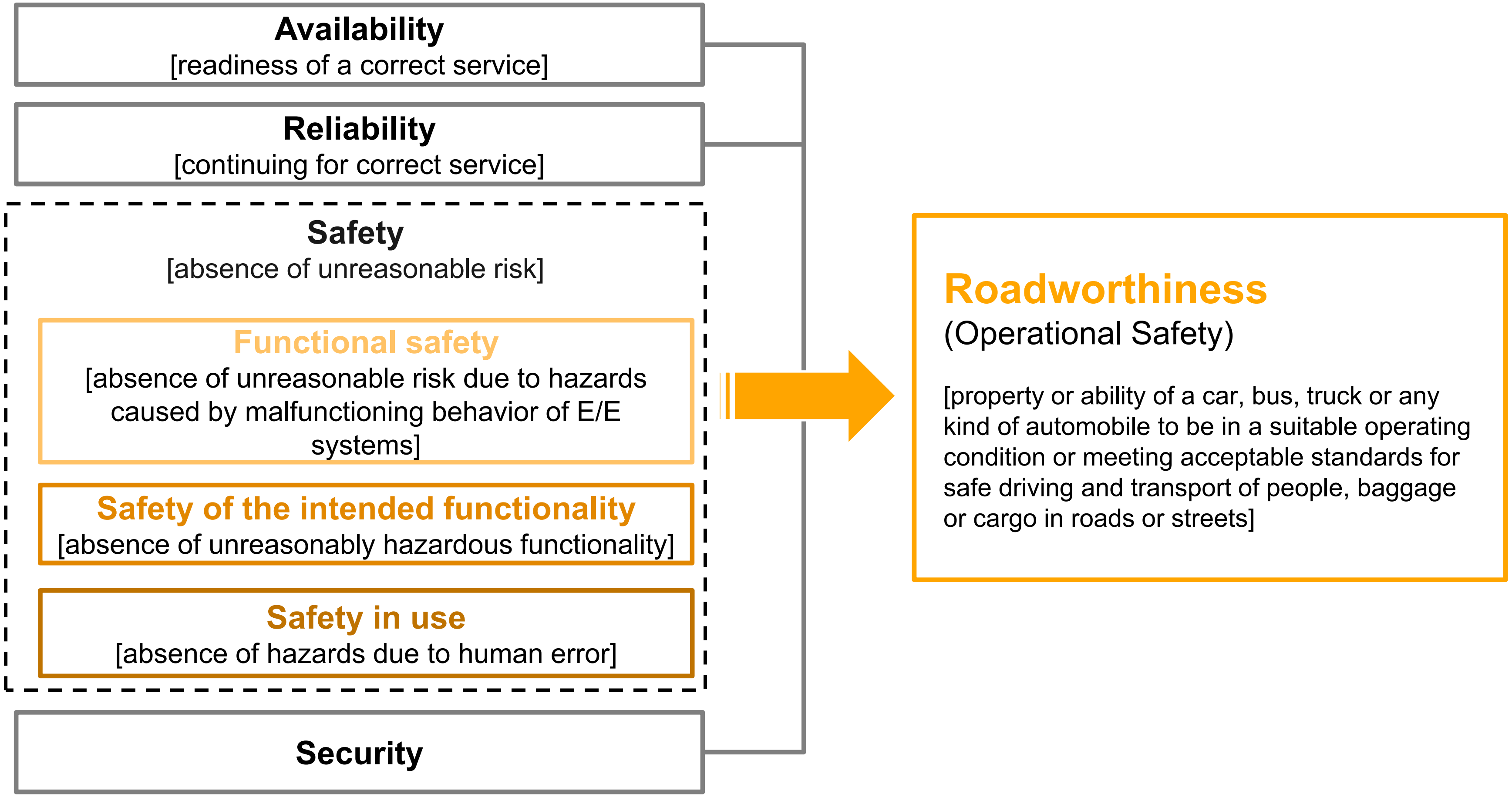
Vehicle E/E – Architecture needs a holistic approach

e.g Service Oriented Architectures, Cloud services, Update over the air

- Safety & system architecture/ interface must be **defined together**
- Safety, reliability and availability has important implications for **analyzing**
- **Fail Operational Behavior** – fail silent may not be suitable any longer

Operational Safety in Automotive Domain

Ensuring a high level of operational safety



Availability
[readiness of a correct service]

Reliability
[continuing for correct service]

Safety
[absence of unreasonable risk]

Functional safety
[absence of unreasonable risk due to hazards caused by malfunctioning behavior of E/E systems]

Safety of the intended functionality
[absence of unreasonably hazardous functionality]

Safety in use
[absence of hazards due to human error]

Security

Roadworthiness
(Operational Safety)

[property or ability of a car, bus, truck or any kind of automobile to be in a suitable operating condition or meeting acceptable standards for safe driving and transport of people, baggage or cargo in roads or streets]

[Abdulkhaleq, Lammering et al., 2016]

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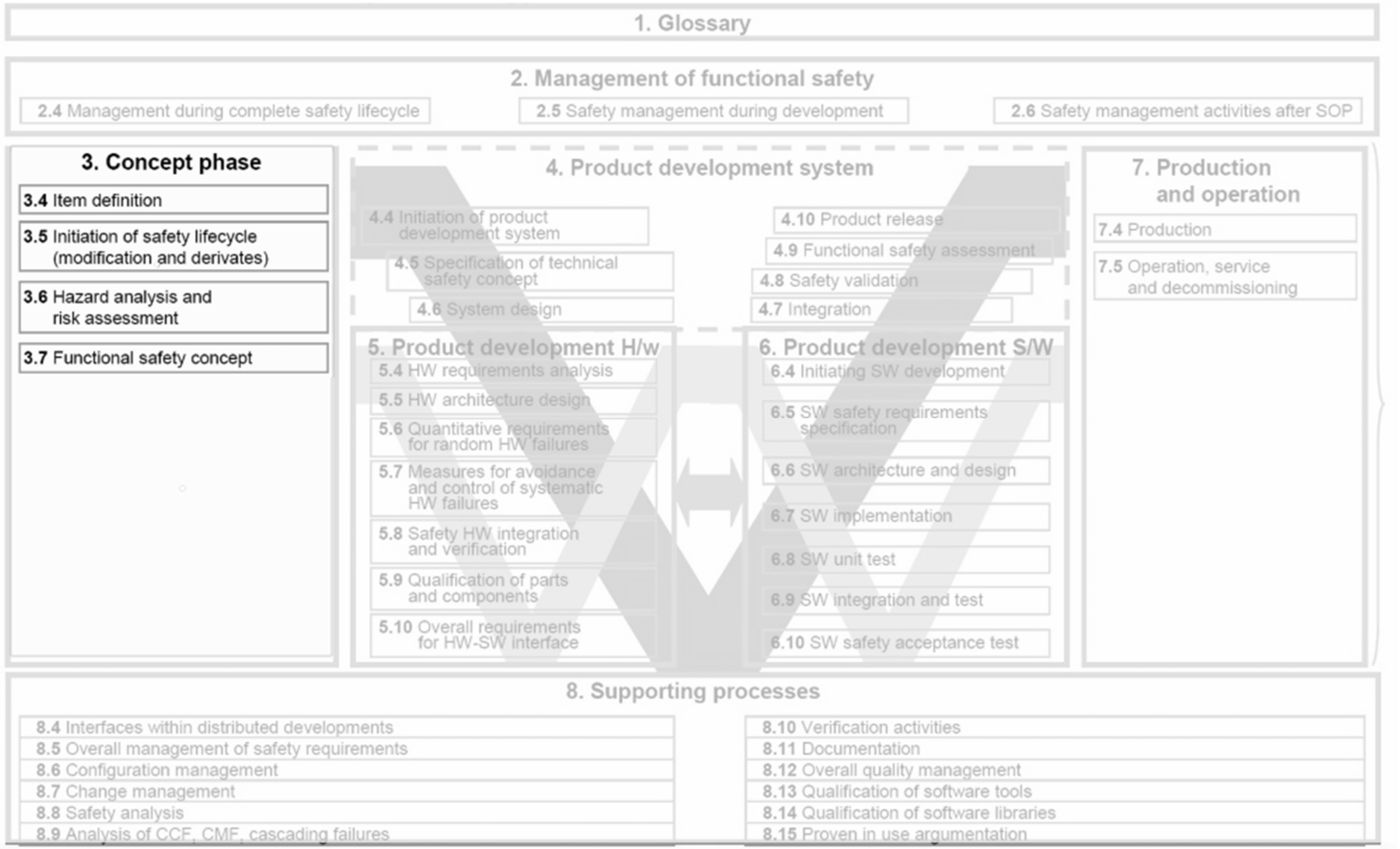
HARA & ISO26262 Lifecycle

Road Vehicles Functional Safety



1. Glossary

2. Management of functional safety

- 2.4 Management during complete safety lifecycle
- 2.5 Safety management during development
- 2.6 Safety management activities after SOP

3. Concept phase

- 3.4 Item definition
- 3.5 Initiation of safety lifecycle (modification and derivates)
- 3.6 Hazard analysis and risk assessment
- 3.7 Functional safety concept

4. Product development system

- 4.4 Initiation of product development system
- 4.5 Specification of technical safety concept
- 4.6 System design
- 4.10 Product release
- 4.9 Functional safety assessment
- 4.8 Safety validation
- 4.7 Integration

5. Product development H/w

- 5.4 HW requirements analysis
- 5.5 HW architecture design
- 5.6 Quantitative requirements for random HW failures
- 5.7 Measures for avoidance and control of systematic HW failures
- 5.8 Safety HW integration and verification
- 5.9 Qualification of parts and components
- 5.10 Overall requirements for HW-SW interface

6. Product development S/W

- 6.4 Initiating SW development
- 6.5 SW safety requirements specification
- 6.6 SW architecture and design
- 6.7 SW implementation
- 6.8 SW unit test
- 6.9 SW integration and test
- 6.10 SW safety acceptance test

7. Production and operation

- 7.4 Production
- 7.5 Operation, service and decommissioning

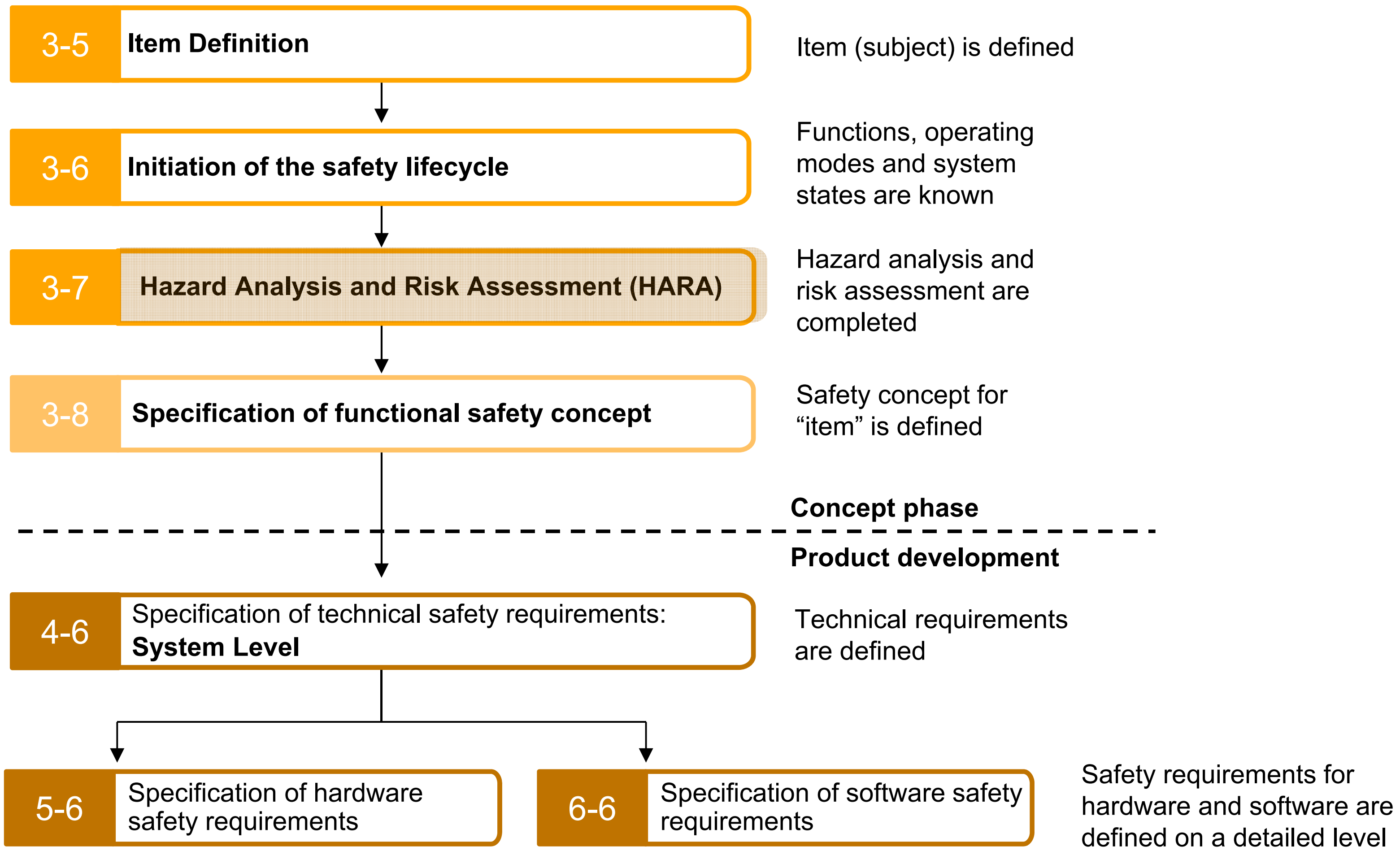
8. Supporting processes

- 8.4 Interfaces within distributed developments
- 8.5 Overall management of safety requirements
- 8.6 Configuration management
- 8.7 Change management
- 8.8 Safety analysis
- 8.9 Analysis of CCF, CMF, cascading failures
- 8.10 Verification activities
- 8.11 Documentation
- 8.12 Overall quality management
- 8.13 Qualification of software tools
- 8.14 Qualification of software libraries
- 8.15 Proven in use argumentation

[ISO26262]

HARA & ISO26262 Lifecycle

Concept Phase (ISO 26262-part 3)



3-5 **Item Definition**

Item (subject) is defined

3-6 **Initiation of the safety lifecycle**

Functions, operating modes and system states are known

3-7 **Hazard Analysis and Risk Assessment (HARA)**

Hazard analysis and risk assessment are completed

3-8 **Specification of functional safety concept**

Safety concept for "item" is defined

Concept phase

Product development

4-6 Specification of technical safety requirements: **System Level**

Technical requirements are defined

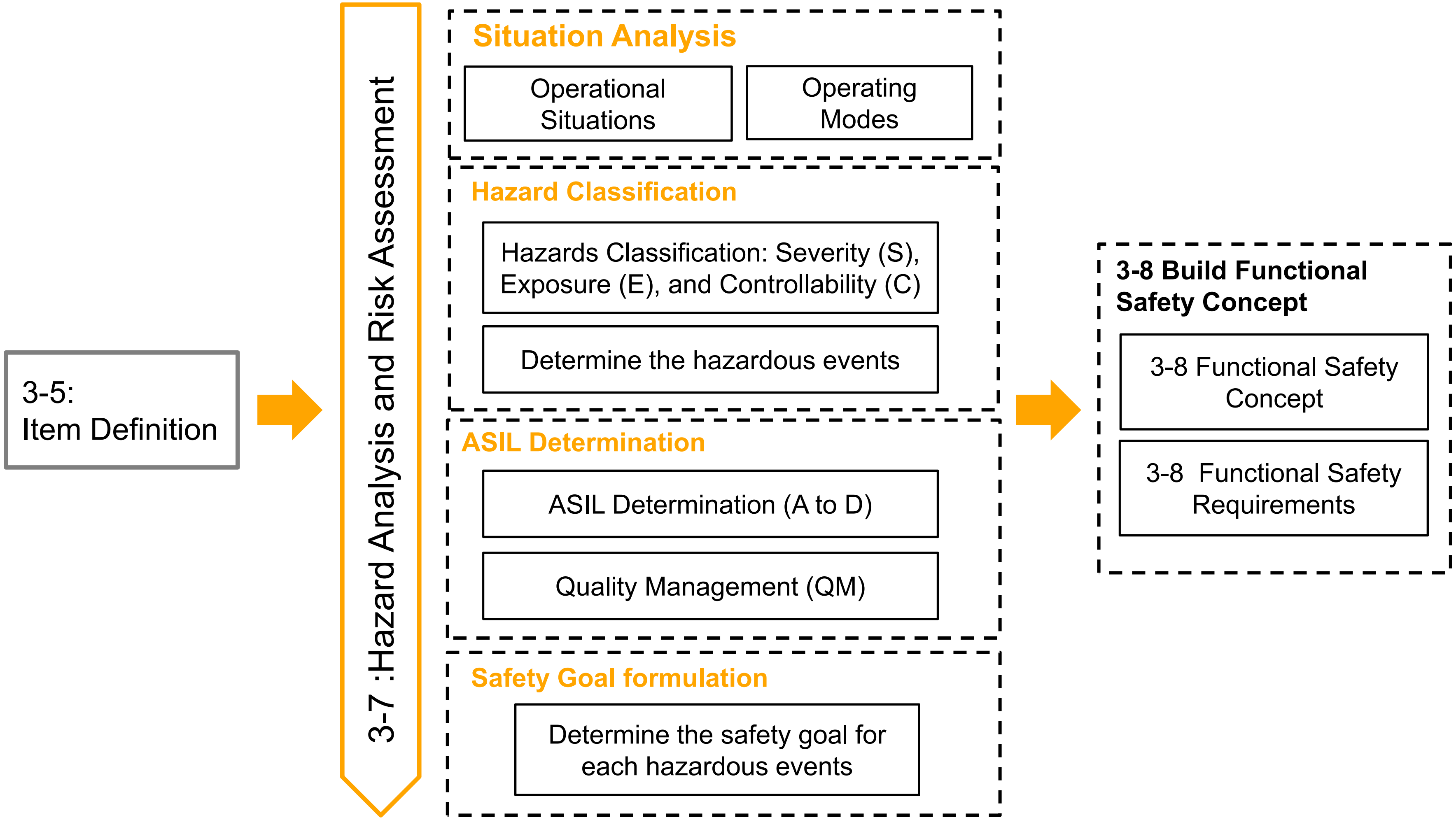
5-6 Specification of hardware safety requirements

6-6 Specification of software safety requirements

Safety requirements for hardware and software are defined on a detailed level

HARA & ISO 26262 Lifecycle

Hazard Analysis and Risk Assessment (HARA)



3-5:
Item Definition

3-7 :Hazard Analysis and Risk Assessment

Situation Analysis

- Operational Situations
- Operating Modes

Hazard Classification

- Hazards Classification: Severity (S), Exposure (E), and Controllability (C)
- Determine the hazardous events

ASIL Determination

- ASIL Determination (A to D)
- Quality Management (QM)

Safety Goal formulation

- Determine the safety goal for each hazardous events

3-8 Build Functional Safety Concept

- 3-8 Functional Safety Concept
- 3-8 Functional Safety Requirements

HARA & ISO 26262 Lifecycle

ISO 26262 challenges for autonomous vehicles

- ISO 26262 has no recommended method for the item definition
- ISO 26262 recommends various analysis techniques (e.g. FTA, FMEA, HARA)
- ISO 26262 is not established for fully automated driving vehicles (autonomous vehicles)
- No controllability assessment method for the hazardous events of fully automated vehicle (no driver in loop, SAE level 5)

Using STPA in Compliance with ISO26262

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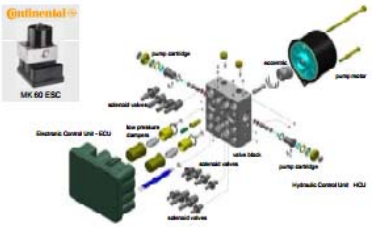
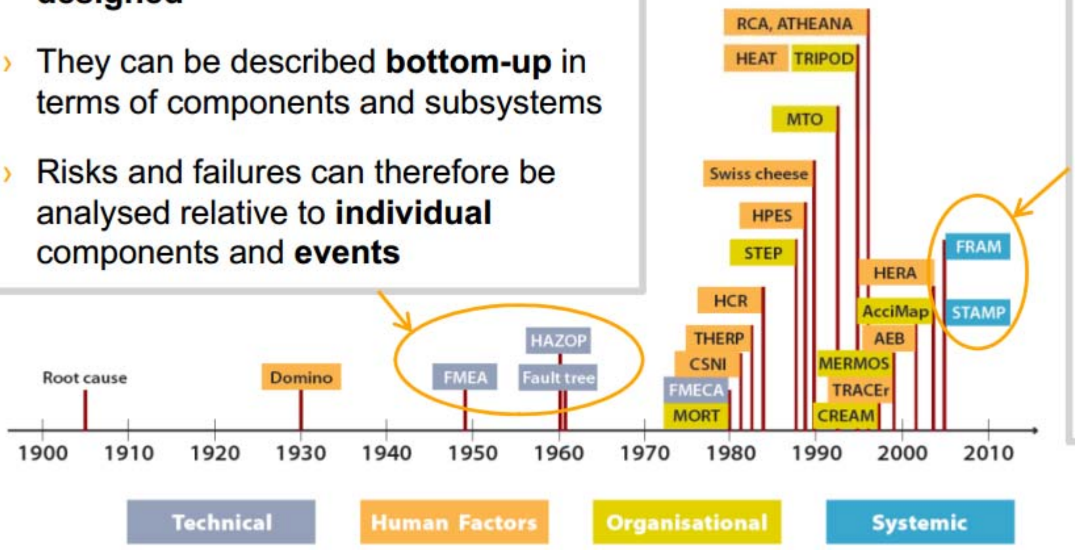
Introduction to STAMP/STPA

Assessment Methodologies

Technical Systems



- Decomposition works for technical systems, because they have been **designed**
- They can be described **bottom-up** in terms of components and subsystems
- Risks and failures can therefore be analysed relative to **individual** components and **events**

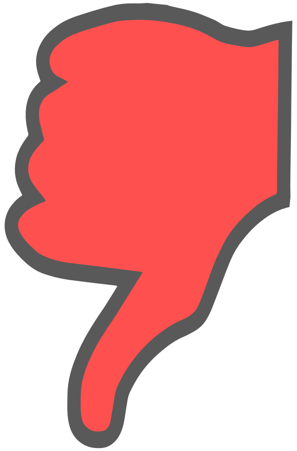


Socio-Technical Systems

- Decomposition does **not** work for socio-technical systems, because they are emergent
- Must be described **top-down** in terms of functions and objectives
- Risks and failures must therefore be described relative to functional wholes

[Hollnagel2009,2014], [Leveson2011]

Introduction to STAMP/STPA
Limitation of traditional accident models



- Technology is changing faster than the engineering techniques
- Changing nature of accidents.
- New types of hazards (e.g. unacceptable physical, scientific, or financial losses)
- Decreasing tolerance for single accidents
- Increasing complexity and coupling
- More complex relationships between human and automation
- Changing regulations and public view of safety

[Leveson 2004, A new Accident Model for Engineering Safer Systems]

Introduction to STAMP/STPA
STAMP New Accident Model

STAMP (**S**ystems-**T**heoretic **A**ccident **M**odel and **P**rocesses)

is an accident causality model based on system theory and system thinking

- Developed by Nancy Leveson, MIT in 2004
- Accidents are more than a chain of events, they involve **complex dynamic processes**.
- Treat accidents as **a control problem,** not a failure problem
- Prevent accidents by enforcing constraints on component behaviour and **interactions**.
- Capture **more causes** of accidents:
  - Component failure accidents.
  - Unsafe interactions among components
  - Complex human, software behaviour
  - Design errors
  - Software-related accidents

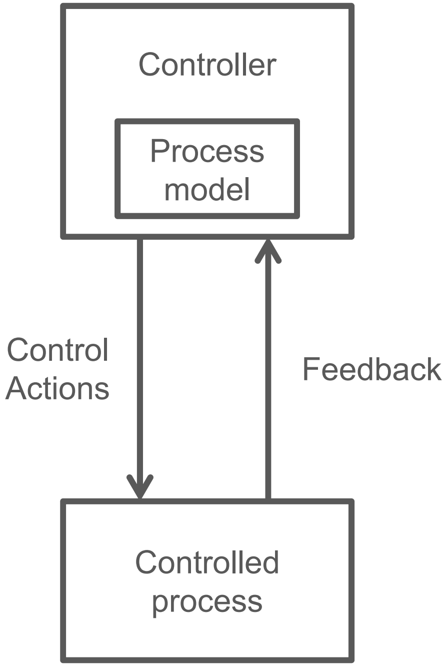
Source: N. G. Leveson. Engineering A Safer World: Systems Thinking Applied to Safety, MIT Press. Cambridge, MA. 2011.

Introduction to STAMP/STPA
Methodology

STPA (**S**ystem-**T**heoretic **P**rocess **A**nalysis)

Technique based on systems thinking by a STAMP model

- Based on system theory rather than reliability theory
- Integrates safety into system engineering and can also analyze hazards in existing design
- Drive the earliest design decisions (Safety by Design)
- Identify unexpected accident scenarios
- In systems theory, instead of breaking systems into interacting components, systems are viewed (modeled) as a hierarchy of organizational levels.

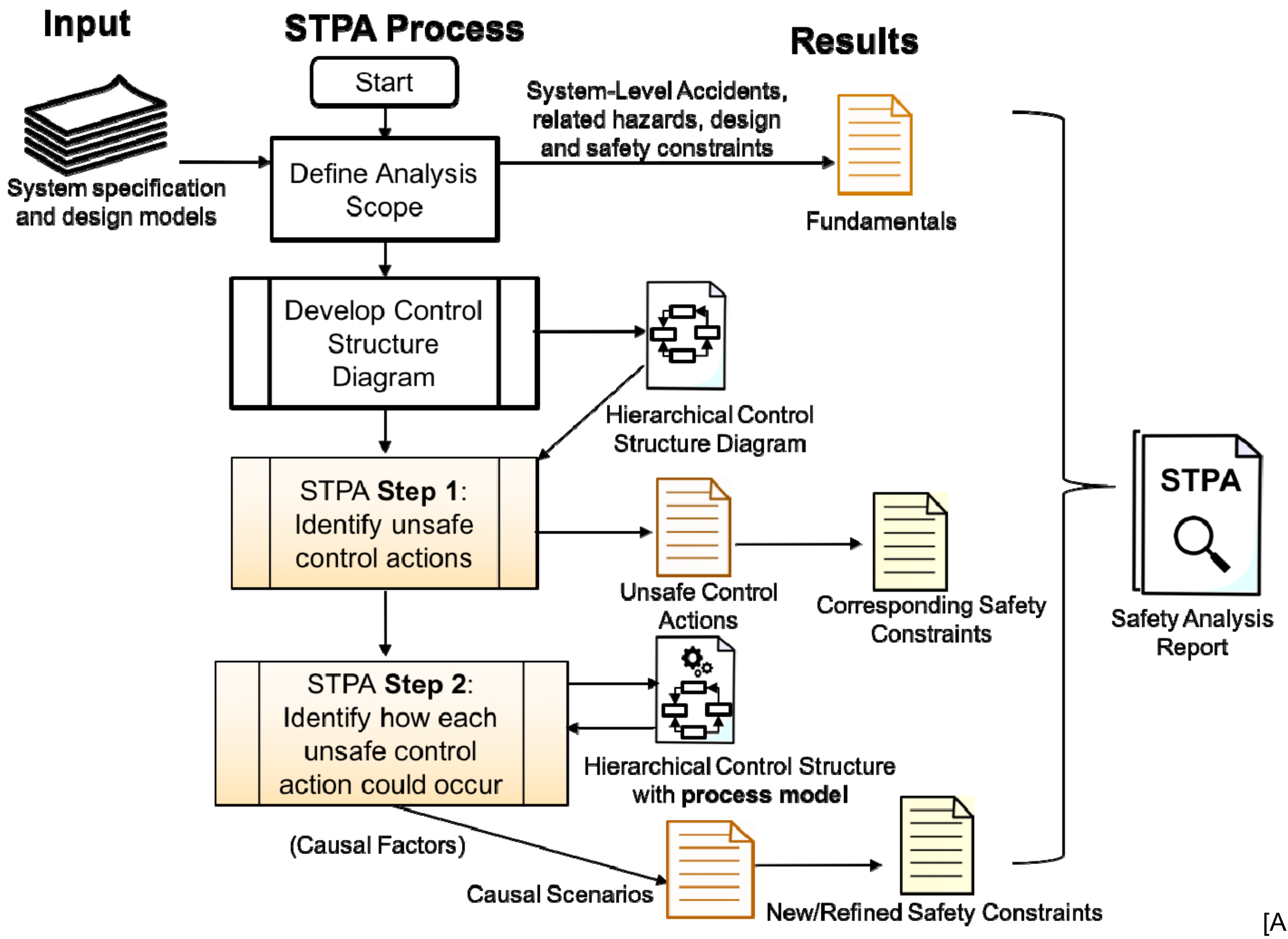


Control Loop

Source: N. G. Leveson. Engineering A Safer World: Systems Thinking Applied to Safety, MIT Press. Cambridge, MA. 2011.

Introduction to STAMP/STPA

Safety Analysis Approach



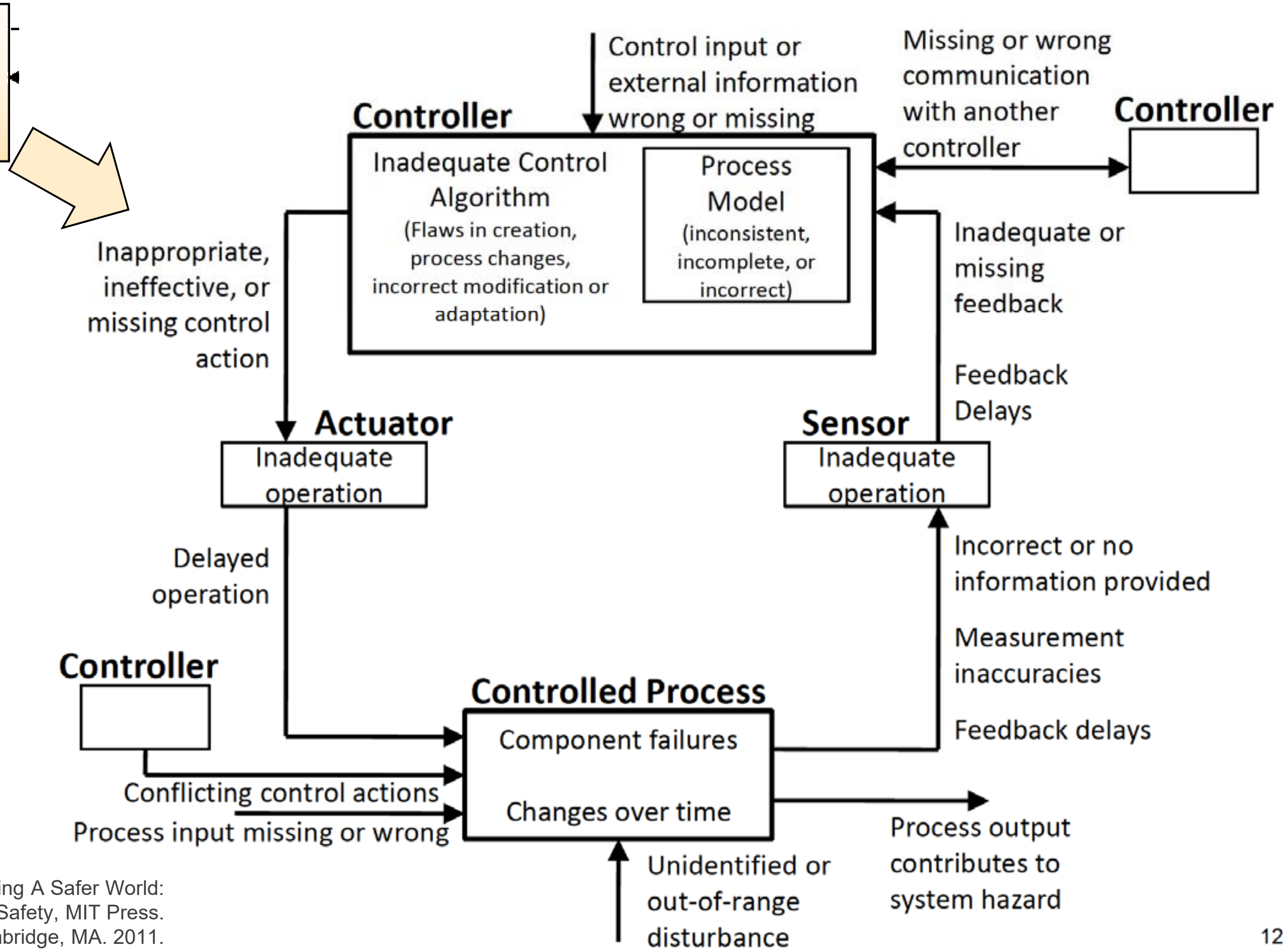
Input
STPA Process
Results
Start
System specification and design models
Define Analysis Scope
System-Level Accidents, related hazards, design and safety constraints
Fundamentals
Develop Control Structure Diagram
Hierarchical Control Structure Diagram
STPA Step 1: Identify unsafe control actions
Unsafe Control Actions
Corresponding Safety Constraints
STPA
Safety Analysis Report
STPA Step 2: Identify how each unsafe control action could occur
Hierarchical Control Structure with process model
(Causal Factors)
Causal Scenarios
New/Refined Safety Constraints

[Abdulkhaleq 2017]

Introduction to STAMP/STPA

Causal Factors Analysis (Qualitative Analysis)

STPA **Step 2**: Identify how each unsafe control action could occur



Controller
Control input or external information wrong or missing
Missing or wrong communication with another controller
Controller
Inadequate Control Algorithm
(Flaws in creation, process changes, incorrect modification or adaptation)
Process Model
(inconsistent, incomplete, or incorrect)
Inadequate or missing feedback
Feedback Delays
Inappropriate, ineffective, or missing control action
Actuator
Inadequate operation
Sensor
Inadequate operation
Delayed operation
Incorrect or no information provided
Measurement inaccuracies
Feedback delays
Controller
Controlled Process
Component failures
Changes over time
Conflicting control actions
Process input missing or wrong
Unidentified or out-of-range disturbance
Process output contributes to system hazard
12

Source: N. G. Leveson. Engineering A Safer World: Systems Thinking Applied to Safety, MIT Press. Cambridge, MA. 2011.

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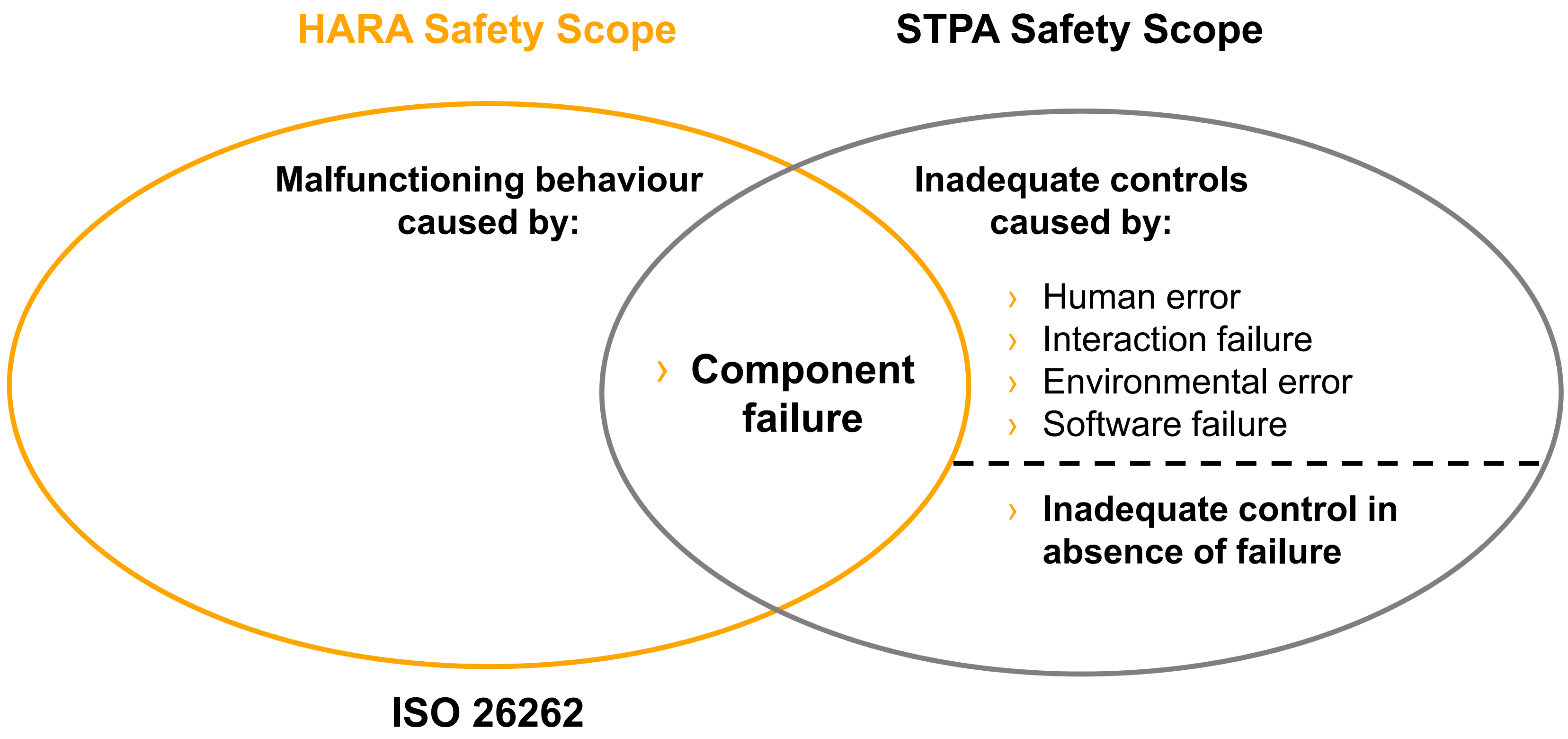
Methodology & Results
STPA vs HARA



HARA Safety Scope

STPA Safety Scope

Malfunctioning behaviour caused by:

- Component failure

Inadequate controls caused by:

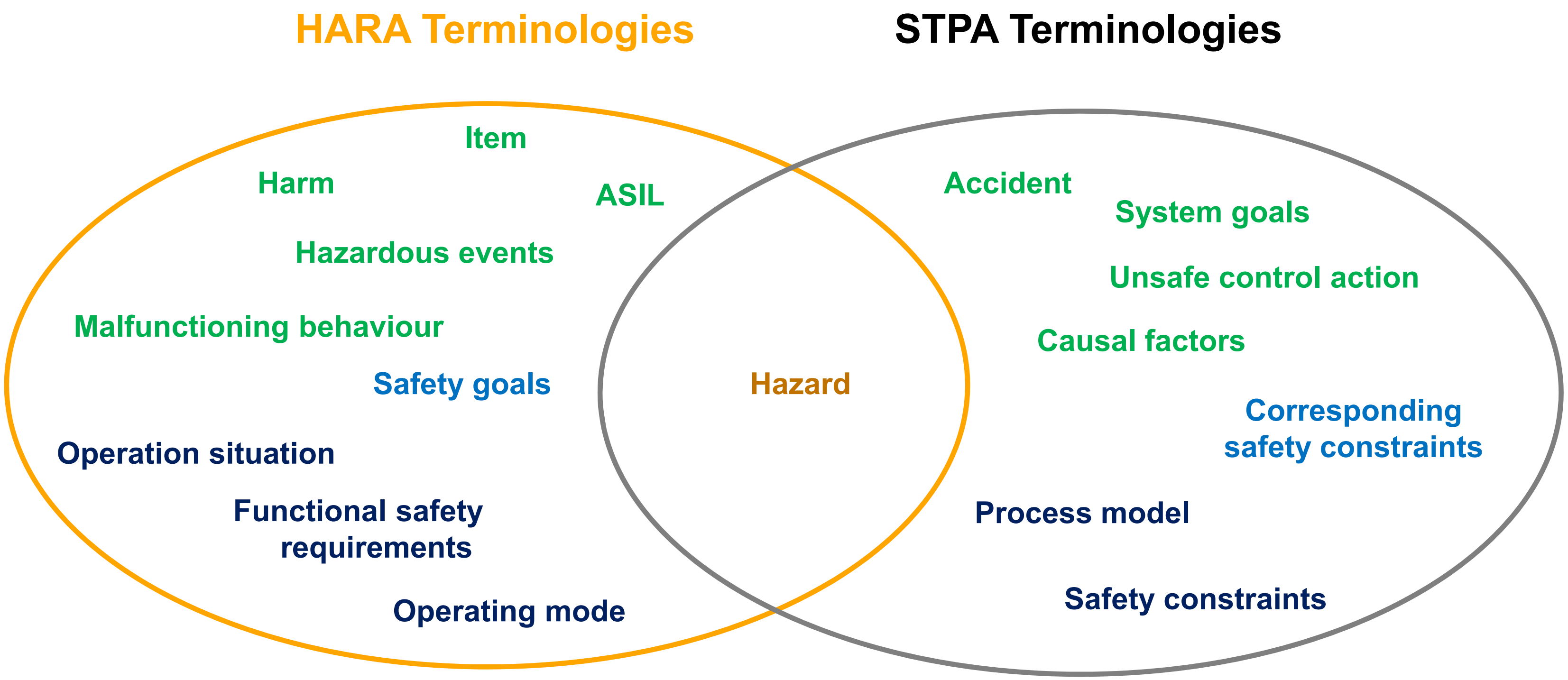
- Human error
- Interaction failure
- Environmental error
- Software failure

- Inadequate control in absence of failure

ISO 26262

Operational Safety

Methodology & Results
STPA vs HARA



HARA Terminologies

STPA Terminologies

Item

Harm

ASIL

Hazardous events

Malfunctioning behaviour

Safety goals

Operation situation

Functional safety requirements

Operating mode

Hazard

Accident

System goals

Unsafe control action

Causal factors

Corresponding safety constraints

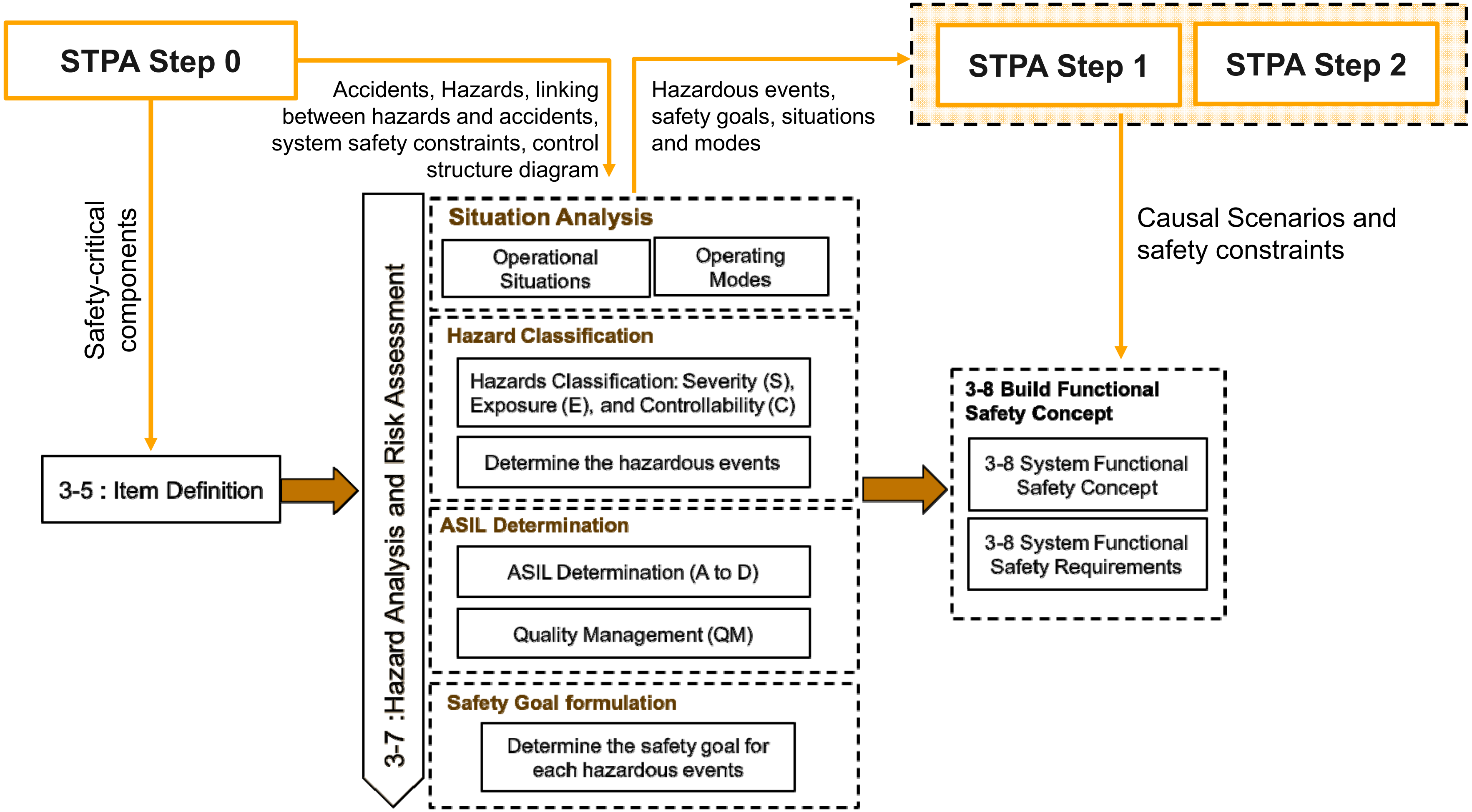
Process model

Safety constraints

🟢	No corresponding term	🔵	Somehow match
●	Partially match	🟤	Exactlly match

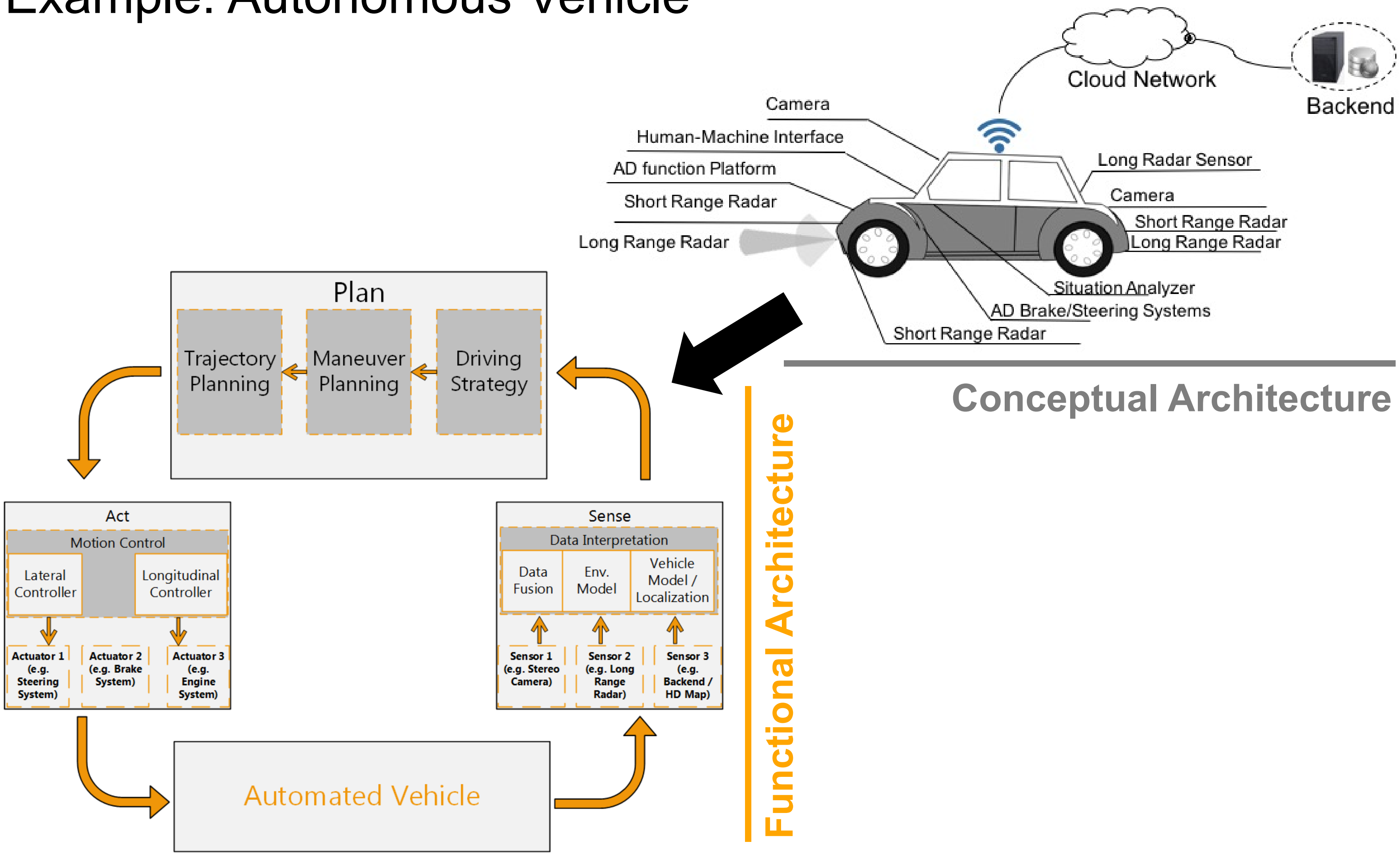
Methodology & Results

STPA in ISO 26262


STPA Step 0
Accidents, Hazards, linking between hazards and accidents, system safety constraints, control structure diagram
Hazardous events, safety goals, situations and modes
STPA Step 1
STPA Step 2
Safety-critical components
Causal Scenarios and safety constraints
3-5 : Item Definition
3-7 :Hazard Analysis and Risk Assessment
Situation Analysis
Operational Situations
Operating Modes
Hazard Classification
Hazards Classification: Severity (S), Exposure (E), and Controllability (C)
Determine the hazardous events
ASIL Determination
ASIL Determination (A to D)
Quality Management (QM)
Safety Goal formulation
Determine the safety goal for each hazardous events
3-8 Build Functional Safety Concept
3-8 System Functional Safety Concept
3-8 System Functional Safety Requirements

Methodology & Results

Example: Autonomous Vehicle

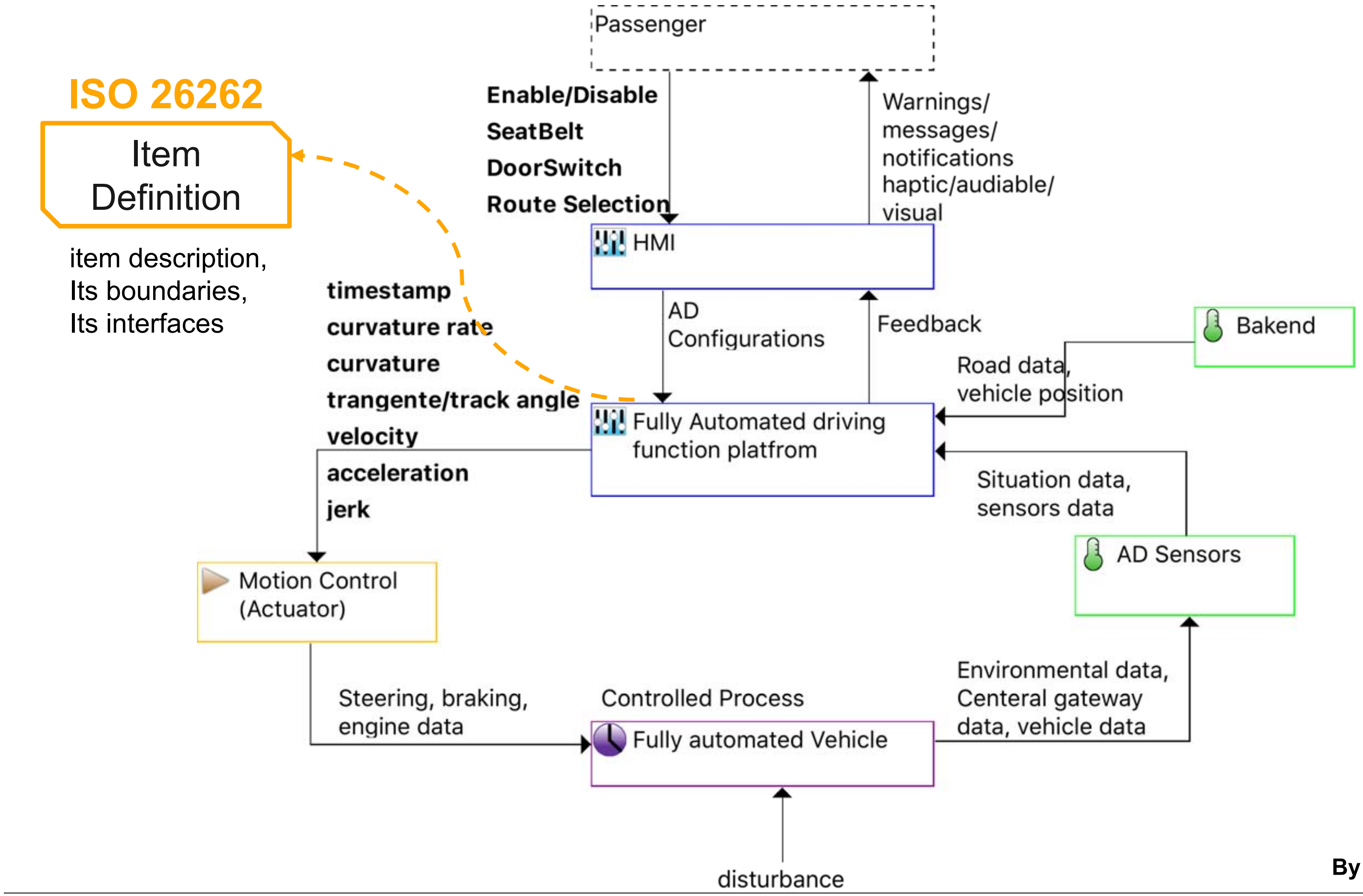


Conceptual Architecture

Functional Architecture

Methodology & Results

STPA Step 0: Safety Control Structure Diagram

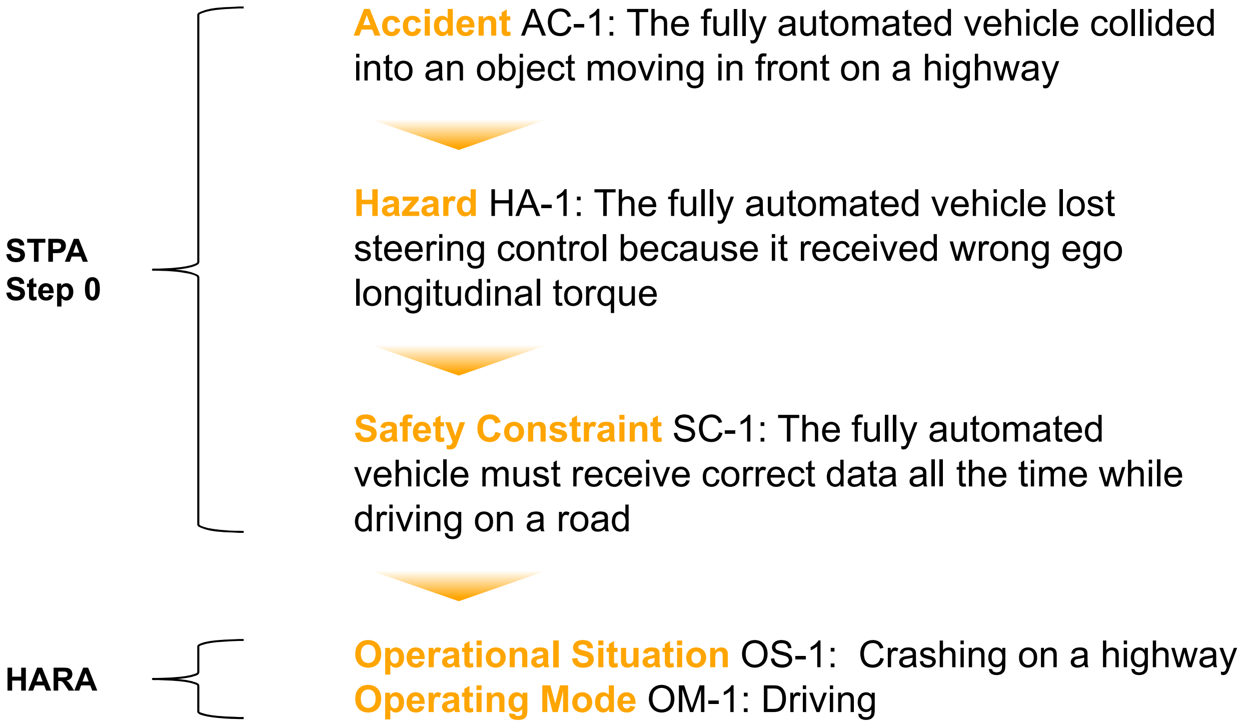


By XSTAMPP

Methodology & Results

STPA Step 0: Accidents & Hazards

- We identify 26 accidents which fully automated driving vehicle can lead to
- We identify 176 hazards which are grouped into the 9 hazard categories



STPA Step 0

Accident AC-1: The fully automated vehicle collided into an object moving in front on a highway

Hazard HA-1: The fully automated vehicle lost steering control because it received wrong ego longitudinal torque

Safety Constraint SC-1: The fully automated vehicle must receive correct data all the time while driving on a road

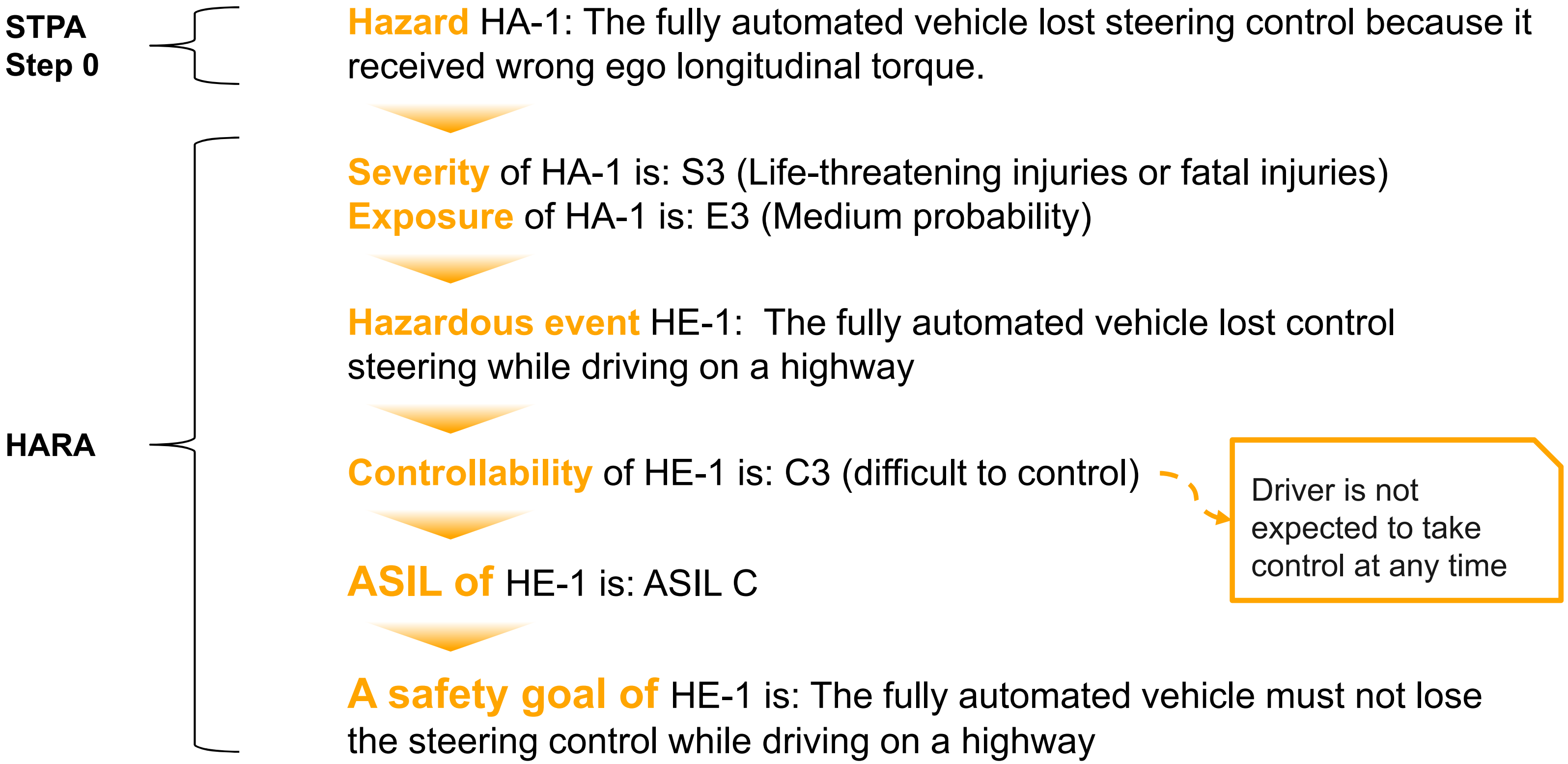
HARA

Operational Situation OS-1: Crashing on a highway

Operating Mode OM-1: Driving

Methodology & Results
Risk Assessement & Hazards Classification

- We estimated the severity and exposure of each hazard identified in STPA Step 0
- We identified the hazardous events for each hazard and estimated its controllability



STPA Step 0

Hazard HA-1: The fully automated vehicle lost steering control because it received wrong ego longitudinal torque.

HARA

Severity of HA-1 is: S3 (Life-threatening injuries or fatal injuries)
Exposure of HA-1 is: E3 (Medium probability)

Hazardous event HE-1: The fully automated vehicle lost control steering while driving on a highway

Controllability of HE-1 is: C3 (difficult to control)

Driver is not expected to take control at any time

ASIL of HE-1 is: ASIL C

A safety goal of HE-1 is: The fully automated vehicle must not lose the steering control while driving on a highway

Methodology & Results

STPA Step 1: Unsafe Control Actions

- We identify the unsafe control actions of the fully automated driving platform
- We translate each unsafe control action into a corresponding safety constraint

Safety-critical control action CA-1: Trajectory

Unsafe control action UCA-1: The fully automated driving function platform does not provide a valid trajectory to motion control while driving too fast on a highway [HA-1]

Corresponding safety constraint SC-1: The fully automated driving function platform must always provide a valid trajectory to motion control while driving too fast on a highway

Methodology & Results

STPA Step 2: Causal Factors and Scenarios

- We use the results of the situation analysis to determine the process model of AD
- We identify the causal factors and scenarios of each unsafe control action

Process Model Variables PMV: road_type (highway, parking, intersection, mountain, city, urban) throttle position, brake friction, etc.

Unsafe control action UCA-1: The fully automated driving function platform does not provide a valid trajectory to motion control while driving too fast on a highway [HA-1]

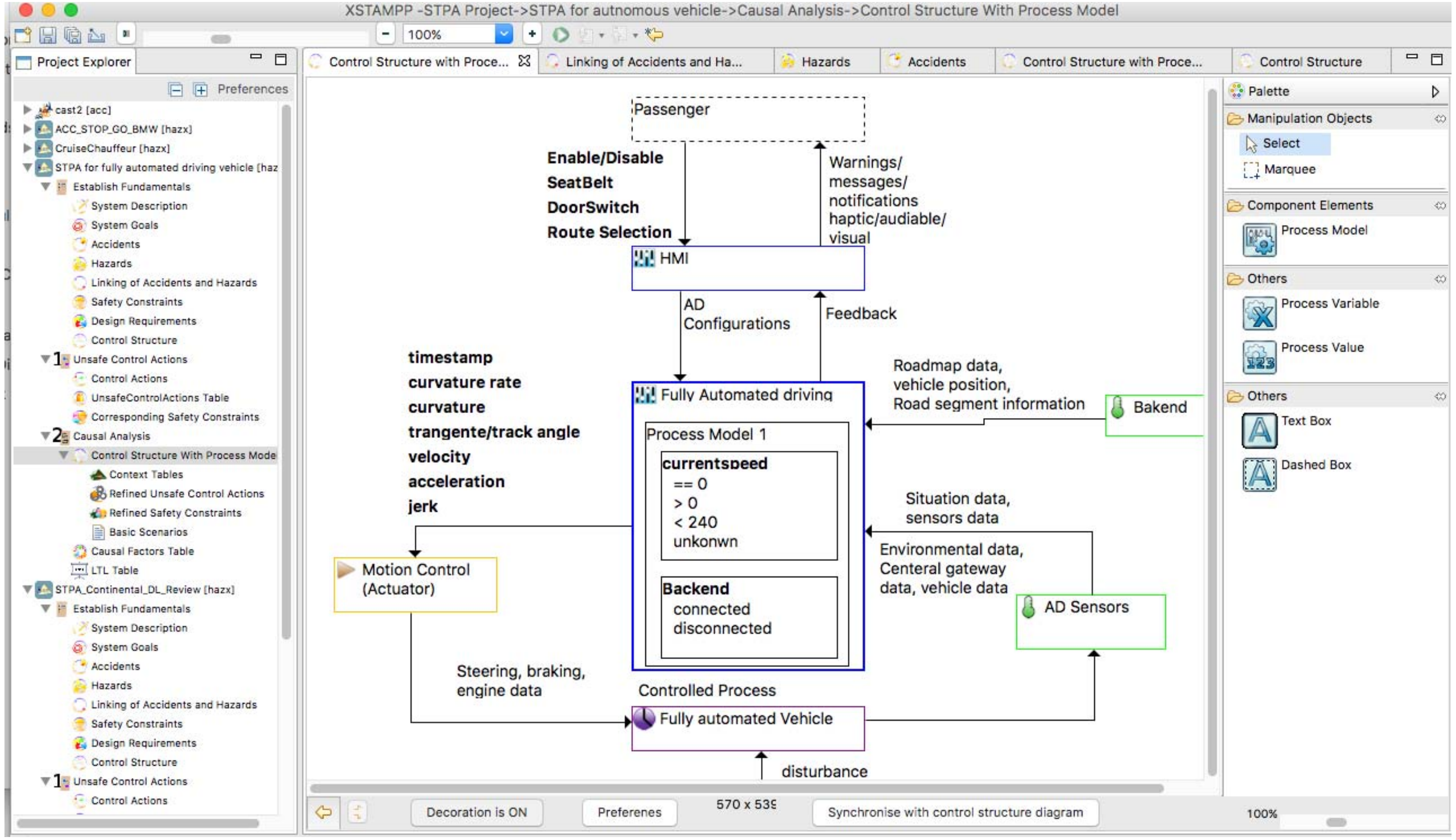
Causal Factor: Lack of Communication
Causal Scenario CS-1: The fully automated driving function platform receives wrong signals from backend due to the lack of communication while driving too fast on a highway

Safety Constraint SC-1: The fully automated driving function platform must always provide the trajectory to enable motion control to adjust the throttle position and apply brake friction when the vehicle is driving too fast on a highway and there is traffic ahead to avoid a potential collision.

XSTAMPP Tool Support (www.xstampp.de)

XSTAMPP for Safety Engineering based on STAMP

- We used an open source tool called XSTAMPP which we developed to support the STAMP methodologies and its extensions to other applications such as **security, privacy.**



University of Stuttgart
Germany

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STPA in compliance with ISO 26262

Conclusion

- 👍 We used STPA as a assessment approach for the functional architecture of automated driving vehicle.
- We show how to use STPA in compliance with ISO 26262 to extend the safety scope of ISO 26262
- We provide a guidance on how use the STPA into the ISO 26262 lifecycle.
- We found that STPA and HARA can be applied with a little bit knowledge about the detailed design of the system at early stage of development.

- 👎 STPA and HARA have different base assumptions.
- The integration of STPA into HARA activities still needs modification in the assumptions and terms of both STPA and HARA to directly map the results of STPA into HARA
- STPA has no guidance on how to define the process model and its variables.
- Our tool support XSTAMPP does not support the HARA activities

STPA will be recommended in the next version of ISO 26262 (2018)

STPA in compliance with ISO 26262

Future Work

- Use of STPA as a qualitative analysis in an advanced development project (e.g. fully automated driving vehicle)
- We plan to explore the use of STPA approach in compliance with ISO 26262 at different levels of the fully automated driving architecture (e.g. software level) to develop detailed safety requirements.
- We plan to develop an extension to our tool XSTAMPP to support the HARA activities.
- We plan to conduct empirical case study evaluating our proposed concept with functional safety engineers at Continental to understand the benefits and limitations.

To download our tool: www.xstampp.de

Thank you
for your attention

Q & A

Joint work with

- Prof. Dr. Stefan Wagner, University of Stuttgart, Stuttgart, Germany
- Pierre Blüher, Hagen Boehmert, Continental Teves AG & Co. oHG, Frankfurt am Main, Germany