33rd Annual INCOSE international symposium

hybrid event

Honolulu HI USA

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A Conceptual Framework for the SE of AI Intensive Systems Considering Data Through the Life-Cycle

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RAAF B707 – 1979 to 2008

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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!

0.17 — Third pilot: May-day! 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.

A RAAF 707 like the one which crashed near Sale.

RAAF B707 – 29 October 1991

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, ….”

29 October 1991

RAAF B707-368C (A20-103) – Board of Inquiry
“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

Personal Journey in High-Fidelity M&S





1994 - 2019

Individual → Team → Tactics → Joint Combined → MR





A Need to Train the "*HI*" Right

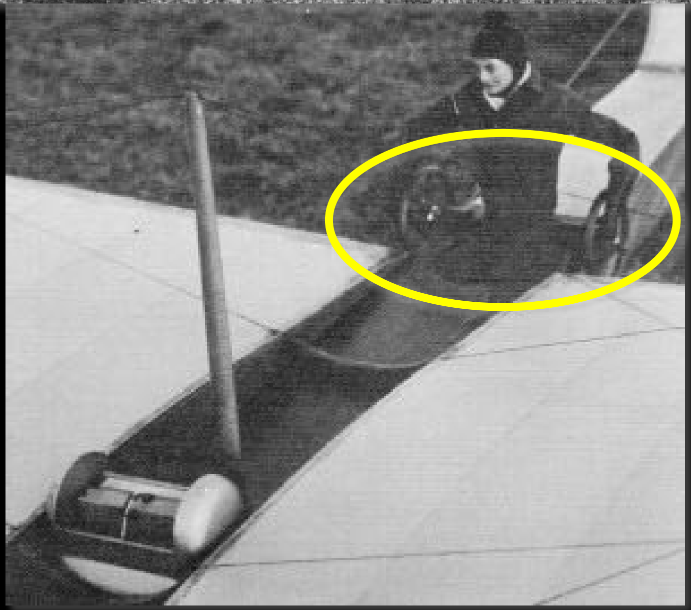

Image credit virtualanz.net

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A Need to Train the "*HI*" Right

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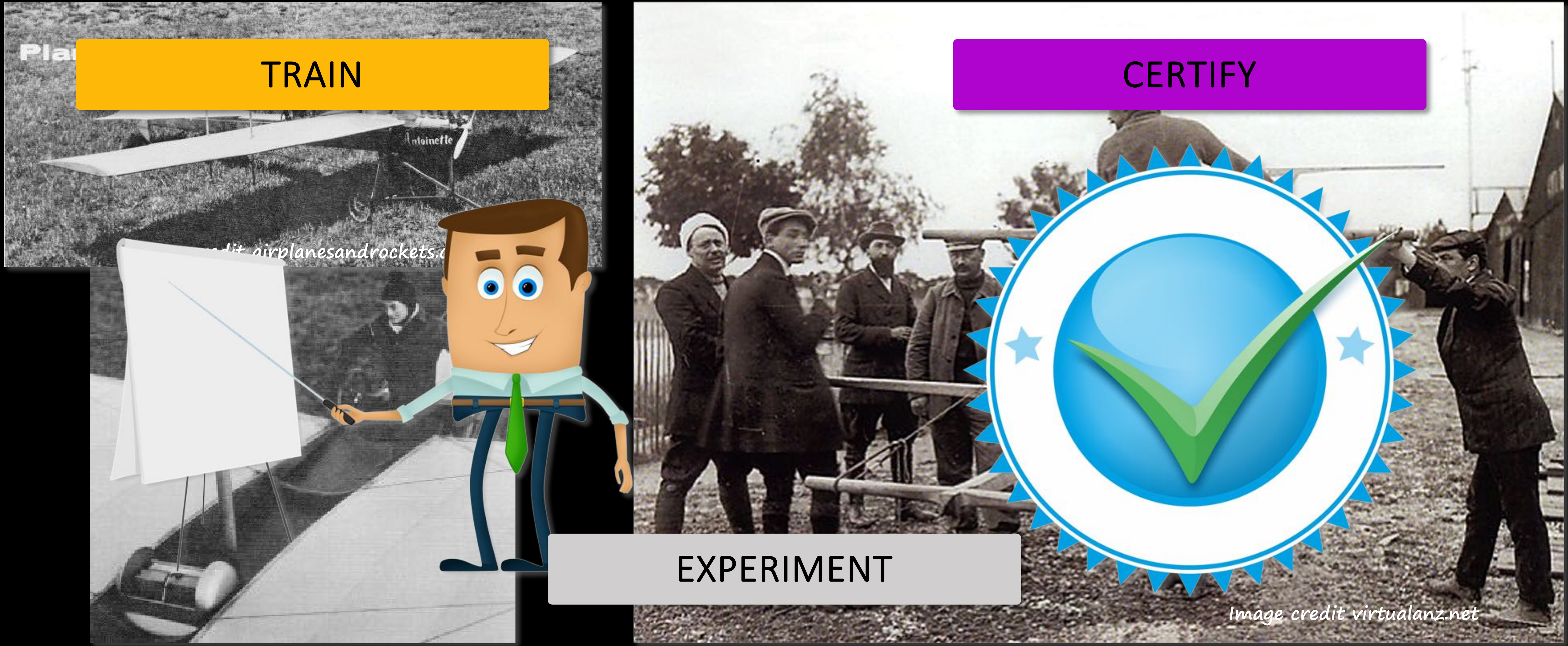

A Need to Train the "*HI*" Right

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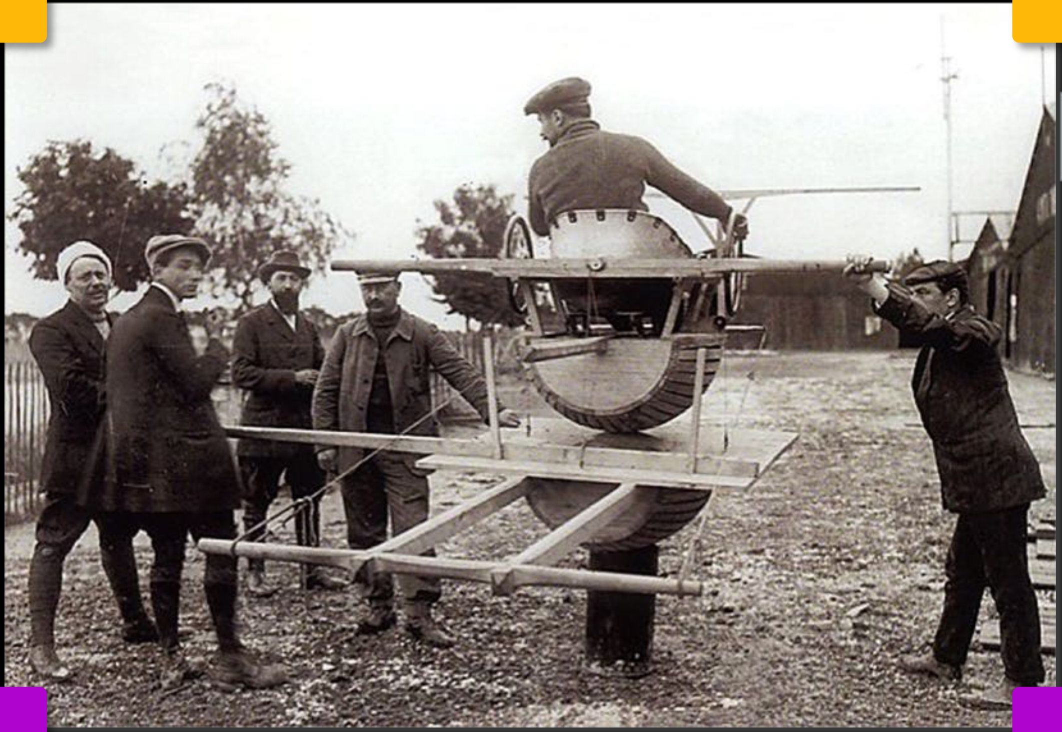
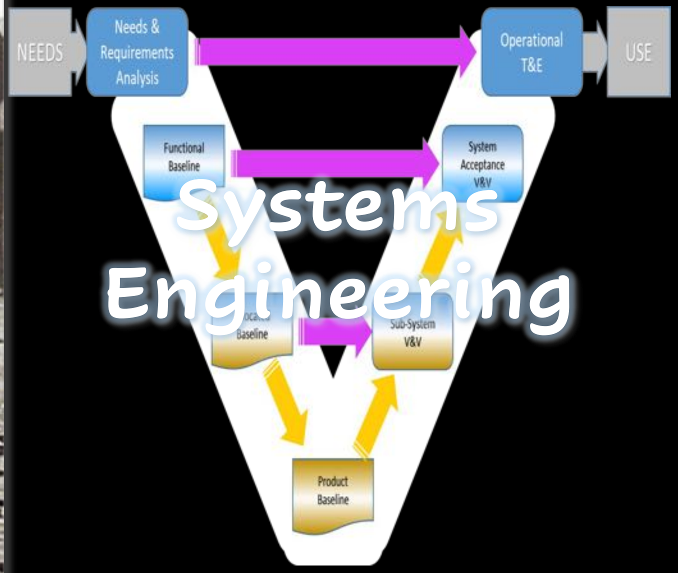
TRAIN

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*]

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Structure & Acknowledgement

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Introduction
- Problem Identification
- Paper Scope & Focus

- AI Development Approaches
- Core Enabling Concepts
- A Conceptual SE Framework
- Related Future Work

Conclusion
- Key Points
- References

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

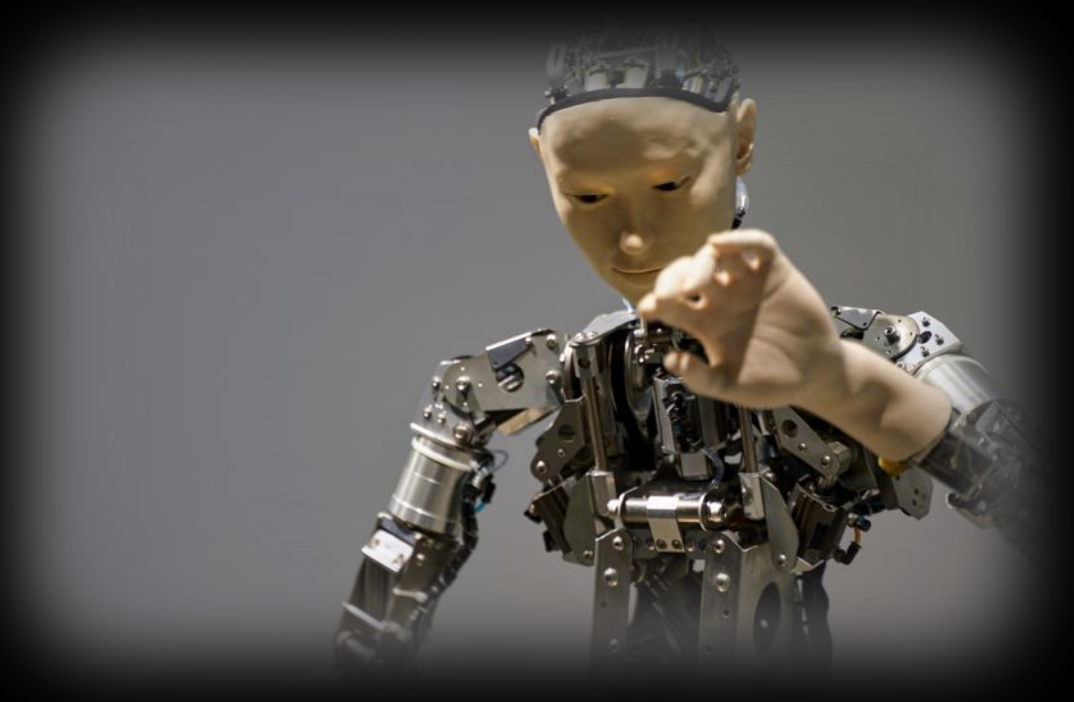
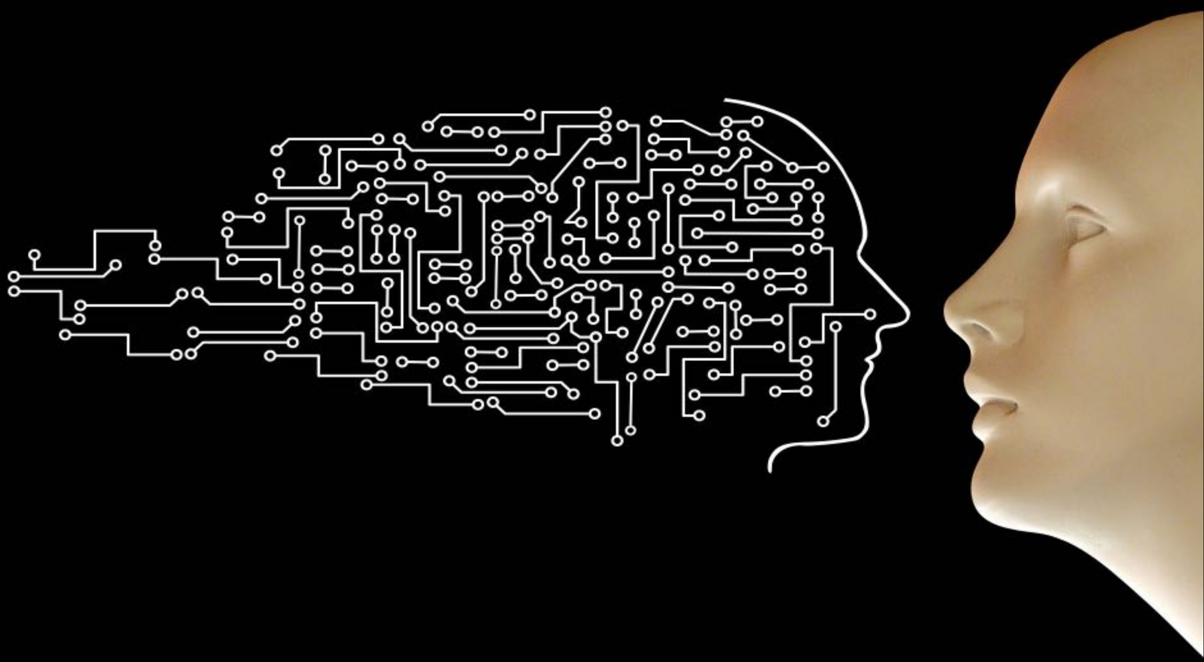


Image Credit – Pixabay



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Artificial Intelligence / Machine Learning are growing exponentially (Paleyes et al., 2021)
However "industry strength, production quality ML" is proving to be a challenge (Bosch et al., 2020)

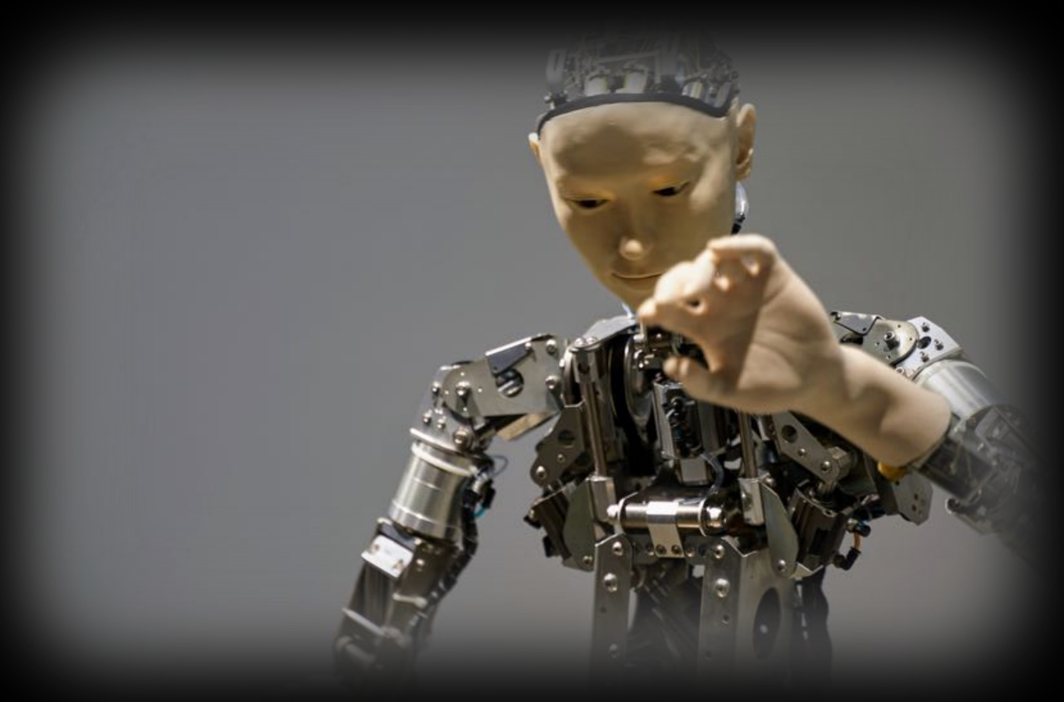


Image Credit – Pixabay

Image Credit – thepassanger, Pixabay

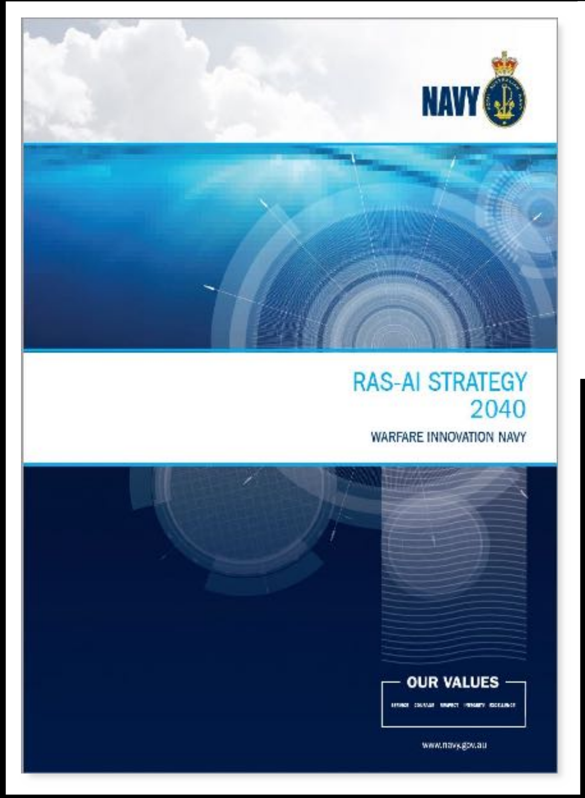
Autonomous vehicles (AV), autonomous transport, and robotics are gaining popularity

Majority of research for autonomous vehicle navigation largely "focused around the automotive industry" (Brandsæter and Knutsen, 2018)

"The lack of a clear and transparent framework and methodologies to assure the safety associated with the usage" are "key barriers" to implementation of autonomous navigation solutions at scale (Brandsæter and Knutsen, 2018)

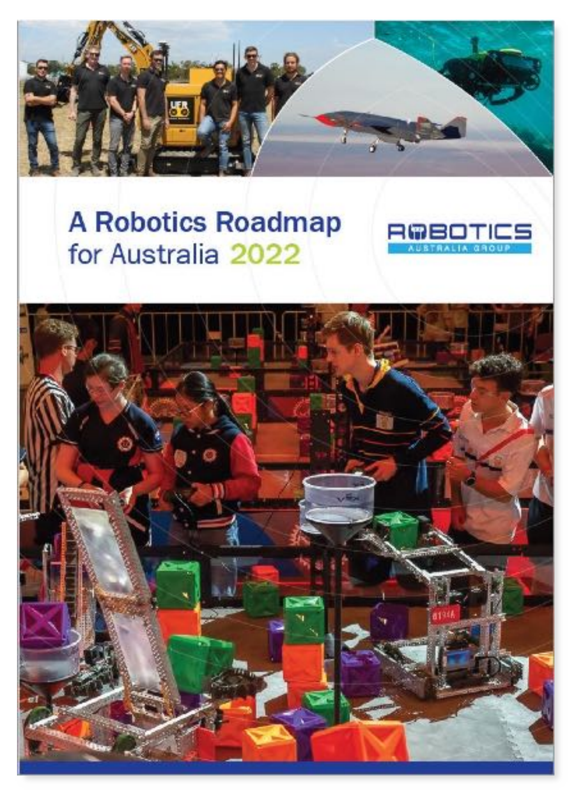
Image Credit – Thomas Ehrardt Pixabay

The advent of advanced AVs is anticipated as being "one of the biggest technological disruptions of the next decade" (Aniculaesei et al.) and the "technology trend with the highest potential to disrupt the transport sector in the future."(Brandsæter and Knutsen, 2018)



"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"
(Noonan, 2021)

Priority – "Develop and adopt governance systems to ensure robotics and AI solutions improve Australia's well-being and protect democratic values"
(Australia, 2021)



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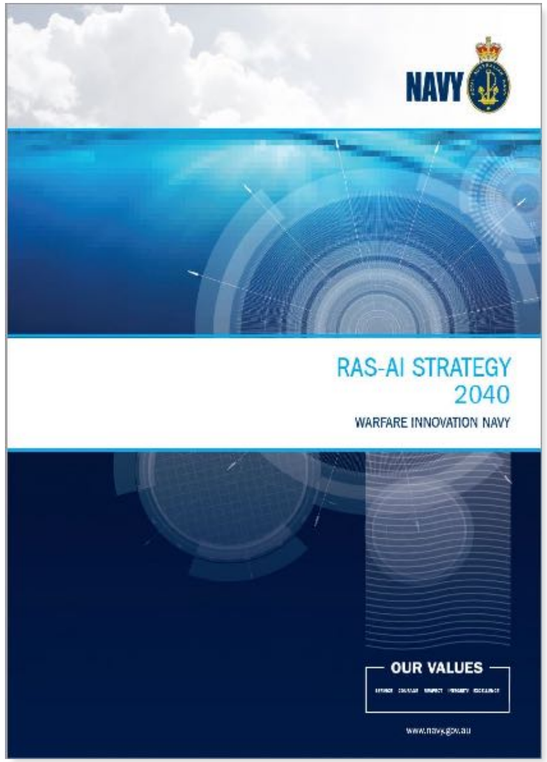


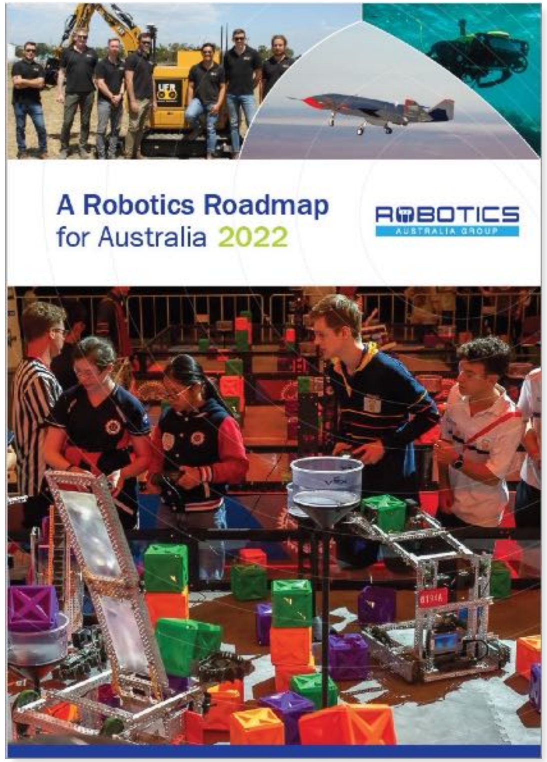
Increased complexity of ML systems raising concerns in safety critical domains – difficult to verify design / explain behaviour (Cluzeau et al., 2020)

47% of all AI projects remain prototypes due to a lack of tools to develop and maintain production-grade AI systems(Giray, 2021)

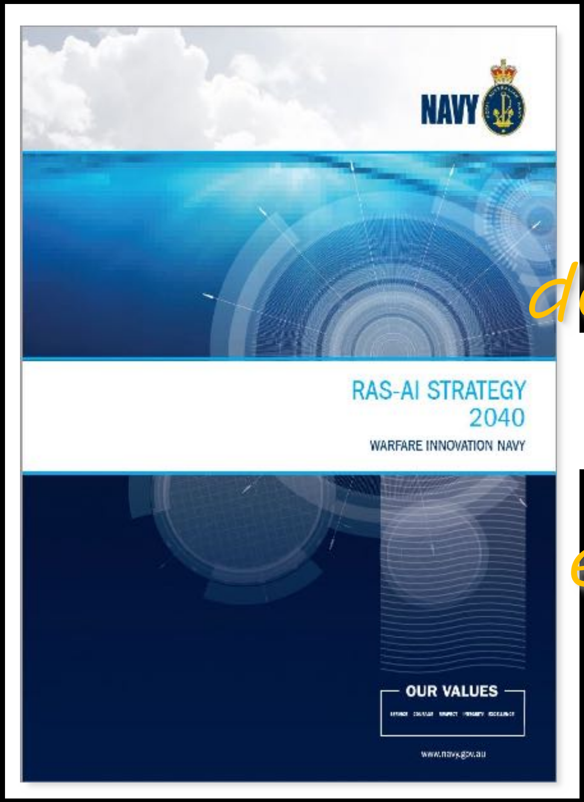
AI development approaches largely been technologically driven – enabled by advances in computing power and data availability

…while the building blocks are in place, the principles for putting these building blocks together are not (Jordan, 2019)

There is a perceived need for "a holistic view of engineering software-intensive systems with ML capabilities (Giray, 2021)

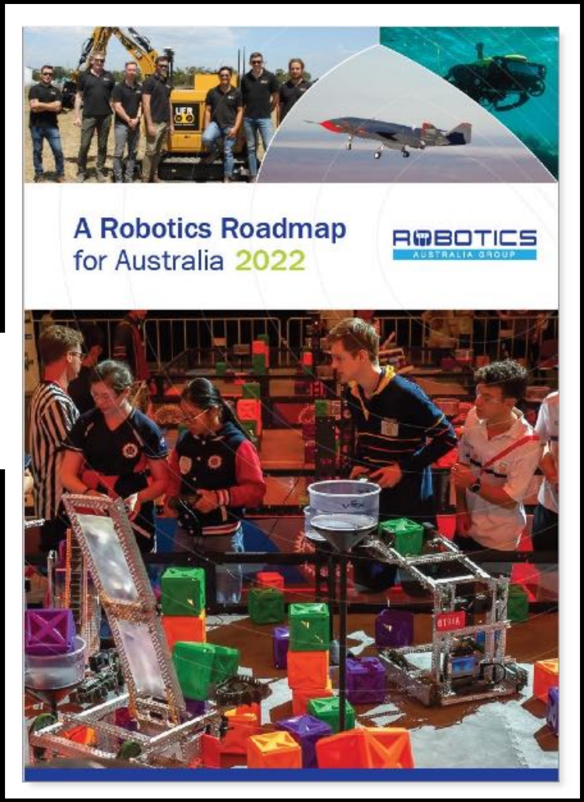


There is a need to engineer and assure safe and secure AI applications holistically from a first-principles, systems perspective, considering their nuances to tailor the core SE pillars of *Requirements Engineering* (RE), *Architectural Design, Verification and Validation* (V&V) and *end-to-end traceability*



A need for an SE for AI (SE4AI) 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.

design integrity
safety
security
assurance
evolutionary



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Evolving Operational Needs

Evolving Operational Environments

Evolving Regulations

CONCEPT

Design & Build the ***Right System***

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

Design & Build the ***System Right***

Safety of Operation (and Evolution)

Integrity of Design & Build (and Evolution)

Certificate of Operation (MAS)

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

Certificate of Survey (MAS)

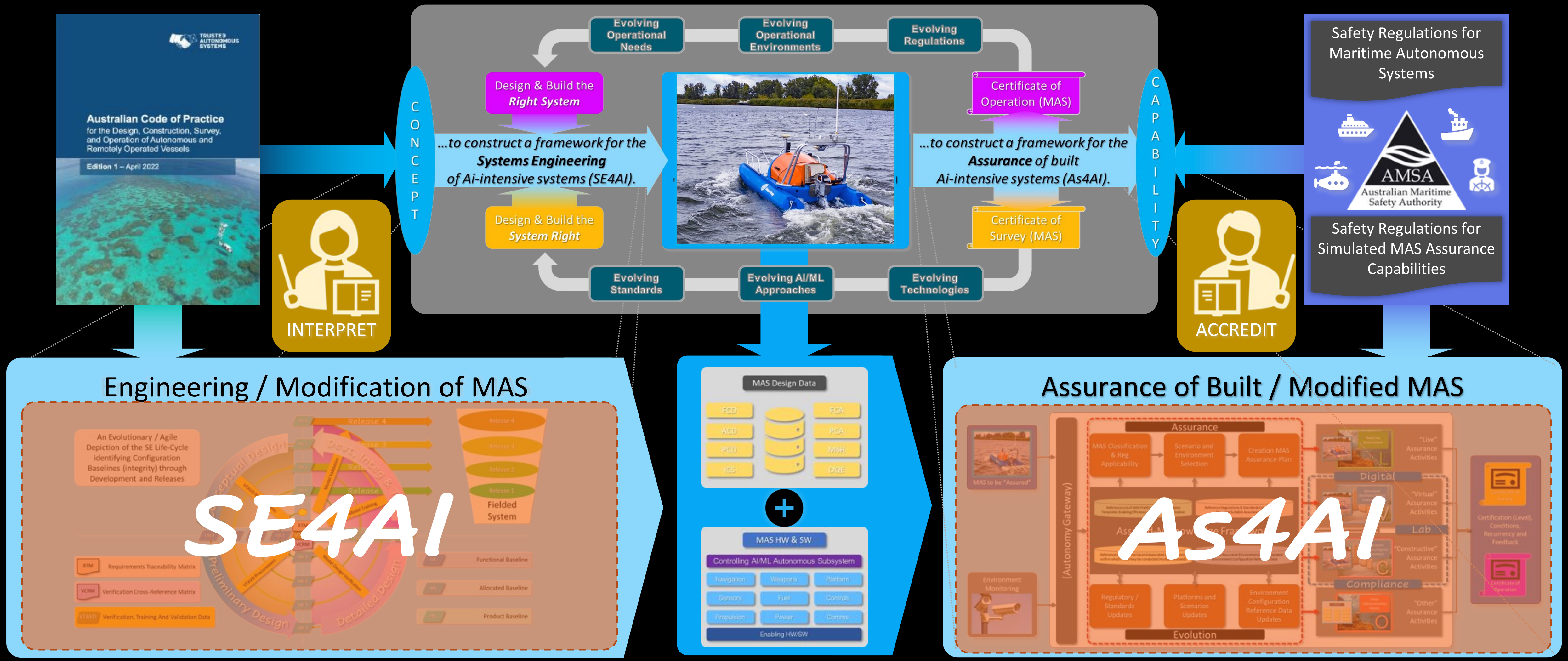
CAPABILITY

Evolving Standards

Evolving AI/ML Approaches

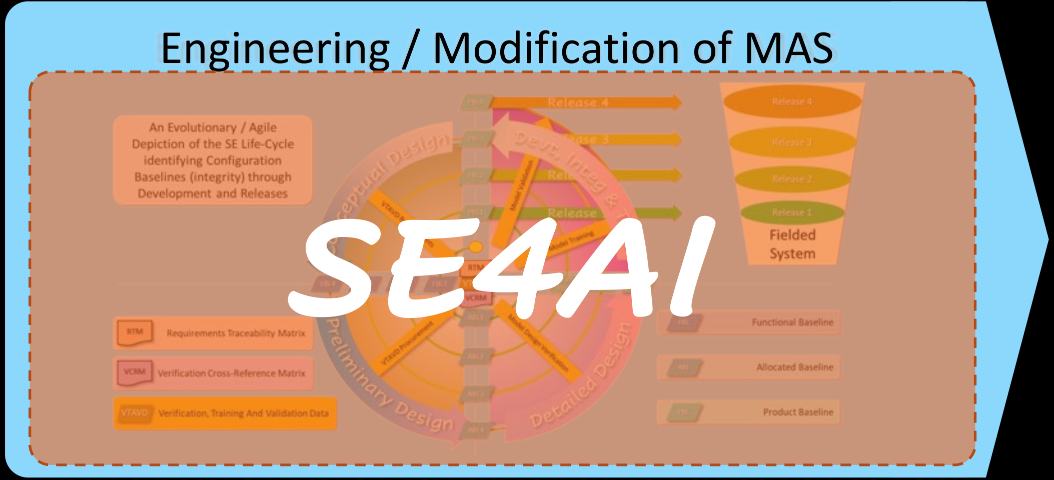
Evolving Technologies

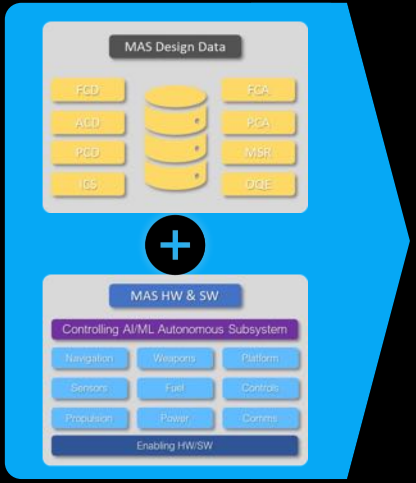
A need for an SE for AI (SE4AI) framework that would build in *design integrity*, system *safety*, and *security* and enable ongoing *assurance* through a highly *evolutionary* AI capability life-of-type context.


TRUSTED AUTONOMOUS SYSTEMS
Australian Code of Practice
for the Design, Construction, Survey, and Operation of Autonomous and Remotely Operated Vessels
Edition 1 – April 2022
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
Evolving Standards
Evolving AI/ML Approaches
Evolving Technologies
Certificate of Operation (MAS)
...to construct a framework for the Assurance of built Ai-intensive systems (As4AI).
Certificate of Survey (MAS)
CAPABILITY
Safety Regulations for Maritime Autonomous Systems
AMSA
Australian Maritime Safety Authority
Safety Regulations for Simulated MAS Assurance Capabilities
INTERPRET
ACCREDIT
Engineering / Modification of MAS
SE4AI
Fielded System
MAS Design Data
MAS HW & SW
Controlling AI/ML Autonomous Subsystem
Enabling HW/SW
Assurance of Built / Modified MAS
As4AI

The objective of this paper is to propose a conceptual refinement to contemporary evolutionary developmental practice for the SE of AI-Intensive systems (SE4AI).

A particular 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) identify ***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

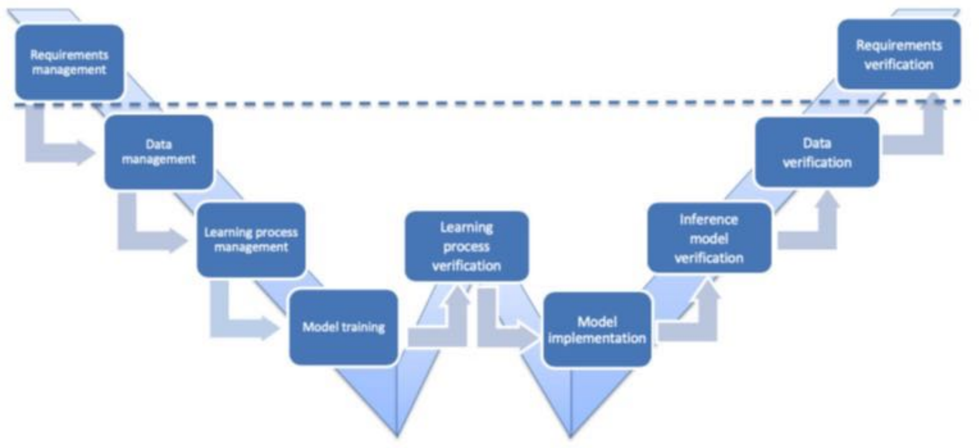
Teams at Microsoft blend data management tools with their ML frameworks to avoid the fragmentation of data and model management activities, and the rapid evolution of data sources (Amershi et al., 2019)

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

The European Aviation Safety Agency (EASA) examining the challenges posed by the use of neural networks in aviation (Cluzeau et al, 2020), recognised the "current aviation regulatory framework, in particular Development Assurance" did not provide a means for compliance for ML-based safety-critical aviation applications.

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

Model Performance
(Verification) - Training & Operational Scope



[Figure 6 from Cluzeau at al., (2020)]

EASA has defined a "W-shaped" <u>Learning Assurance Lifecycle</u> as a foundation for future guidance on ML and DL applications in aviation, however, is <u>more aligned with typical software development approaches</u> over the standard SE V-Model, with regards to concepts of <u>end-to-end traceability</u> and of <u>verification and validation</u>.

"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".

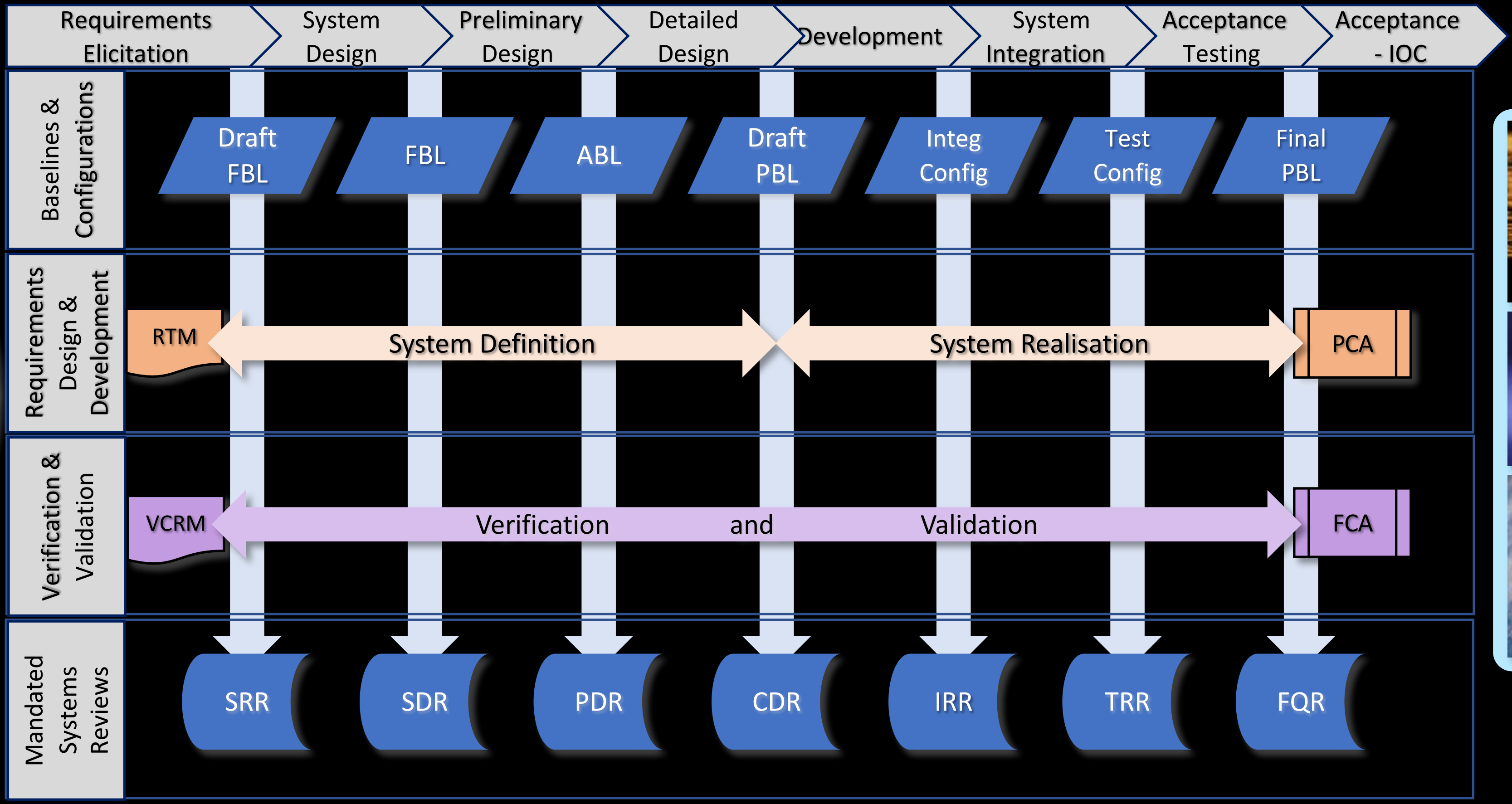
DATA Quality
Sufficiency of data sets / streams for Training & Inference

Model Performance
(Verification) - Training & Operational Scope

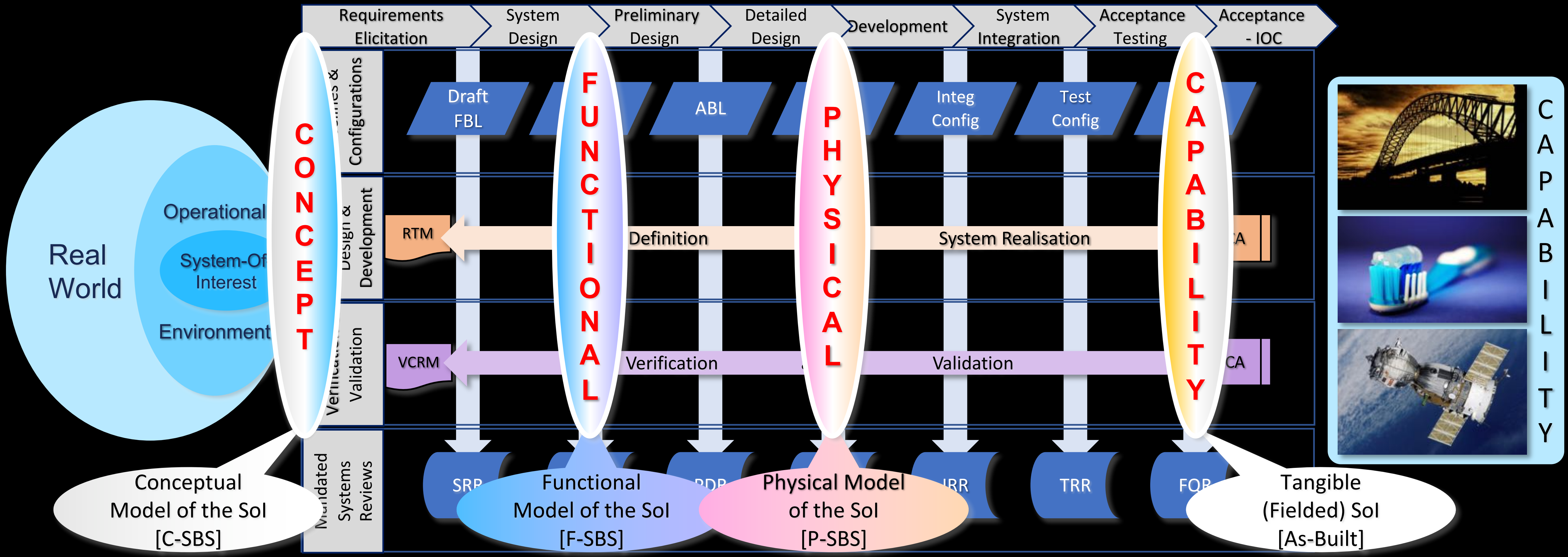
- Evolutionary focus on the PBL with regards to CM
- A perceived lack of explicit traceability (FBL, ABL, PBL, Data)
- V&V inherently a "Validation add-on" based on Data

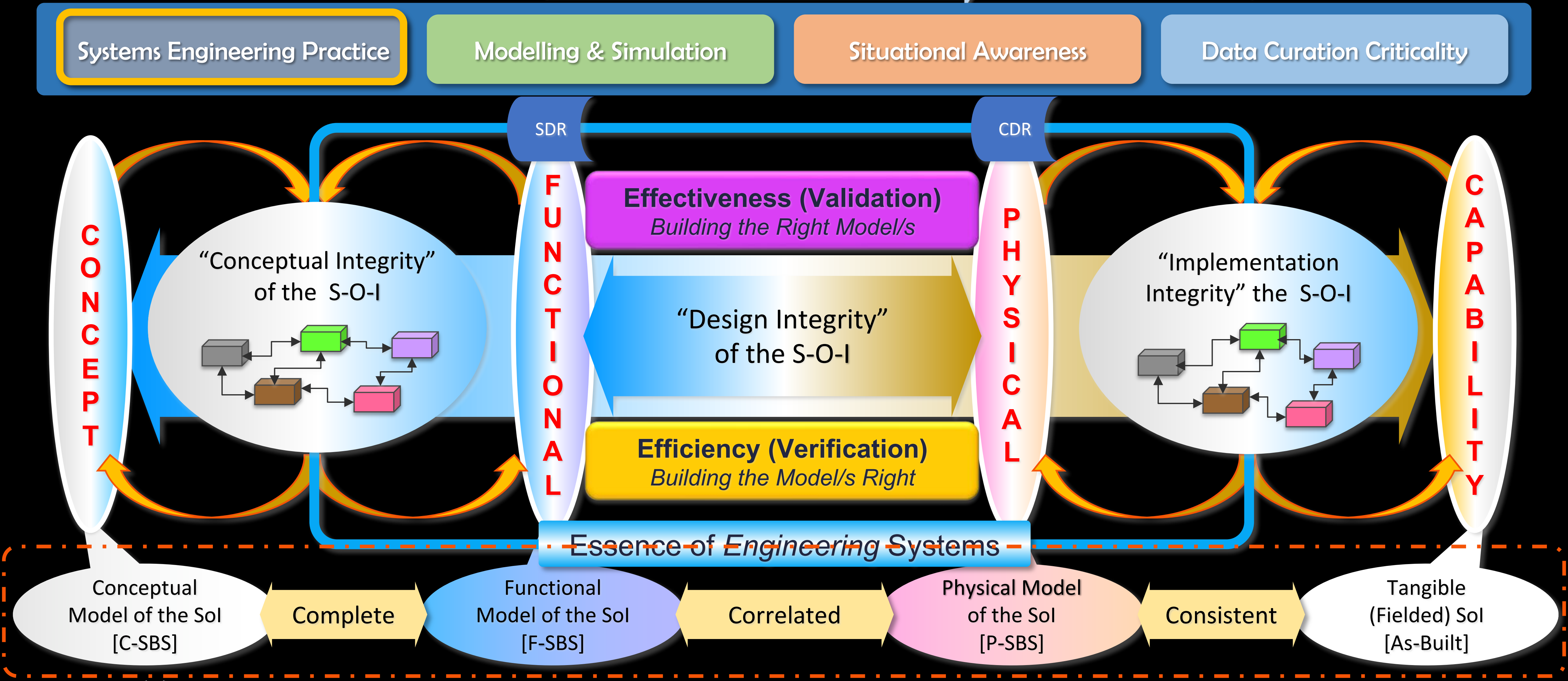
SE CM baseline rigor (FBL, ABL, PBL) and design integrity control (traceability across baselines), essentially shifts focus (post first iteration) to a progressive evolution of a PBL – exacerbates objective dependability/explainability.

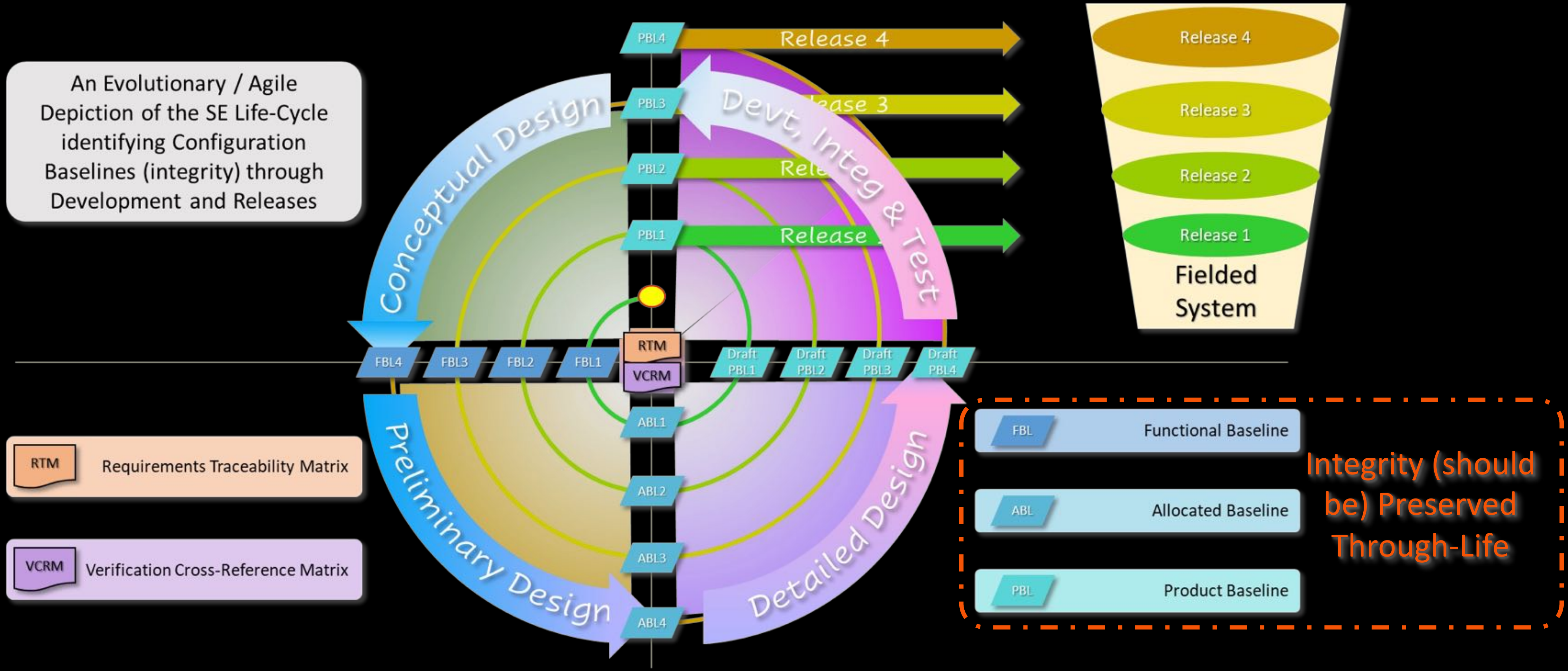
Systems Engineering Practice | Modelling & Simulation | Situational Awareness | Data Curation Criticality



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



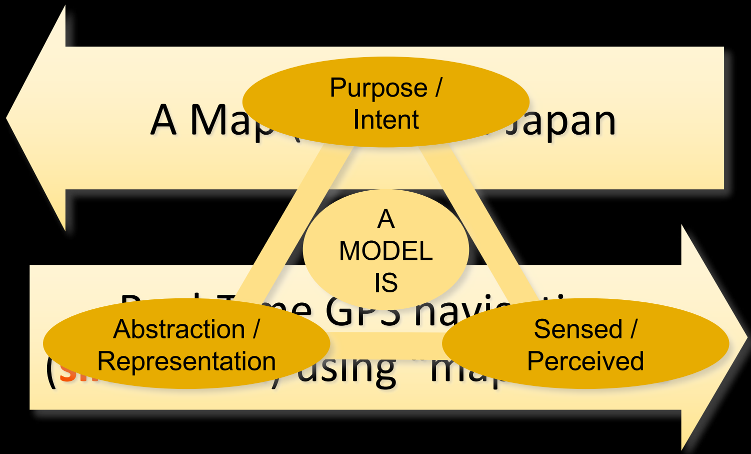

Systems Engineering Practice
Modelling & Simulation
Situational Awareness
Data Curation Criticality
SDR
CDR
CONCEPT
FUNCTIONAL
PHYSICAL
CAPABILITY
"Conceptual Integrity" of the S-O-I
Effectiveness (Validation)
Building the Right Model/s
"Design Integrity" of the S-O-I
Efficiency (Verification)
Building the Model/s Right
"Implementation Integrity" the S-O-I
Essence of Engineering Systems
Conceptual Model of the SoI [C-SBS]
Complete
Functional Model of the SoI [F-SBS]
Correlated
Physical Model of the SoI [P-SBS]
Consistent
Tangible (Fielded) SoI [As-Built]


An Evolutionary / Agile Depiction of the SE Life-Cycle identifying Configuration Baselines (integrity) through Development and Releases
Conceptual Design
Preliminary Design
Detailed Design
Devt, Integ & Test
PBL4
PBL3
PBL2
PBL1
Release 4
Release 3
Release
FBL4
FBL3
FBL2
FBL1
RTM
VCRM
Draft PBL1
Draft PBL2
Draft PBL3
Draft PBL4
ABL1
ABL2
ABL3
ABL4
Release 4
Release 3
Release 2
Release 1
Fielded System
RTM Requirements Traceability Matrix
VCRM Verification Cross-Reference Matrix
FBL Functional Baseline
ABL Allocated Baseline
PBL Product Baseline
Integrity (should be) Preserved Through-Life

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

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



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

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

Fidelity → Concept of “Goodness” or “Suitability” of a Model

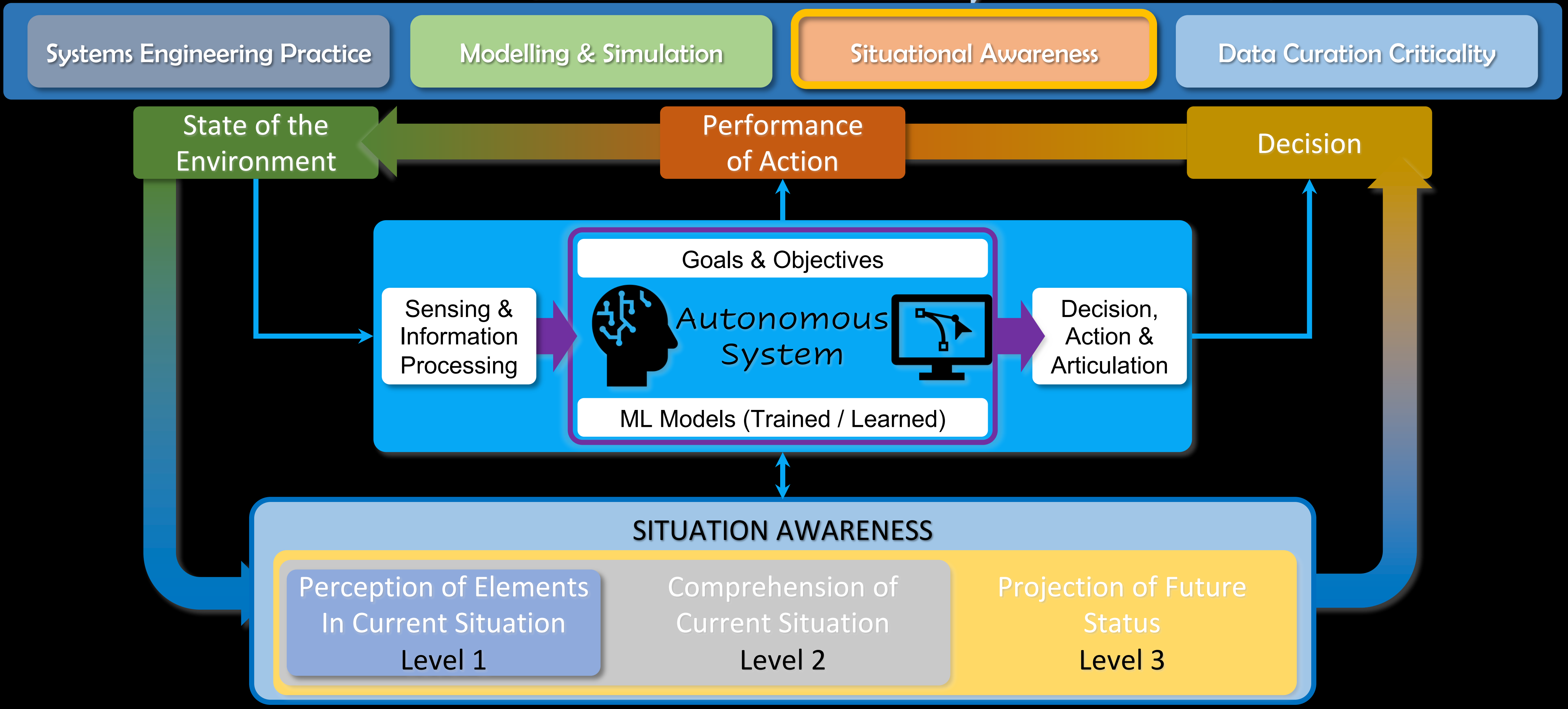
Lift Floor Tone ⇄ Re-Use ⇄ Home Theatre ⇄ Re-Use ⇄ Full Flight Simulator

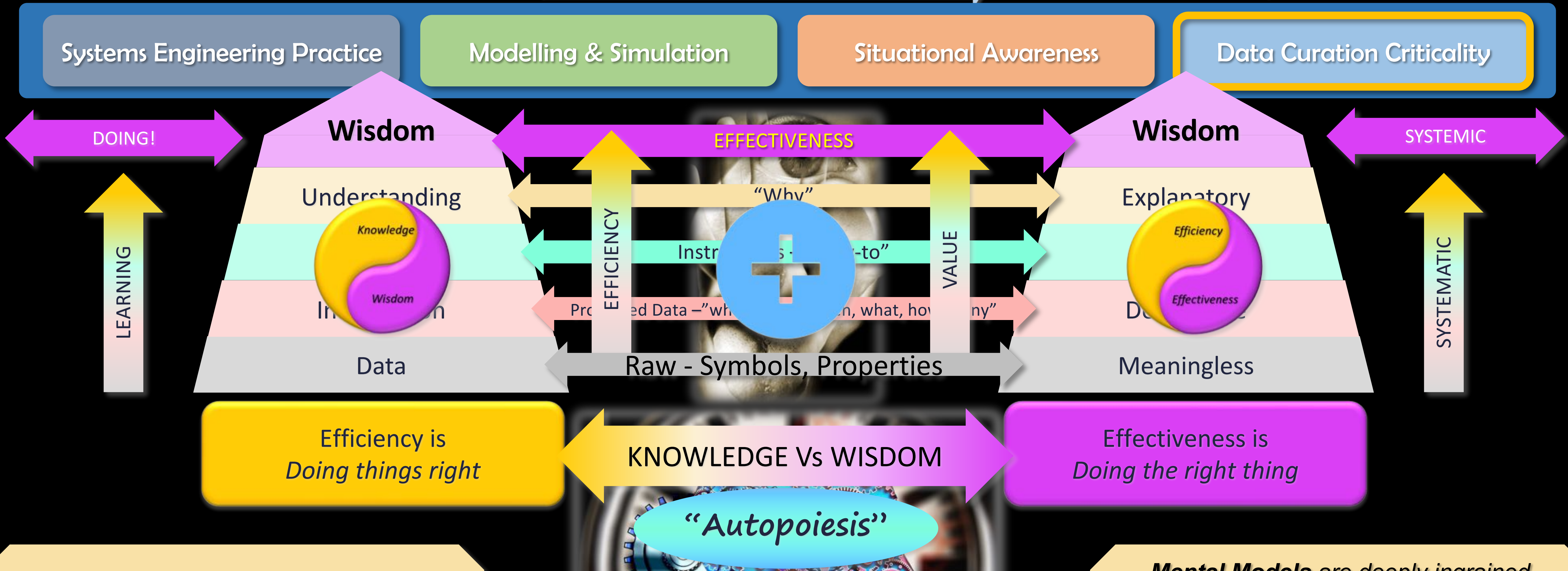
FFS

Sound

ABSTRACTION | EMERGENCE | INTEROPERABILITY

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


Systems Engineering Practice
Modelling & Simulation
Situational Awareness
Data Curation Criticality
State of the Environment
Performance of Action
Decision
Goals & Objectives
Sensing & Information Processing
Autonomous System
Decision, Action & Articulation
ML Models (Trained / Learned)
SITUATION AWARENESS
Perception of Elements In Current Situation Level 1
Comprehension of Current Situation Level 2
Projection of Future Status Level 3



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

MENTAL Models

***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 | Situational Awareness | Data Curation Criticality

DOING! — Wisdom — EFFECTIVENESS — Wisdom — SYSTEMIC

Confidence in the suitability of the ML models is inherently a function of the data used in their design, training and validation having the right fidelity *consistent with their operational use-cases*. Brown (2022) identifies four aspects to ML model data selection fidelity - diversity, augmentation, distribution, and synthesis (DADS).

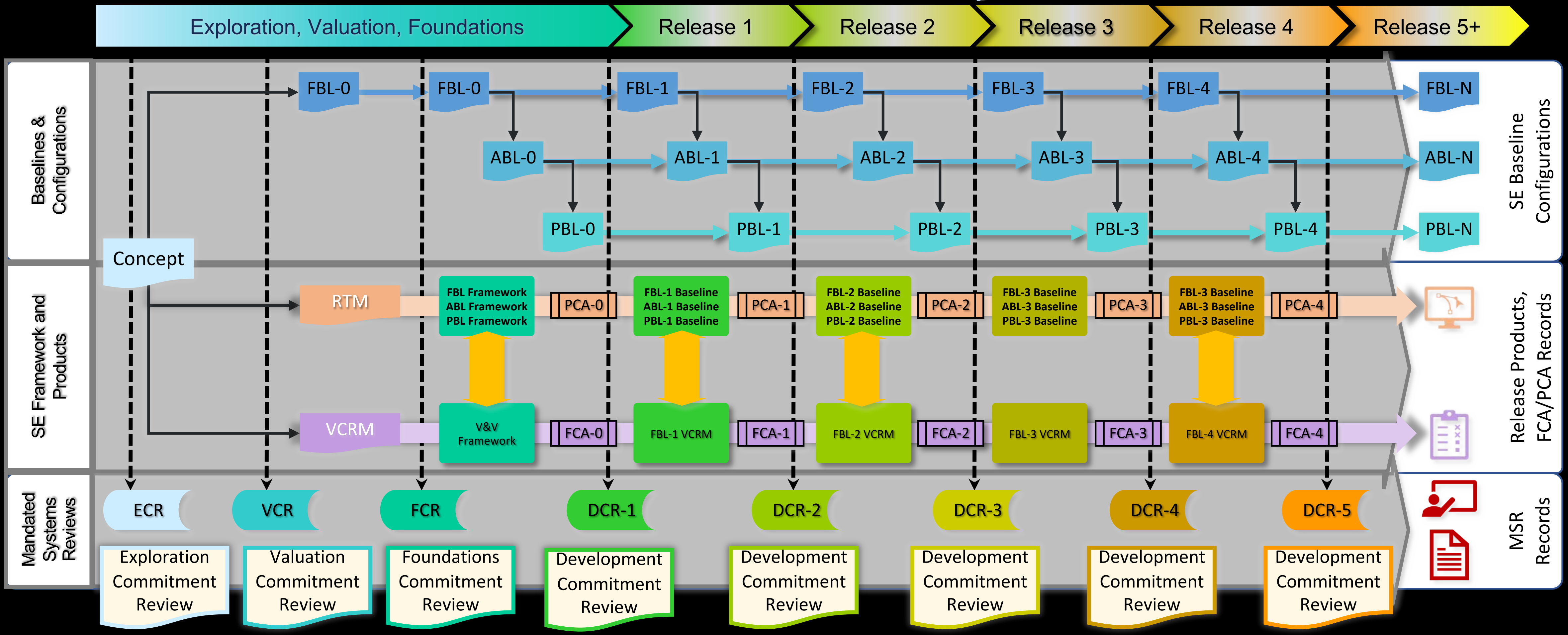
Efficiency is *Doing things right*

KNOWLEDGE Vs WISDOM

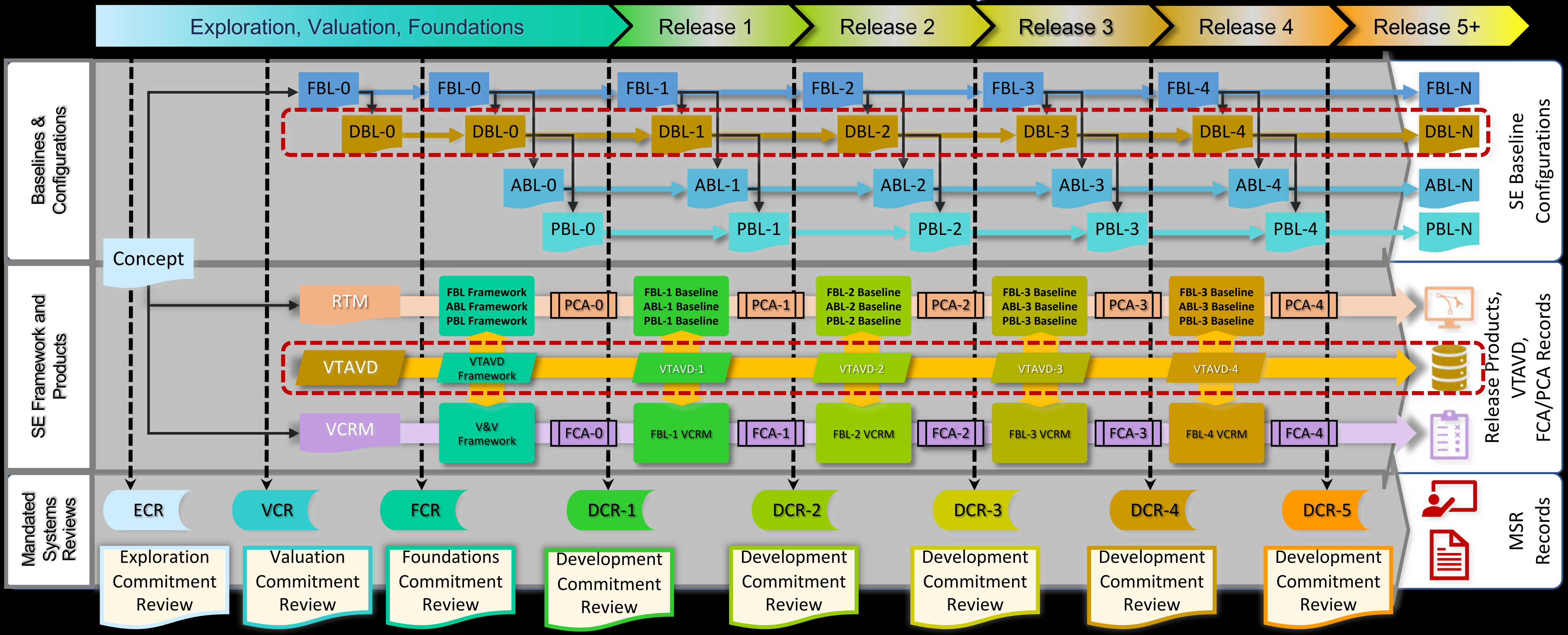
Effectiveness is *Doing the right thing*

"Autopoiesis"

The curation of data for ML model development is therefore fundamental to ensuring their design integrity and assurance of their operational suitability.



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

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

- Taking a structured approach to design and development of a conceptual framework, considering all the identified updates for data-centricity from this paper.
- Instantiating the conceptual framework for a specific application instance (MAS proposed)
  - a. Tailoring a conceptual SE4AI framework for MAS with regards to "situational awareness" in terms of sensor-types, sensed model fidelity scope (breadth and depth), environmental aspects and associated VTAVD scope;
  - b. Instantiating the tailored conceptual framework in a selected MBSE tool (to be confirmed with the University of Adelaide); and
  - c. Confirming/refining the suitability of the conceptual framework via instantiation against a specific MAS vessel type.
- Considering "run-time evolution" – i.e. is it feasible to allow for modification of ML capabilities while in-operation (noting the current EASA limitation that fielded ML system architectures are non-adaptive through operations), and if so, how does this impact the design and what limitations (if any) will need to be placed around the scope of live-modifications?
- Reviewing and revising the journal paper on "Towards a Systems Framework for the Assurance of Maritime Autonomous Systems", to be published by the Australian Journal of Mu-ti-Disciplinary Engineering (AJMDE) (Bhalla et al, 2023).
- Drafting a conceptual framework for assurance of MAS Assurance Environments.

This paper has considered the challenge of SE of AI-Intensive 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*.

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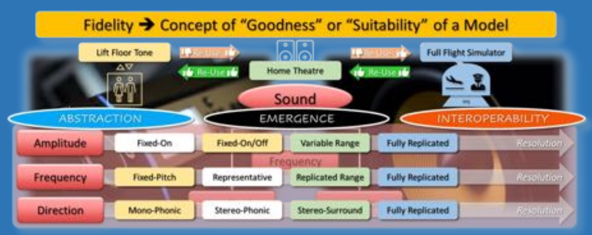
AI Development Approaches

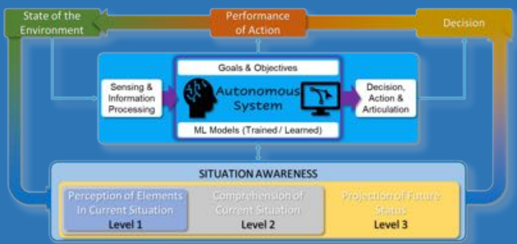
SE CM *baseline rigor* (FBL, ABL, PBL) and *design integrity control* (traceability across baselines), essentially shifts focus (post first iteration) to a *progressive evolution of a PBL* – exacerbates objective dependability/explainability.

Systems Engineering Practice

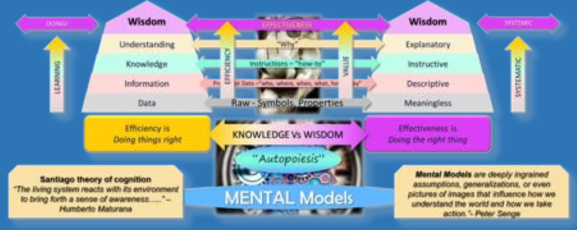
Modelling & Simulation



Situational Awareness



Data Curation Criticality



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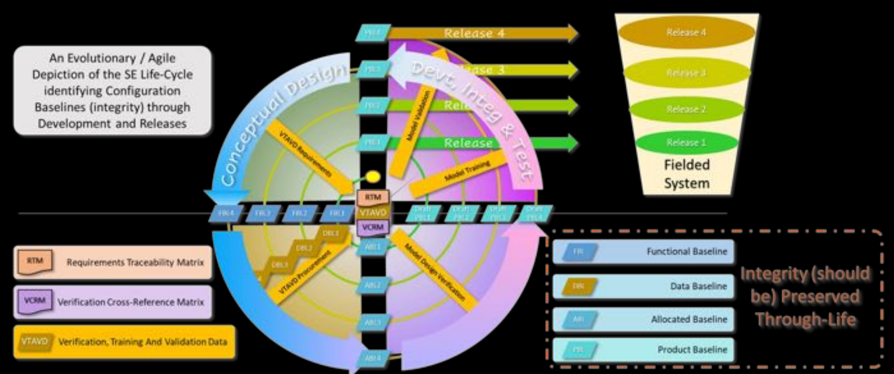

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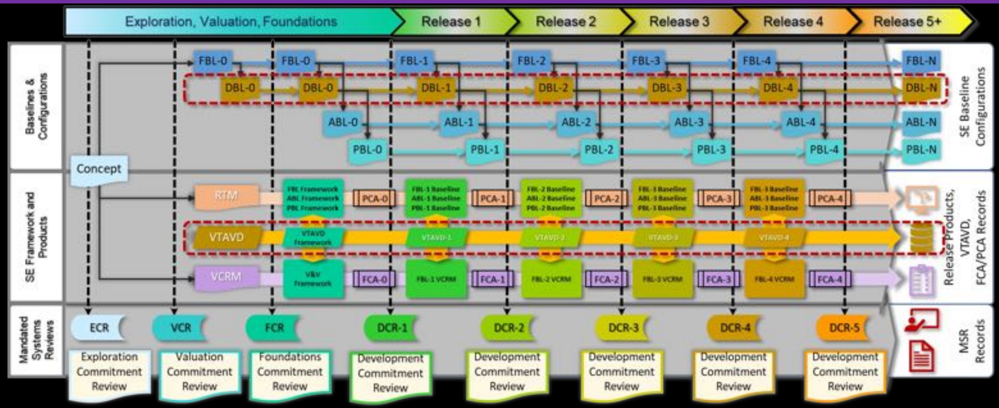
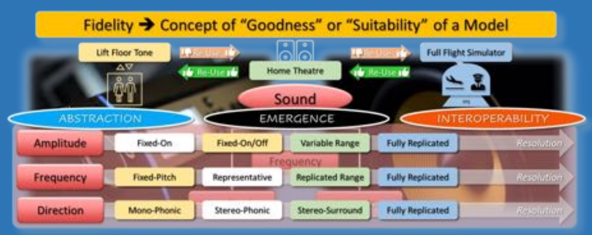
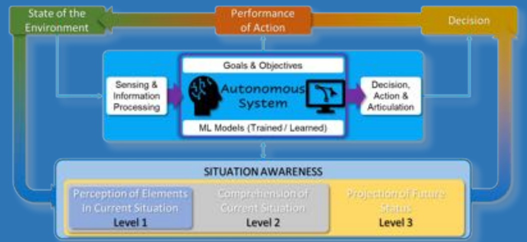


Systems Engineering Practice

Modelling & Simulation



Situational Awareness



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A Conceptual Framework for the SE of AI Intensive Systems Considering Data Through the Life-Cycle