Hi-Drive – 1st Summer School, Porto Heli, Greece

Towards a Quantitative SOTIF Validation of Automated Driving Systems

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German Aerospace Center (DLR) e.V.
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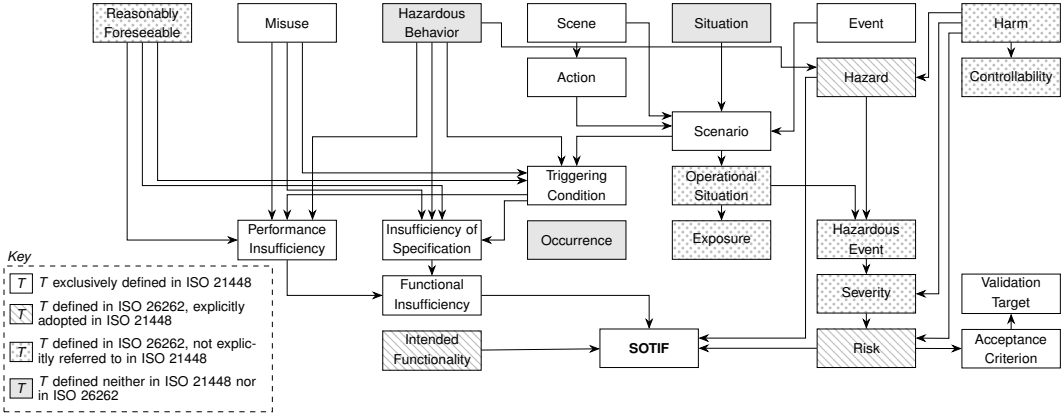

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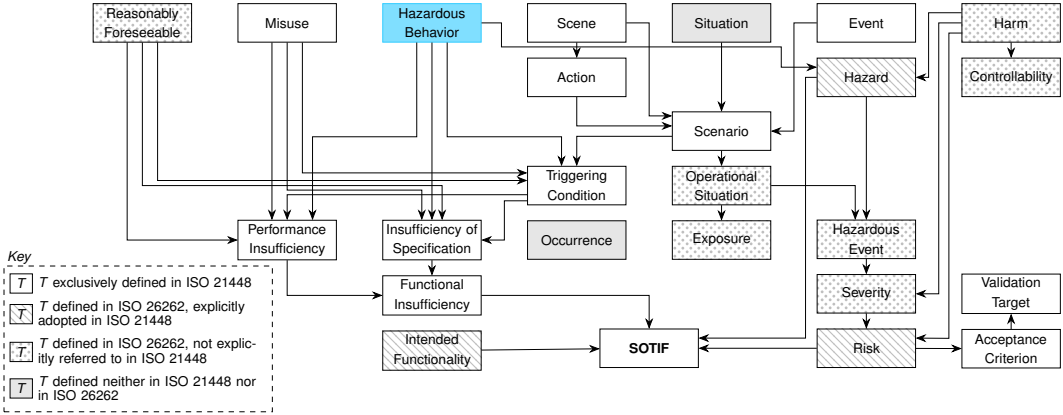

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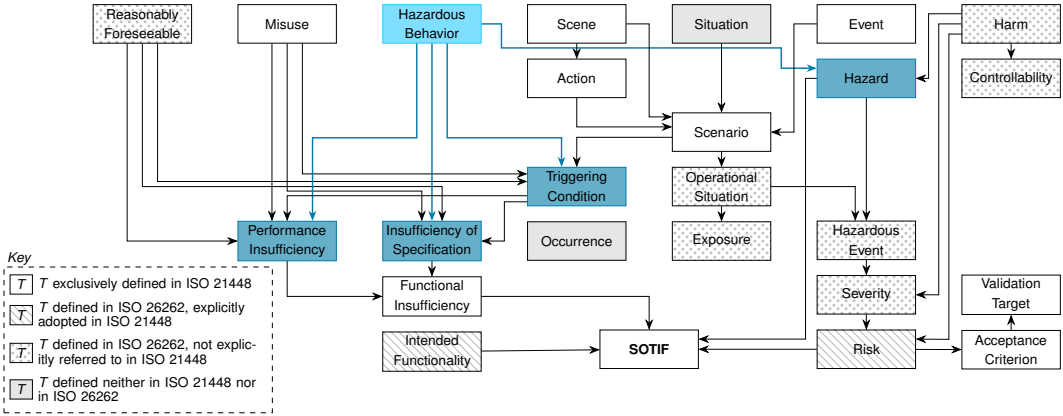

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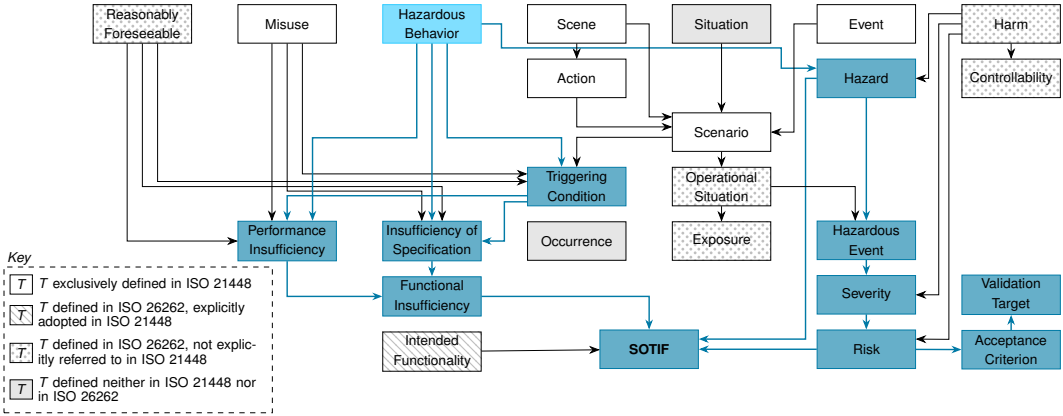

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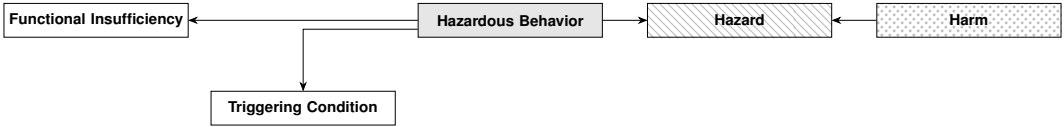

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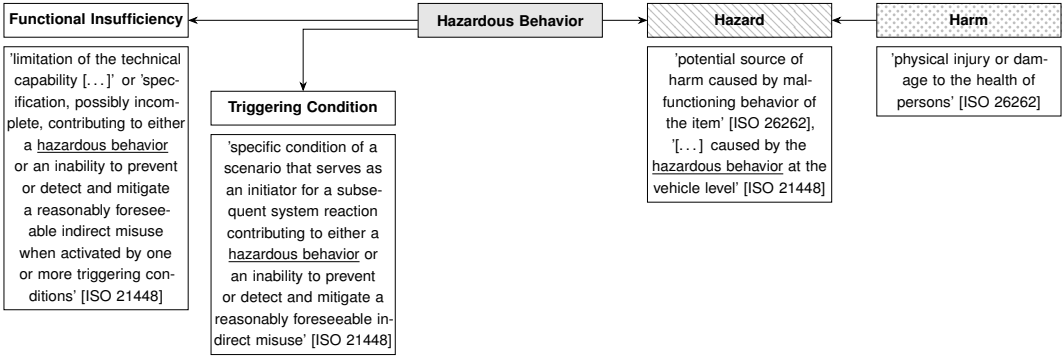

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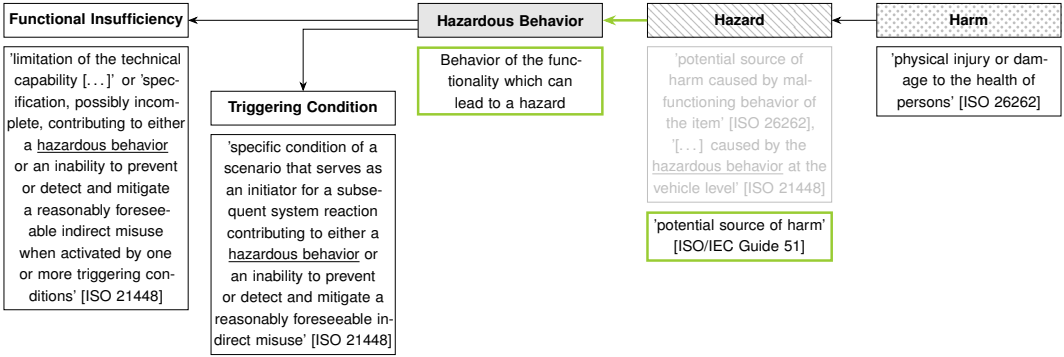

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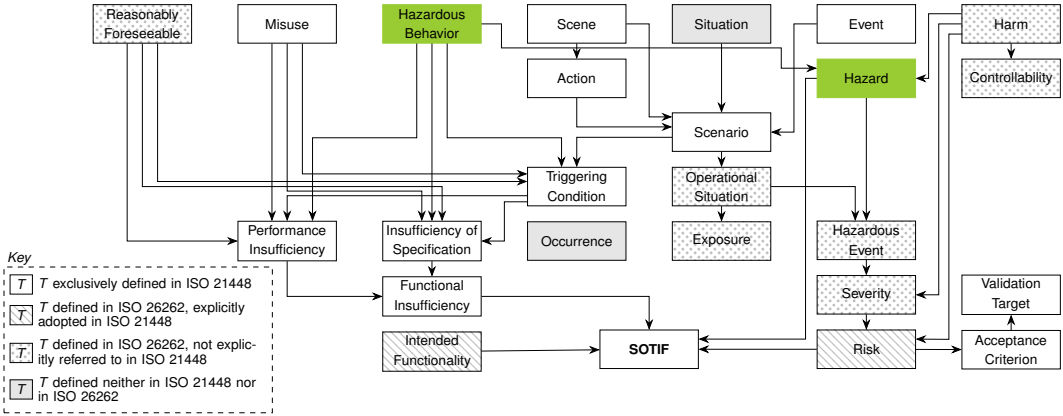

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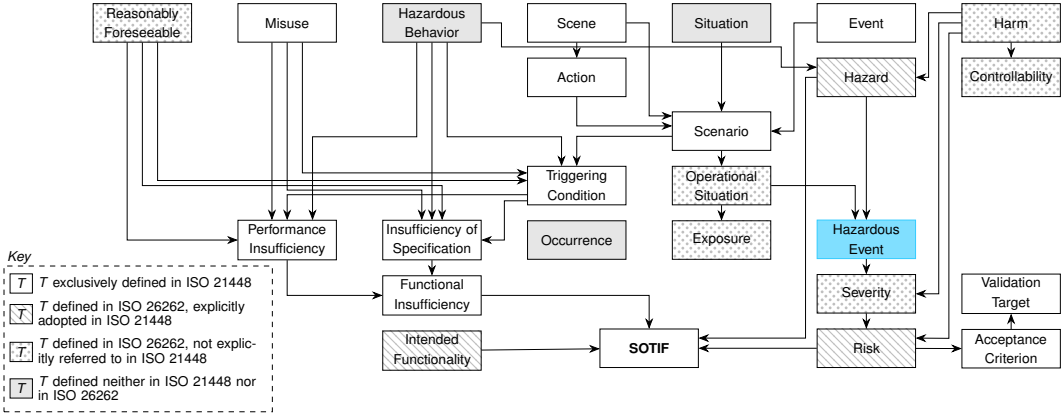

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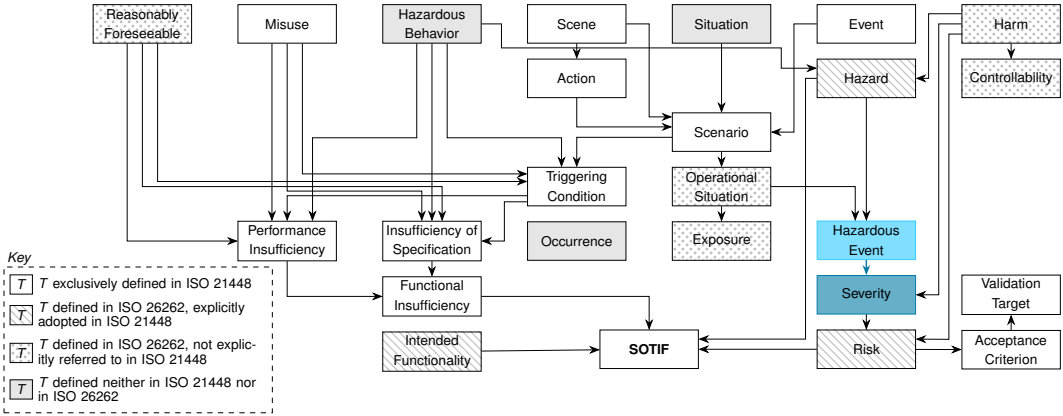

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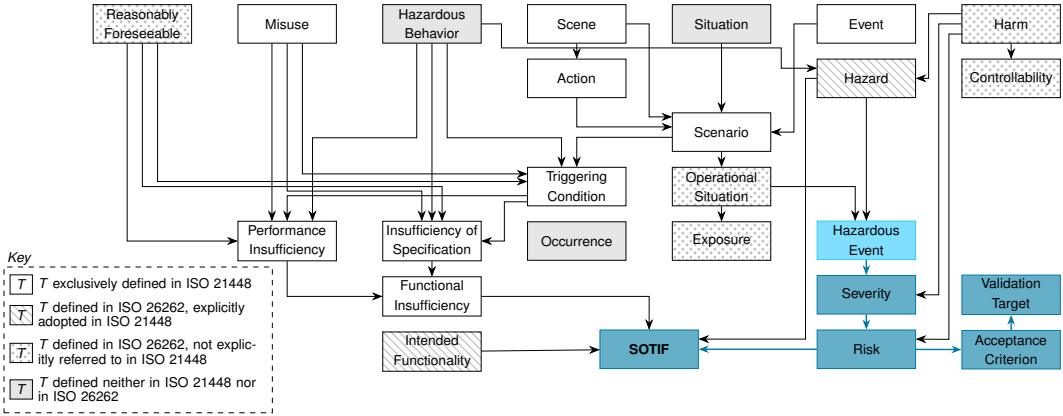

Relations of Definitions

Hazardous Event

'combination of
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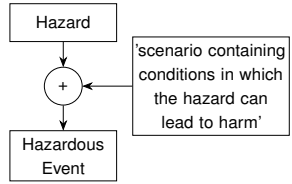

[ISO 21448, Figure 12]

Relations of Definitions

Hazardous Event

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'occurrence at a point in time' [ISO 21448]

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[ISO 21448, Figure 12]

event that is a combination of a hazard and a scenario containing conditions in which the hazard can lead to harm

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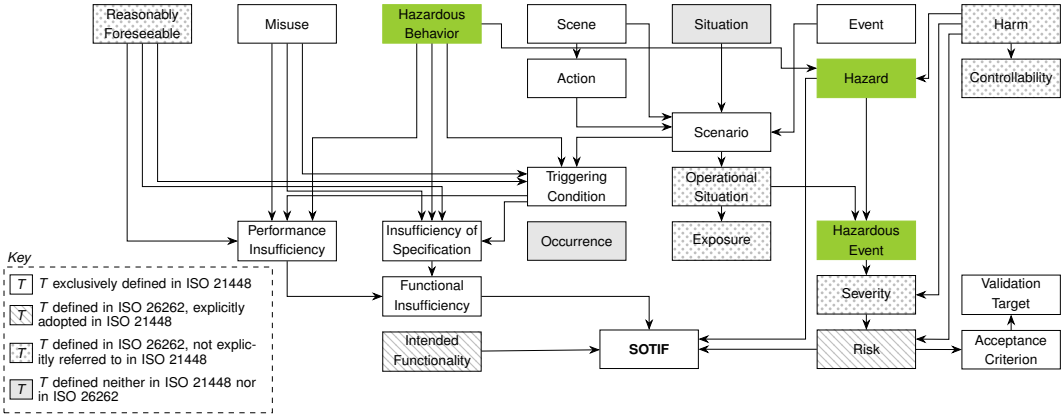

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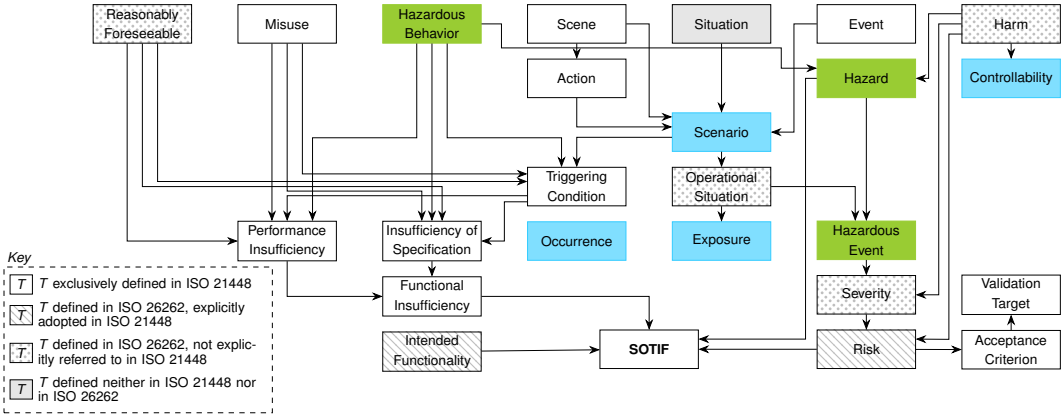
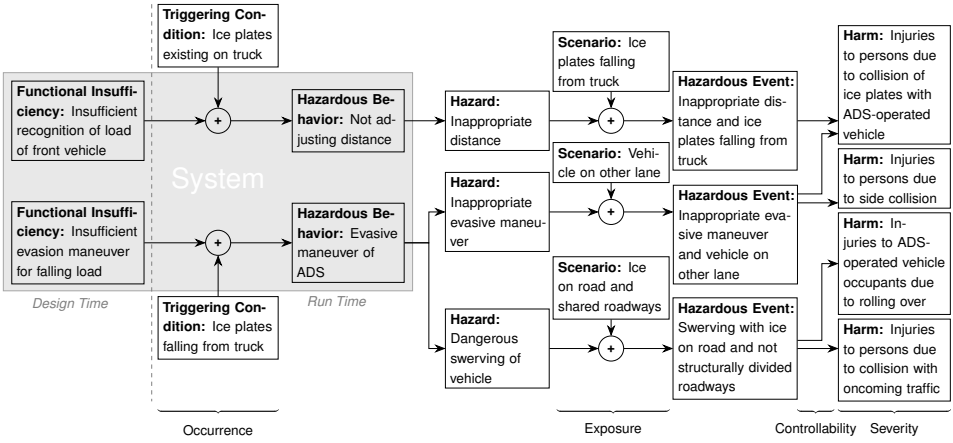


Example of the Terminological Risk Framework



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Relevant clauses within the normative part:

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Remark: The normative part of the ISO 21448 is rather sparse with requirements compared to other standards

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  - quantitative acceptance criteria are exclusively mentioned: GAMAB, PRB, ALARP, MEM

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- systematic qualitative or quantitative analysis of potential functional insufficiencies and associated triggering conditions demanded
- for scenarios containing identified triggering conditions SOTIF-achievability needs to be demonstrated

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Clause 9: Definition of the verification and validation strategy

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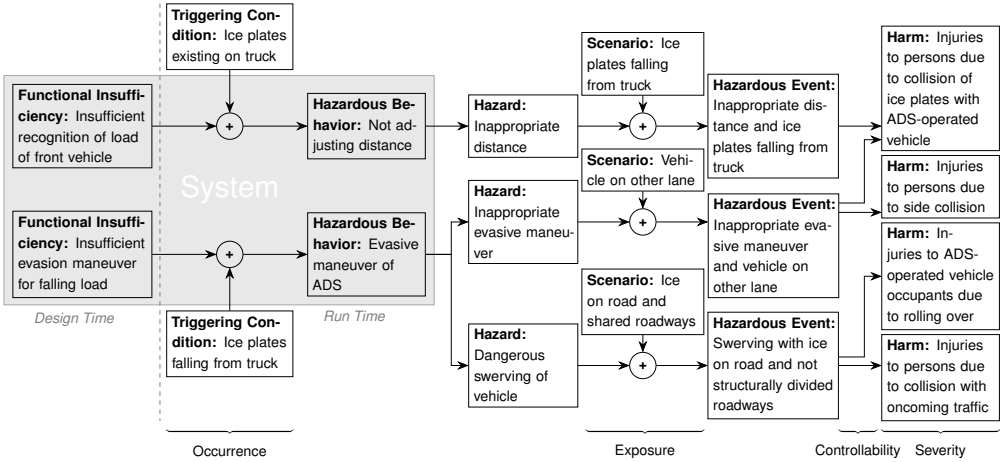
  - ✗ 1-to-1 relation between hazardous behavior and harm is implicitly assumed

Validation of the SOTIF using Quantitative Acceptance Criteria



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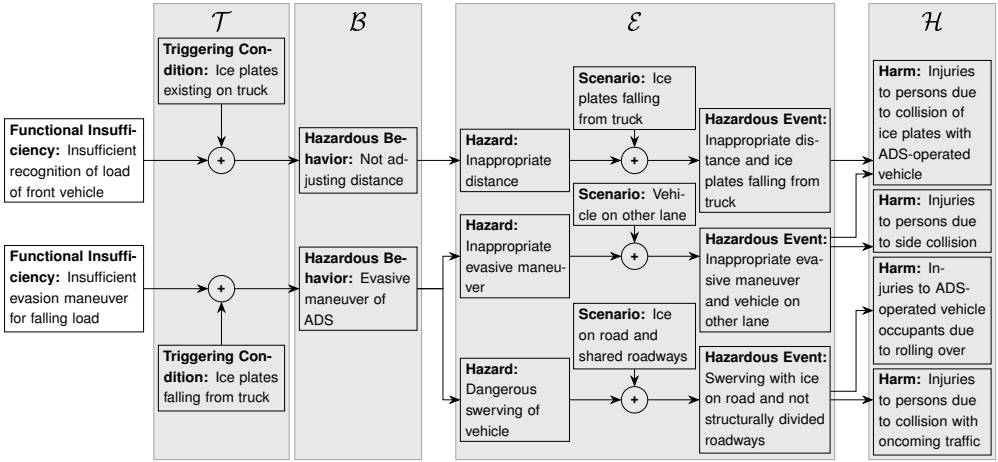

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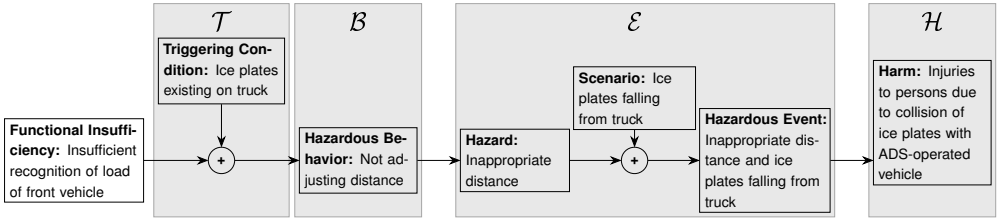

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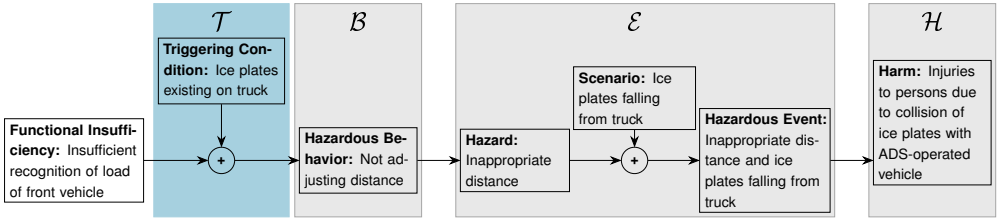

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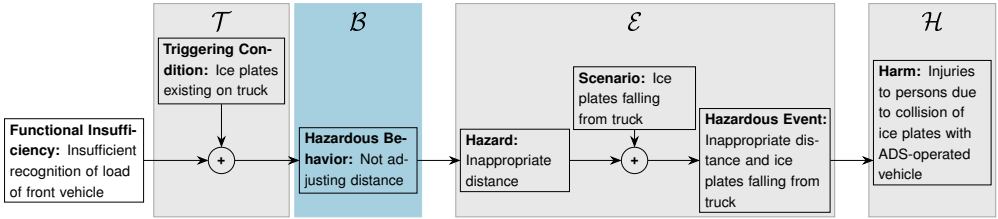

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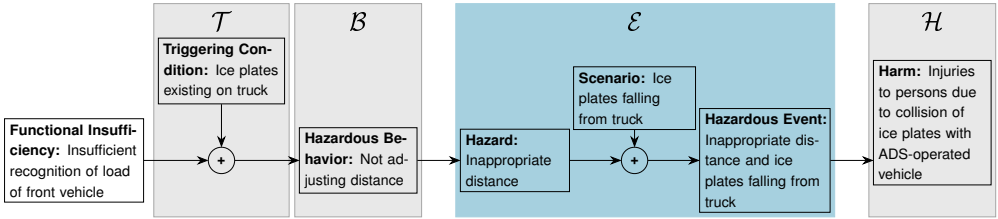

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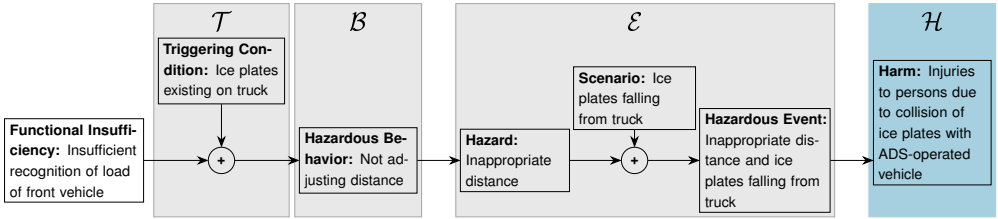

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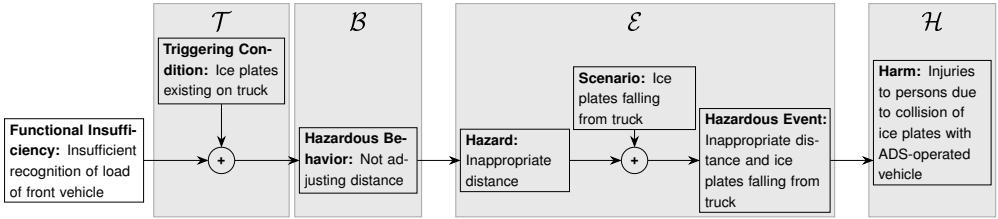

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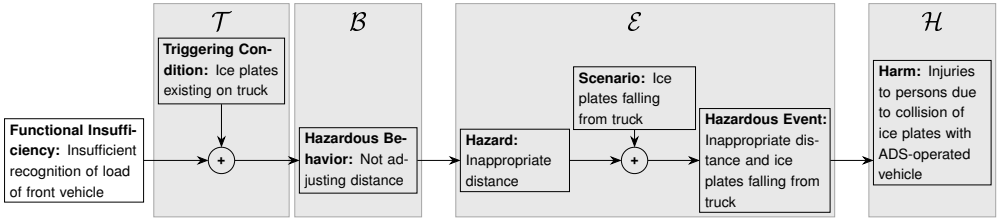

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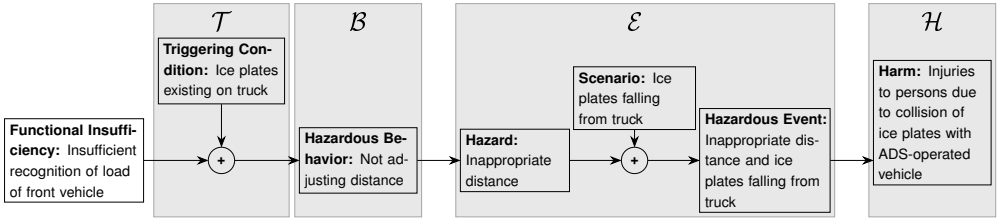

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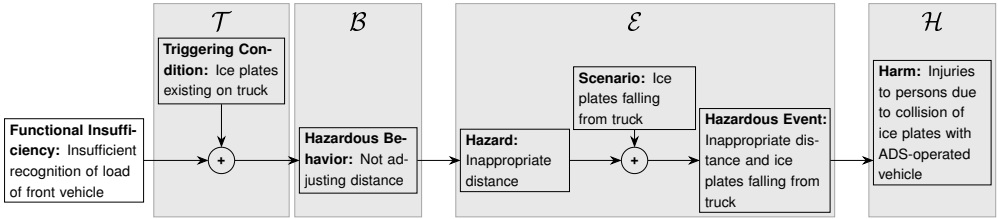

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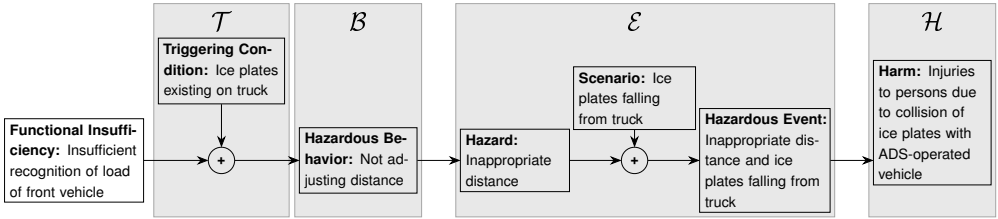

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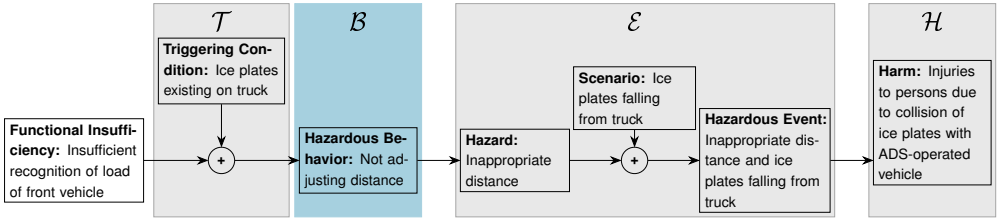

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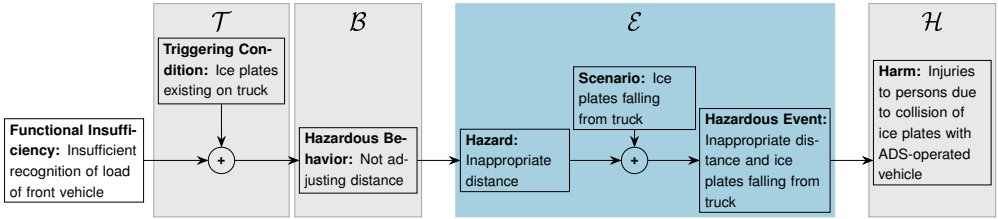

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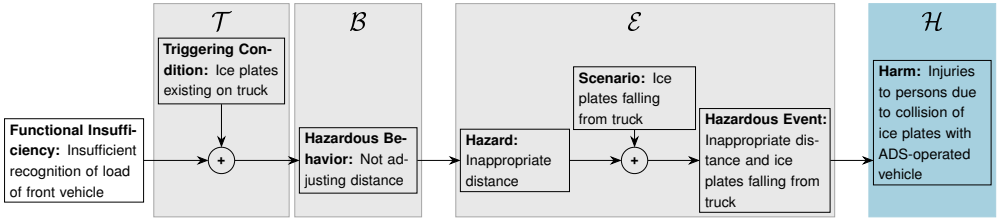

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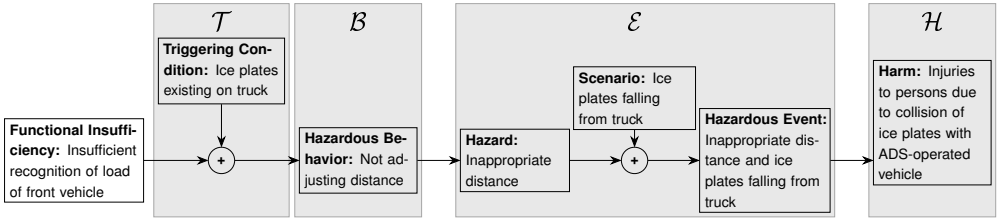
$$P(\mathcal{H}, \mathcal{S}) \leq \sum_{\mathcal{E},\mathcal{B},\mathcal{T}} P(\mathcal{T})P(\mathcal{B}|\mathcal{T})P(\mathcal{E}|\mathcal{B},\mathcal{T})P(\mathcal{H}|\mathcal{E},\mathcal{B},\mathcal{T})P(\mathcal{S}|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$$

Validation of the SOTIF using Quantitative Acceptance Criteria



✗ Decomposition given in the Annex C.2 of the ISO 21448:

$$A_H = R_{HB} \cdot P_{E|HB} \cdot P_{C|E} \cdot P_{S|C}$$

✓ Approach proposed:

$$P(\mathcal{H}, \mathcal{S}) \leq \sum_{\mathcal{E},\mathcal{B},\mathcal{T}} P(\mathcal{T})P(\mathcal{B}|\mathcal{T})P(\mathcal{E}|\mathcal{B},\mathcal{T})P(\mathcal{H}|\mathcal{E},\mathcal{B},\mathcal{T})P(\mathcal{S}|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$$

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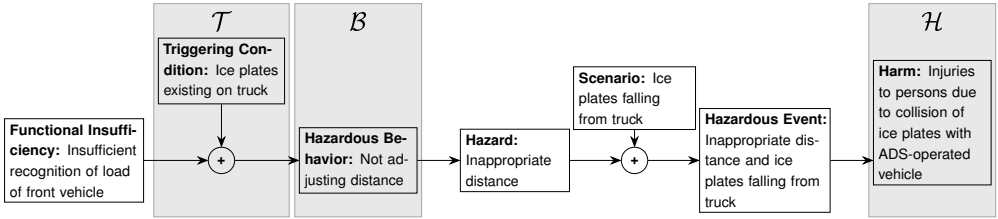

- Other discretizations are also conceivable, for example:

$$P(\mathcal{H}) \leq \sum_{\mathcal{B},\mathcal{T}} P(\mathcal{T})P(\mathcal{B}|\mathcal{T})P(\mathcal{H}|\mathcal{B},\mathcal{T})$$

$$P(\mathcal{H},\mathcal{S}) \leq \sum_{\mathcal{B},\mathcal{T}} P(\mathcal{T})P(\mathcal{B}|\mathcal{T})P(\mathcal{H}|\mathcal{B},\mathcal{T})P(\mathcal{S}|\mathcal{H},\mathcal{B},\mathcal{T})$$

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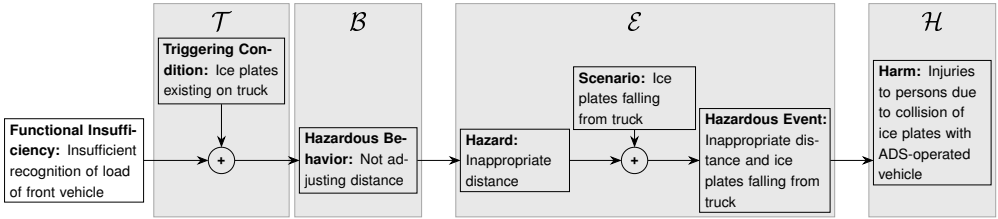
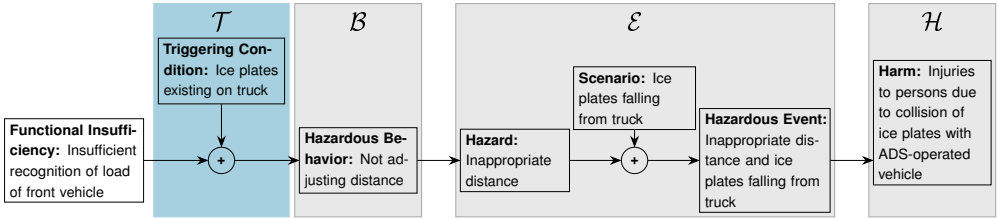


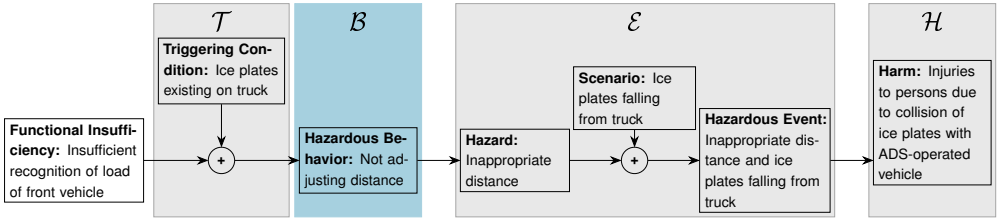
	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data					
Proving Ground					
Simulation					

Validation of the SOTIF using Quantitative Acceptance Criteria



	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data	✗				
Proving Ground	✗				
Simulation	✗				

Validation of the SOTIF using Quantitative Acceptance Criteria



	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data	✗	✗			
Proving Ground	✗	✓			
Simulation	✗	✓			

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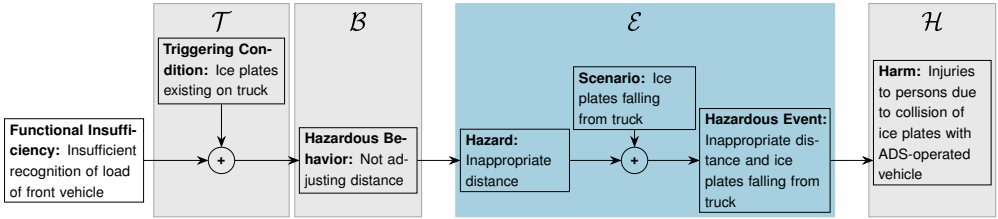
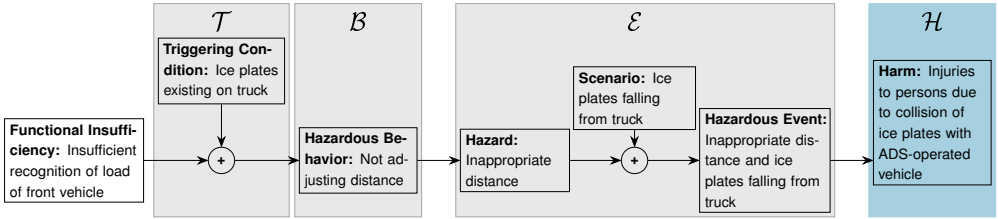


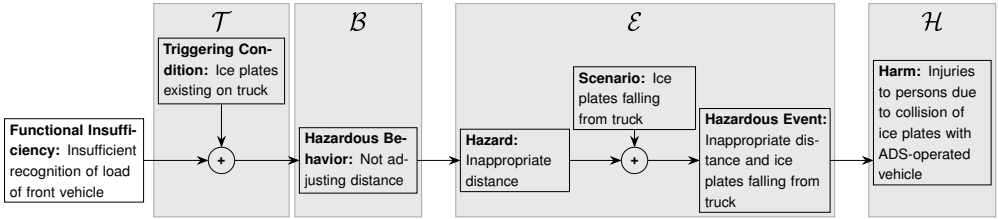
	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data	✗	✗	✓		
Proving Ground	✗	✓	(✗)		
Simulation	✗	✓	(✗)		

Validation of the SOTIF using Quantitative Acceptance Criteria



	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data	✗	✗	✓	(✓)	
Proving Ground	✗	✓	(✗)	✓	
Simulation	✗	✓	(✗)	✓	

Validation of the SOTIF using Quantitative Acceptance Criteria



	$P(\mathcal{T})$	$P(\mathcal{B}\|\mathcal{T})$	$P(\mathcal{E}\|\mathcal{B},\mathcal{T})$	$P(\mathcal{H}\|\mathcal{E},\mathcal{B},\mathcal{T})$	$P(\mathcal{S}\|\mathcal{H},\mathcal{E},\mathcal{B},\mathcal{T})$
Traffic Data	✗	✗	✓	(✓)	(✓)
Proving Ground	✗	✓	(✗)	✓	✓
Simulation	✗	✓	(✗)	✓	✓

Discussion

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- Does a scenario-based approach (sufficiently) reduce the validation effort?
- Is a quantitative risk assessment possible before employment?
- How to deal with updates – even post employment?

Thank you for the attention.

Contact:

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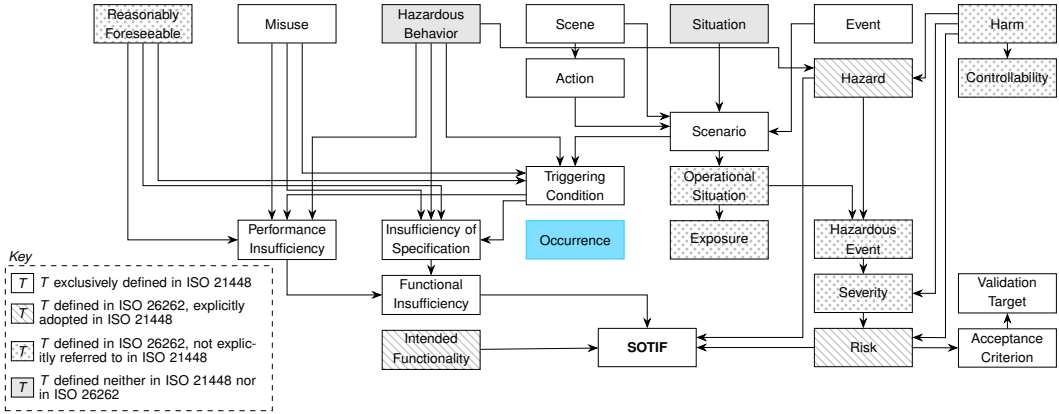
Institute of Systems Engineering for Future Mobility
lina.putze@dlr.de

Definition Occurrence



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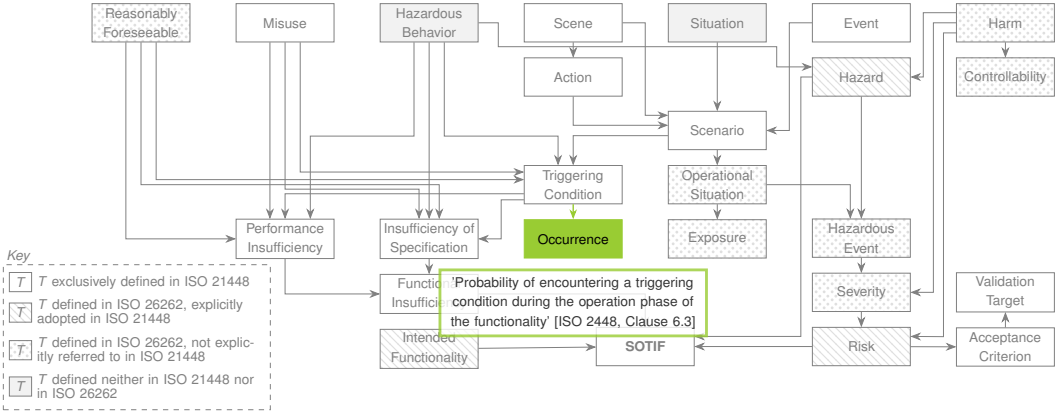
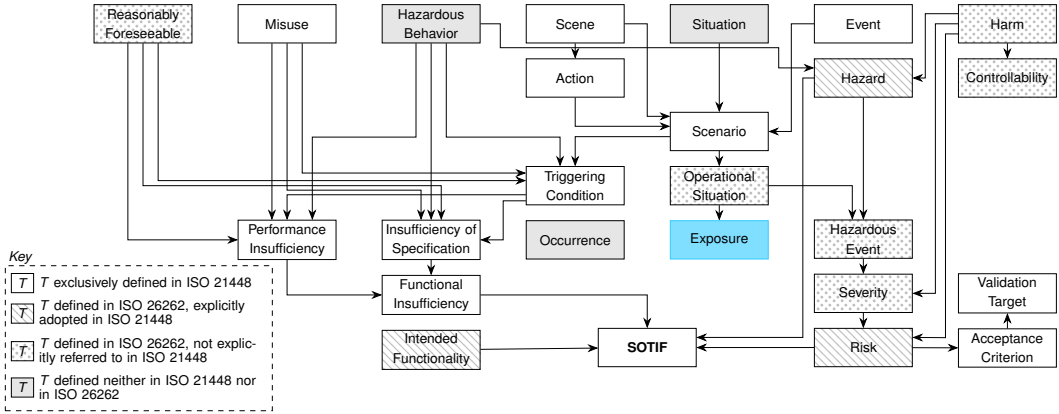


Definition Exposure



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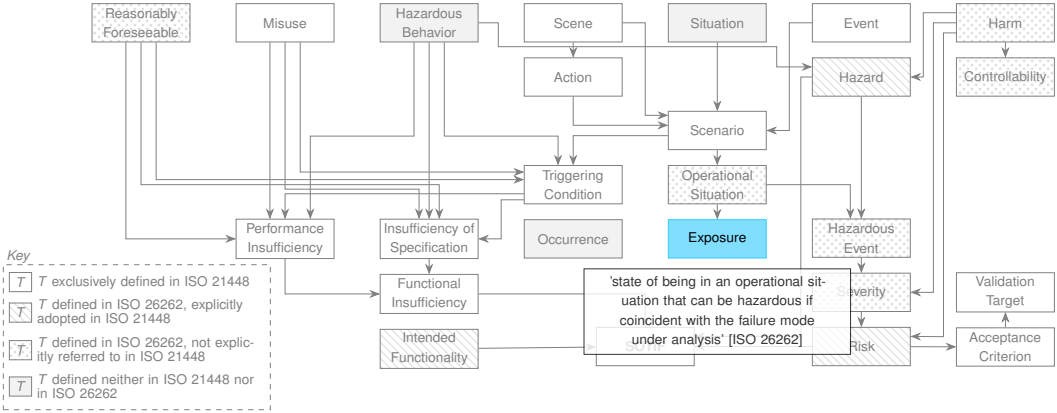

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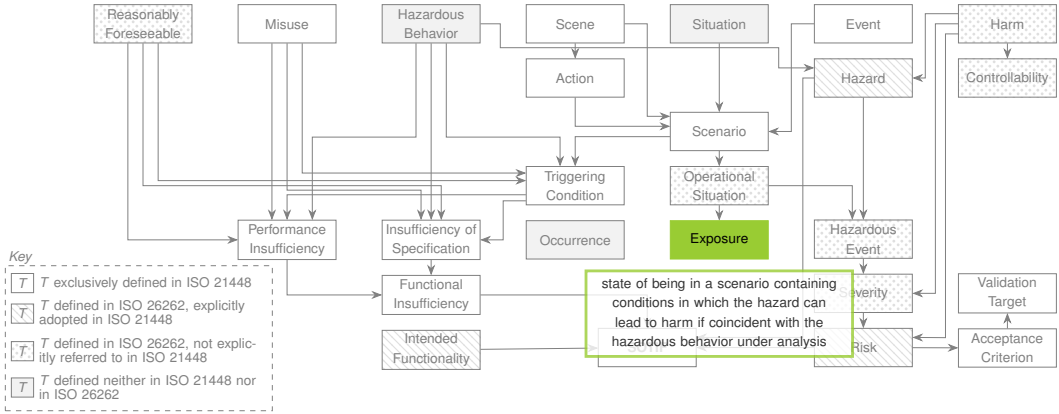
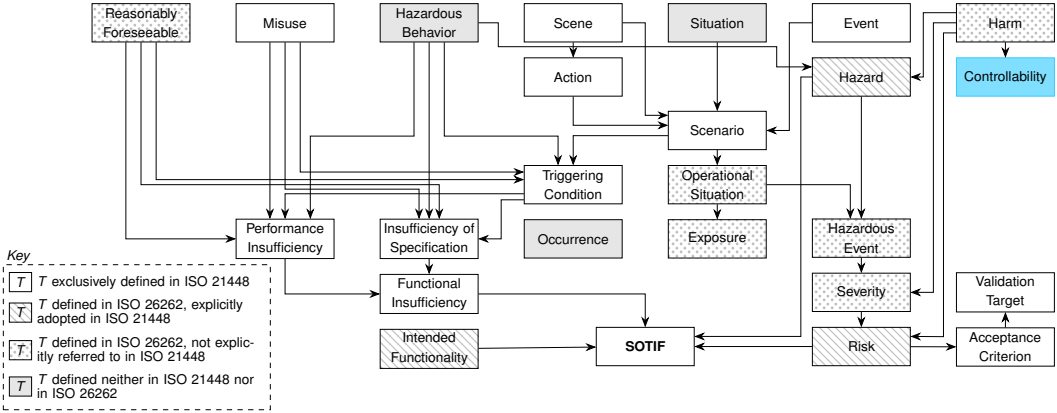
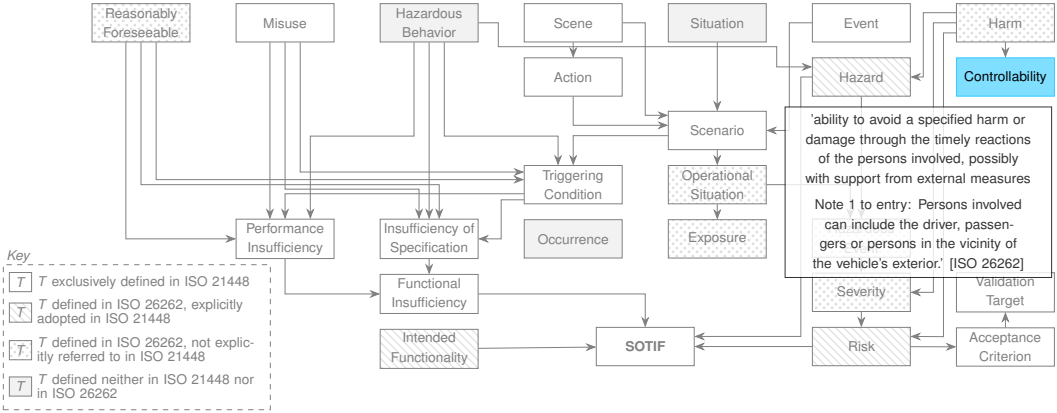


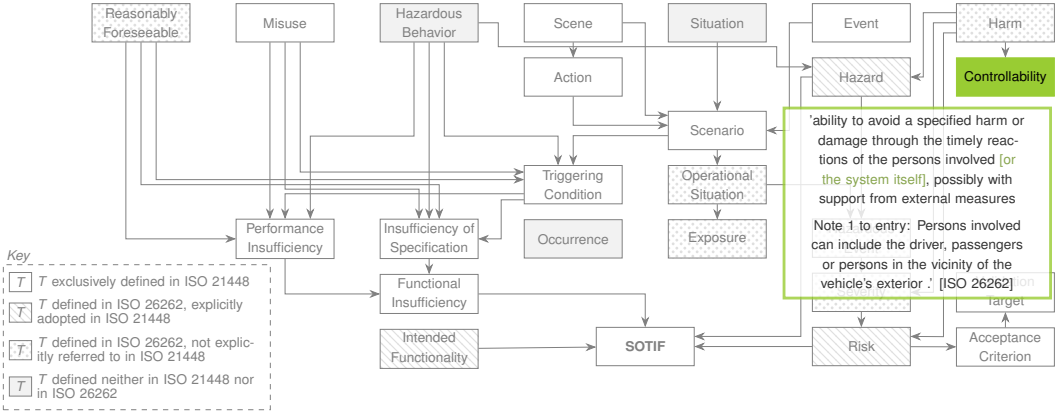
Definition Controllability



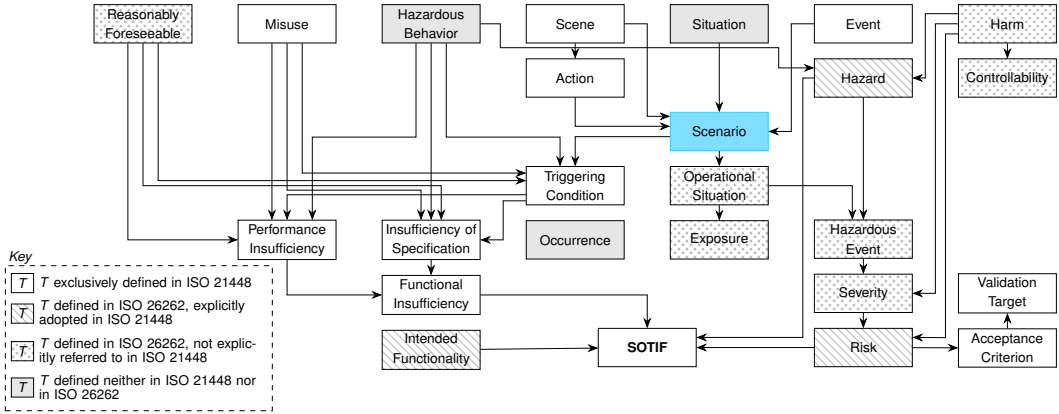
Definition Controllability



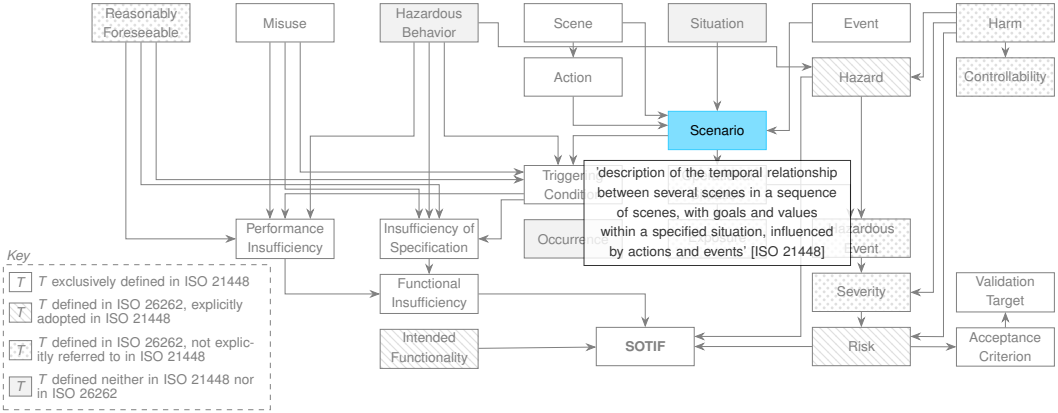
Definition Controllability



Definition Scenario



Definition Scenario



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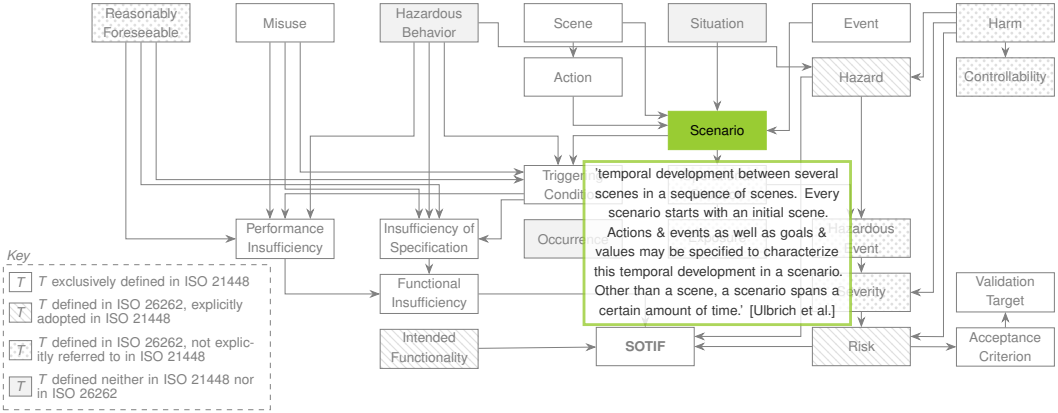
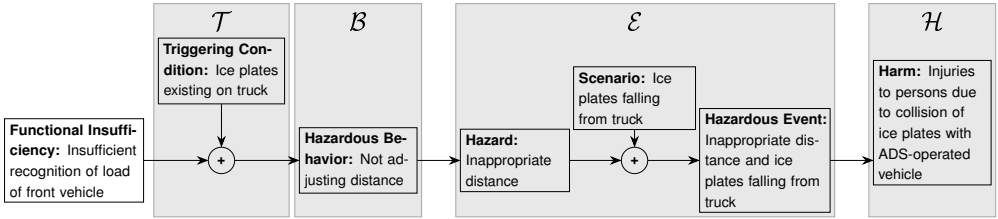
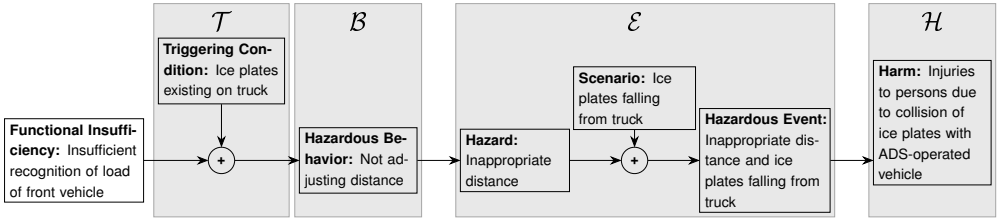


Derivation of Validation Targets



- Suggestion given in the Annex C.2 of the ISO 21448

Derivation of Validation Targets



- Suggestion given in the Annex C.2 of the ISO 21448
  - Solving the factorization of the acceptance criterion A_H for R_{HB}:

$$R_{HB} = \frac{A_H}{P_{E|HB} \cdot P_{C|E} \cdot P_{S|C}}$$

  - Estimation of a validation target τ that is sufficent for A_H with confidence level α:

$$\tau = -\ln(1-\alpha)/R_{HB}$$

References

[ISO 21448] International Organization for Standardization, "ISO 21448: Road vehicles – Safety of the intended functionality," 2022.

[ISO 26262] International Organization for Standardization, "ISO 26262: Road vehicles – Functional safety," 2018.

[ISO/IEC Guide 51] International Organization for Standardization, "ISO/IEC Guide 51: Safety aspects — Guidelines for their inclusion in standards," 2014.

[Ulbrich et al.] S. Ulbrich, T. Menzel, A. Reschka, F. Schuldt, and M. Maurer, "Defining and substantiating the terms scene, situation, and scenario for automated driving," in *2015 IEEE 18th international conference on intelligent transportation systems.* IEEE, 2015, pp. 982–988.