SYSTEMS ENGINEERING RESEARCH CENTER

A SE4AI Framework for the SE of Autonomous Systems
Considering Data Through the Life-Cycle

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AI4SE & SE4AI RESEARCH AND APPLICATION WORKSHOP
SEPTEMBER 17-18, 2024
Arlington, VA, USA

SHOAL™

Image Depicted is an integration of Images from Pixabay

THE UNIVERSITY of ADELAIDE

RAAF B707 – 1979 to 2008

29 October 1991

RAAF B707 – 29 October 1991

The last minute in the lives of five flyers

THE last minute of recorder tape during the training exercise.

0.58 — Sound of decreasing engine.

0.53 — Captain: Trell . . . wrestle with the beastie!

0.50 — Landing gear unsafe warning horn sounds briefly.

Co-pilot: OK, I can afford to wash off a bit more speed.

0.40 — Co-pilot: Got, ah 10 degrees of bank and full rudder and I'm still starting to veer away. I'm still . . .

Captain: OK.

0.32 — Co-pilot: . . . put a bit more aileron in — I can —

Captain: So, how are we going to get out of it?

0.28 — Co-pilot: OK

0.27 — Captain or third pilot: Watch out!

Captain: Woah! Woah!

Sound of objects flying around the cockpit.

0.22 — Captain: Taking over!

Co-pilot: Handing over!

A RAAF 707 like the one which crashed near Sale.

0.17 — Third pilot: Mayday! Mayday! Windsor

Sounds of grunting. Sound of warning horn.

Captain: Ah!

0.10 — Co-pilot: You want, you want the rudder boost on?

Captain: Yeah! Boost on!

Sale air traffic controller: Windsor 380, Approach?

0.07 — Co-pilot: Windsor 380, Mayday!

Sale: Windsor 380, Roger Mayday!

0.00 — Exclamations. Tape stops.

RAAF B707 – 29 October 1991

"The RAAF Boeing 707 stalled and crashed into the sea. The crash was attributed to a simulation of asymmetric flight resulting in a sudden and violent departure from controlled flight."

"It's the first fatal accident in Airlift Group or the transport force since 1961, that's 30 years of accident-free flying."
Richmond RAAF Base Air Commodore Stan Clark

29 October 1991

RAAF B707-368C (A20-103) - Board of Inquiry concluded…
"There were deficiencies in the documented procedures and limitations pertaining to asymmetric flight in the 707 and a lack of fidelity in the RAAF 707 simulator in the flight regime in which the accident occurred, …."

Airlift Simulators Project (ALSIM)

Personal Journey in High-Fidelity M&S





1994 - 2019 CAE

Individual → Team → Tactics → Joint Combined → MR





Personal Journey in High-Fidelity M&S

Icons used from Pixabay

Situational Awareness

Mica Endsley – *Towards a Theory of Situation Awareness in Dynamic Systems*. Human Factors Journal 37(1), 32-64

Joint / DMT

Team

Individual

State of the Environment

Performance of Action

Decision

Mission Rehearsal

Tactics

Procedures

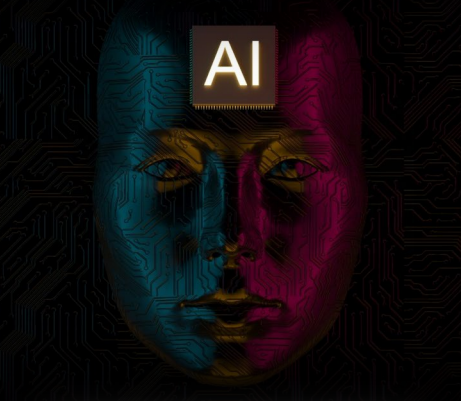
Image Credit - RUSI Lecture, June 2011 (CAE VP & CTO)

SITUATION AWARENESS

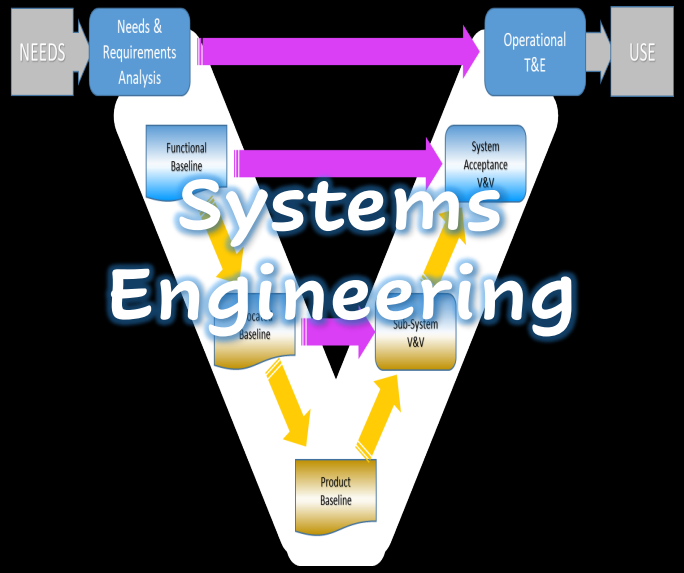
Perception of Elements In Current Situation Level 1	Comprehension of Current Situation Level 2	Projection of Future Status Level 3

A Need to Train the "*AI*" Right

TRAIN



VERIFY



CERTIFY

VALIDATE

Exaptation, also **radical repurposing**, is the *taking of an idea, concept, tool, method, framework, etc., intended to address one thing, and using it to address a different thing*, often in another domain [*Cynefin.io/wiki/exaptation*]

A Need to Train the "*AI*" Right

TRAIN

CERTIFY

Motivation & Focus

AI Development Approaches

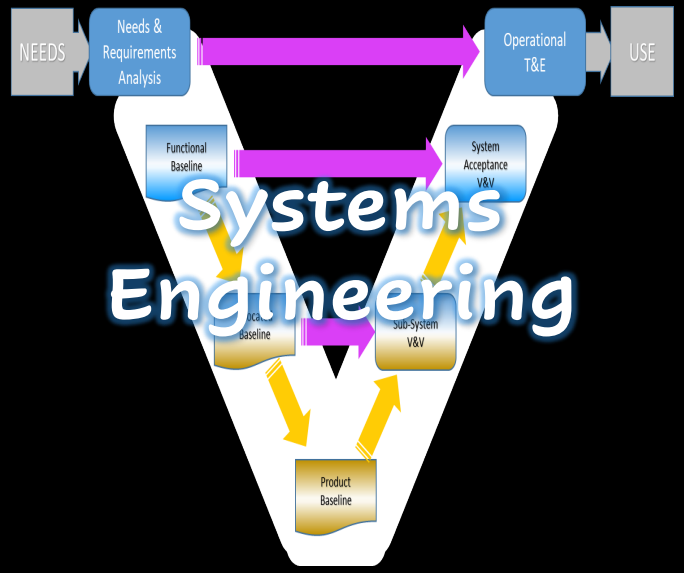
Core Enabling Concepts

A Conceptual SE4AI Framework

Related & Future Work

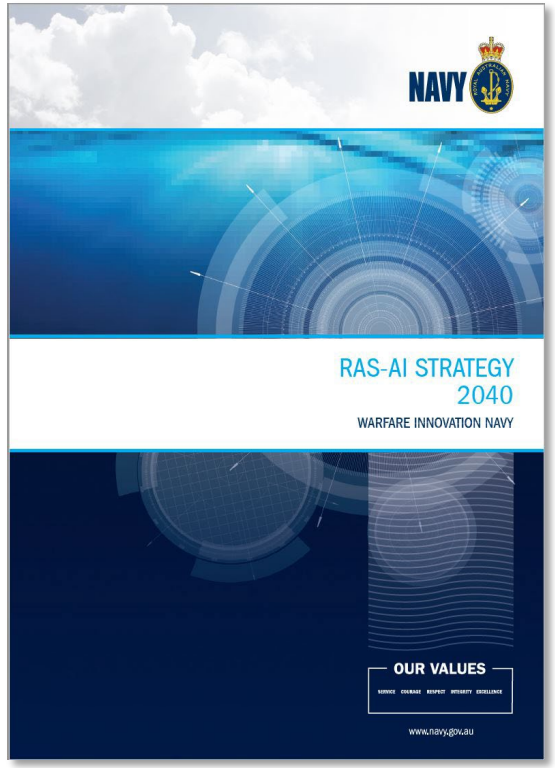
Key Points

VERIFY



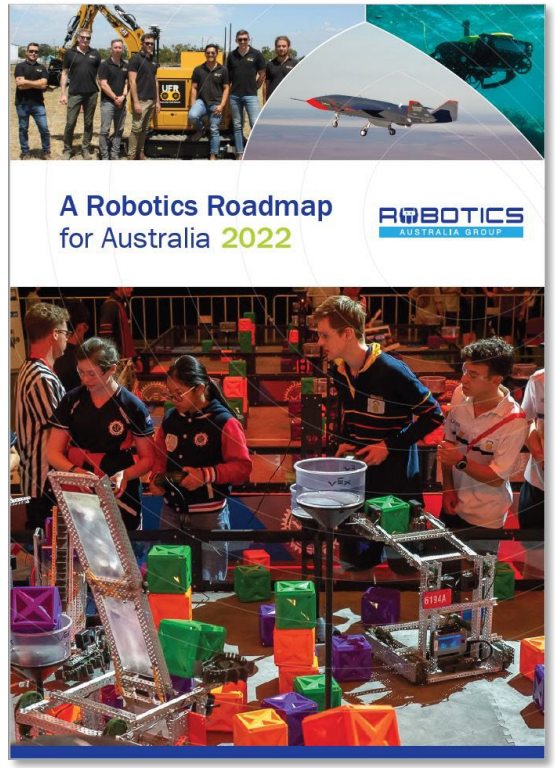
VALIDATE

This research is supported by an Australian Government Research Training Program (RTP) Scholarship through the University of Adelaide with Industry Partner, Shoal Group



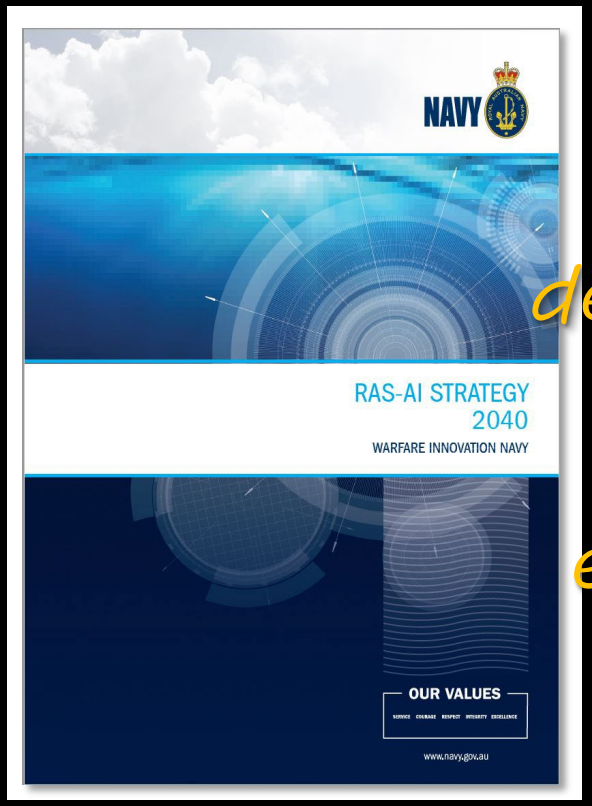
"Navy needs marinized RAS-AI (*Robotics, Autonomous Systems and Artificial Intelligence*) capabilities which address factors including geography; the maritime and strategic environment; and the national Defence ecosystem"

Priority – "Develop and adopt governance systems to ensure robotics and AI solutions improve Australia's well-being and protect democratic values"

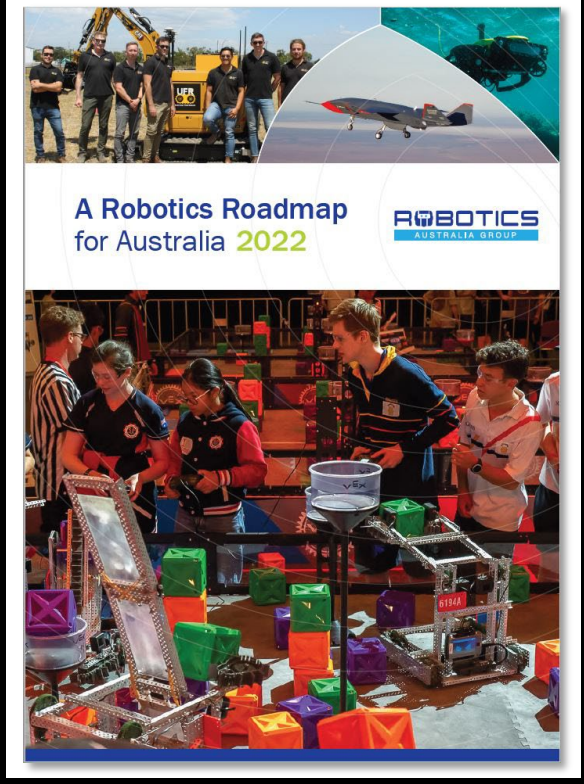


AI4SE & SE4AI Research and Application Workshop 2023 identified "**Data Management**" as being foundational to dealing with the Challenges for Test & Evaluation of AI

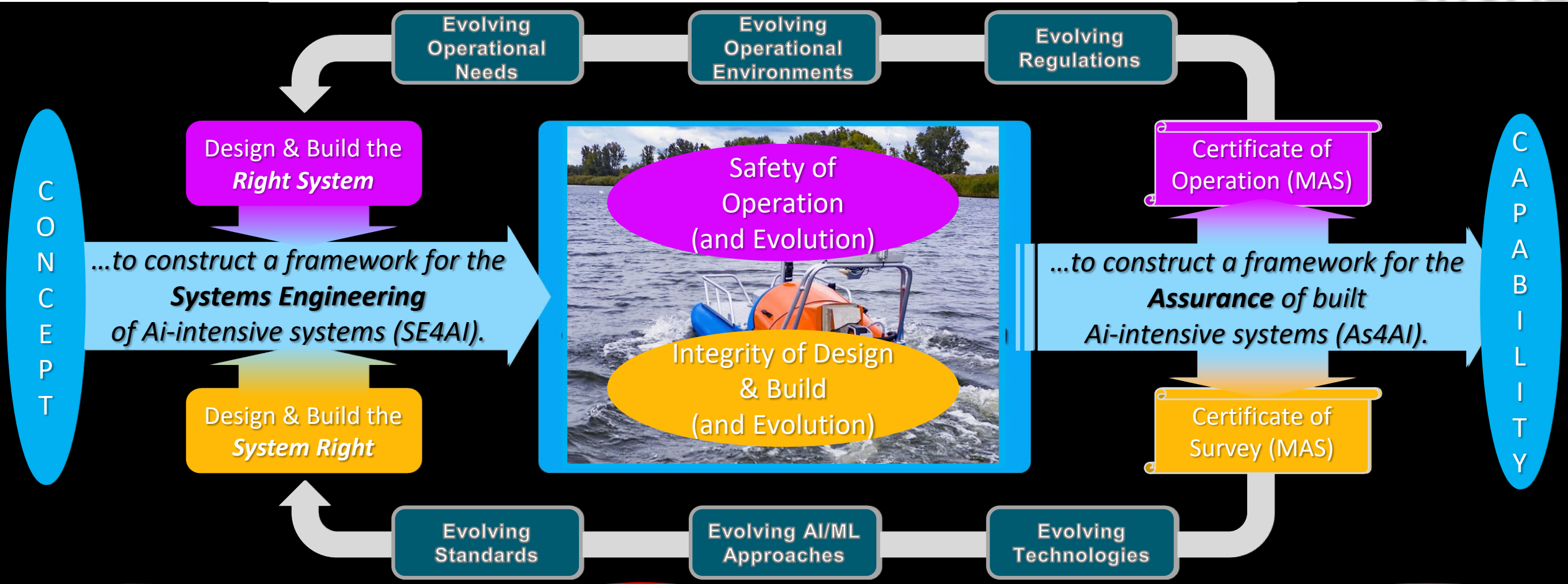
["SE IN THE ERA OF HUMAN-MACHINE TEAMING - ROADMAP FOR AI AND SE", Tom McDermott, SERC]



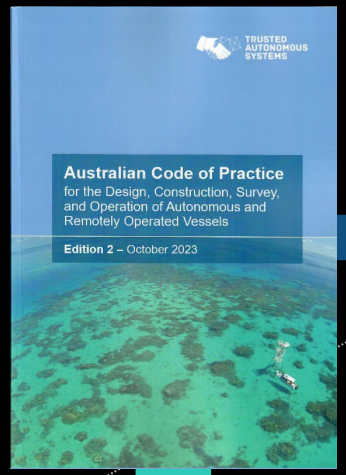
A need for a *SE & Assurance* framework that would build in *design integrity*, system *safety*, *security* and enable ongoing *assurance* through a highly *evolutionary* AI capability life-of-type context.



There is a need to engineer and assure safe and secure AI applications holistically from a first-principles, systems perspective, considering their nuances to tailor the core SE pillars of *Requirements Engineering* (RE), *Architectural Design, Verification and Validation* (V&V) and *end-to-end traceability*



A need for an SE & Assurance for AI framework that would build in design integrity, system safety, and security and enable ongoing assurance through a highly evolutionary AI capability life-of-type context.



INTERPRET

CONCEPT

Evolving Operational Needs | Evolving Operational Environments | Evolving Regulations

Design & Build the *Right System*

...to construct a framework for the ***Systems Engineering*** of Ai-intensive systems (SE4AI).

Design & Build the *System Right*

Certificate of Operation (MAS)

...to construct a framework for the ***Assurance*** of built Ai-intensive systems (As4AI).

Certificate of Survey (MAS)

Evolving Standards | Evolving AI/ML Approaches | Evolving Technologies

CAPABILITY

ACCREDIT

Safety Regulations for Maritime Autonomous Systems

AMSA Australian Maritime Safety Authority

Safety Regulations for Simulated MAS Assurance Capabilities

Engineering / Modification of MAS

SE4AI

An Evolutionary / Agile Depiction of the SE Life-Cycle identifying Configuration Baselines (integrity) through Development and Releases

Release 4 | Release 3 | Release 2 | Release 1 | Fielded System

Conceptual Design | Preliminary Design | Detailed Design | Dev. Integ. & Test

RTM Requirements Traceability Matrix
VCRM Verification Cross-Reference Matrix
VTAVD Verification, Training And Validation Data

Functional Baseline | Allocated Baseline | Product Baseline

MAS Design Data

FCD | FCA | ACD | PCA | PCD | MSR | ICS | OOE

MAS HW & SW

Controlling AI/ML Autonomous Subsystem

Navigation | Weapons | Platform | Sensors | Fuel | Controls | Propulsion | Power | Comms

Enabling HW/SW

Assurance of Built / Modified MAS

As4AI

MAS to be "Assured"

Environment Monitoring

(Autonomy Gateway)

Assurance

MAS Classification & Reg Applicability | Scenario and Environment Selection | Creation MAS Assurance Plan

Regulatory / Standards Updates | Platforms and Scenarios Updates | Environment Configuration Reference Data Updates

Evolution

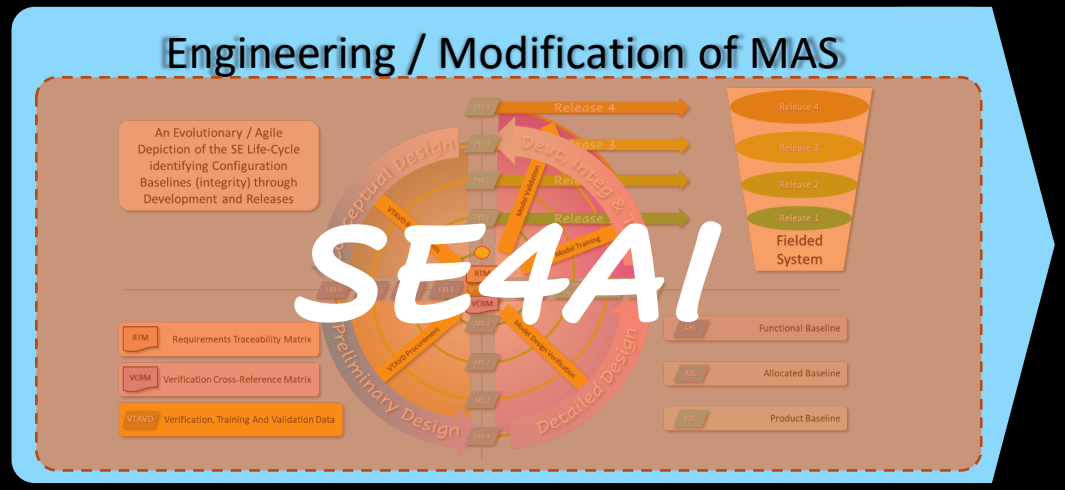
Digital | Lab | Compliance

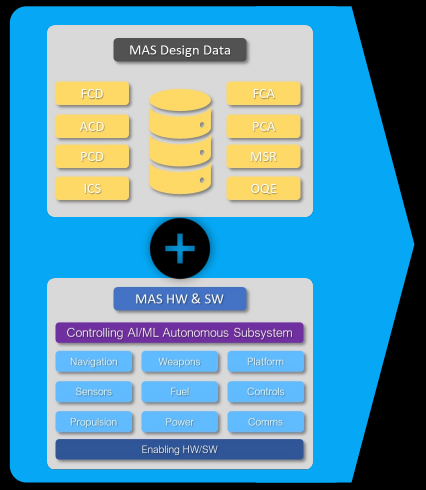
"Live" Assurance Activities | "Virtual" Assurance Activities | "Constructive" Assurance Activities | "Other" Assurance Activities

Certification (Level), Conditions, Recurrency and Feedback

This presentation outlines a conceptual refinement to contemporary evolutionary developmental practice for the SE of AI-Intensive systems (SE4AI).

The focus is on the end-to-end curation of reference data used as a basis for ML model *design verification*, *model-training*, and *model-validation*.

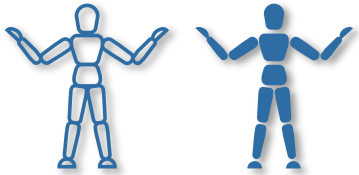




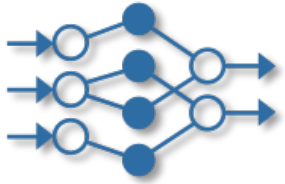
"A set of methods and tools that originated from software engineering in a system lifecycle" (Bosch et al., 2020)

AI systems "have inherently different characteristics than software systems alone" (Ozkaya, 2020) and Fujii et al (2020) and Bosch et al (2020) identifed ***four developmental focus areas*** unique to AI applications.

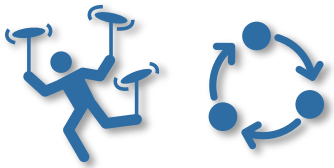
DATA Quality
Sufficiency of data sets / streams for Training & Inference



Model Performance
(Verification) - Training & Operational Scope



Design Methods & Processes
Scalability & Repeatability



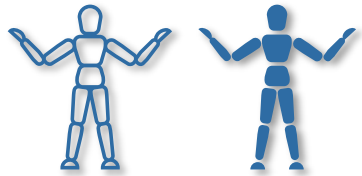
Deployment & Compliance
Monitoring, Logging, Testing, Troubleshooting

Teams at Microsoft blend data management tools with their ML frameworks to avoid the fragmentation of data and model management activities, and the rapid evolution of data sources (Amershi et al., 2019)

"A set of methods and tools that originated from software engineering in a system lifecycle" (Bosch et al., 2020)

There is an implicit (and natural evolutionary "bottom-up") focus on the realization of a fielded software system or "Product Baseline", with at best, implied reference (via requirements) to an associated "Functional Baseline".

DATA Quality
Sufficiency of data sets / streams for Training & Inference

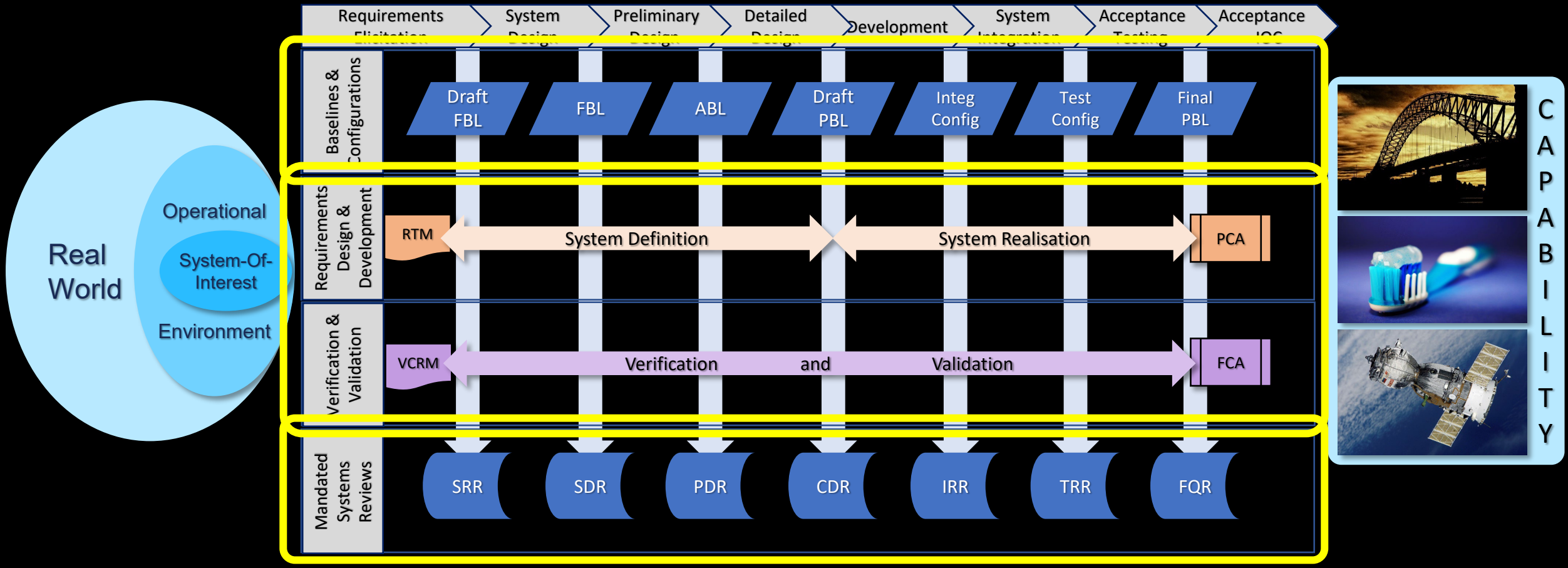


Model Performance
(Verification) - Training & Operational Scope

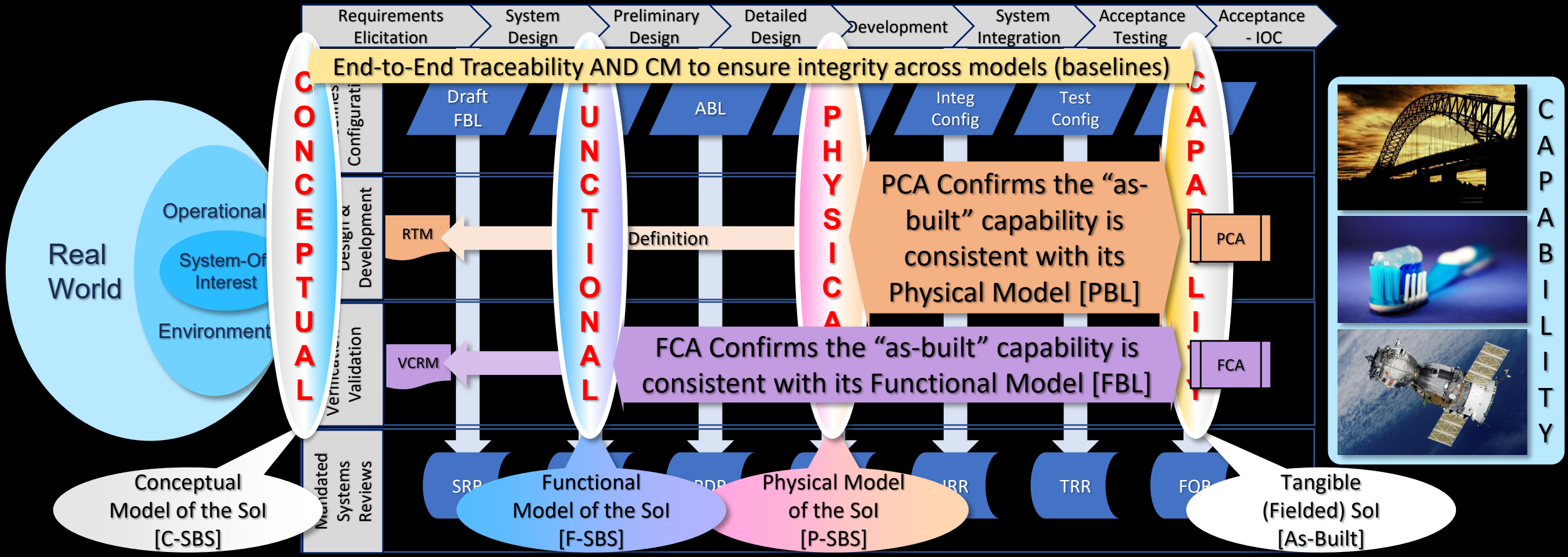
- Evolutionary focus on the PBL with regards to CM
- A perceived lack of explicit traceability (FBL, ABL, PBL, Data)
- V&V inherently a "Validation add-on" based on Data

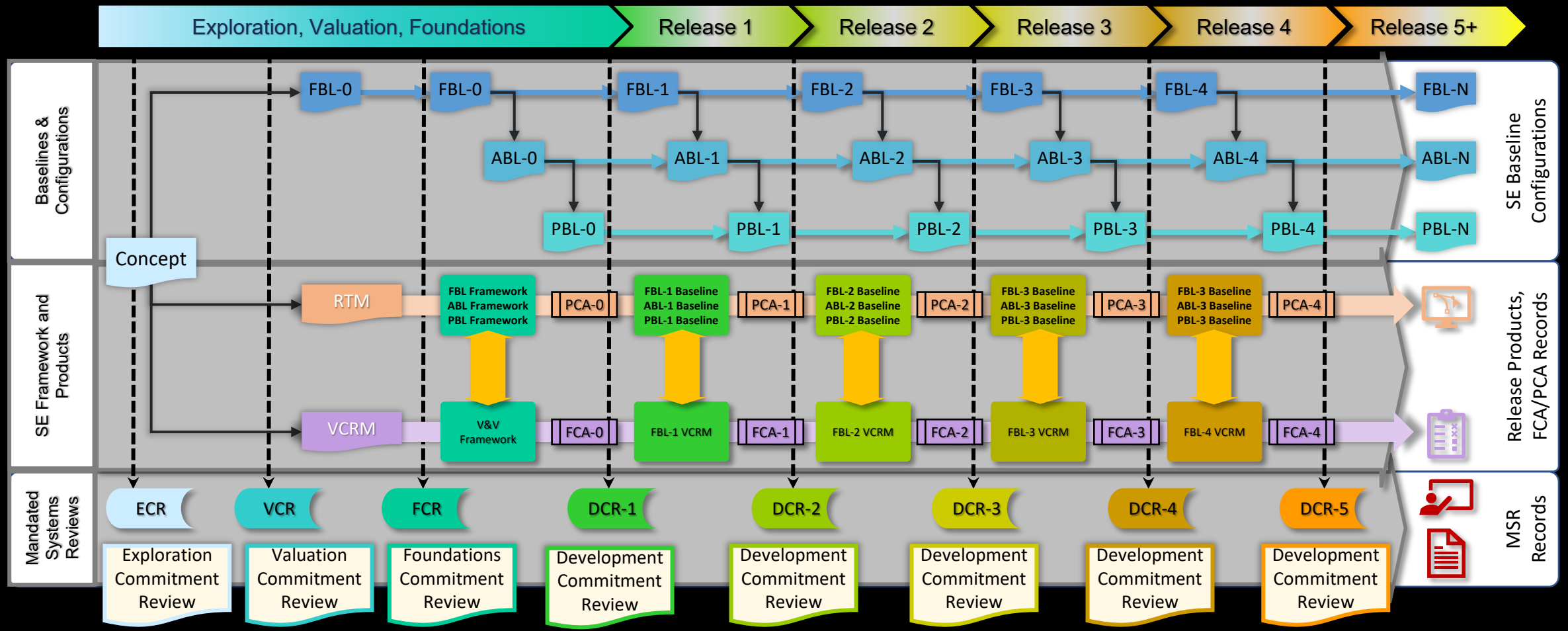
SE CM baseline rigor (FBL, ABL, PBL) and design integrity control (traceability across baselines), essentially shifts focus (post first iteration) to a progressive evolution of a PBL – exacerbates objective dependability/explainability.

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness



Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

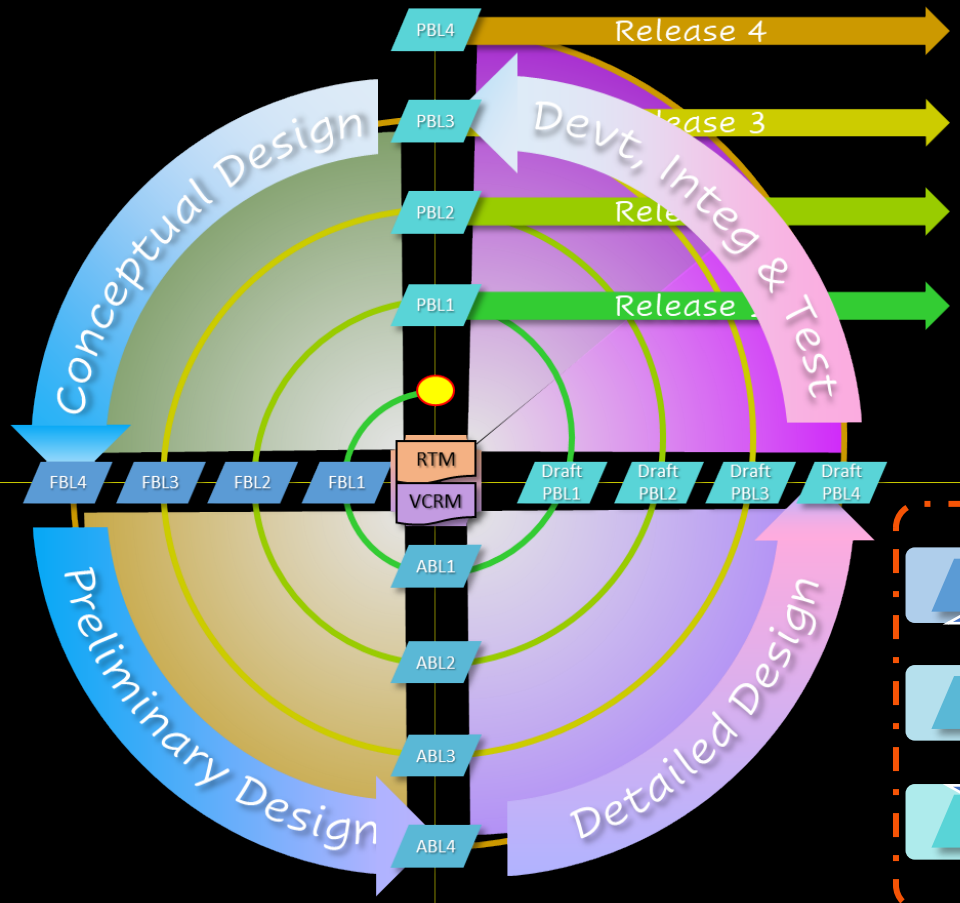




Alternative View – Evolutionary / Agile / Incremental Life-Cycle (depicted serially)

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

An Evolutionary / Agile Depiction of the SE Life-Cycle identifying Configuration Baselines with traced integrity preserved across and through Releases



RTM — Requirements Traceability Matrix

VCRM — Verification Cross-Reference Matrix

FBL — Functional Baseline

ABL — Allocated Baseline

PBL — Product Baseline

"Digital Threads" Integrity Preserved Through-Life

A Model is a Physical, Mathematical or Logical *abstraction* (of a System, Entity, Phenomenon, Activity or Process) for a *particular purpose* (i.e. a *suitable representation*)

A **Simulation** is an Enactment (Method of Implementing) a **Model** over Time

Image Credit – Michael Gaida (Pixabay)

A Map (**model**) of Sydney

Real-Time GPS navigation (**simulation**) using "map **models**"

Image Credit – giphy.com

A ***Simulator*** ➔ The Tool that Executes the **Simulation**

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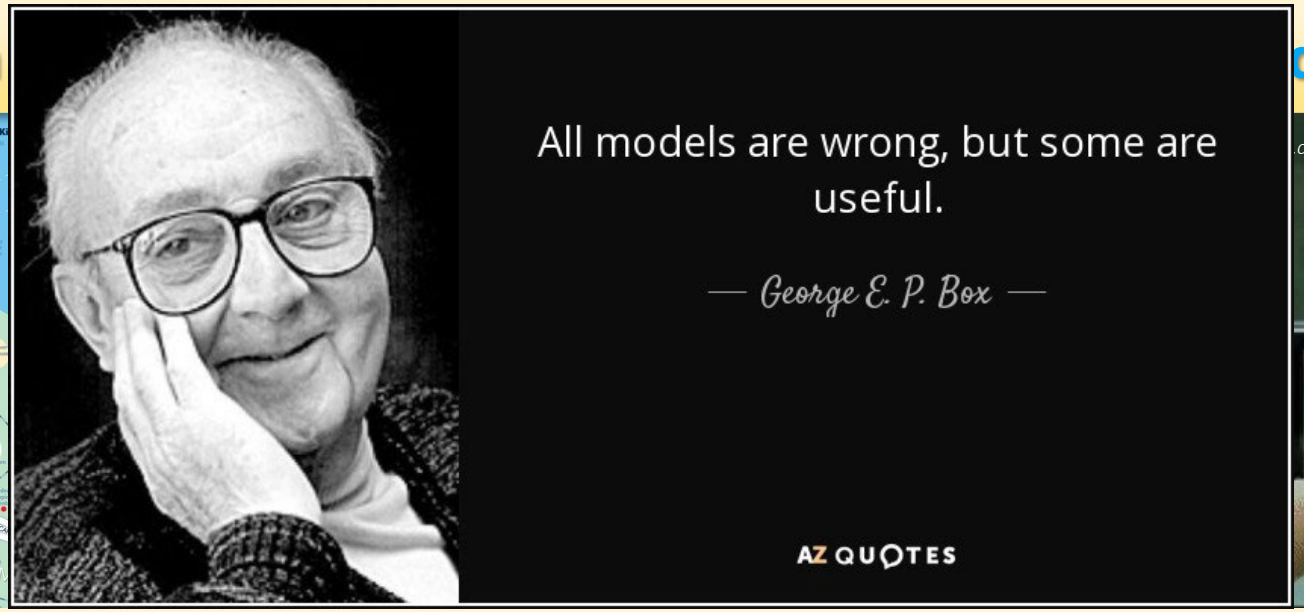
A Simulation

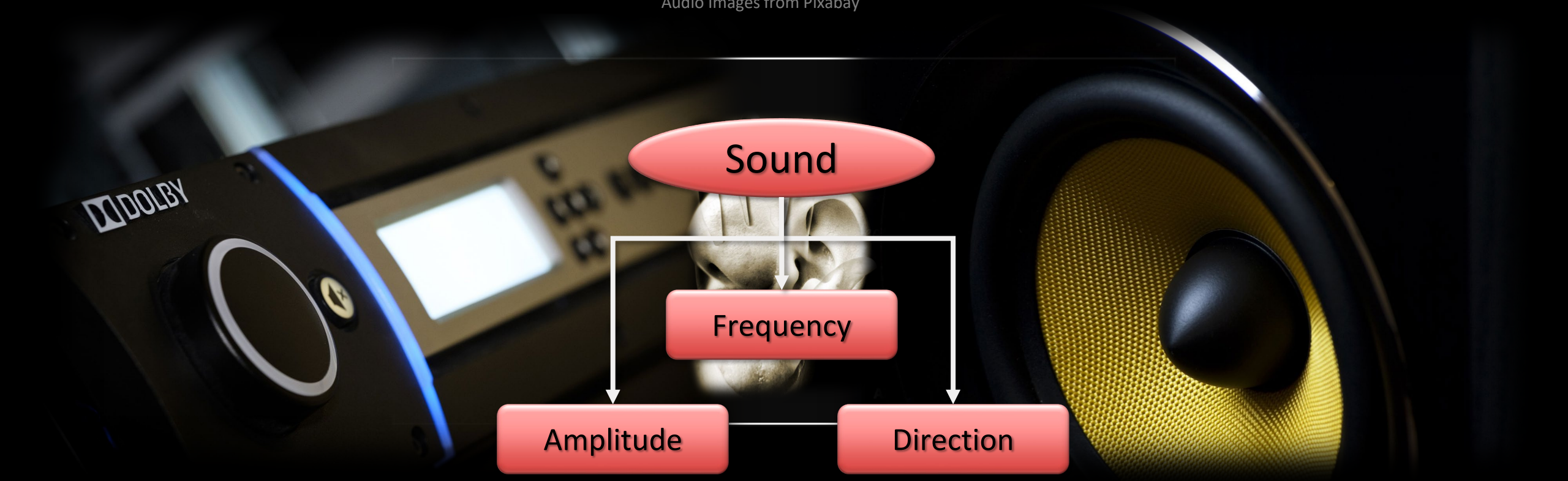


del over Time

A ***Simulator*** ➔ The Tool that Executes the Simulation

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

Audio Images from Pixabay



Fidelity ➔ Concept of "Goodness" or "Suitability" of a Model

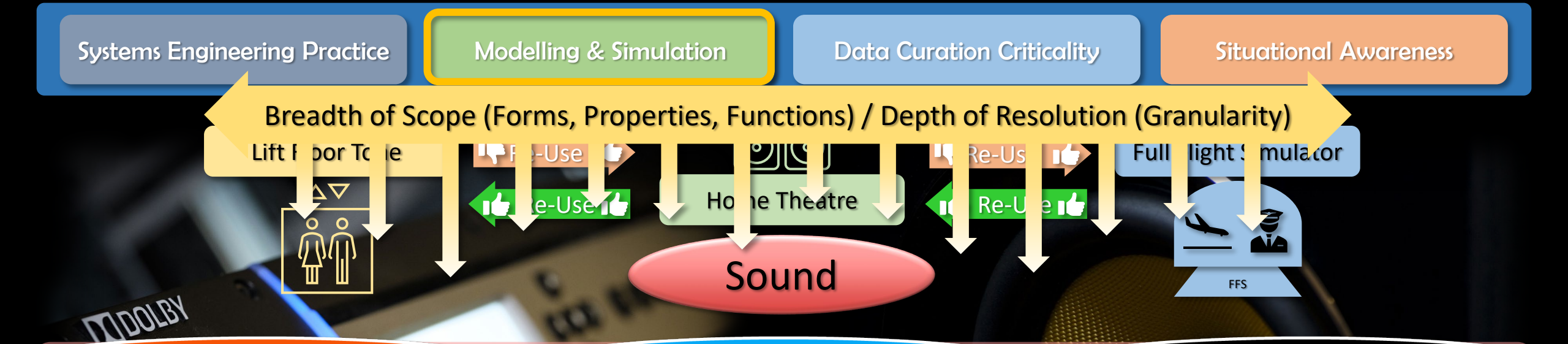
Systems Engineering Practice | **Modelling & Simulation** | Data Curation Criticality | Situational Awareness

Amplitude	Fixed-On	Fixed-On/Off	Variable Range	Fully Replicated	*Resolution*
Frequency	Fixed-Pitch	Representative	Sensed Range	Fully Replicated	*Resolution*
Direction	Mono-Phonic	Stereo-Phonic	Stereo-Surround	Fully Replicated	*Resolution*

Fidelity → Concept of "Goodness" or "Suitability" of a Model

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

Breadth of Scope (Forms, Properties, Functions) / Depth of Resolution (Granularity)



INTEROPERABILITY | ABSTRACTION | EMERGENCE

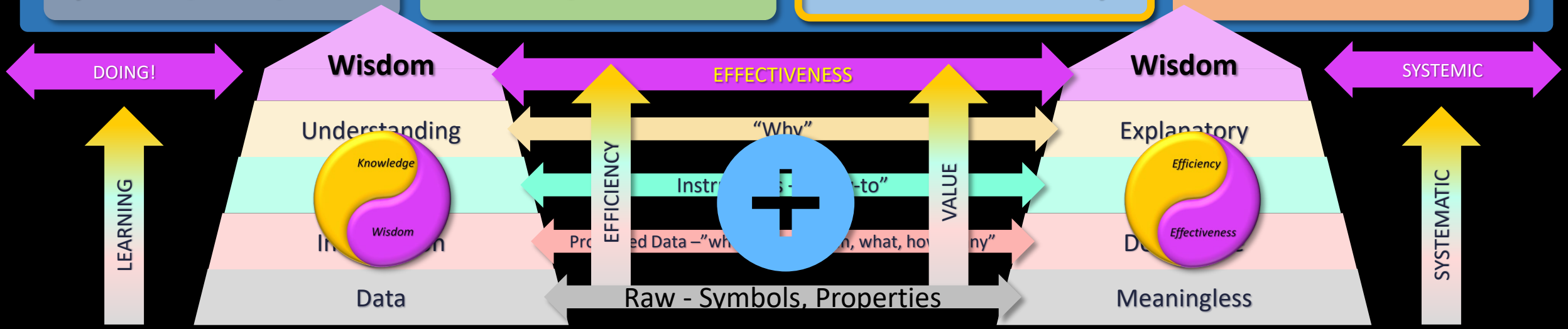
Amplitude	Fixed-On	Fixed-On/Off	Variable Range	Fully Replicated	Resolution

A Model is a Physical, Mathematical or Logical *abstraction* (of a System, Entity, Phenomenon, Activity or Process) for a *particular purpose* (i.e. a *suitable representation*)

Direction	Mono-Phonic	Stereo-Phonic	Stereo-Surround	Fully Replicated	Resolution

Fidelity → Concept of "Goodness" or "Suitability" of a Model

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness



Efficiency is *Doing things right*

KNOWLEDGE Vs WISDOM

Effectiveness is *Doing the right thing*

"Autopoiesis"

MENTAL Models

Santiago theory of cognition
"The living system reacts with its environment to bring forth a sense of awareness….." – Humberto Maturana

***Mental Models** are deeply ingrained assumptions, generalizations, or even pictures of images that influence how we understand the world and how we take action."- Peter Senge*

Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

DOING! ← EFFECTIVENESS → SYSTEMIC

LEARNING

Wisdom
Understanding
Knowledge
Information
Data

Wisdom
Meaningless

Raw - Symbols, Properties

Confidence in the suitability of the ML models is inherently a function of the data used in design, training and validation having the right **fidelity** *consistent with their operational use-cases*.

Efficiency is *Doing things right*

KNOWLEDGE Vs WISDOM

Effectiveness is *Doing the right thing*

"Autopoiesis"

ML Models

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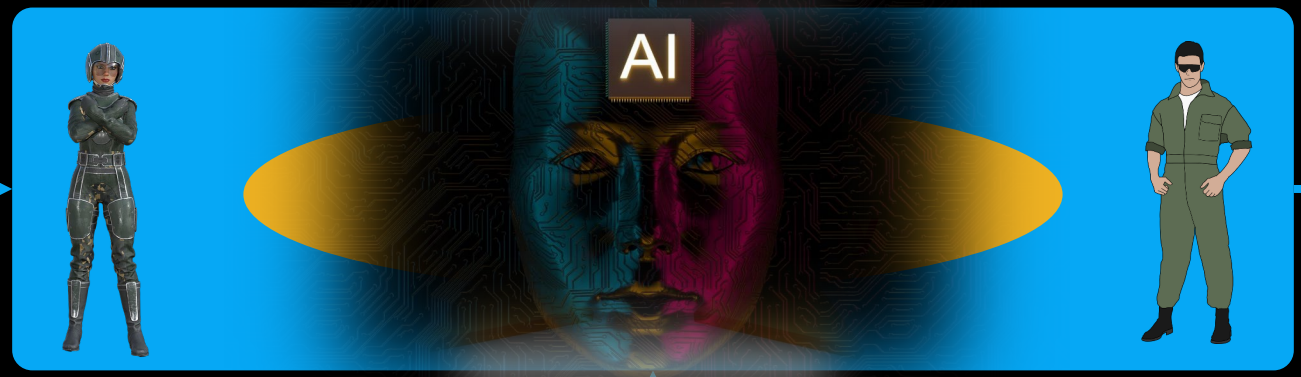
Systems Engineering Practice | Modelling & Simulation | Data Curation Criticality | Situational Awareness

State of the Environment

Performance of Action

Decision

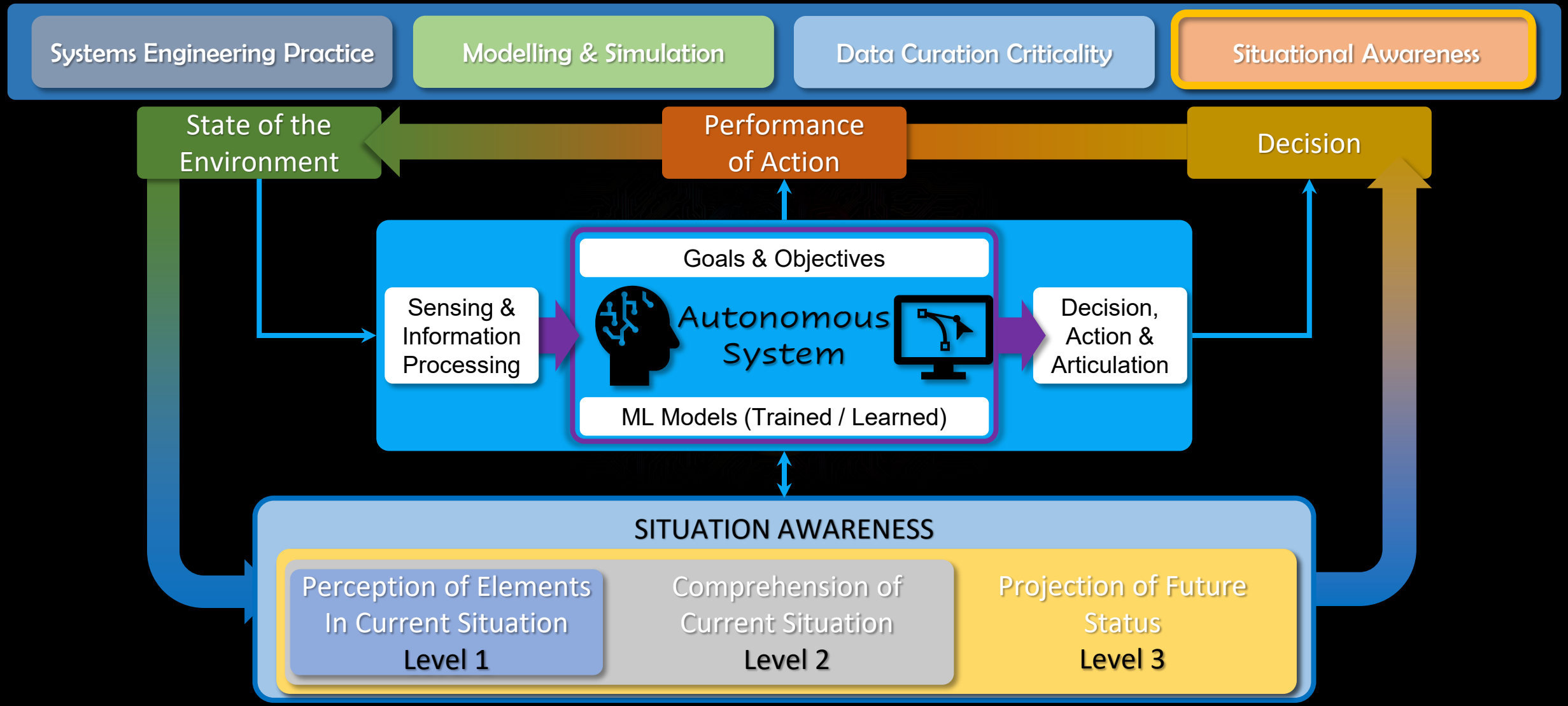


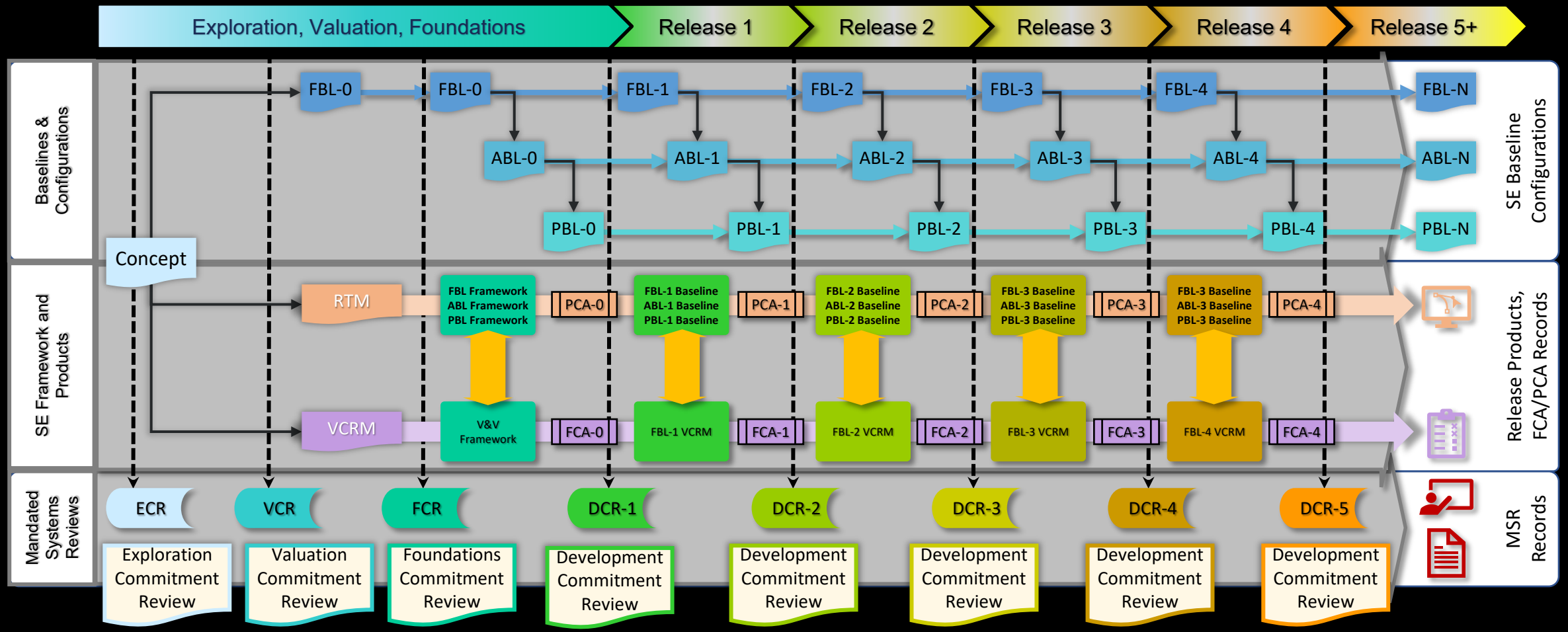
SITUATION AWARENESS

Perception of Elements In Current Situation
Level 1

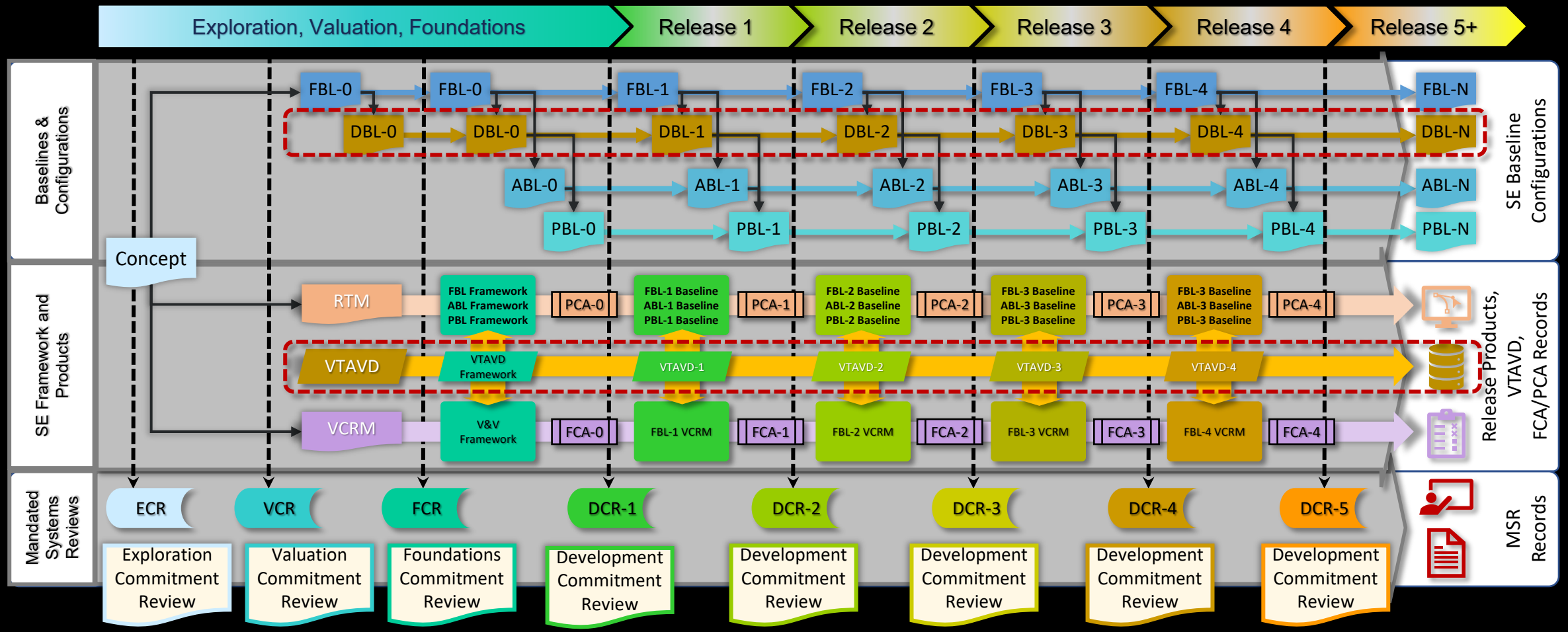
Comprehension of Current Situation
Level 2

Projection of Future Status
Level 3





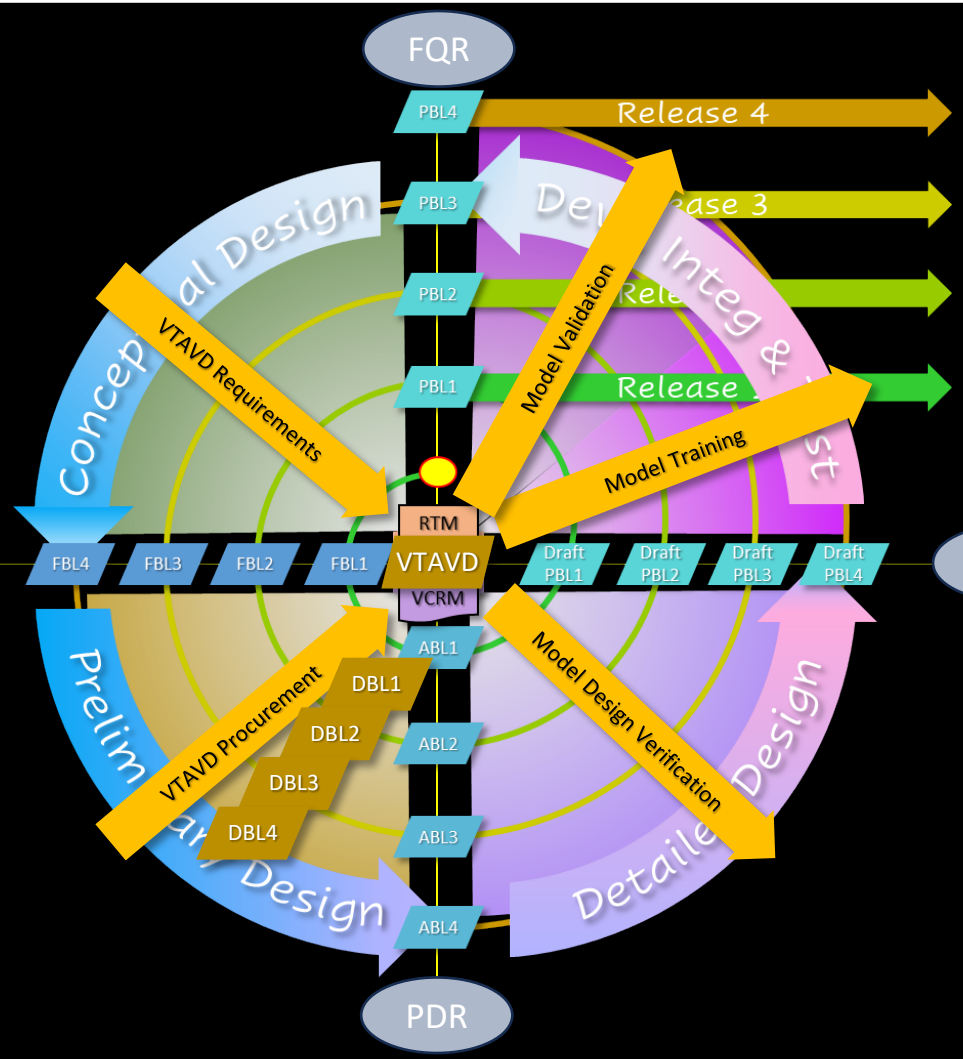
Proposed Refinement - Evolutionary SE Life-Cycle (ICMS view) with ML Focused VTAVD Overlay



Proposed Refinement - Evolutionary SE Life-Cycle (ICMS view) with ML Focused VTAVD Overlay

VTAVD Requirements
Across applicable Use-Cases & Sensors including changes to previous baselines
- VTAVD Category [Ver, Trg, Val]
- Scope, range and units
- Source/s for procurement of VTAVD
- Associated Constraints/Conditions/IP

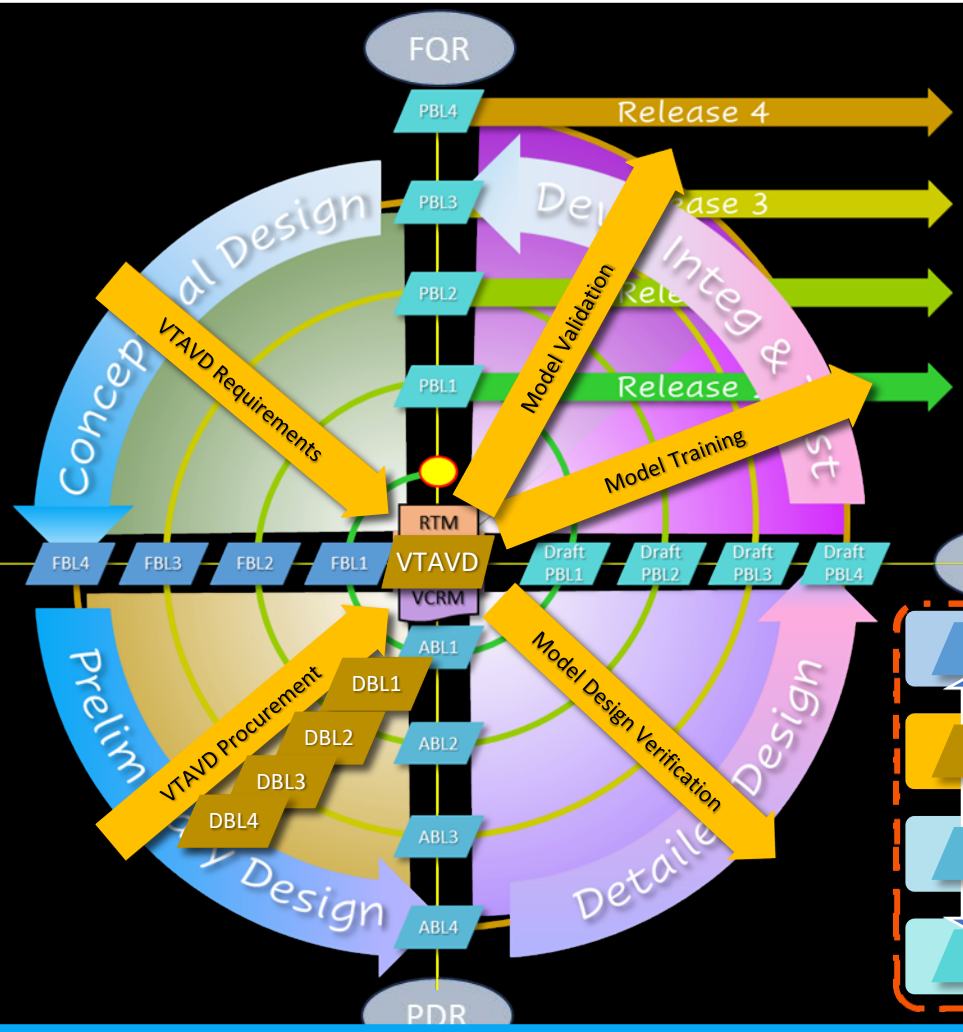
VTAVD Procurement
In accordance with the required VTAVD
- Procurement from nominated source/s
- Suitability Review / Corrective actions
- VTAVD refinement (cleaning) and
- **VTAVD Authorisation** as the **Data Baseline (DBL)** for design **V**erification, model **T**raining **A**nd model **V**alidation.

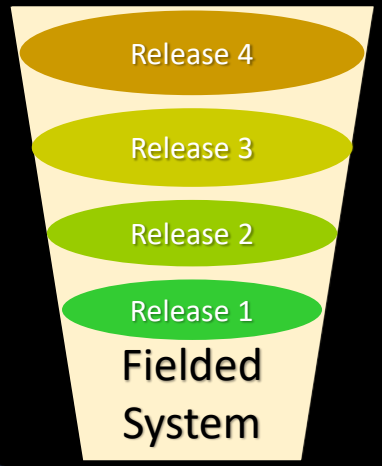


Model Training & Validation
In accordance with the A-VTAVD Training and Validation reference data that forms the DBL with "***ECP action***" for any changes or discrepancies identified in the FBL, DBL, ABL and PBL.

Model Design Verification
Conduct of Model Design Verification IAW the A-VTAVD Model Verification Data that forms part of the DBL with "***ECP action***" for any changes to the FBL, DBL or ABL.

An Evolutionary / Agile Depiction of the SE Life-Cycle identifying Configuration Baselines (integrity) through Development and Releases



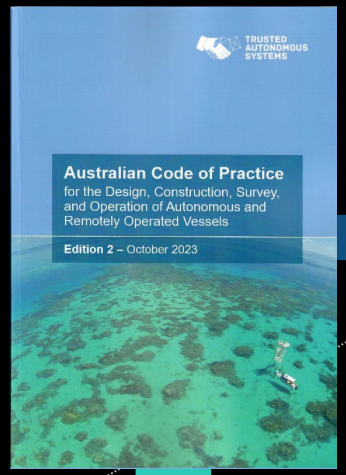


- RTM — Requirements Traceability Matrix
- VTAVD — Verification, Training And Validation Data
- VCRM — Verification Cross-Reference Matrix

- FBL — Functional Baseline
- DBL — Data Baseline
- ABL — Allocated Baseline
- PBL — Product Baseline

"Digital Threads" Integrity Preserved Through-Life

Proposed Refinement - Evolutionary SE Life-Cycle (ICMS view) with ML Focused VTAVD Overlay



INTERPRET

CONCEPT

Evolving Operational Needs | Evolving Operational Environments | Evolving Regulations

Design & Build the *Right System*

...to construct a framework for the ***Systems Engineering*** of Ai-intensive systems (SE4AI).

Design & Build the *System Right*

Certificate of Operation (MAS)

...to construct a framework for the ***Assurance*** of built Ai-intensive systems (As4AI).

Certificate of Survey (MAS)

Evolving Standards | Evolving AI/ML Approaches | Evolving Technologies

CAPABILITY

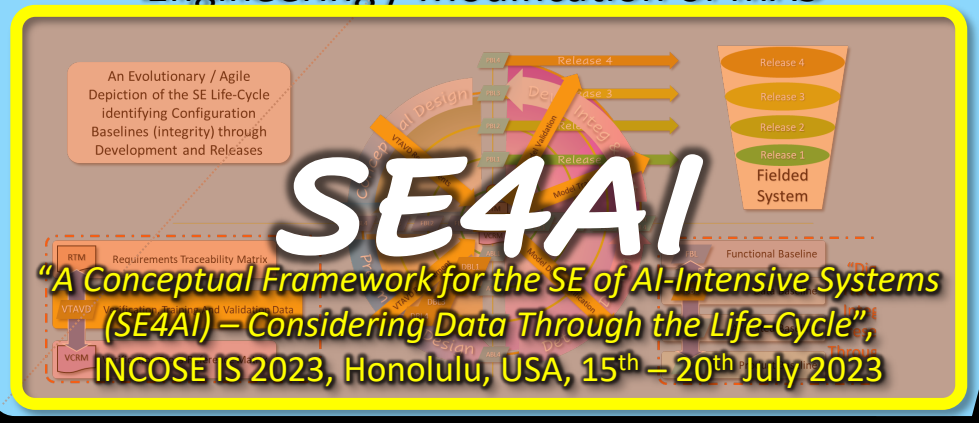
ACCREDIT

Safety Regulations for Maritime Autonomous Systems

AMSA Australian Maritime Safety Authority

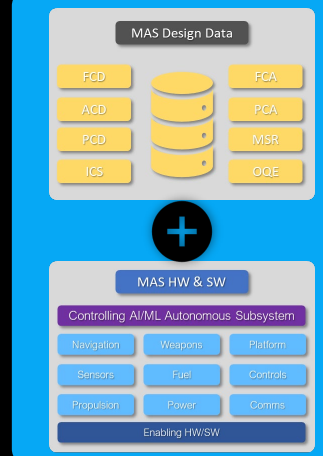
Safety Regulations for Simulated MAS Assurance Capabilities

Engineering / Modification of MAS

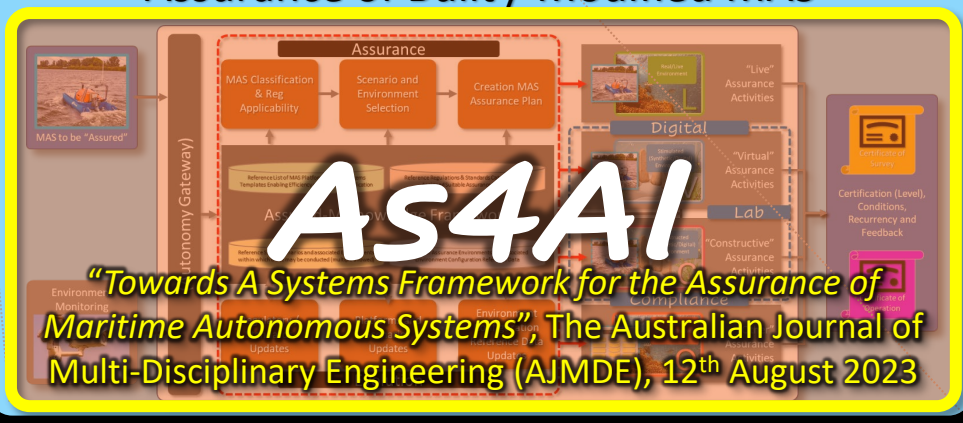


SE4AI

"A Conceptual Framework for the SE of AI-Intensive Systems (SE4AI) – Considering Data Through the Life-Cycle",
INCOSE IS 2023, Honolulu, USA, 15th – 20th July 2023

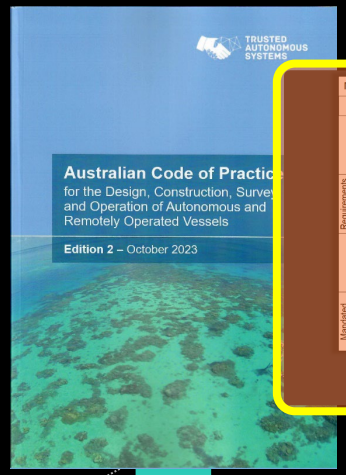


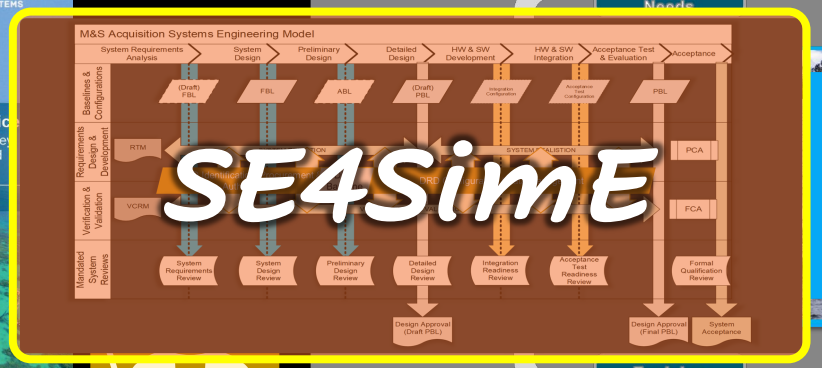
Assurance of Built / Modified MAS

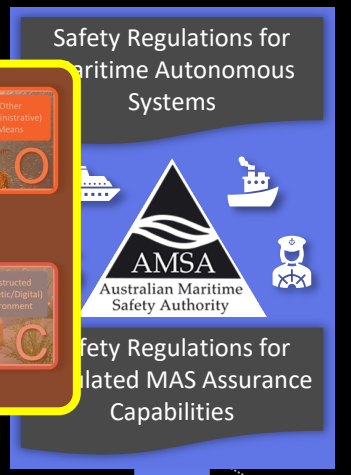


As4AI

"Towards A Systems Framework for the Assurance of Maritime Autonomous Systems", The Australian Journal of Multi-Disciplinary Engineering (AJMDE), 12th August 2023



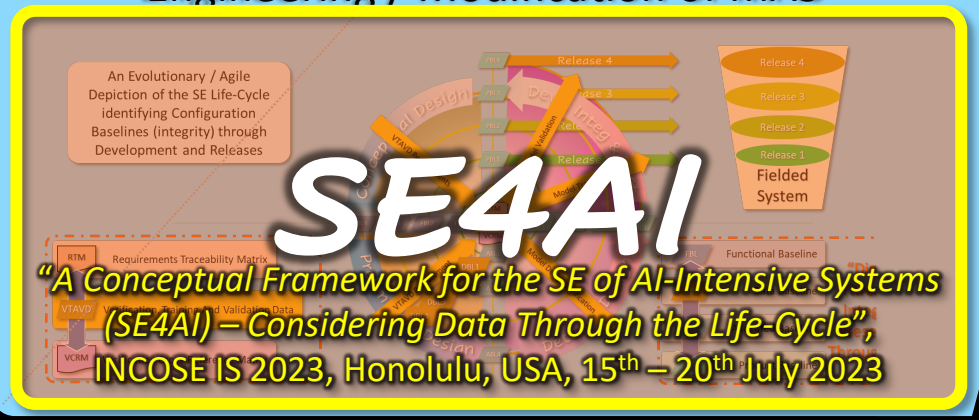




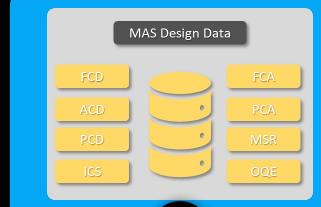
INTERPRET

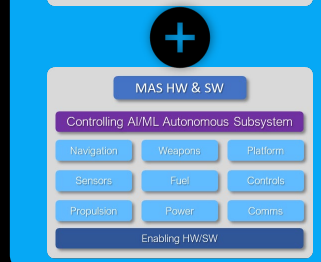
ACCREDIT

Engineering / Modification of MAS

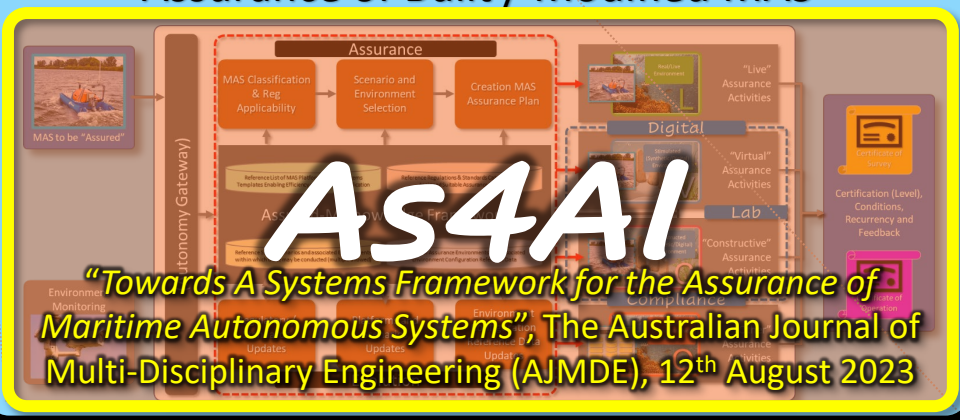


"A Conceptual Framework for the SE of AI-Intensive Systems (SE4AI) – Considering Data Through the Life-Cycle", INCOSE IS 2023, Honolulu, USA, 15th – 20th July 2023



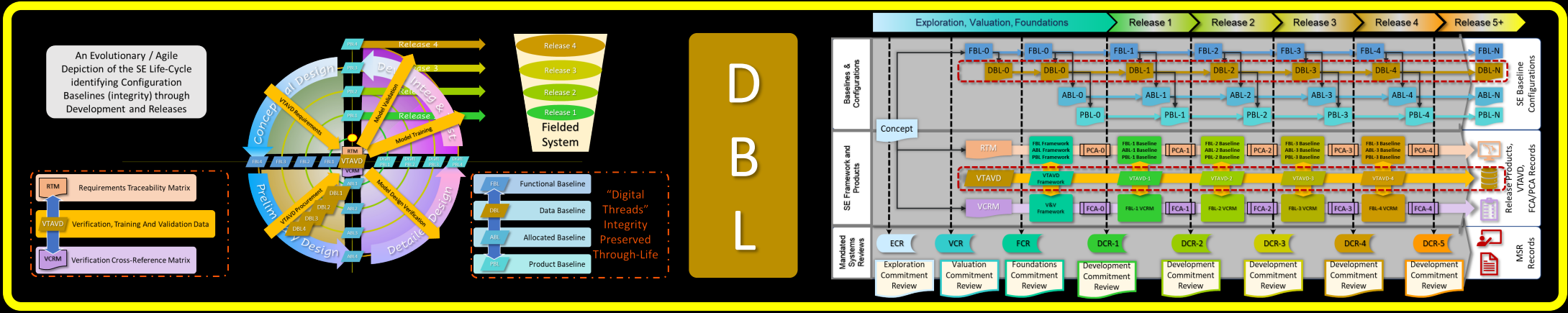


Assurance of Built / Modified MAS

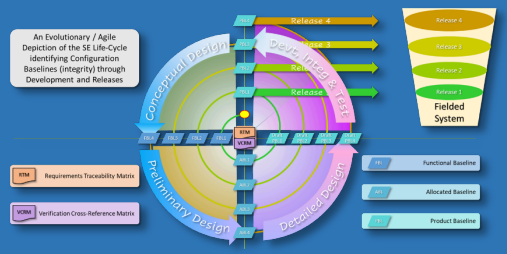


"Towards A Systems Framework for the Assurance of Maritime Autonomous Systems", The Australian Journal of Multi-Disciplinary Engineering (AJMDE), 12th August 2023

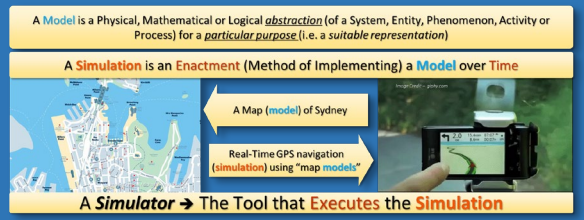
This presentation has considered the challenge of SE of Autonomous Systems with a particular focus on the end-to-end curation of reference data used as a basis for ML model design verification, model-training, and model-validation.



Systems Engineering Practice

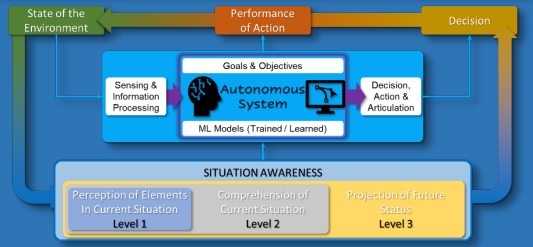


Modelling & Simulation



Data Curation Criticality

Situational Awareness



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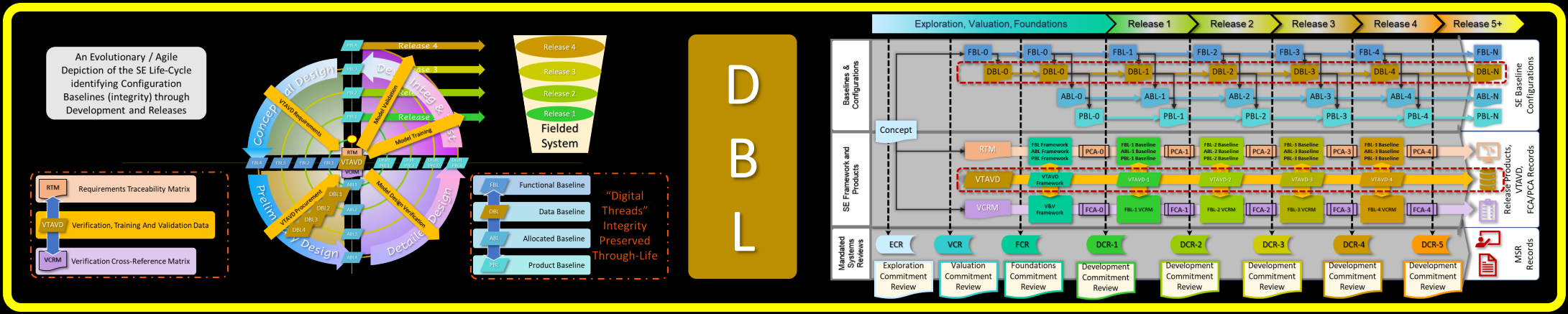

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