The Challenge of System-of-Systems: FROM DEFINING THE PROBLEM TO SHAPING THE SOLUTION ARCHITECTURE

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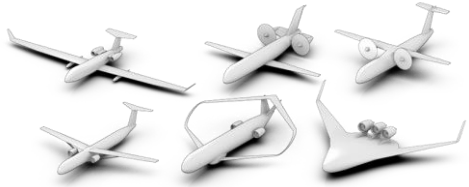
Jasamin Akbari | Institute of System Architectures in Aeronautics (SL) | German Aerospace Center (DLR)

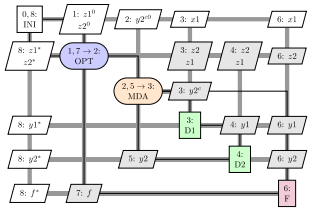
DLR

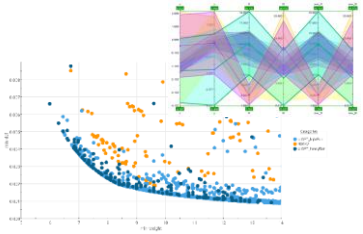
State of the Art
AGILE Framework

*An **MBSE** process, integrating **MDO** and **Trade-Space Exploration***

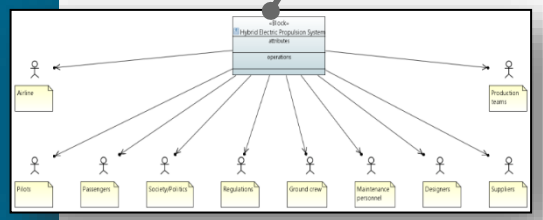
Problem Definition → **System Specification** → **System Architecting** → **System Design and Optimization** → **System Solutions Exploration**



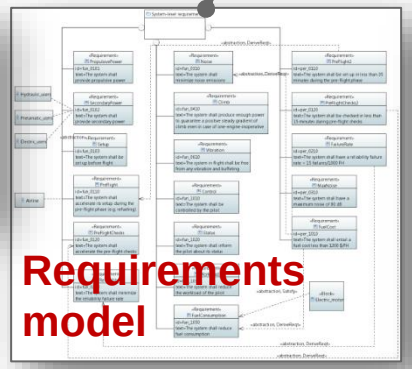




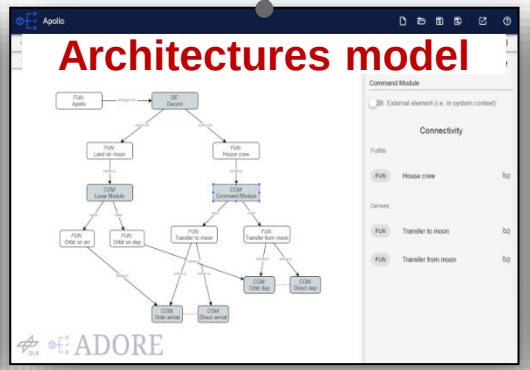
Stakeholders & Needs — *Requirements* — *Architecture Alternatives* — *Domain tools & MDO* — *Trade-off & Decision-Making*



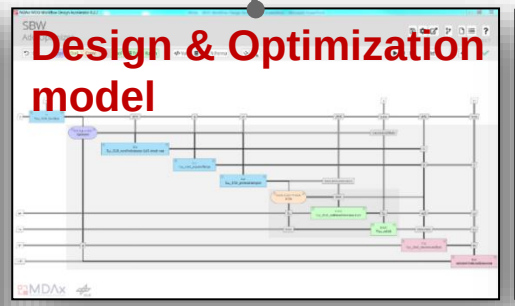
Stakeholders model



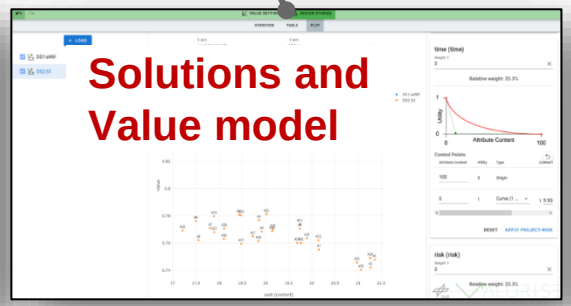
Requirements model



Architectures model



Design & Optimization model

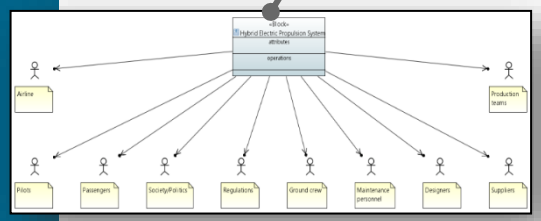


Solutions and Value model

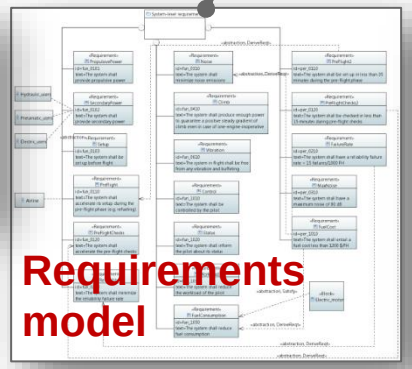
State of the Art
AGILE Framework

*An **MBSE** process, integrating **MDO** and **Trade-Space Exploration***

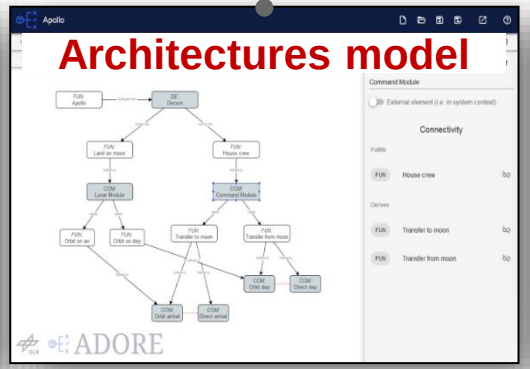
How can established **MBSE processes** be adapted and scaled to support the development of **System-of-Systems**?



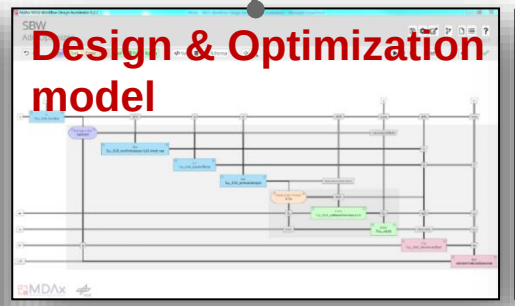
Stakeholders model



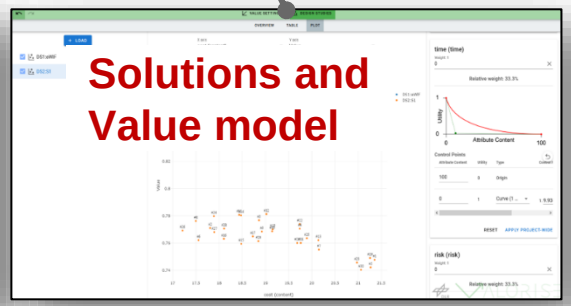
Requirements model



Architectures model

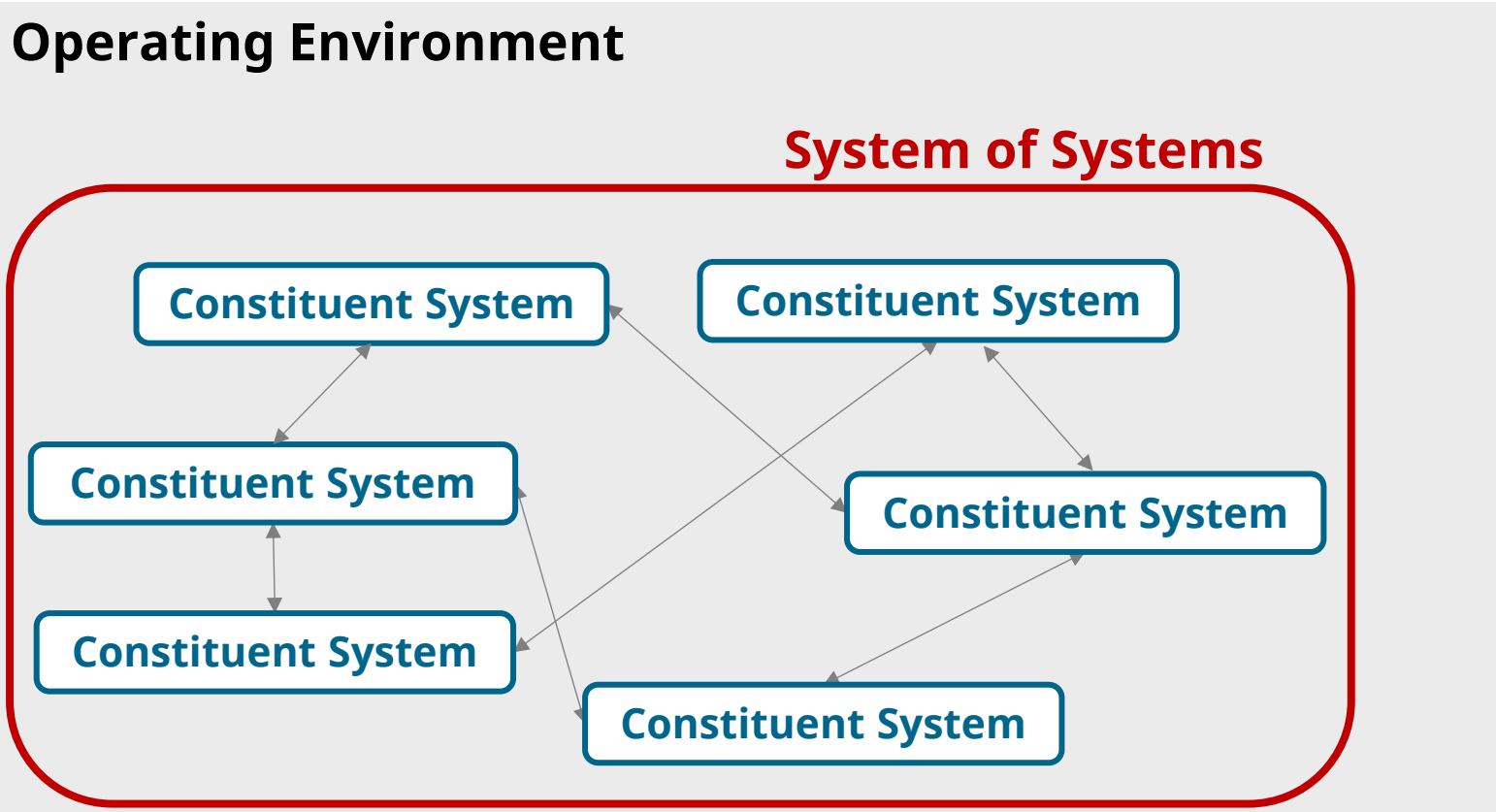


Design & Optimization model



Solutions and Value model

Definitions
What is a System-of-Systems?



"A **system-of-systems** (SoS) is a collection of independent systems, integrated into a larger system that delivers **unique capabilities**." [1]

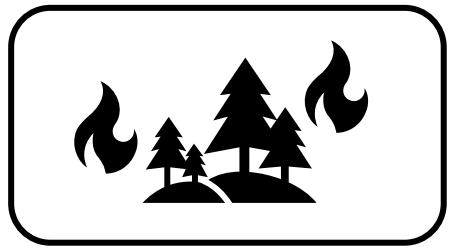
Distintinguishing Criteria [2]:

1. **Operational Independence**
2. **Managerial Independence**

[1] INCOSE, SoS Primer
[2] Maier, Mark W. (1998): Architecting principles for systems-of-systems. In: The Journal on International Systems Engineering 1, S. 267–284.

Overview of the Methodology
From a Problem to a Solution

Application Case:
Wildfire Fighting SoS



SoS Problem Definition

Capture the current system-of-systems, capabilities and derive desired capabilities

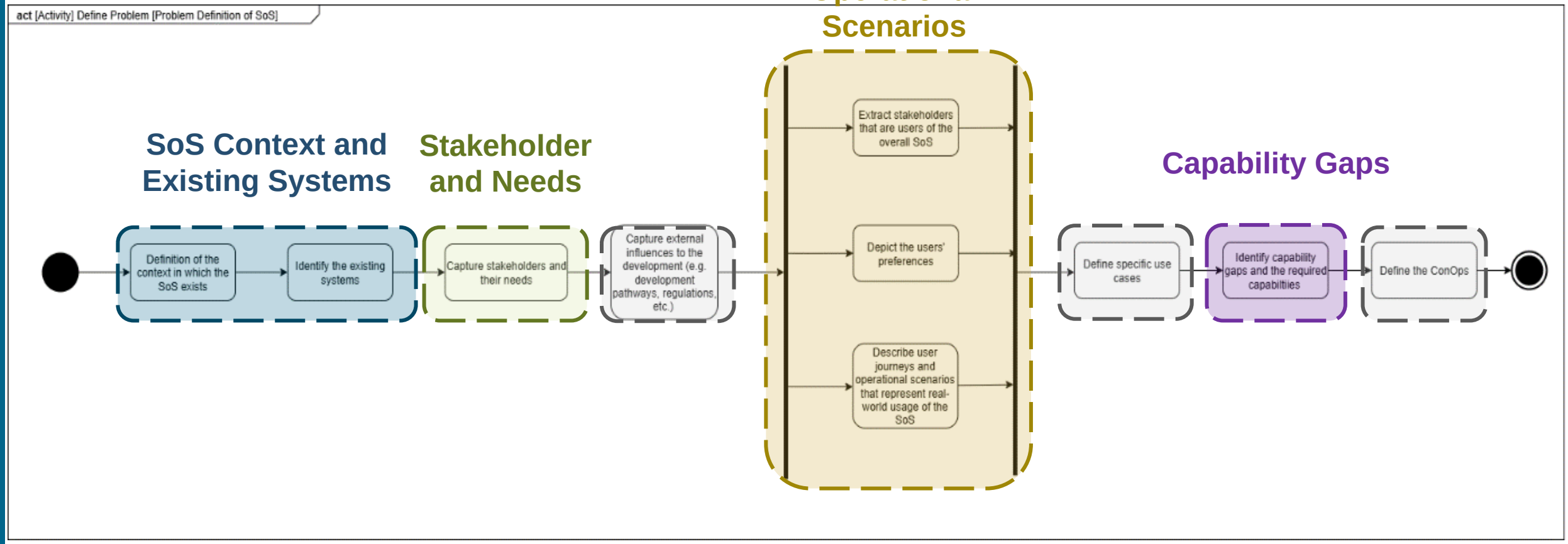
SoS Architecting

Define what the SoS architecture is, capture the architectural decisions

Decision-Making

Support decisions about system acquisition based on given problem, enterprises, existing systems

SoS Problem Definition
Process Overview



SoS Problem Definition
SoS Context and Existing Systems

Geographical and Urban Context of Andalusia

- Mediterranean climate with extreme summer conditions
- Large, topographically heterogeneous territory
- Extensive wildland-urban interface
- Critical civil and economic infrastructure embedded in fire-prone areas

Source: ©Adobe Stock/Tandem Stock

Existing Infrastructure Landscape

- Established aerial firefighting support infrastructure
- Regional wildfire brigades
- Fixed-wing firefighting aircraft

SoS Problem Definition
Modification of the Meta-Model

- **Capability**
  The SYSTEM-OF-SYSTEMS shall provide CAPABILITY while in CONDITION

  Example: *The SoS shall provide continuous wildfire observation while in the entire mission.*

- **Performance**
  The SYSTEM-OF-SYSTEMS shall provide CAPABILITY with PERFORMANCE while in CONDITION

  Example: *The SoS shall provide wildfire suppression with a fire containment effectiveness of 80% within 2 hours while in operating in wind speeds up to 30 km/h.*

- **Design (constraint)**
  The SYSTEM-OF-SYSTEMS shall DESIGN CONSTRAINTS [in accordance
  in CONDITION]

  Example: The SoS shall have technologies with maturity TRL 9

N.B. Patterns adapted from [1]

Armade

ID	Name	Statement Template	Attributes
RT-5	Capability Requirement	The [System] shall provide [Capability] [Condition]	Capability, Condition, System
RT-4	Performance Requirement	The [System] shall provide [Capability] with [Parameter] [Constraint] [Value] [Unit] [Condition]	Value, Parameter, Capability, Unit, Constraint, Condition, System
RT-3	Suitability Requirement (Constraint)	The [System] shall exhibit [Parameter] [Constraint] [Value] [Unit] [Condition]	Value, Parameter, Unit, Constraint, Condition, System
RT-1	Need		

[1] R. Carson, Implementing structured requirements to improve requirements quality, INCOSE IS, Seattle, WA, 2015

Problem Definition and Specification
Stakeholders and Needs

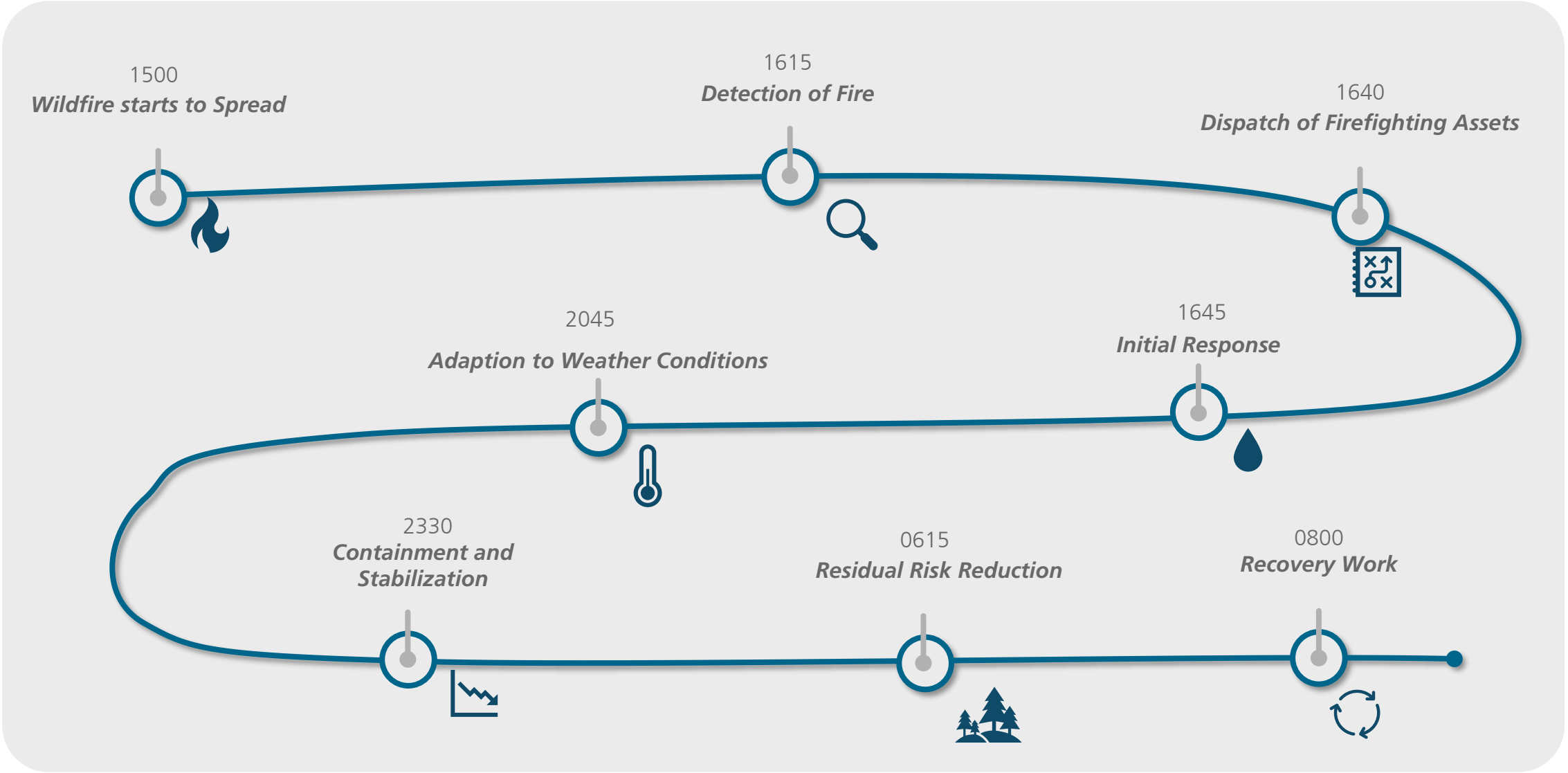
Stakeholder Overview

ID	Name
SH-14	Regulator
SH-8	Vehicle Operator
SH-2	Community
SH-7	Fire Departments
SH-11	Maintenance, Repair, Overhaul
SH-3	Manufacturer/ OEM
SH-4	Air Traffic Management

Needs Definition

ID	Name	Statement	Links:
RQ-6	N004	The SoS has to mininimize its environmental impact	Policy Maker, SReq002, Community
RQ-7	N005	The SoS has to maximize effectiveness of firefighting	PReq005, Disaster Relief, SoS Operator, ›
RQ-3	N001	One ojective of the two scenarios is to minimize damage to vegetation, property, infrastructure and humal life in case of wildfire	Community, Policy Maker, CReq002, CReq001
RQ-4	N002	The SoS has to operate in two scenarios: inland (landlocked) and island (seaside)	CReq004, SoS Operator, Community
RQ-5	N003	The SoS has to minimize greenhouse emissions from the fire	Policy Maker, SReq001, Community

SoS Problem Definition
Operational Scenarios



SoS Problem Definition
Required Capabilties

Armade

ID	Name	Statement	Links:
RQ-2	CReq002	The SoS shall provide wildfire supression while in night conditions	N001

Capability Requirements

ID	Name	Statement	Links:
RQ-2	CReq002	The SoS shall provide wildfire supression while in night conditions	N001
RQ-8	CReq003	The SoS shall provide operational capabilities while wildfire conditions	CReq001
RQ-9	CReq004	The SoS shall provide operational capabilities while wildfire conditions and in both landlocked and seaside environments	N002
RQ-1	CReq001	The SoS shall provide wildfire supression while in day conditions	CReq003, N001
RQ-12	CReq005	The SoS shall provide operational capabilities in EU regulated spaces	SReq003

SoS Problem Definition
Capability Requirements

ID	Name	Statement	Links:
RQ-2	CReq002	The SoS shall provide wildfire supression while in night conditions	N001

Capability
(derived from Stakeholder Need)

Condition
(derived from Scenario Descriptions)

RQ-3	N001	One ojective of the two scenarios is to minimize damage to vegetation, property, infrastructure and humal life in case of wildfire	Community, Policy Maker, CReq002, CReq001

SoS Problem Definition
Performance Requirements

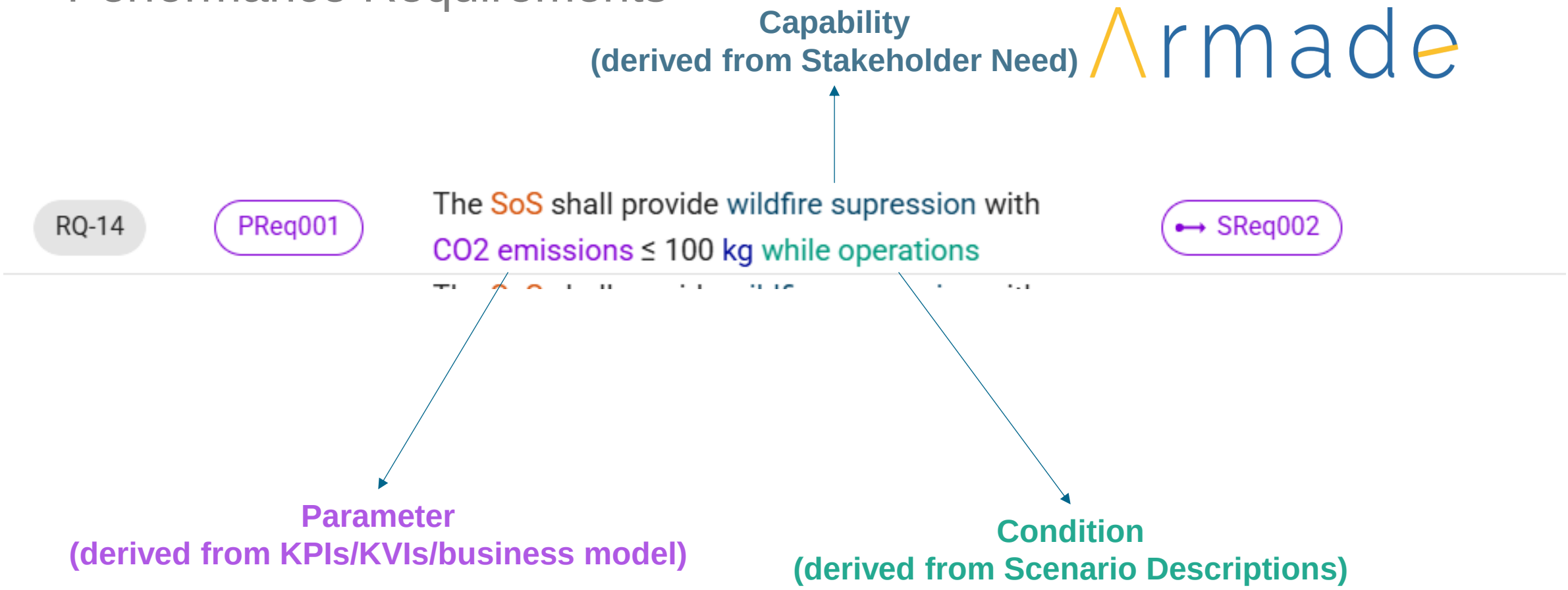
Armade

RQ-14	PReq001	The SoS shall provide wildfire supression with CO2 emissions ≤ 100 kg while operations	⟼ SReq002

Performance Requirements

ID	Name	Statement	Links:
RQ-15	PReq002	The SoS shall provide wildfire supression with NOx emissions ≤ 100 kg while operations	⟼ SReq002
RQ-14	PReq001	The SoS shall provide wildfire supression with CO2 emissions ≤ 100 kg while operations	⟼ SReq002
RQ-16	PReq003	The SoS shall provide wildfire supression with particulate emissions ≤ 100 kg while operations	⟼ SReq002
RQ-18	PReq005	The SoS shall provide wildfire supression with containment effectiveness ≥ 50 % in wind speeds up to 80 km/h	⟼ N005
RQ-17	PReq004	The SoS shall provide wildfire supression with firefighting operations initialization ≤ 30 min while emergency condition and after emergency call	

SoS Problem Definition
Performance Requirements



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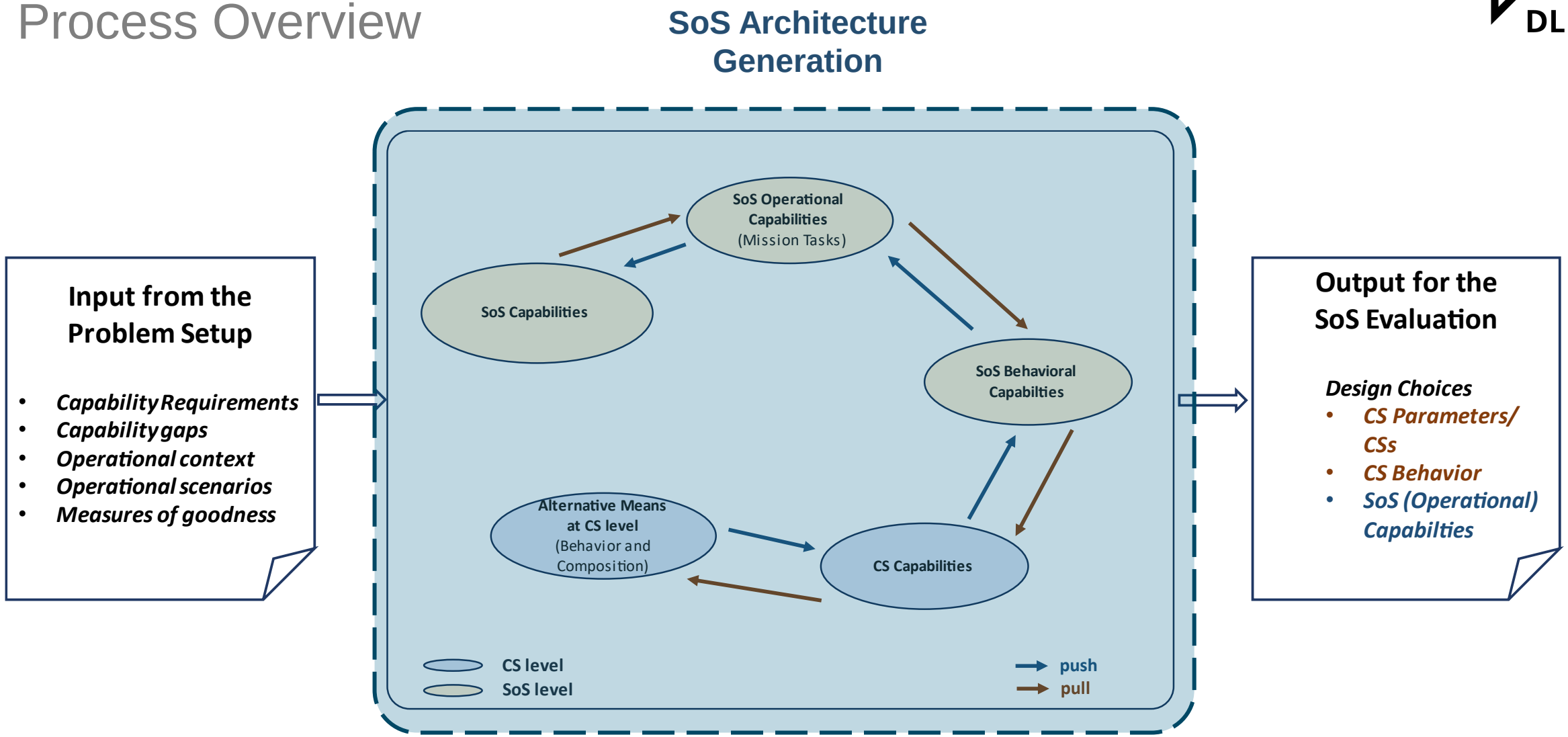
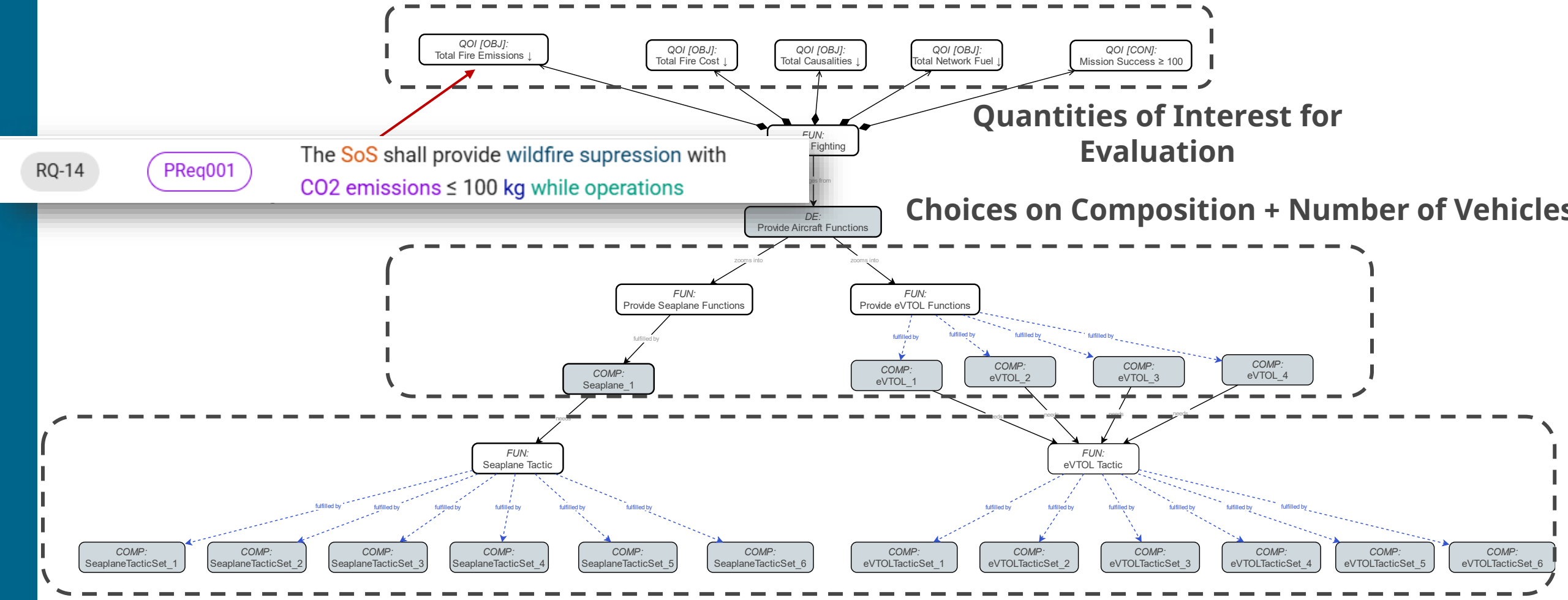


SoS Architecting
Architectural Design Space



Quantities of Interest for Evaluation

Choices on Composition + Number of Vehicles

Choices on Tactics

ADORE

SoS Architecting
Automated Design Space Evaluation

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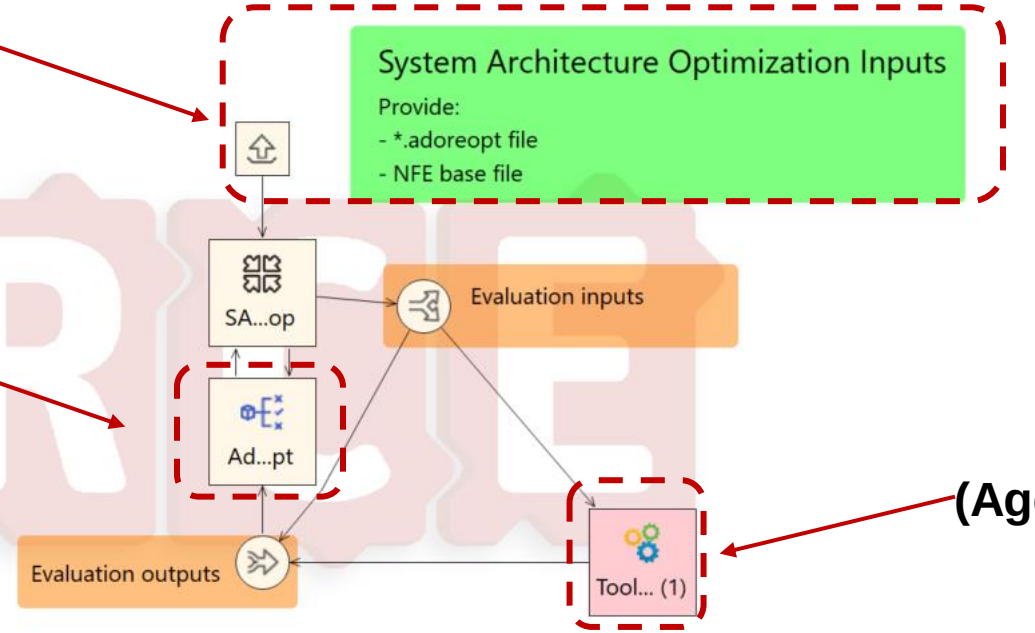
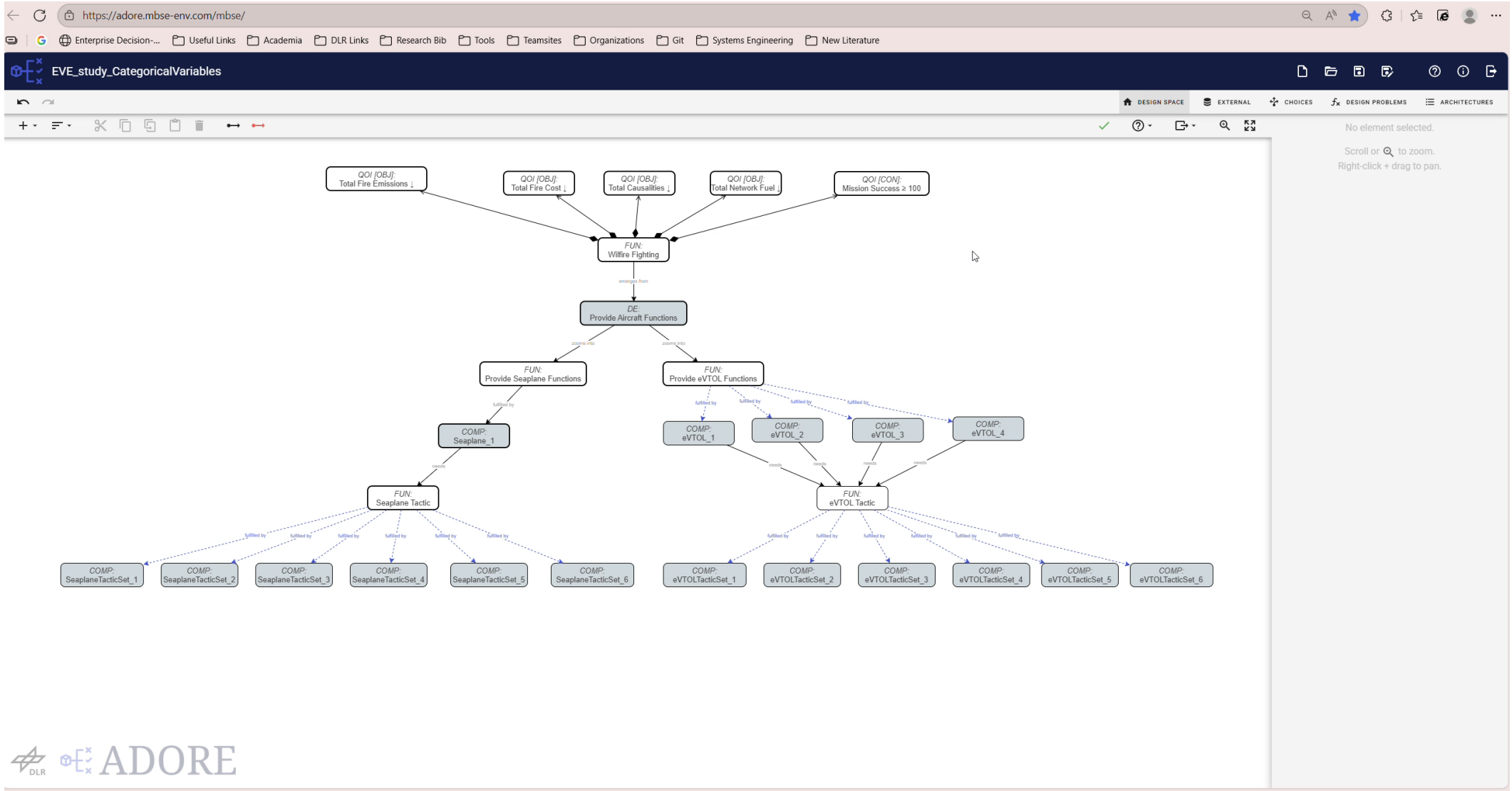
Rule-based translation

Architecture Generator

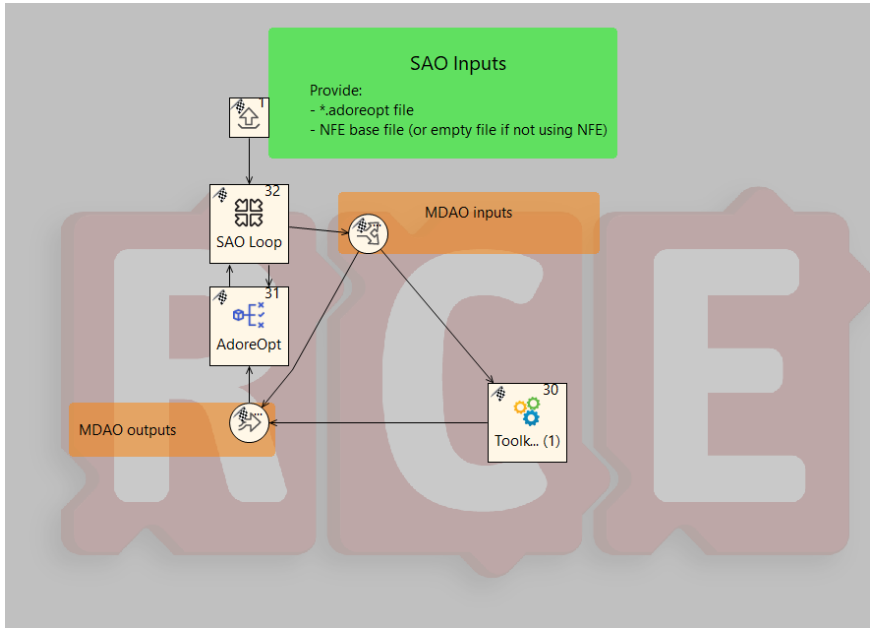


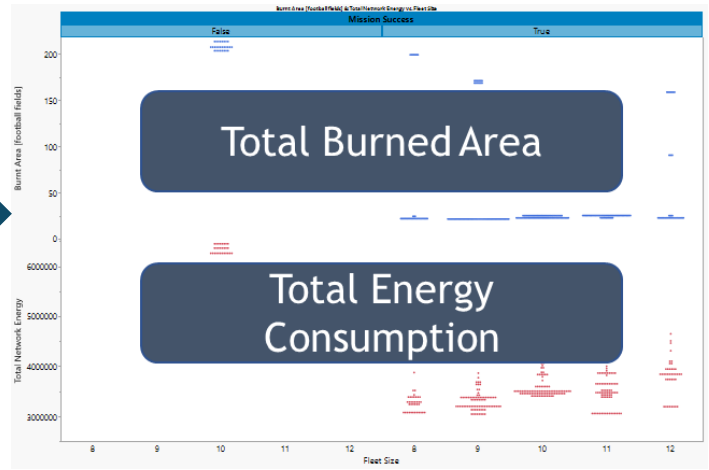
Evaluation Tool
(Agent-Based Simulation Tool „SoSID Toolkit“)

SoS Architecting
Automated Design Space Evaluation (DEMO)



SoS Architecting
Architecture Selection





Choices on the vehicles involved in firefighting and the chosen tactics

Conclusion and Outlook
Challenge of System-of-Systems

Summary

How can established **MBSE processes** be adapted and scaled to support the development of **System-of-Systems**?

- **Solution-agnostic processes** for SoS problem definition and SoS architecting
- **Implementation** with selected MBSE tools and evaluations tools

Next Steps

- Shift to System-of-Systems Engineering requires **evolutionary thinking** in SoS architecting (in contrast to SE)
- **Desicion-making** requires consideration of **distributed ownership** of constituent systems

COLOSSUS
COLLABORATIVE SYSTEM OF SYSTEMS

COLLABORATIVE SYSTEM OF SYSTEMS EXPLORATION OF AVIATION PRODUCTS, SERVICES & BUSINESS MODELS

Akbari, Jasamin[1,*]; Knöös Franzen, Ludvig[2]; Jouannet, Christopher[2]; Nagel, Björn[1]

[1] German Aerospace Center (DLR), Institute of System Architectures in Aeronautics, Hamburg, Germany
[2] Linköping University (LiU), Department of Management and Engineering, Linköping, Sweden
* Correspondence: jasamin.akbari@dlr.de

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