In Pursuit of Robust FMEA in the Design Phase

Capella Days 2023 – Session 3

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Introduction

Steven Huang (ESEP)

- ManTech International
- Engineering Fellow, Intelligent Systems Engineering

Alice Cellamare

- p2m berlin
- Process and site engineer, systems modeller

Cooperation & Collaboration as part of the INCOSE Mentoring Program

Outline

- Safety assessment methods
- Known tools for Capella
- Project scope and workflow
- Developed methods
- Example
- Conclusions

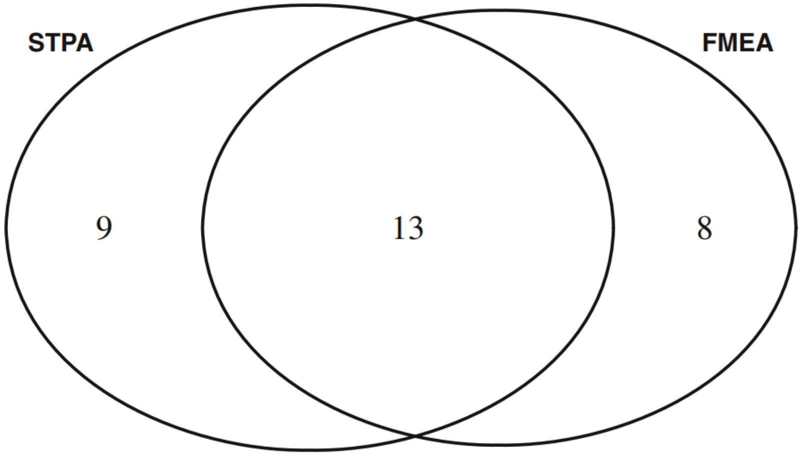
This symbol
means a
poll is coming!

✹

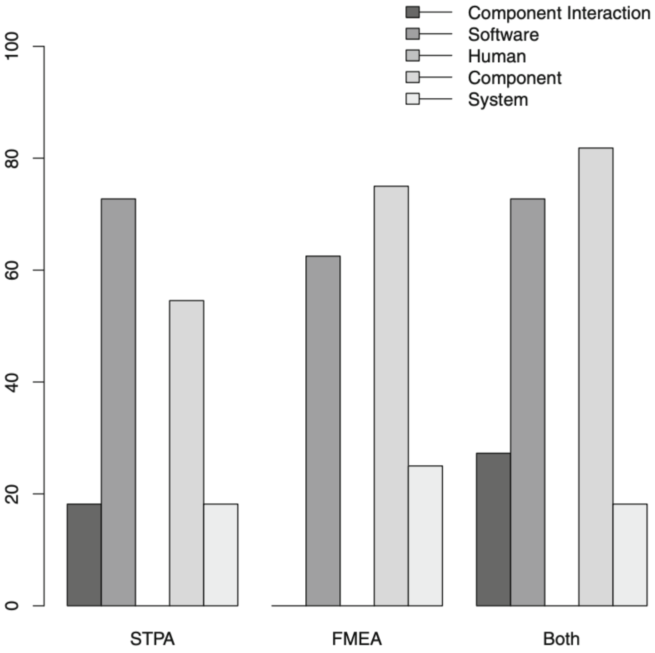
Safety Assessment Methods

Method	Description	Modeling Elements considered	Approach
FHA (Fault Hazard Analysis)	Evaluates functions to identify and classify potential failures	Functions	top-down
FTA (Fault Tree Analysis)	Deductive analysis focusing on causal relationships, using Boolean logic	Functions and their relationships	top-down
STPA (Systems Theoretic Process Analysis)	A systems approach focusing on unsafe control actions	Control actions	top-down
FMEA (Failure Mode and Effects Analysis)	A multi-perspective approach with focus	Components, subsystems, functions, processes	bottom-up

What about completeness?



Number of common and distinct hazards identified by FMEA and STPA



Classification of the identified hazards

Reference [3]

Known tools for Capella

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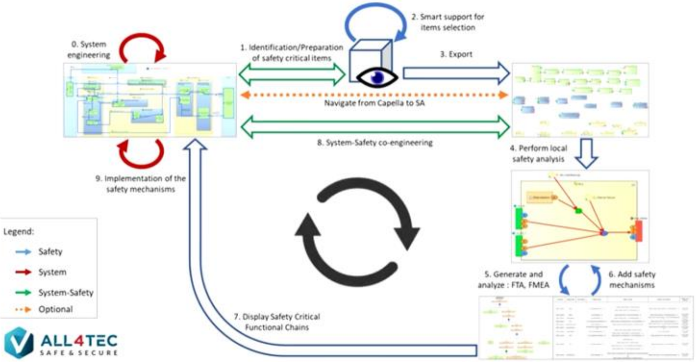
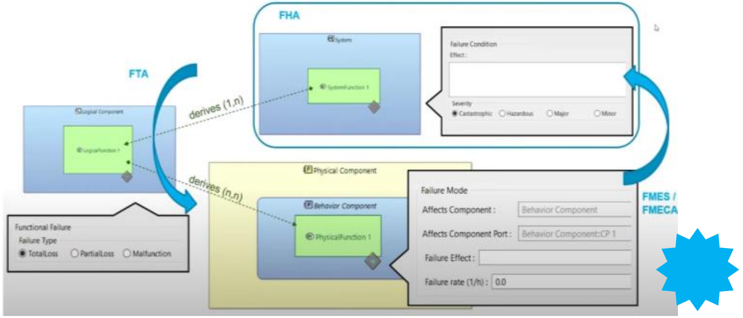
Name	Implemented methods	ARCADIA diagrams
Safety Architect	FHA FTA FMEA	[SAB] →“SFBD“ [PAB] [PAB]
ATICA4 CAPELLA	FHA FTA FMEA	[SFBD], [SAB] [LAB] [PAB]


0. System engineering
1. Identification/Preparation of safety critical items
2. Smart support for items selection
3. Export
Navigate from Capella to SA
8. System-Safety co-engineering
4. Perform local safety analysis
9. Implementation of the safety mechanisms
Legend:
Safety
System
System-Safety
Optional
5. Generate and analyze : FTA, FMEA
6. Add safety mechanisms
7. Display Safety Critical Functional Chains
ALL4TEC
SAFE & SECURE



References [8] and [9]

Project scope

- FAILURE IDENTIFICATION (as opposed to EVALUATION) as priority: this method does not aim at substituting any safety analysis method, but rather at providing the modeller with a model-generated failure list at the start

- „QUANTITY APPROACH“: no qualitative criteria is applied in the failure identification phase. All failure which „the model can imagine“ are listed

- IGNORING CAUSES at first: this approach does not consider possible failure causes. These will be considered in the evaluation phase.

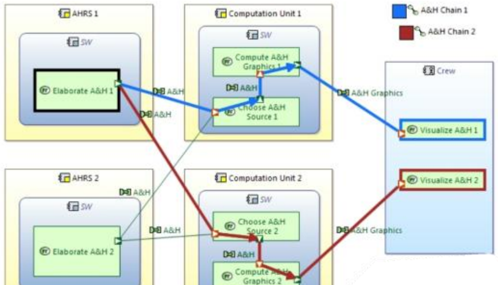
- Tailoring to PHYSICAL ARCHITECTURE: only this layer was considered

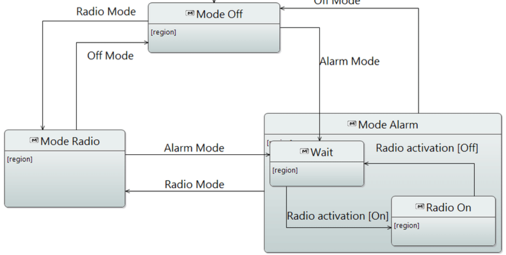
Relevant model elements

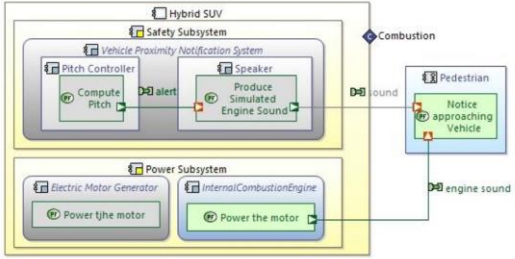
- Functional exchanges, functional chains, exchange scenarios

- Modes / States with triggers and entry/do/exit functions

- Configurations / Situations







References [4], [5] and [6]

The VPMS Viewpoint

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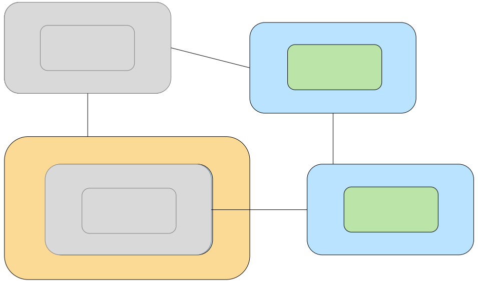
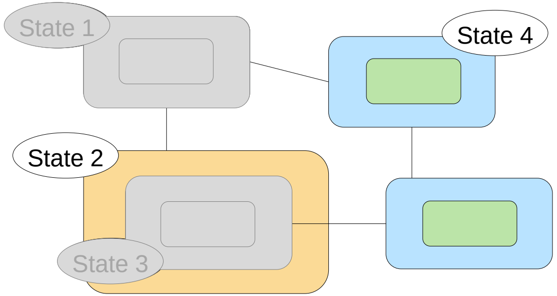
Configuration



= subset of the system

Situation



= collection of states

Project activities

- Determine failure types
- Define ways of identifying failures (depending on type)
- Define ways of assessing the consequences of each failure
- Define ways of rendering the analysis results to a human evaluator
- Code this procedure in python (py-capellambse)
- Test the results on a company model

Failure Types

Name	Description	ARCADIA „translation“	Reference diagram (PA)
Component failure	A component becomes unavailable	A component, a function, a links or an exchange are not available	[PAB]
Function or process failure	A function or process becomes unavailable	A function or state/mode is realized at an unwanted time; An expected function or state/mode realization does not occur	[ES], [PFCD]
Content failure	A message, result or parameter becomes wrong	A component attribute is set to an unexpected value; An exchange item attribute is set to an unexpected value	[ES],

Component failure analysis

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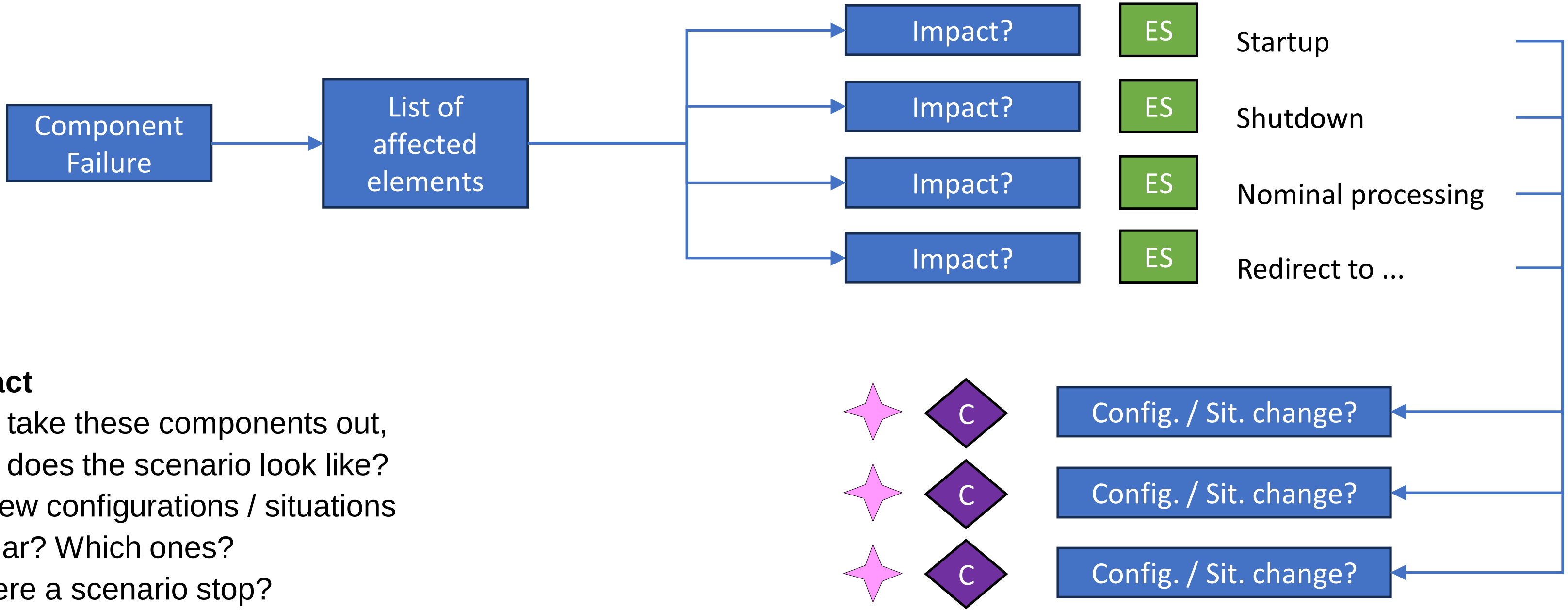

Impact
If we take these components out, what does the scenario look like? Do new configurations / situations appear? Which ones?
Is there a scenario stop?

Analysis of affected elements

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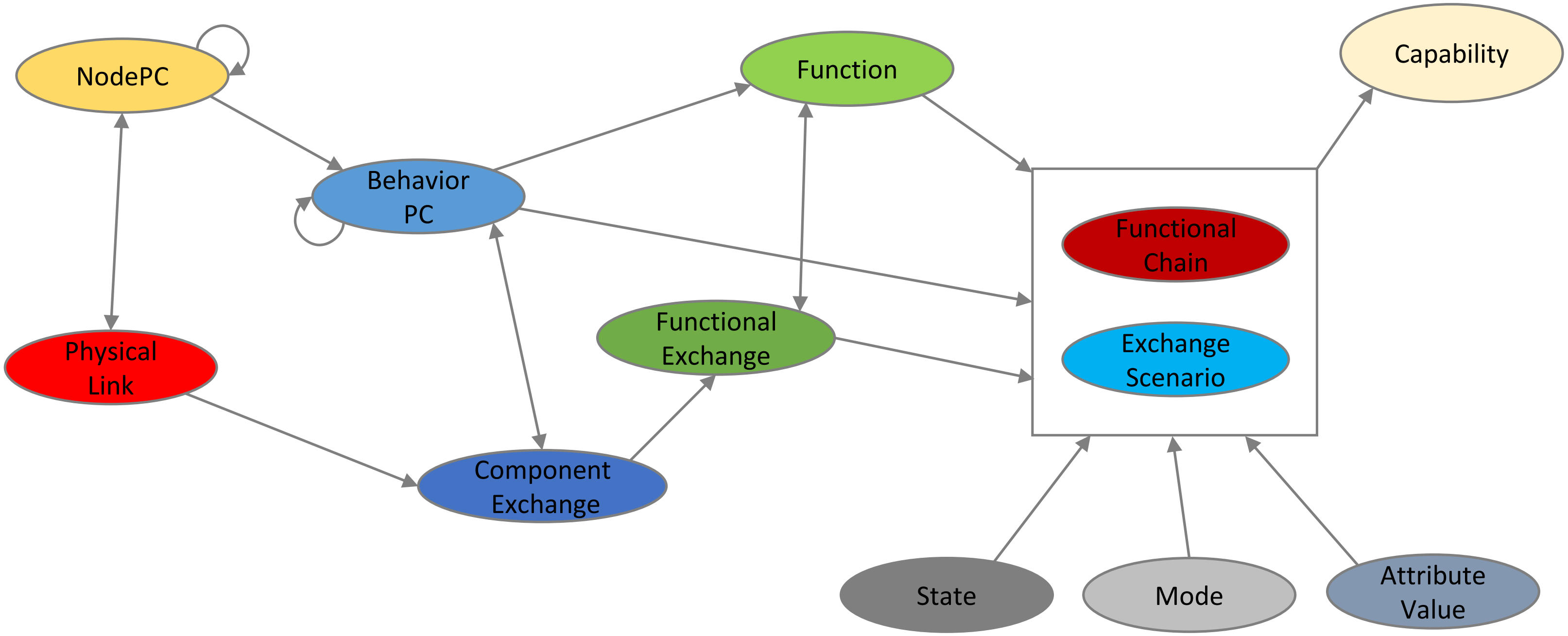
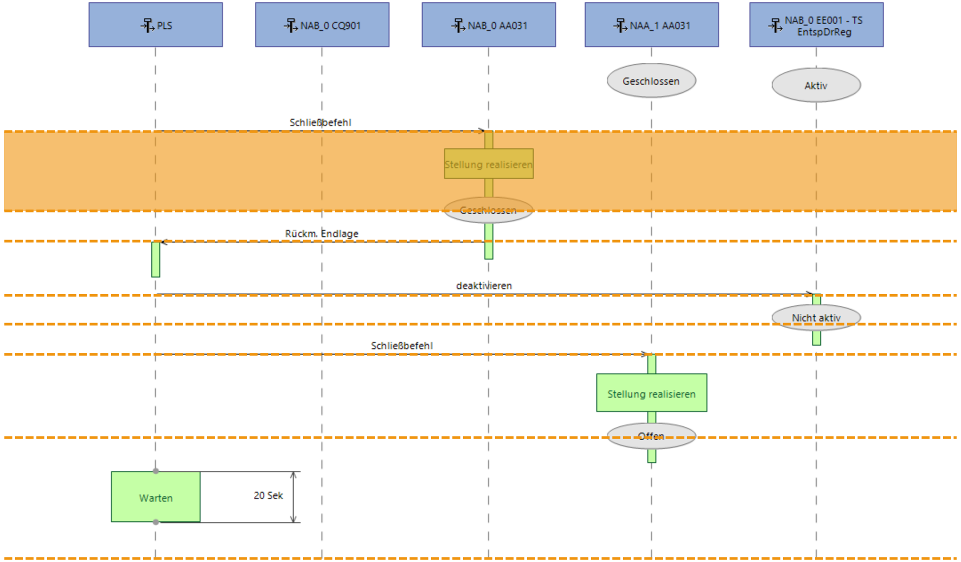
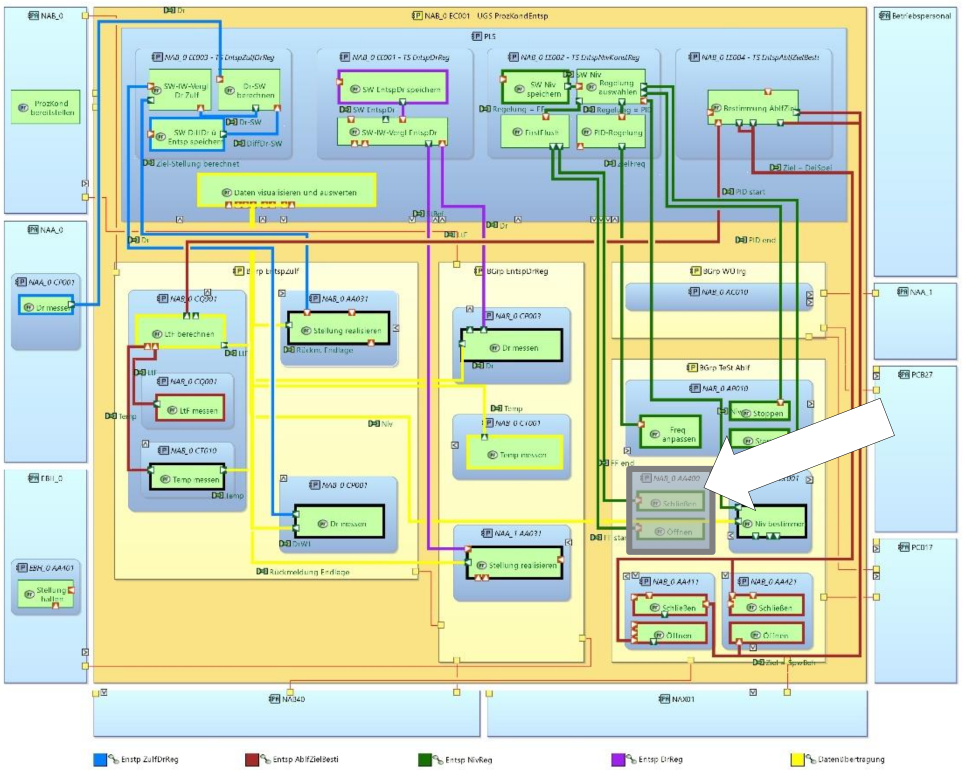


Scenario breakdown



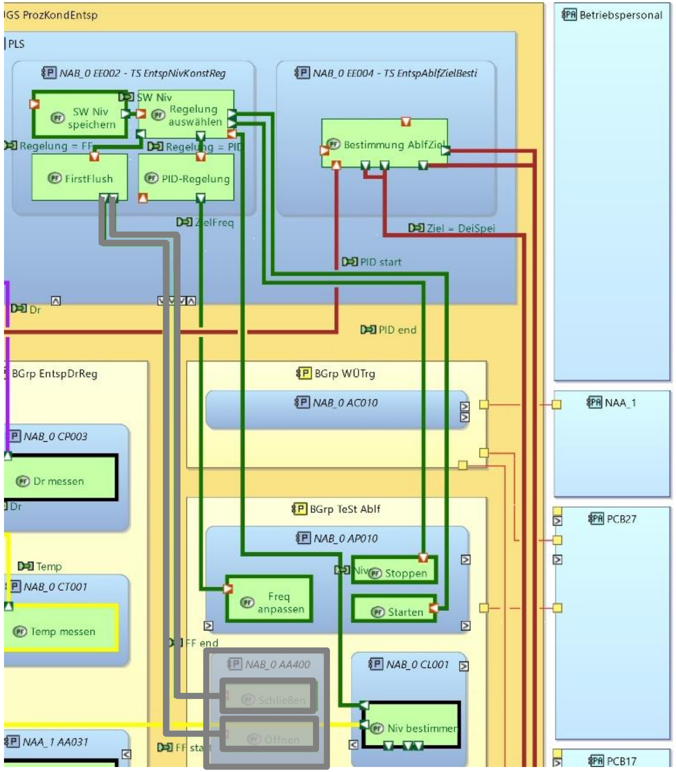
Example: component failure

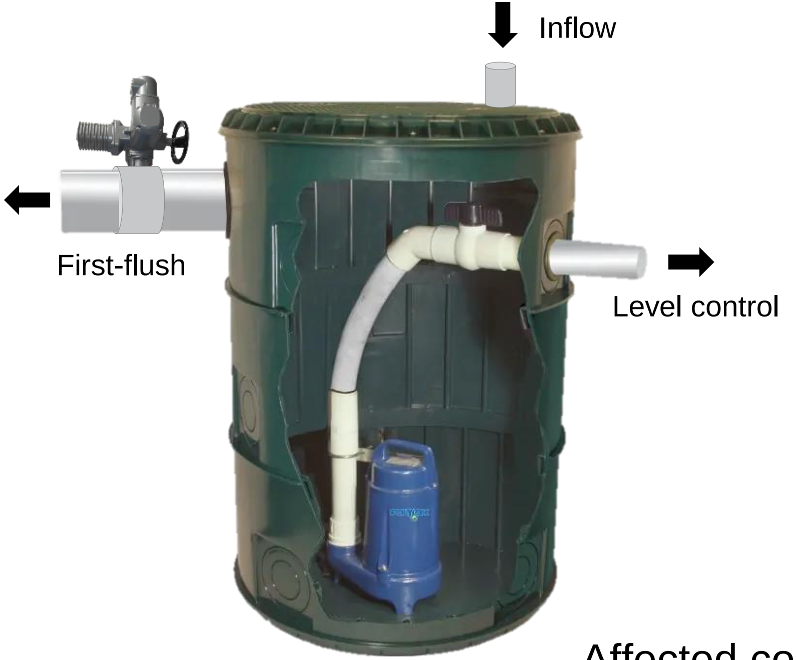


Failure identification:

„NAB_0 AA400„ is not available

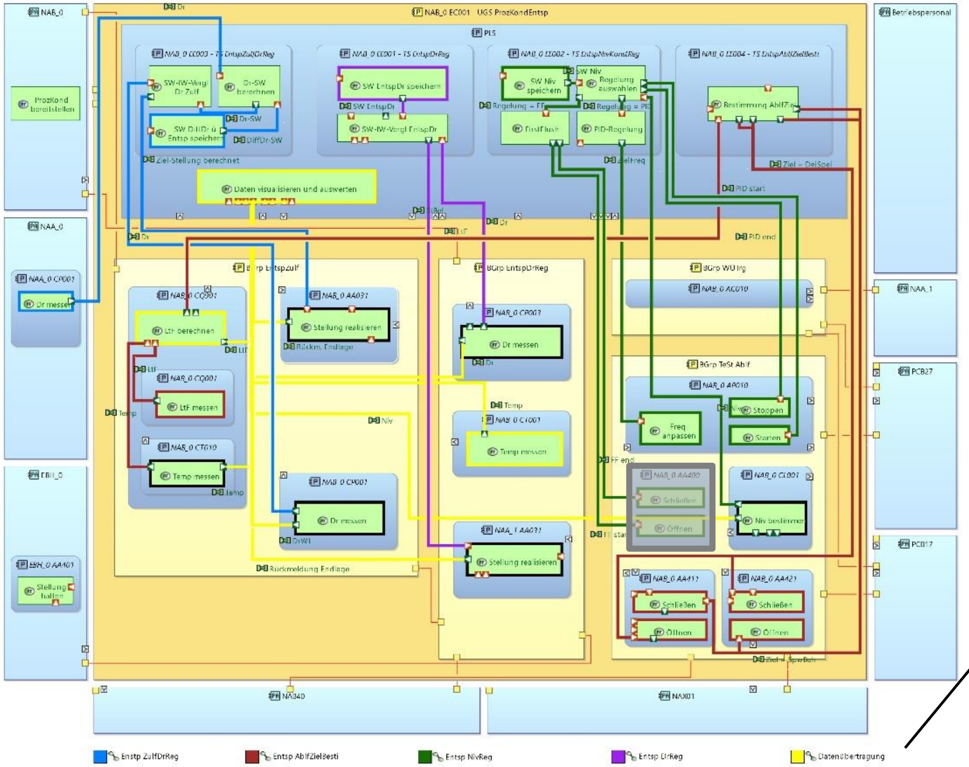
Example: component failure





Affected components identification

Example: component failure



🟦 Enstp ZulfDrReg

🟥 Entsp AblfZielBesti

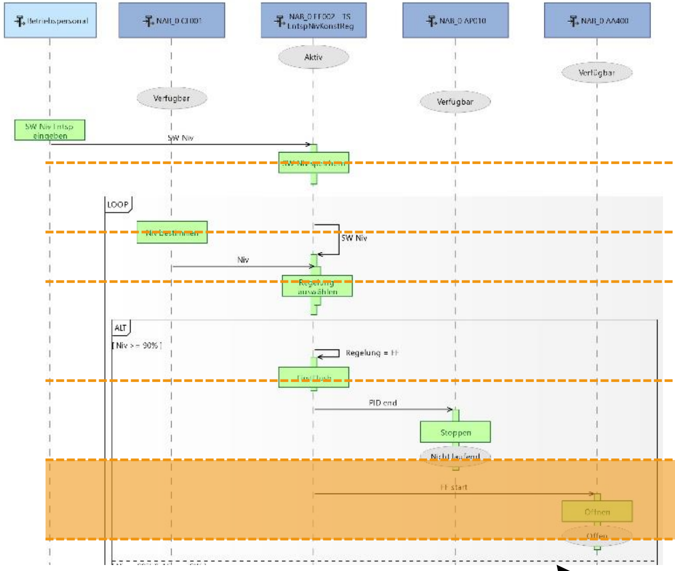
🟩 Entsp NivReg

🟪 Entsp DrReg

🟨 Datenübertragung

Identification of affected Exchange Scenarios

Example: component failure



NAB_0 CL001	NAB_0 EE002 - TS EntspNivKonstReg	NAB_0 AP010		NAB_0 AA400		
SM0	**SM1**	**SM0**	**SM1**	**SM0**	**SM1**	1.1
available	active	available	?	available	?	1.2
available	active	available	?	available	?	1.3
available	active	available	?	available	?	1.4
available	active	available	?	available	?	1.5
available	active	available	not running	Not available	?	1.6
available	active	available	not running	Not available	?	1.7

Control action: activate first-flush when >90% full

Entsp NivReg

[ES] analysis

Example: component failure

NAB_0 CL001	NAB_0 EE002 - TS EntspNivKonstReg	NAB_0 AP010		NAB_0 AA400		
SM0	**SM1**	**SM0**	**SM1**	**SM0**	**SM1**	1.1
available	active	available	?	available	?	1.2
available	active	available	?	available	?	1.3
available	active	available	?	available	?	1.4
available	active	available	?	available	?	1.5
available	active	available	not running	not available	?	1.6
available	active	available	not running	not available	?	1.7

NAB_0 CL001	NAB_0 EE002 - TS EntspNivKonstReg	NAB_0 AP010		NAB_0 AA400		
available	active	available	not running	not available	closed	1.6
available	active	available	not running	not available	closed	1.7

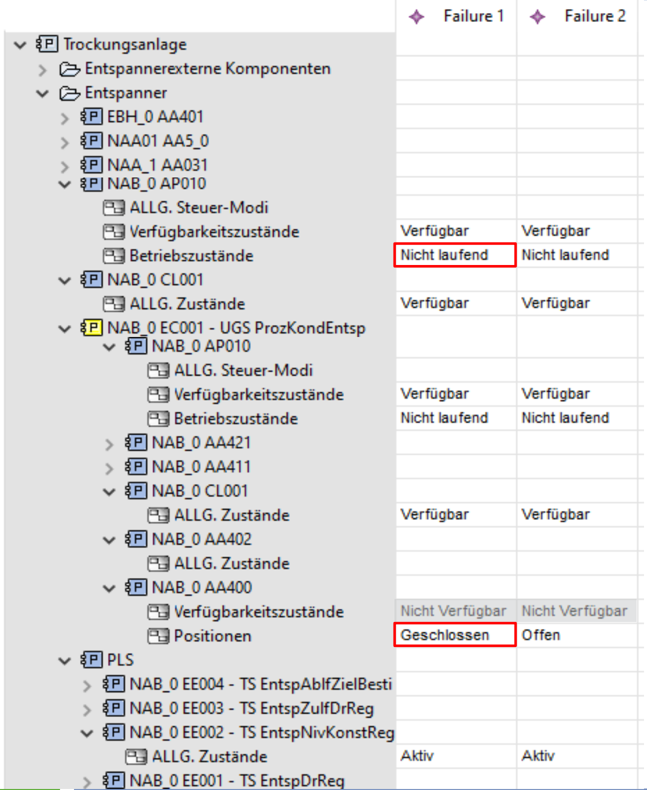
Situation: Failure 1

NAB_0 CL001	NAB_0 EE002 - TS EntspNivKonstReg	NAB_0 AP010		NAB_0 AA400		
available	active	available	not running	not available	open	1.6
available	active	available	not running	not available	open	1.7

Situation: Failure 2

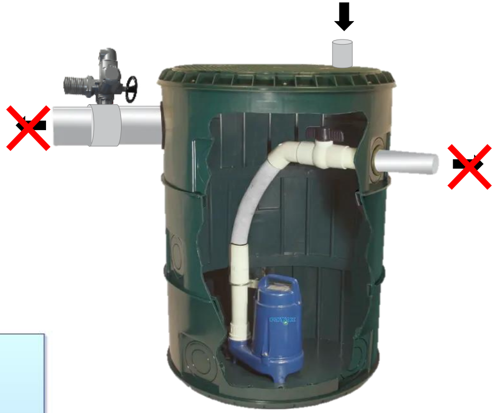
[ES] analysis

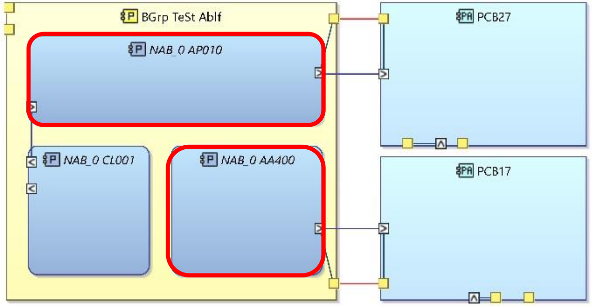
Example: component failure



	✦ Failure 1	✦ Failure 2
Trockungsanlage		
Entspannerexterne Komponenten		
Entspanner		
EBH_0 AA401		
NAA01 AA5_0		
NAA_1 AA031		
NAB_0 AP010		
ALLG. Steuer-Modi		
Verfügbarkeitszustände	Verfügbar	Verfügbar
Betriebszustände	Nicht laufend	Nicht laufend
NAB_0 CL001		
ALLG. Zustände	Verfügbar	Verfügbar
NAB_0 EC001 - UGS ProzKondEntsp		
NAB_0 AP010		
ALLG. Steuer-Modi		
Verfügbarkeitszustände	Verfügbar	Verfügbar
Betriebszustände	Nicht laufend	Nicht laufend
NAB_0 AA421		
NAB_0 AA411		
NAB_0 CL001		
ALLG. Zustände	Verfügbar	Verfügbar
NAB_0 AA402		
ALLG. Zustände		
NAB_0 AA400		
Verfügbarkeitszustände	Nicht Verfügbar	Nicht Verfügbar
Positionen	Geschlossen	Offen
PLS		
NAB_0 EE004 - TS EntspAblfZielBesti		
NAB_0 EE003 - TS EntspZulfDrReg		
NAB_0 EE002 - TS EntspNivKonstReg		
ALLG. Zustände	Aktiv	Aktiv
NAB_0 EE001 - TS EntspDrReg		

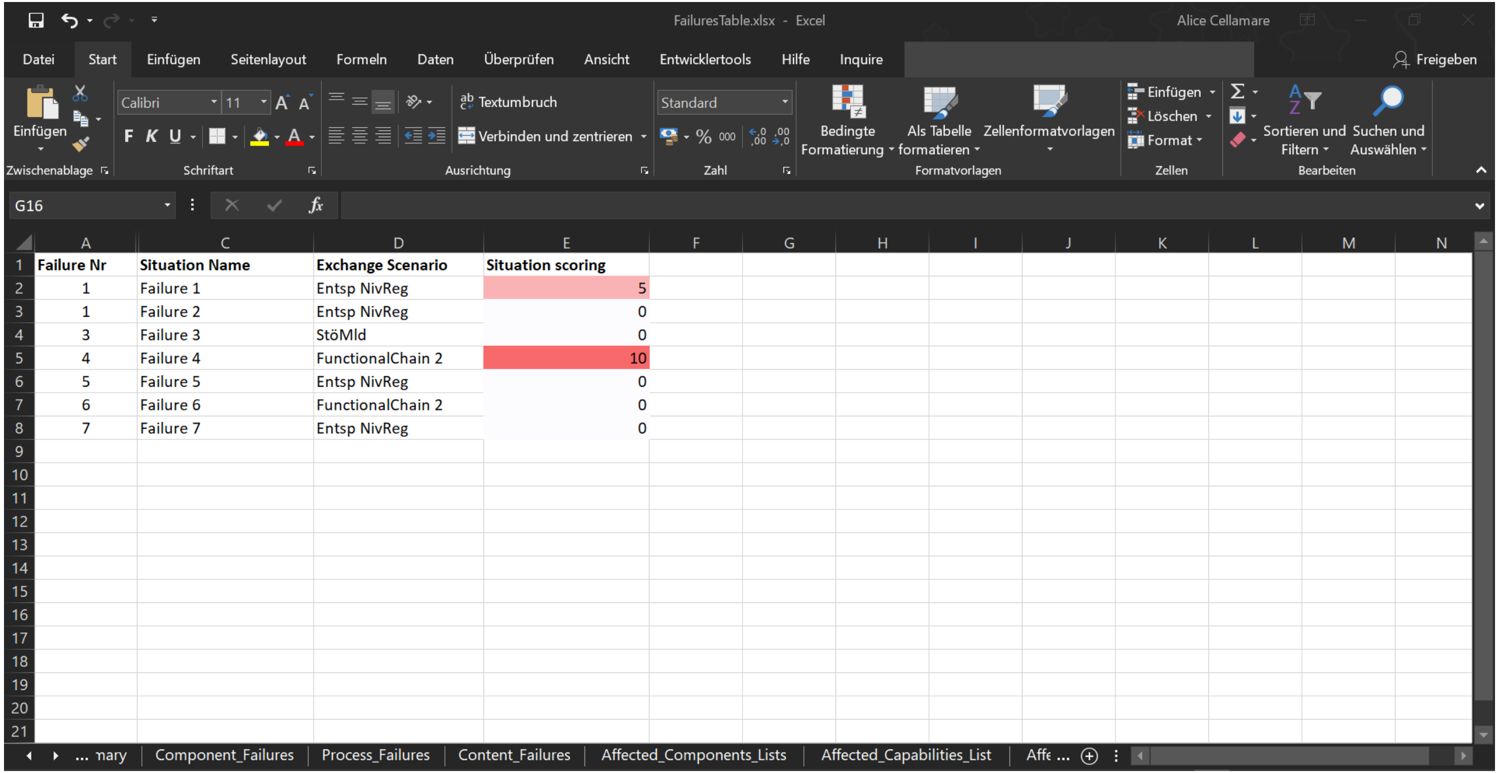
✦ Failure 1





Consequences as Situations

Example: component failure

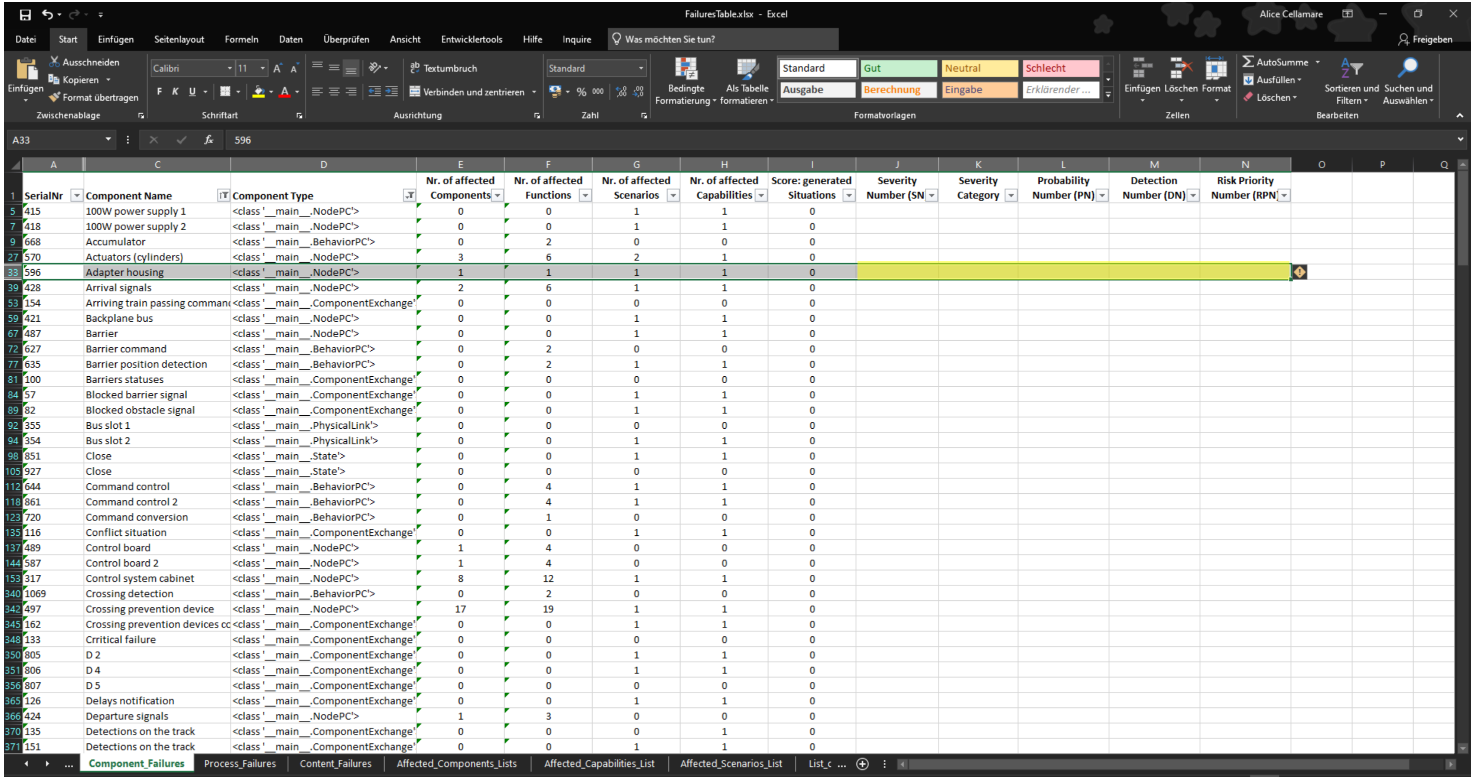


Failure Nr	Situation Name	Exchange Scenario	Situation scoring
1	Failure 1	Entsp NivReg	5
1	Failure 2	Entsp NivReg	0
3	Failure 3	StöMld	0
4	Failure 4	FunctionalChain 2	10
5	Failure 5	Entsp NivReg	0
6	Failure 6	FunctionalChain 2	0
7	Failure 7	Entsp NivReg	0

Situation scoring

Example: component failure

Failure Evaluation



	SerialNr	Component Name	Component Type	Nr. of affected Components	Nr. of affected Functions	Nr. of affected Scenarios	Nr. of affected Capabilities	Score: generated Situations	Severity Number (SN	Severity Category	Probability Number (PN)	Detection Number (DN)	Risk Priority Number (RPN
5	415	100W power supply 1	<class '__main__.NodePC'>	0	0	1	1	0					
7	418	100W power supply 2	<class '__main__.NodePC'>	0	0	1	1	0					
9	668	Accumulator	<class '__main__.BehaviorPC'>	0	2	0	0	0					
27	570	Actuators (cylinders)	<class '__main__.NodePC'>	3	6	2	1	0					
33	596	Adapter housing	<class '__main__.NodePC'>	1	1	1	1	0					
39	428	Arrival signals	<class '__main__.NodePC'>	2	6	1	1	0					
53	154	Arriving train passing comman	<class '__main__.ComponentExchange'	0	0	0	0	0					
59	421	Backplane bus	<class '__main__.NodePC'>	0	0	1	1	0					
67	487	Barrier	<class '__main__.NodePC'>	0	0	1	1	0					
72	627	Barrier command	<class '__main__.BehaviorPC'>	0	2	0	0	0					
77	635	Barrier position detection	<class '__main__.BehaviorPC'>	0	2	1	1	0					
81	100	Barriers statuses	<class '__main__.ComponentExchange'	0	0	0	0	0					
84	57	Blocked barrier signal	<class '__main__.ComponentExchange'	0	0	1	1	0					
89	82	Blocked obstacle signal	<class '__main__.ComponentExchange'	0	0	1	1	0					
92	355	Bus slot 1	<class '__main__.PhysicalLink'>	0	0	0	0	0					
94	354	Bus slot 2	<class '__main__.PhysicalLink'>	0	0	1	1	0					
98	851	Close	<class '__main__.State'>	0	0	1	1	0					
105	927	Close	<class '__main__.State'>	0	0	0	0	0					
112	644	Command control	<class '__main__.BehaviorPC'>	0	4	1	1	0					
118	861	Command control 2	<class '__main__.BehaviorPC'>	0	4	1	1	0					
123	720	Command conversion	<class '__main__.BehaviorPC'>	0	1	0	0	0					
135	116	Conflict situation	<class '__main__.ComponentExchange'	0	0	1	1	0					
137	489	Control board	<class '__main__.NodePC'>	1	4	0	0	0					
144	587	Control board 2	<class '__main__.NodePC'>	1	4	0	0	0					
153	317	Control system cabinet	<class '__main__.NodePC'>	8	12	1	1	0					
340	1069	Crossing detection	<class '__main__.BehaviorPC'>	0	2	0	0	0					
342	497	Crossing prevention device	<class '__main__.NodePC'>	17	19	1	1	0					
345	162	Crossing prevention devices cc	<class '__main__.ComponentExchange'	0	0	1	1	0					
348	133	Crritical failure	<class '__main__.ComponentExchange'	0	0	0	0	0					
350	805	D 2	<class '__main__.ComponentExchange'	0	0	1	1	0					
351	806	D 4	<class '__main__.ComponentExchange'	0	0	1	1	0					
356	807	D 5	<class '__main__.ComponentExchange'	0	0	0	0	0					
365	126	Delays notification	<class '__main__.ComponentExchange'	0	0	1	1	0					
366	424	Departure signals	<class '__main__.NodePC'>	1	3	0	0	0					
370	135	Detections on the track	<class '__main__.ComponentExchange'	0	0	0	1	0					
371	151	Detections on the track	<class '__main__.ComponentExchange'	0	0	1	1	0					

Conclusions

- Overall project impression
- Feasibility
- Critique

We welcome your feedback to improve our evolving approach for holistic fault analysis for Arcadia users

Stay tuned for session 4! →

Efficient and Comprehensive FMECAs: Harnessing the Power of MBSE Models in Capella

Thank you for your participation!

If you have any questions or would like to connect, please contact:

steven.huang@mantech.com alice.cellamare@p2mberlin.de

References

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3. Sulaman, S., Beer, A., Felderer, M. et al. Comparison of the FMEA and STPA safety analysis methods–a case study. Software Qual J 27, 349–387 (2019)

4. Voirin, Jean-Luc & Bonnet, Stéphane & Exertier, Daniel & Normand, Véronique. (2016). Simplifying (and enriching) SysML to perform functional analysis and model instances. INCOSE International Symposium. 26. 253-268. 10.1002/j.2334-5837.2016.00158.x

5. Duhil, Christophe & Babau, Jean-Philippe & Lepicier, Eric & Voirin, Jean-Luc & Navas, Juan. (2020). Chaining Model Transformations for System Model Verification: Application to Verify Capella Model with Simulink. 279-286. 10.5220/0008902302790286

References

6. Modeling states and modes with Arcadia and Capella: method and tool perspectives | Webinar Capella: https://www.youtube.com/watch?v=74eKWrSs8hI

7. https://github.com/eclipse/capella-vpms/

8. https://www.anzenengineering.com/mbse-mbsa/

9. https://www.all4tec.com/en/safety-architect-fmeca-fta-sofware/

EXTRA SLIDES

Analysis output

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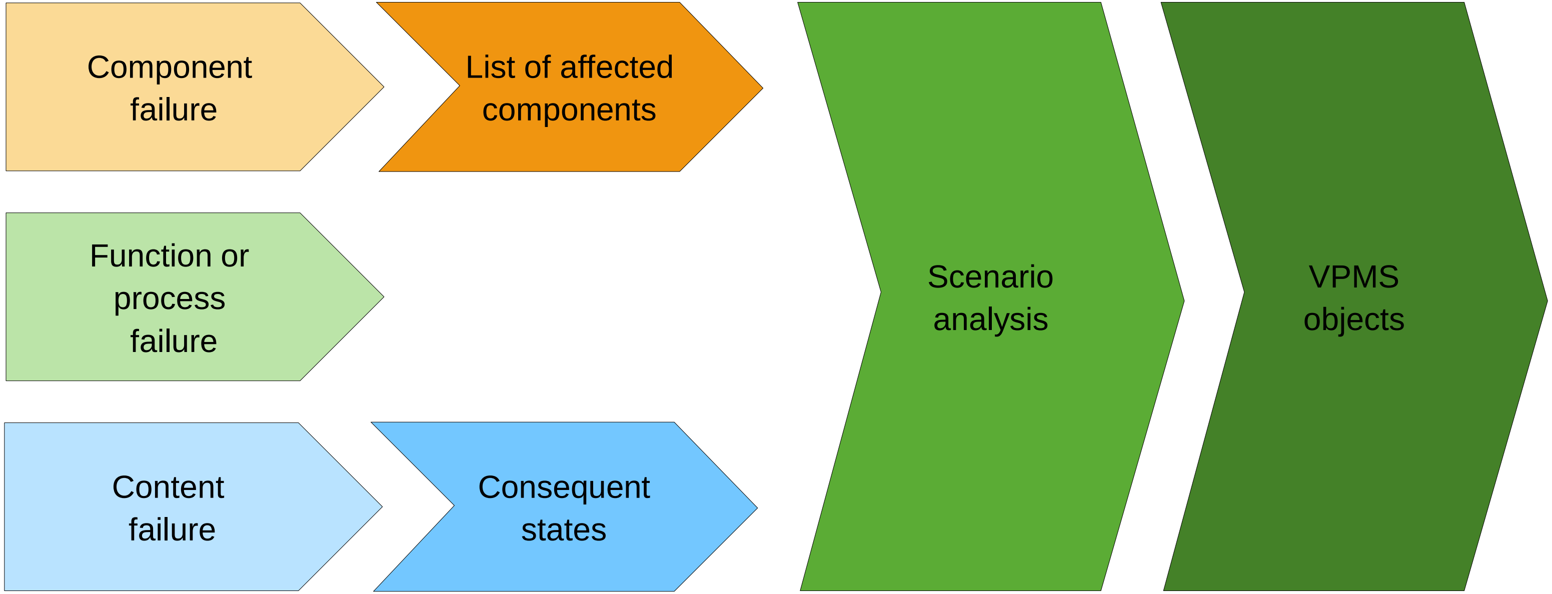
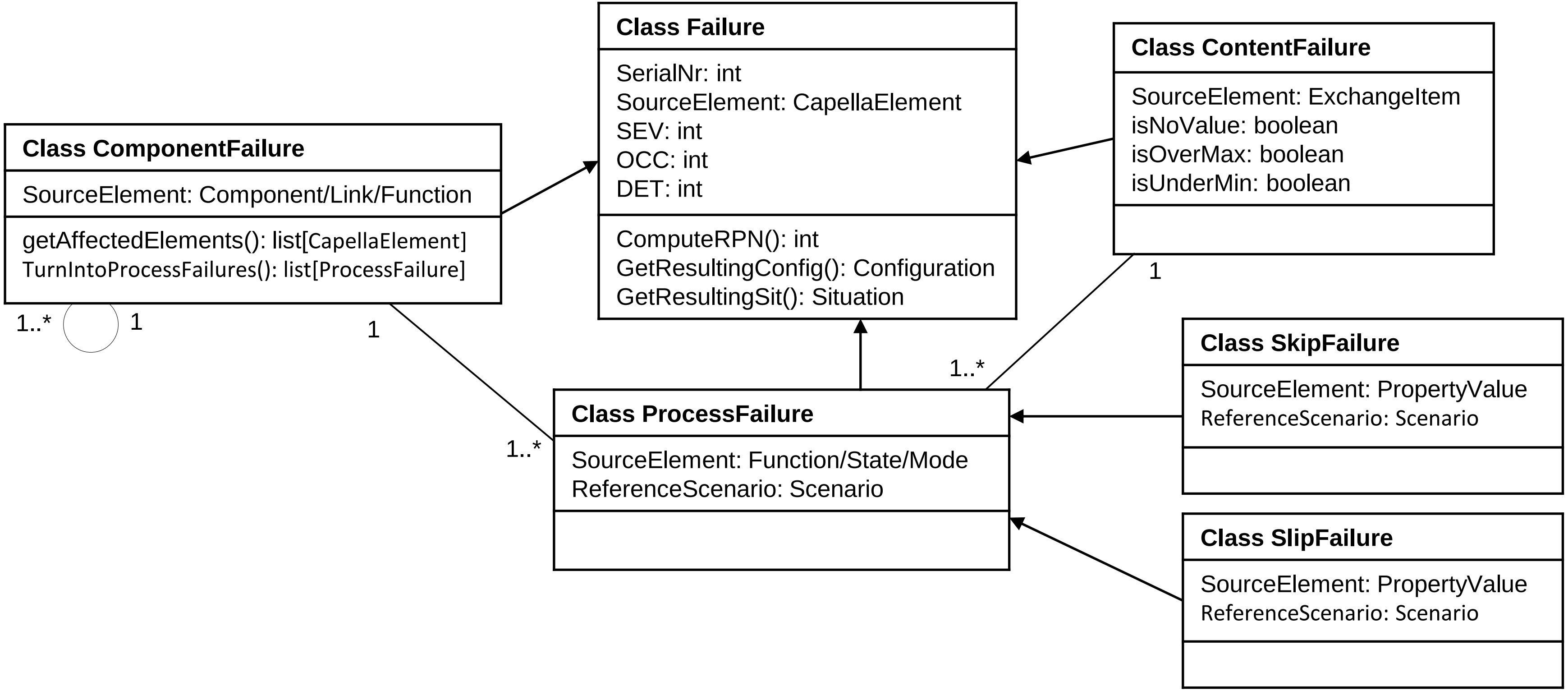


Points to expand

- Failure combinations
- Situation diagrams?
- Limits of the approach: any failure modes that would only come up through, for example, physical modelling?
- Other

Failure classes


Class Failure
SerialNr: int
SourceElement: CapellaElement
SEV: int
OCC: int
DET: int
ComputeRPN(): int
GetResultingConfig(): Configuration
GetResultingSit(): Situation
Class ContentFailure
SourceElement: ExchangeItem
isNoValue: boolean
isOverMax: boolean
isUnderMin: boolean
Class ComponentFailure
SourceElement: Component/Link/Function
getAffectedElements(): list[CapellaElement]
TurnIntoProcessFailures(): list[ProcessFailure]
1..*
1
1
1
1..*
Class SkipFailure
SourceElement: PropertyValue
ReferenceScenario: Scenario
Class ProcessFailure
SourceElement: Function/State/Mode
ReferenceScenario: Scenario
1..*
Class SlipFailure
SourceElement: PropertyValue
ReferenceScenario: Scenario

Scenario breakdown w. ALT

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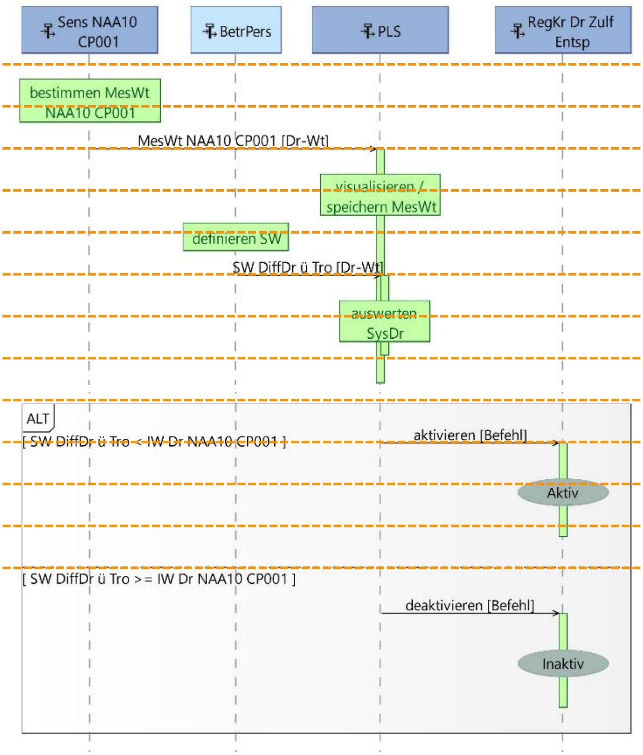
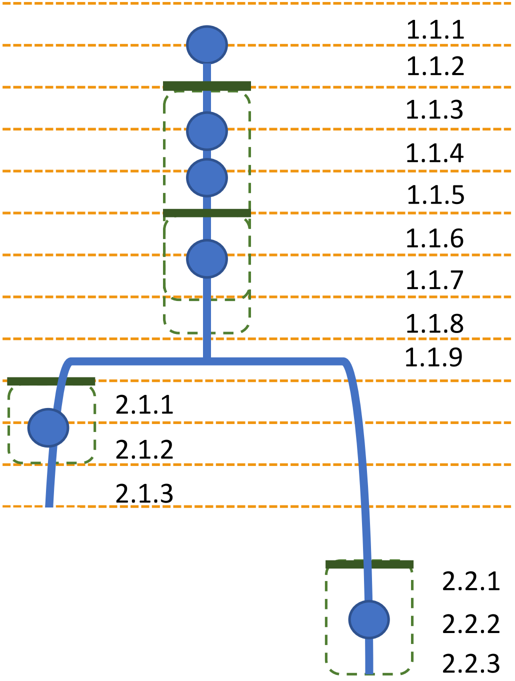
	Sens NAA10 CP001	BetrPers	PLS	RegKr Dr Zulf Entsp
1.1.1	available		available	?
1.1.2	available		available	?
1.1.3	available		available	?
1.1.4	available		available	?
1.1.5	available		available	?
1.1.6	available		available	?
1.1.7	available		available	?
1.1.8	available		available	?
1.1.9	available		available	?
2.1.1	available		available	?
2.1.2	available		available	Active
2.1.3	available		available	Active



Sens NAA10 CP001
BetrPers
PLS
RegKr Dr Zulf Entsp
bestimmen MesWt NAA10 CP001
MesWt NAA10 CP001 [Dr-Wt]
visualisieren / speichern MesWt
definieren SW
SW DiffDr ü Tro [Dr-Wt]
auswerten SysDr
ALT
[SW DiffDr ü Tro < IW Dr NAA10 CP001]
aktivieren [Befehl]
Aktiv
[SW DiffDr ü Tro >= IW Dr NAA10 CP001]
deaktivieren [Befehl]
Inaktiv



1.1.1
1.1.2
1.1.3
1.1.4
1.1.5
1.1.6
1.1.7
1.1.8
1.1.9
2.1.1
2.1.2
2.1.3
2.2.1
2.2.2
2.2.3