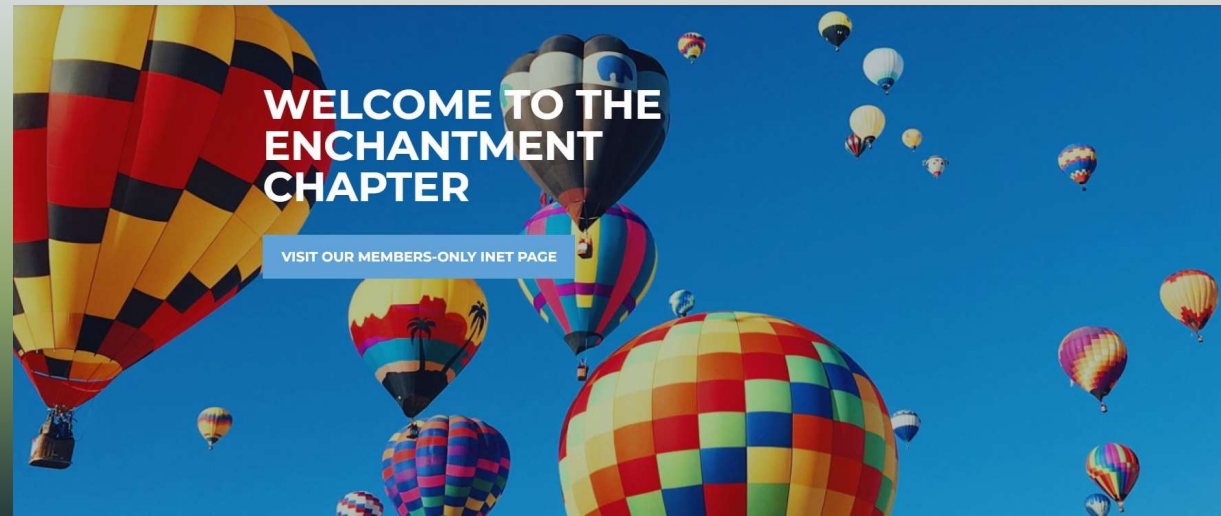


# INCOSE Enchantment Chapter Webinar

Wednesday, October 11, 2023 – 4:45pm-6:00pm MT  
Thursday, October 12, 2023 – 9:45am-11:00am AEDT



Jawahar Bhalla (JB)  
University of Adelaide &  
Shoal Group

Prof Stephen C. Cook  
University of Adelaide &  
Shoal Group

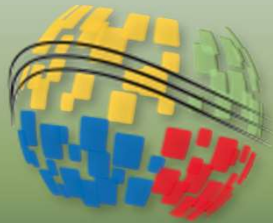
Dr David Harvey  
University of Adelaide

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

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**33<sup>rd</sup>** Annual **INCOSE**  
international symposium

hybrid event

Honolulu HI USA



Jawahar Bhalla (JB)  
University of Adelaide &  
Shoal Group

Prof Stephen C. Cook  
University of Adelaide &  
Shoal Group

Dr David Harvey  
University of Adelaide

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

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THE UNIVERSITY  
*of* ADELAIDE



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 alleron in — I can —

Captain: So, how are we



A RAAF 707 like the one which crashed near Sale.

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: 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!

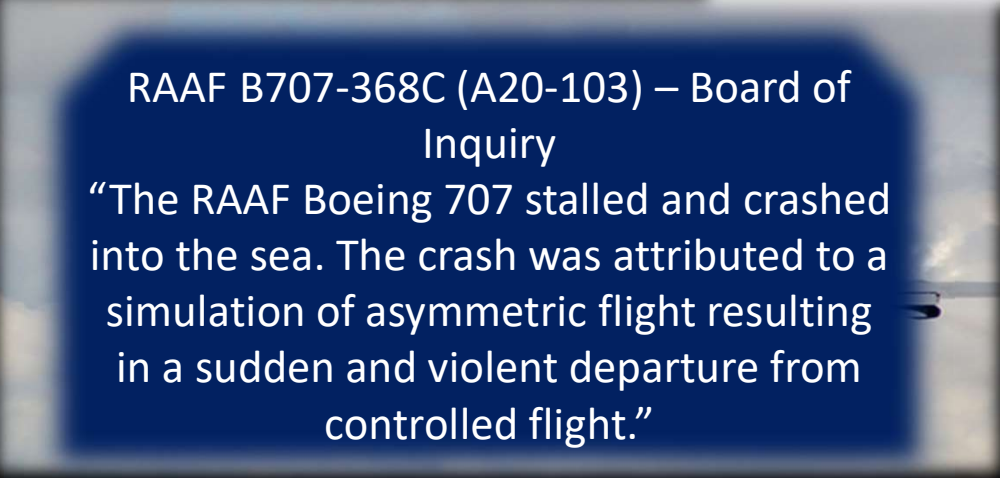
0.00 — Exclamations.  
Tape stops.



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

# SHOAL™

## Personal Journey in High-Fidelity M&S

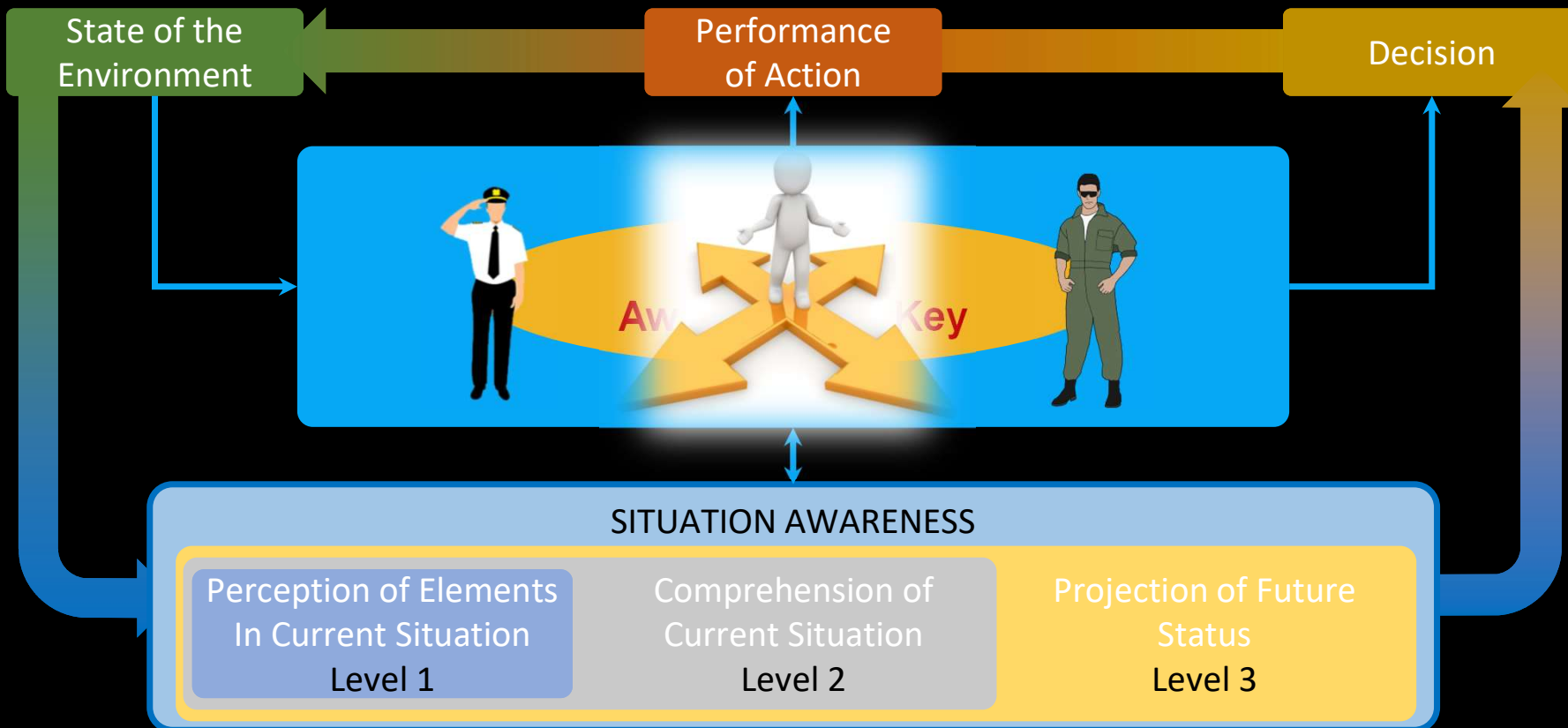


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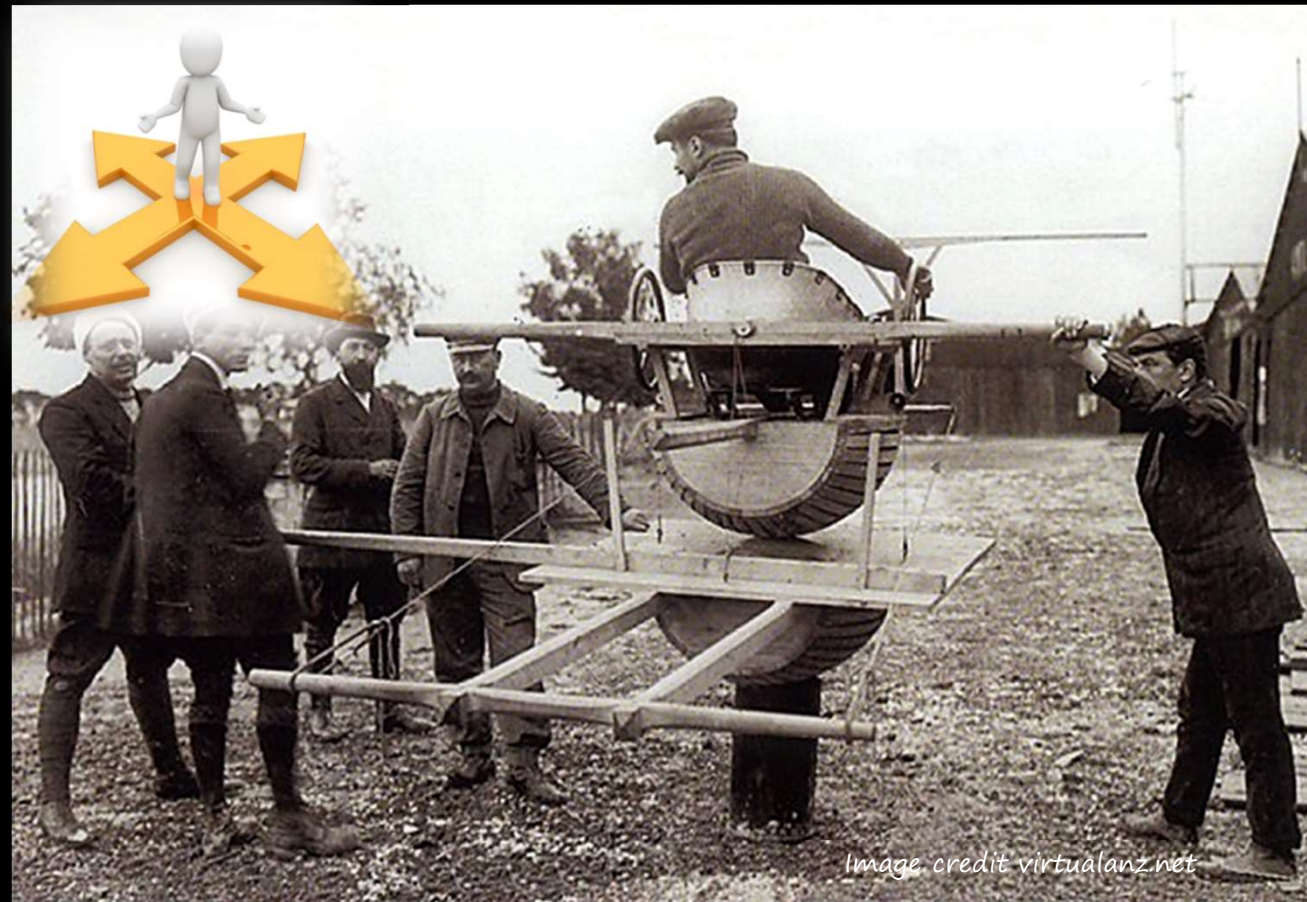
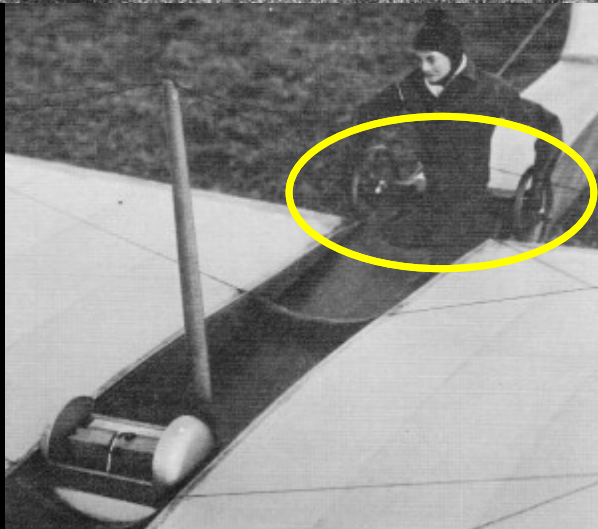
Copyright © 2023 by Jawahar Bhalla, Stephen Cook, David Harvey

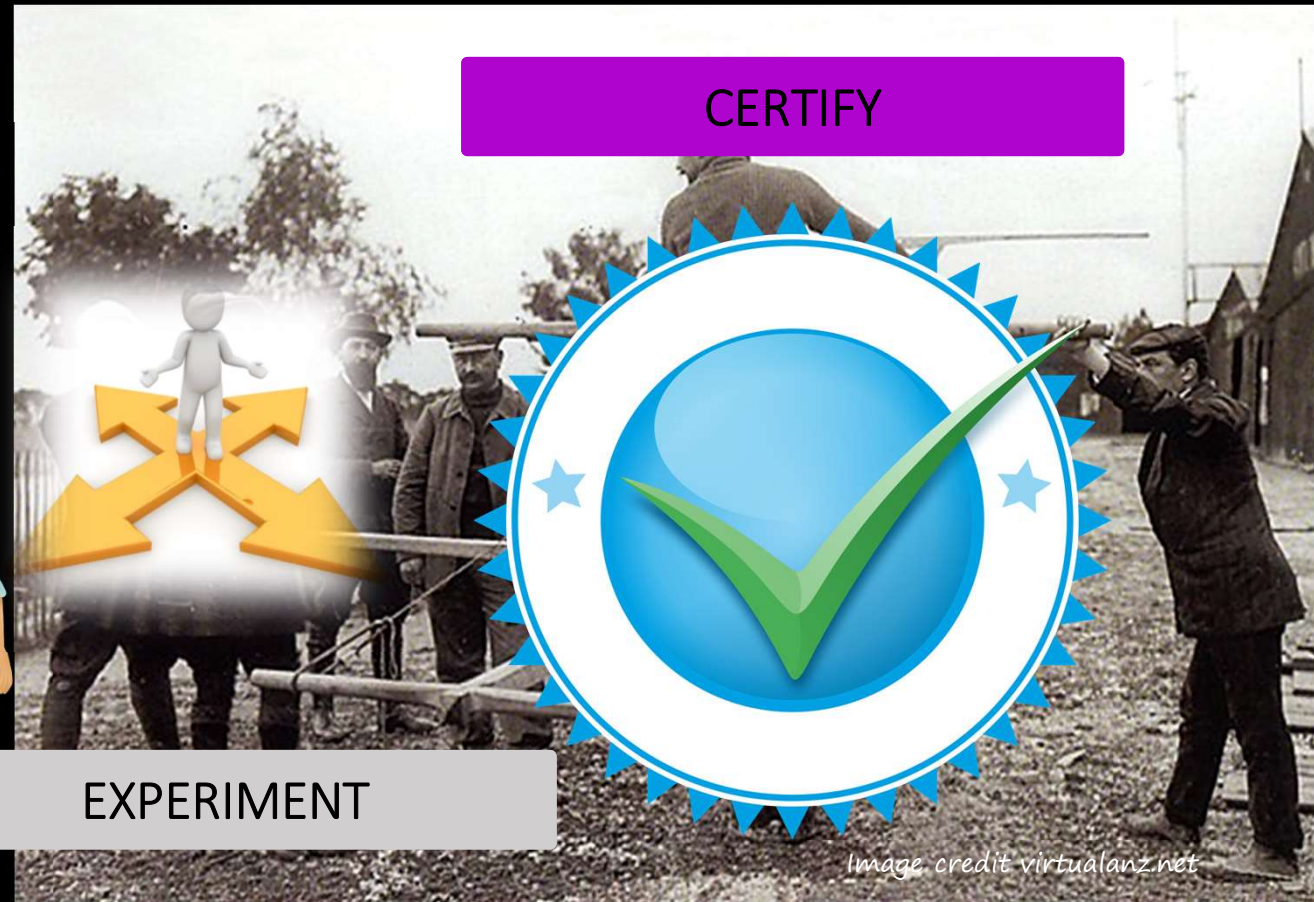
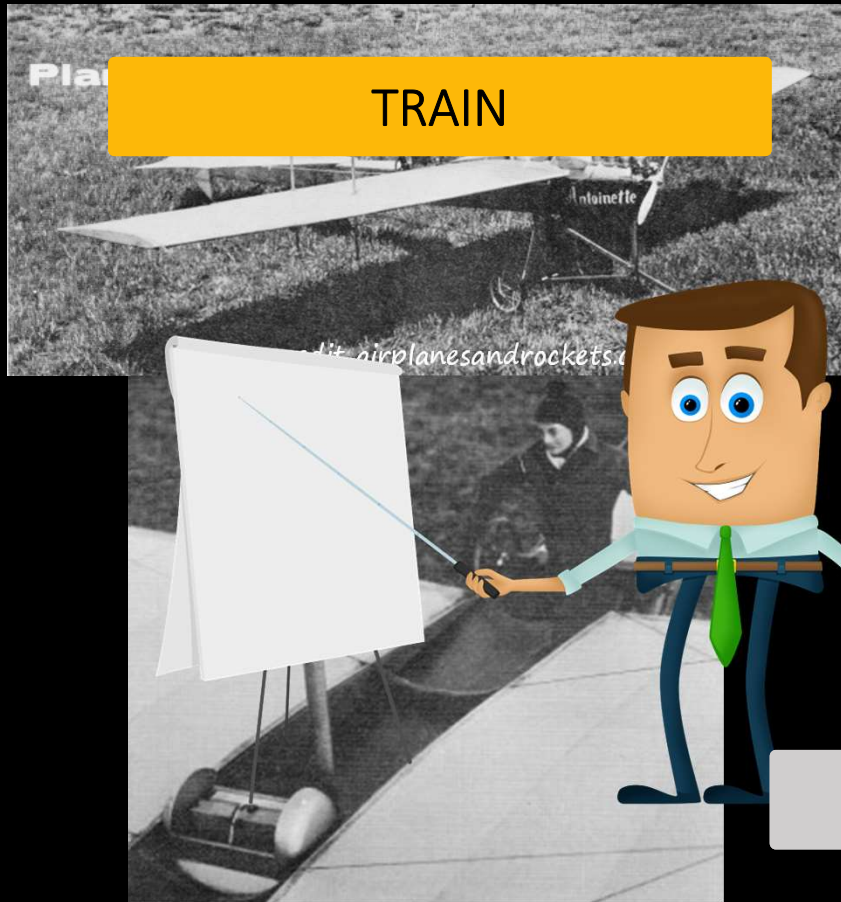


Mica Endsley – *Towards a Theory of Situation Awareness in Dynamic Systems*. Human Factors Journal 37(1), 32-64









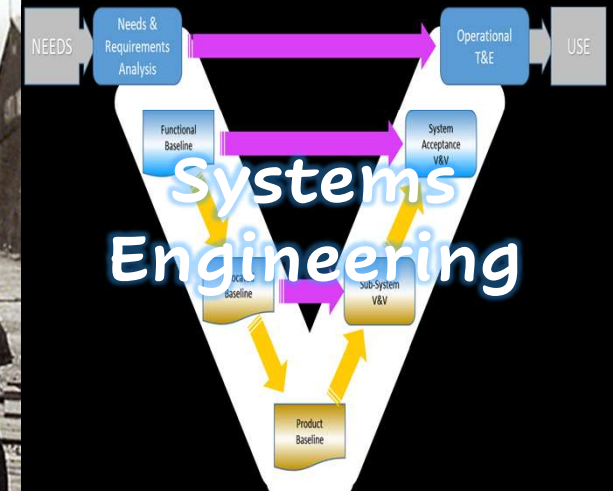
TRAIN



CERTIFY



VERIFY



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](https://cynefin.io/wiki/exaptation)]

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*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

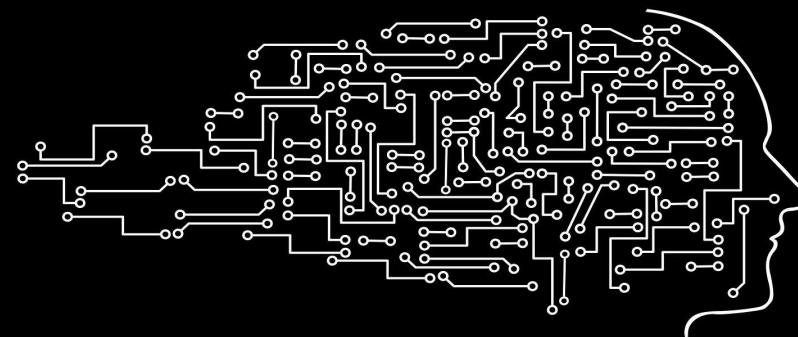


Image Credit – Gerd Altmann, Pixabay

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)

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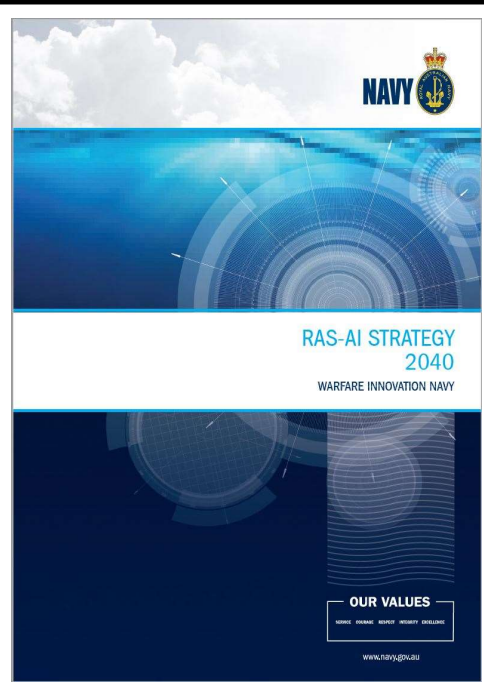
References



Image Credit – Thomas Ehrardt, Pixabay

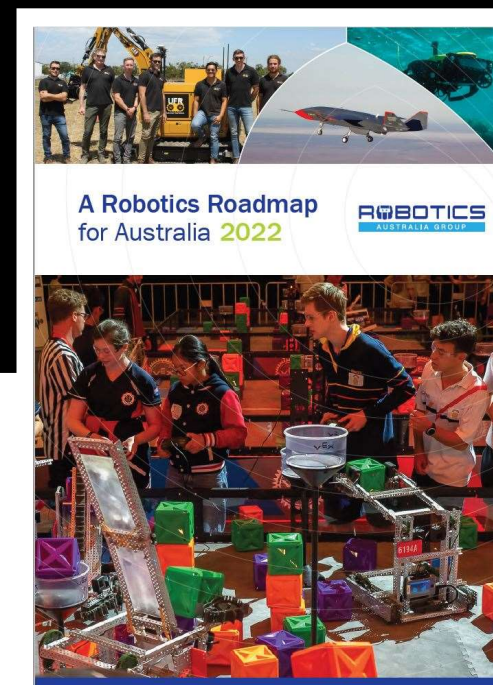
The advent of advanced AVs is anticipated as being “one of the biggest technological disruptions of the next decade” (Aniculaesei et al.) and the “technology trend with the highest potential to disrupt the transport sector in the future.” (Brandsæter and Knutsen, 2018)



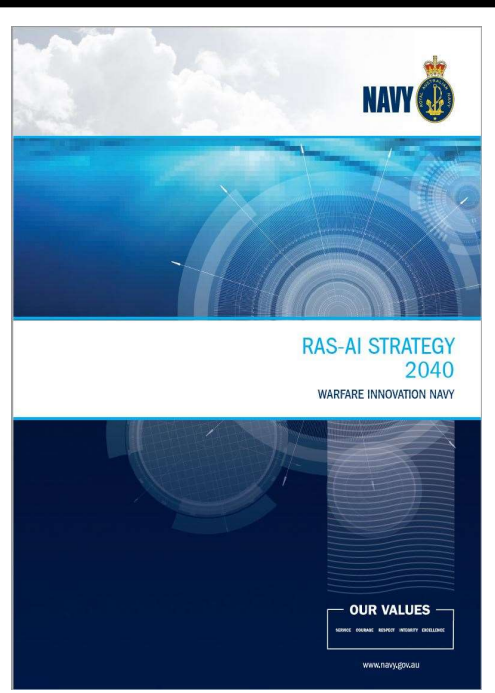


“Navy needs marinized RAS-AI (*Robotics, Autonomous Systems and Artificial Intelligence*) capabilities which address factors including geography; the maritime and strategic environment; and the national Defence ecosystem”  
(Noonan, 2021)

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

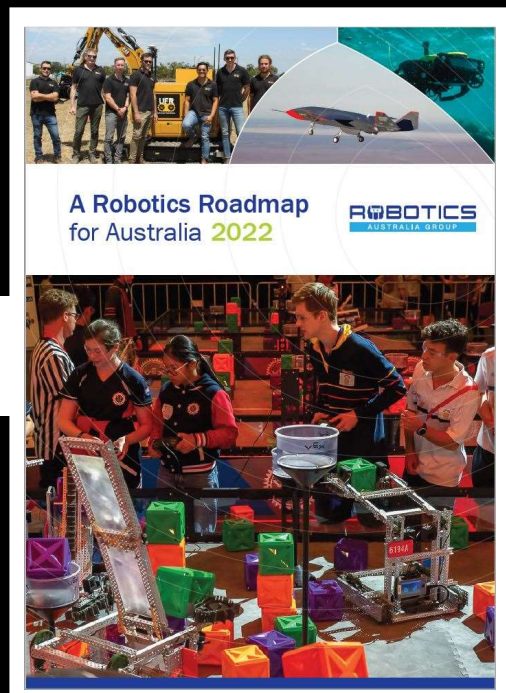


The advent of advanced AVs is anticipated as being “one of the biggest technological disruptions of the next decade” (Aniculaesei et al.) and the “technology trend with the highest potential to disrupt the transport sector in the future.” (Brandsæter and Knutsen, 2018)



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*

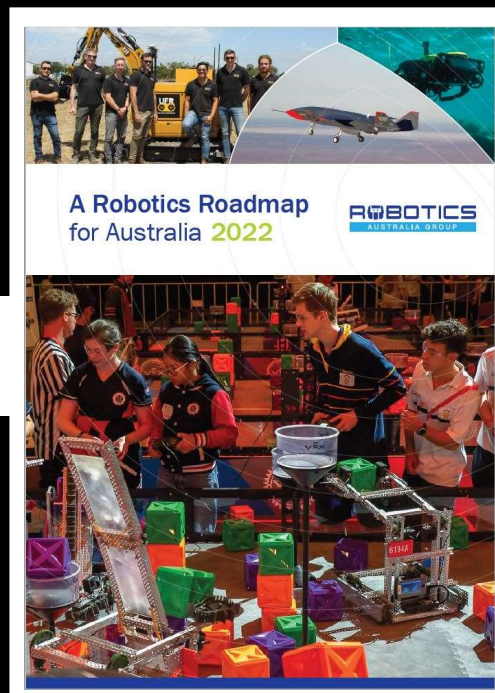
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A need for an SE for AI (SE4AI) framework that would build in *design integrity*, system *safety*, and *security* and enable ongoing *assurance* through a highly *evolutionary* AI capability life-of-type context.



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*

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Evolving Operational Needs

Evolving Operational Environments

Evolving Regulations

Design & Build the *Right System*



Certificate of Operation (MAS)

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

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

Design & Build the *System Right*

Certificate of Survey (MAS)

Evolving Standards

Evolving AI/ML Approaches

Evolving Technologies

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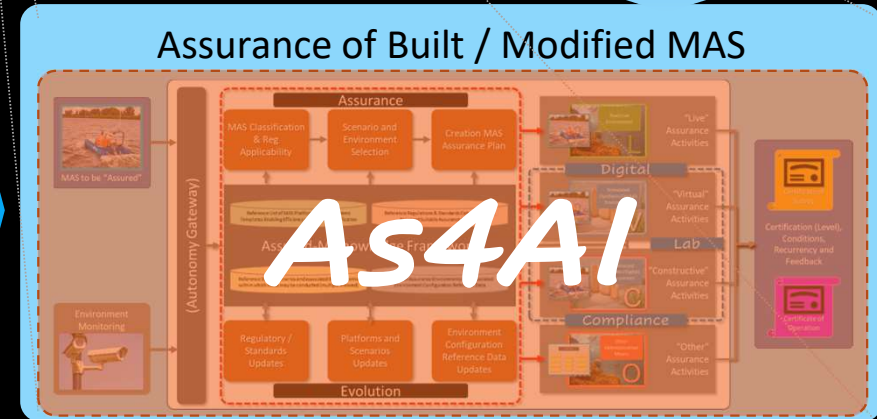
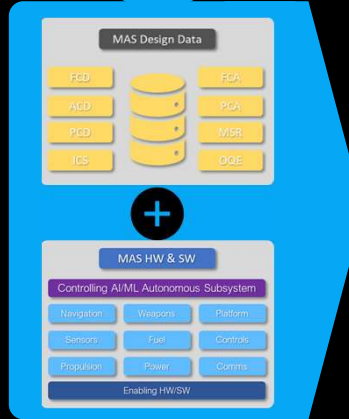
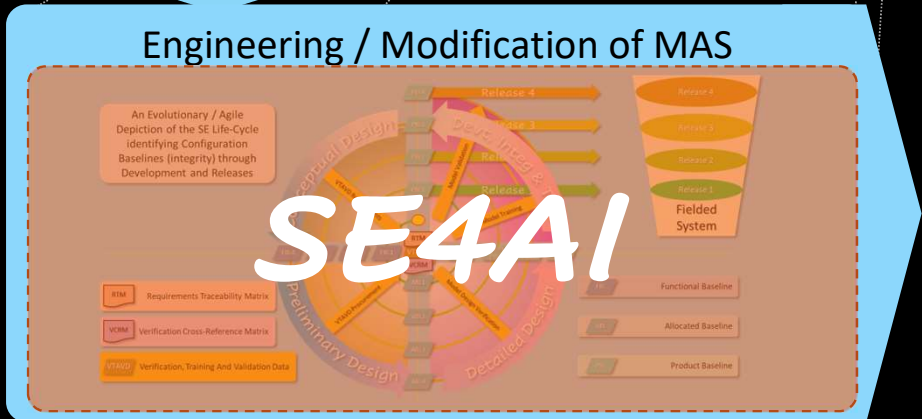
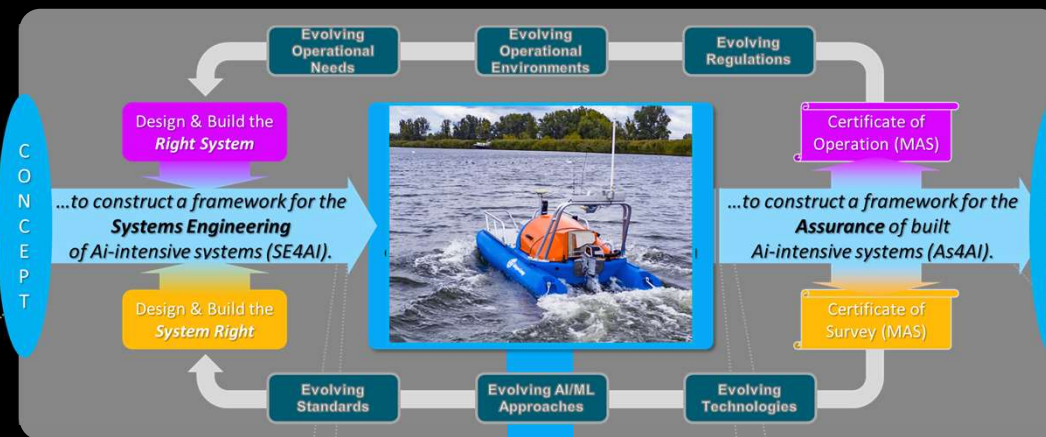
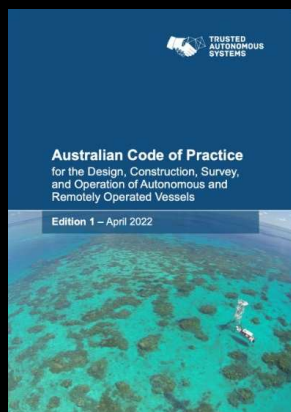
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A need for an SE for AI (SE4AI) framework that would build in *design integrity*, *system safety*, and *security* and enable ongoing *assurance* through a highly *evolutionary AI capability* life-of-type context.

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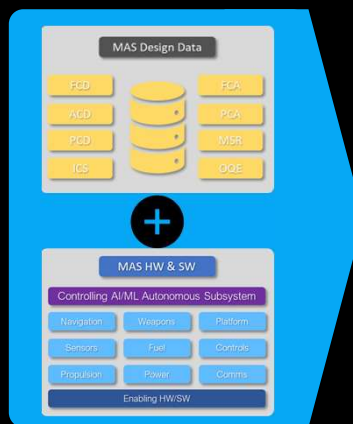
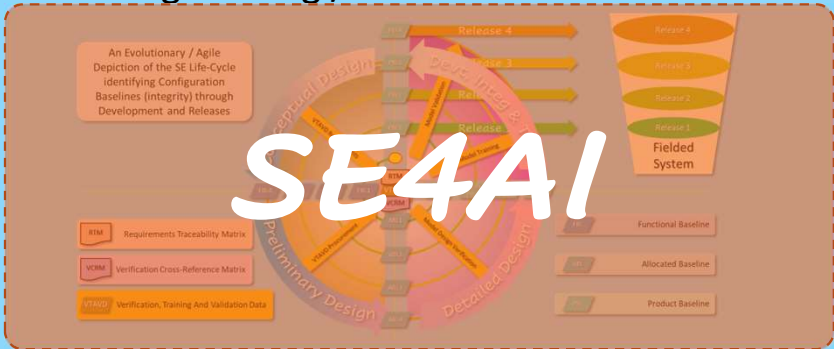




The objective of this paper is to propose a conceptual refinement to contemporary evolutionary developmental practice for the SE of AI-Intensive systems (SE4AI).

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.

## Engineering / Modification of MAS





“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)

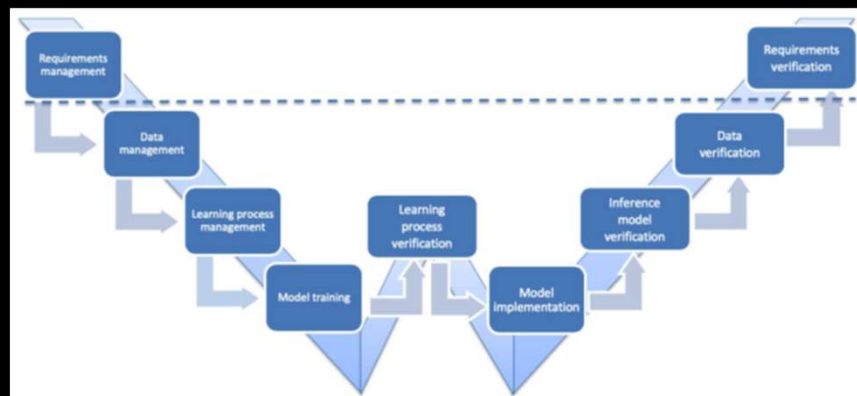
The European Aviation Safety Agency (EASA) examining the challenges posed by the use of neural networks in aviation (Cluzeau et al, 2020), recognised the “current aviation regulatory framework, in particular Development Assurance” did not provide a means for compliance for ML-based safety-critical aviation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



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



**Model Performance**  
(Verification) -  
Training &  
Operational Scope



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

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



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“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.

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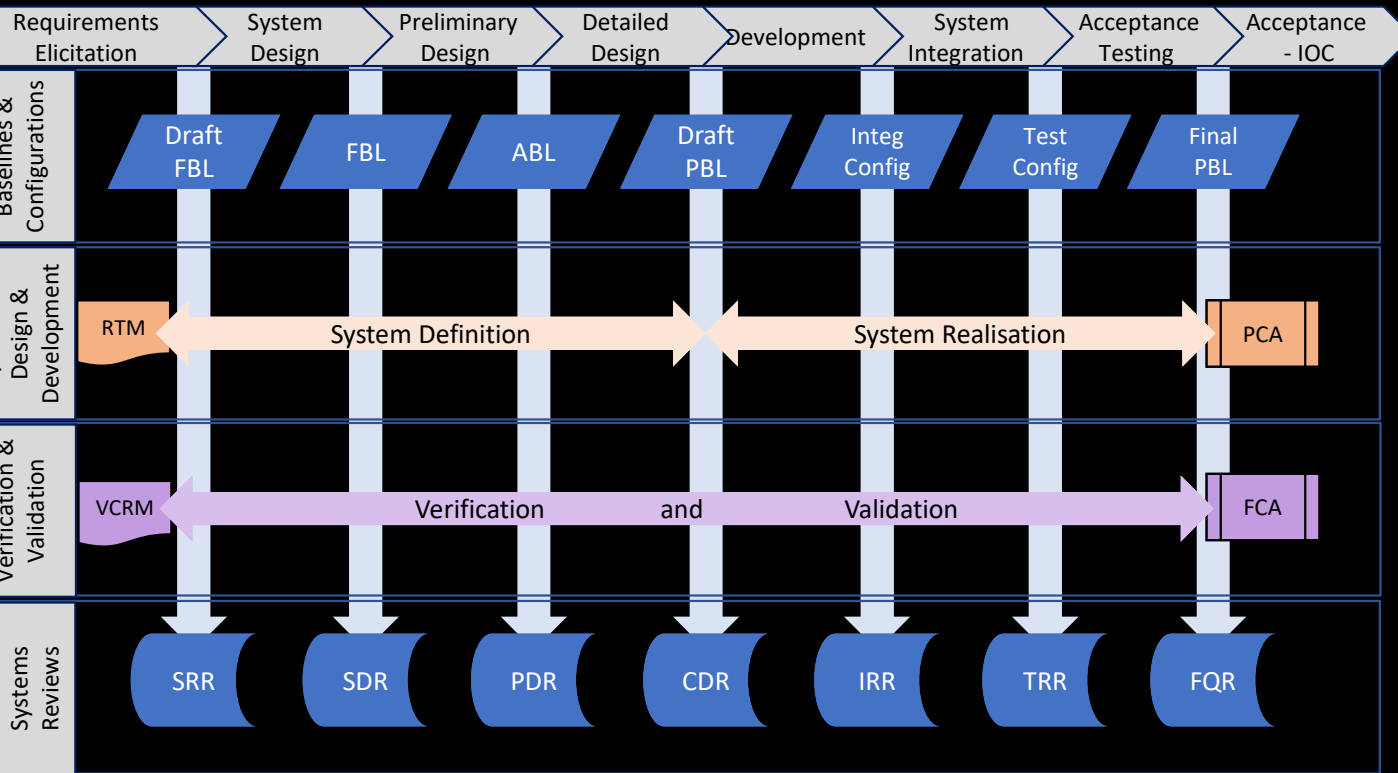
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Systems Engineering Practice

Modelling & Simulation

Situational Awareness

Data Curation Criticality



Real World  
Operational System-Of-Interest  
Environment



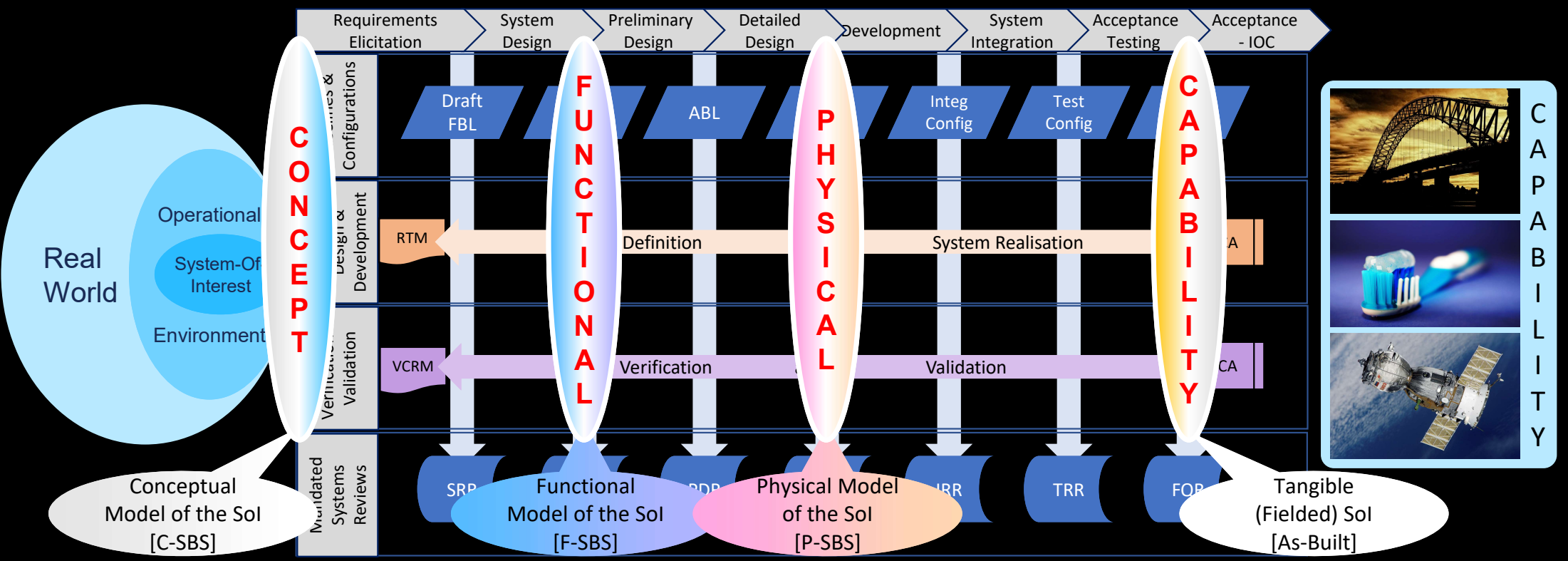
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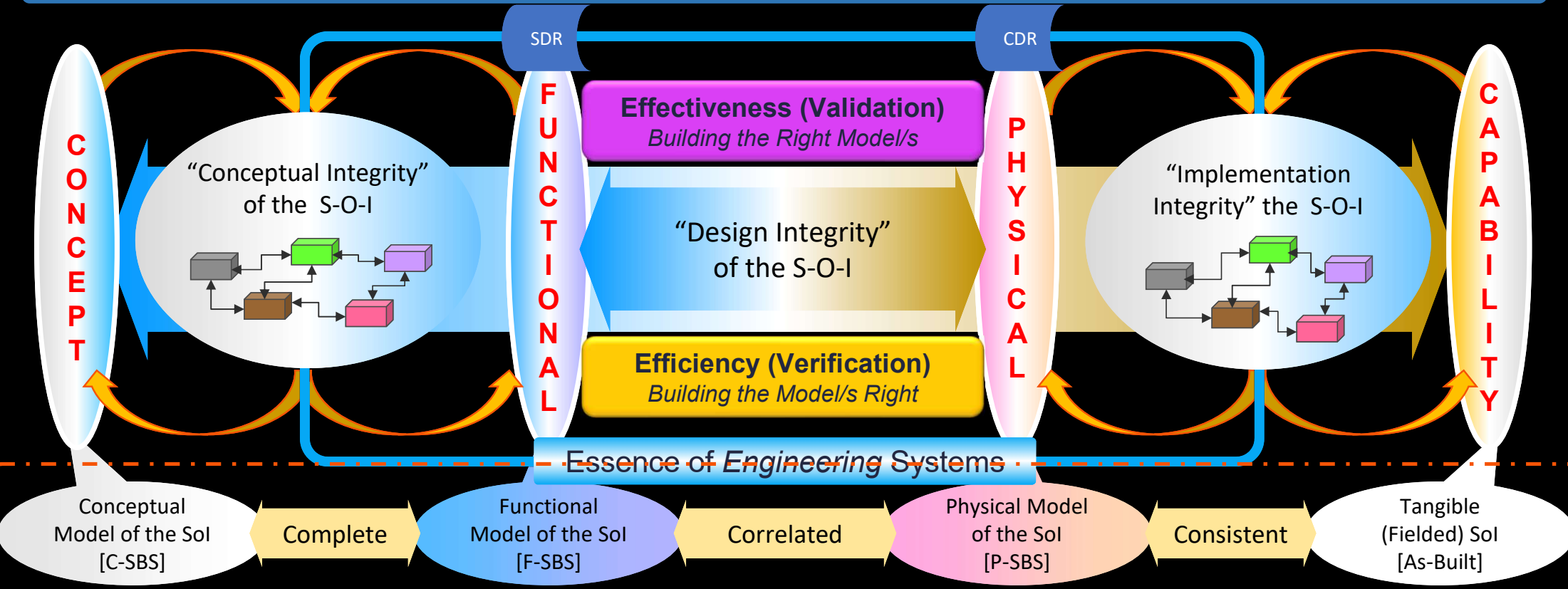
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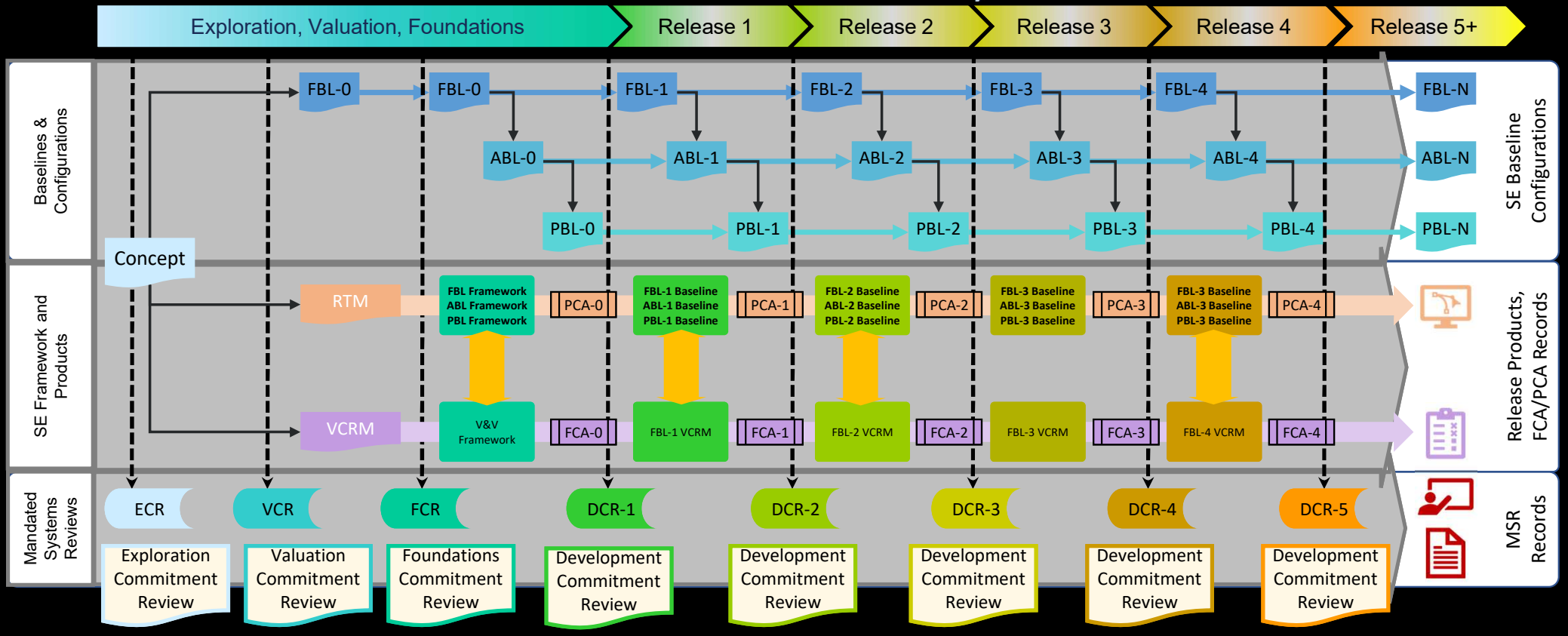
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Systems Engineering Practice    Modelling & Simulation    Situational Awareness    Data Curation Criticality







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

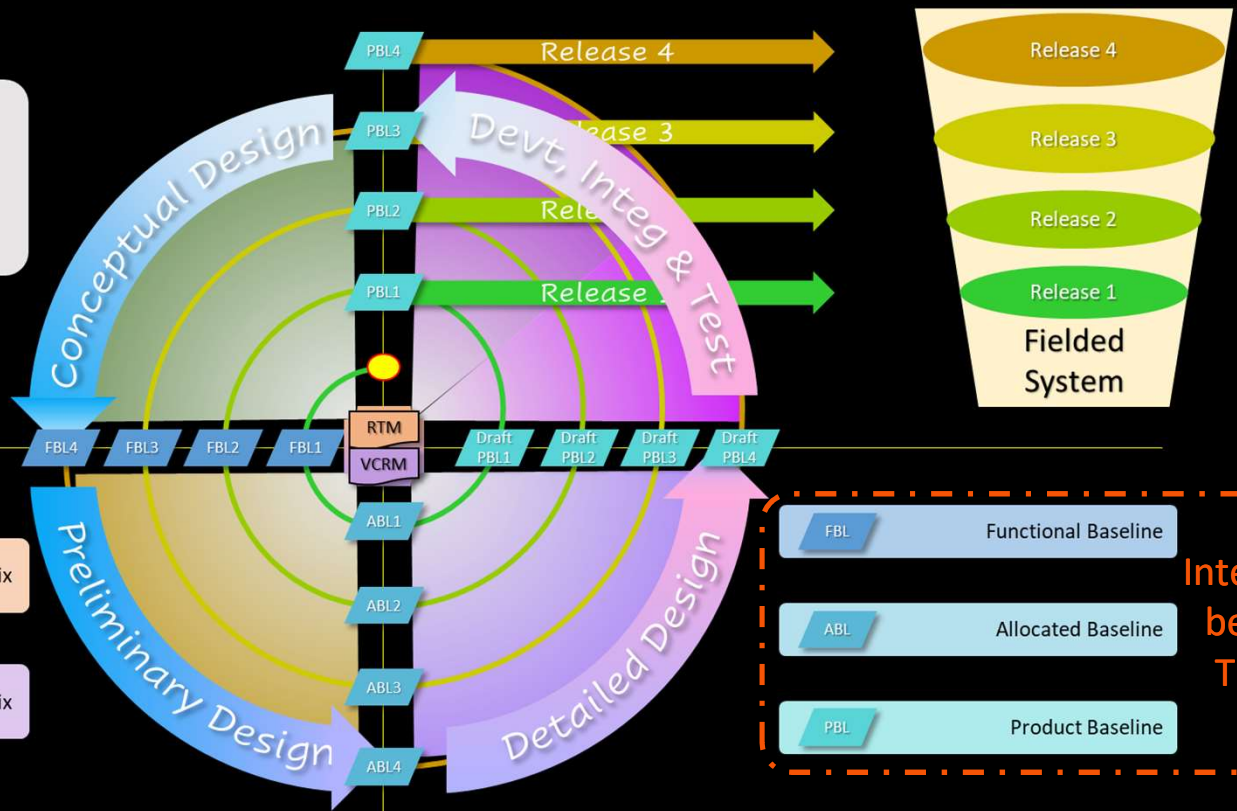
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An Evolutionary / Agile Depiction of the SE Life-Cycle identifying Configuration Baselines (integrity) through Development and Releases



RTM Requirements Traceability Matrix

VCRM Verification Cross-Reference Matrix

Systems Engineering Practice

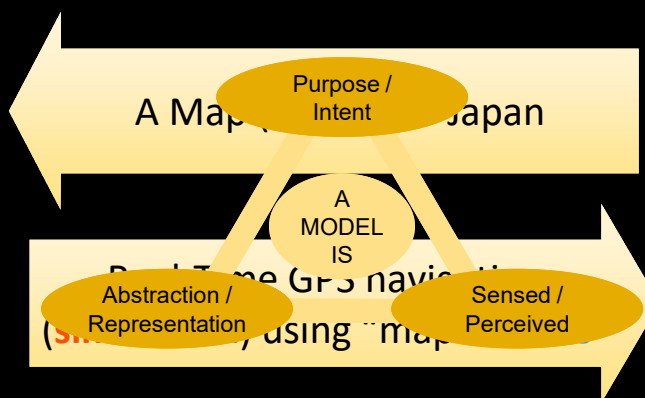
Modelling & Simulation

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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**

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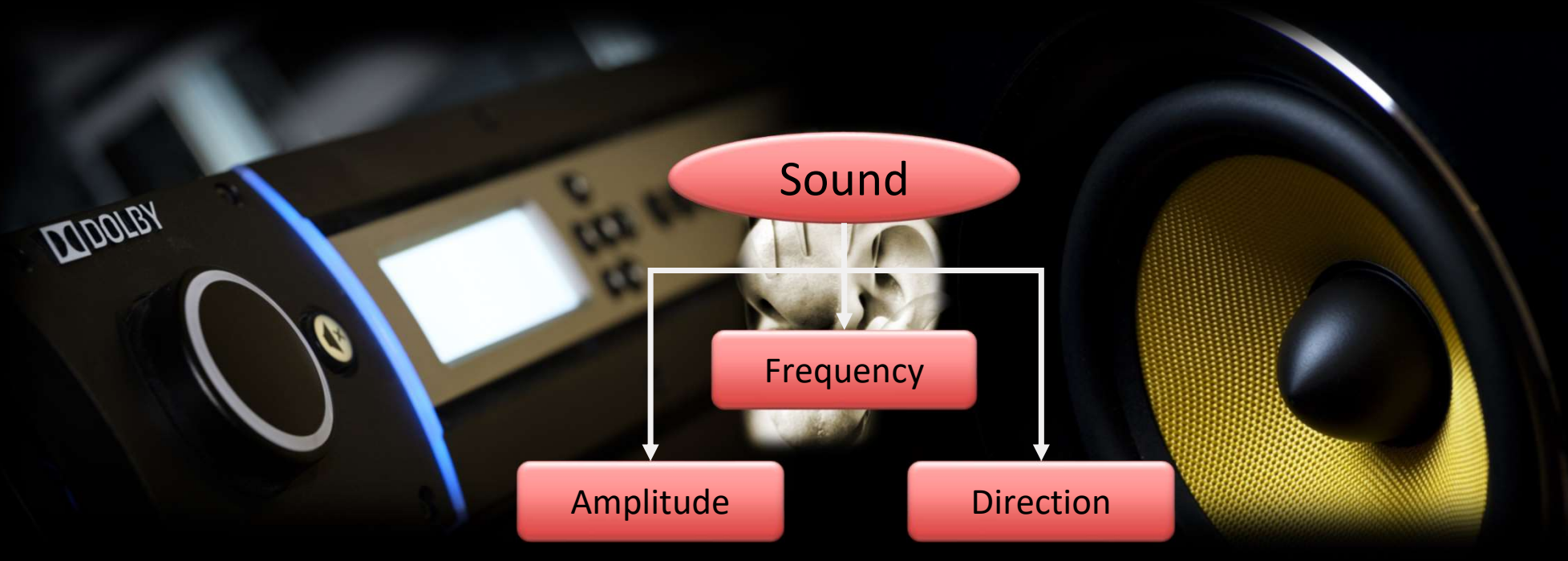
Systems Engineering Practice

Modelling & Simulation

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





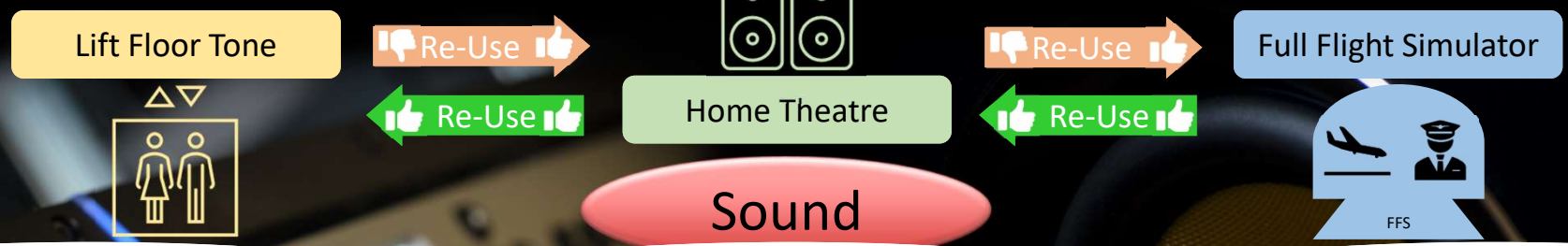
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## Fidelity → Concept of “Goodness” or “Suitability” of a Model



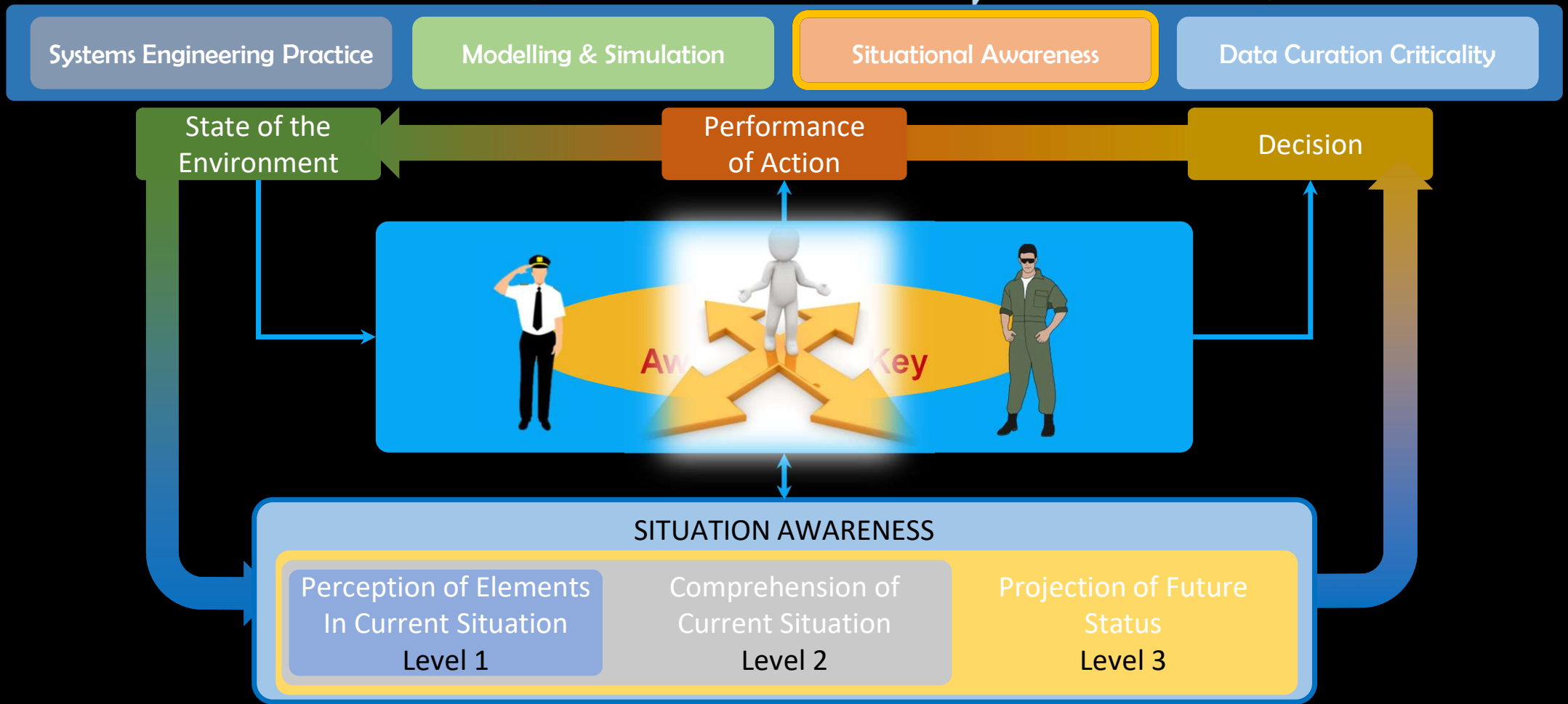
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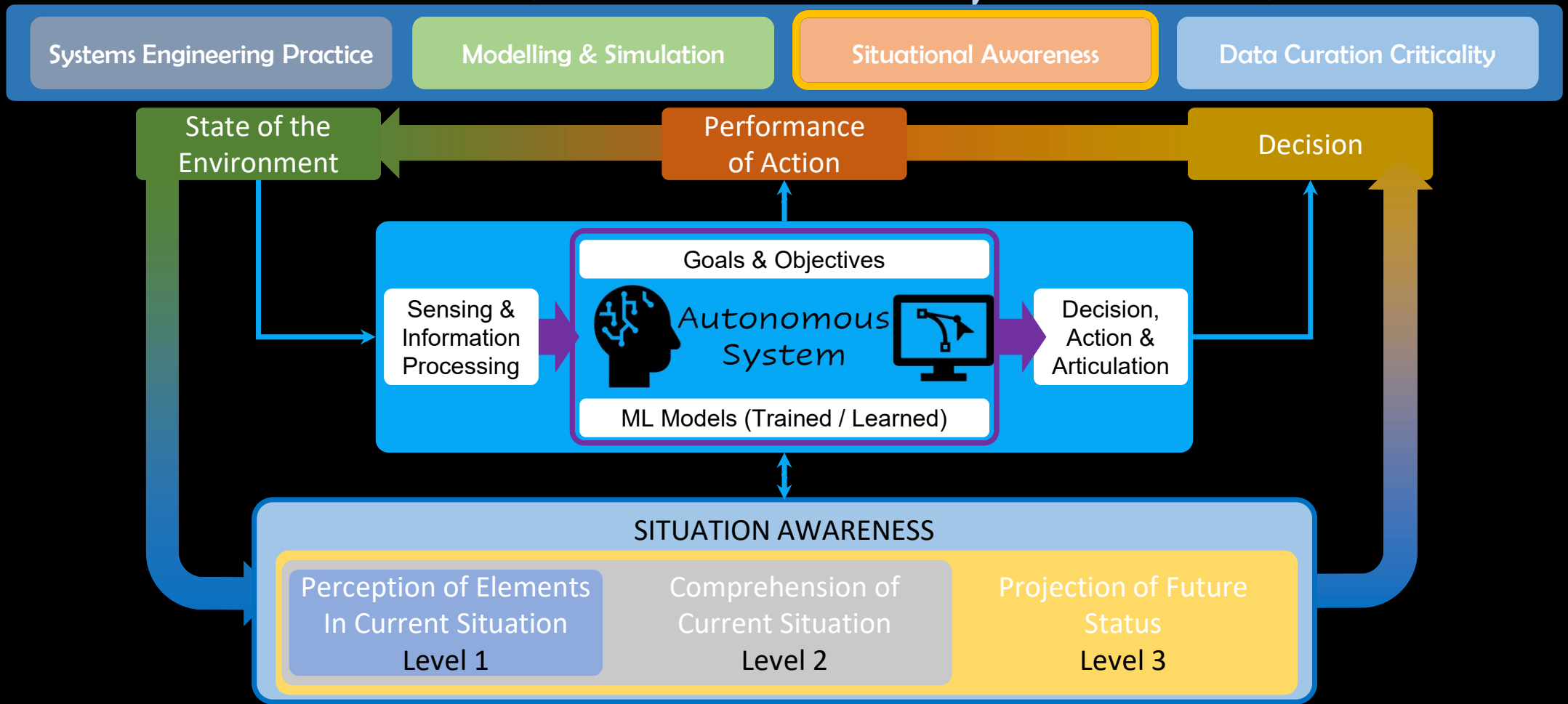
	ABSTRACTION	EMERGENCE	INTEROPERABILITY	
Amplitude	Fixed-On	Fixed-On/Off	Variable Range	Fully Replicated → Resolution
Frequency	Fixed-Pitch	Representative	Replicated Range	Fully Replicated → Resolution
Direction	Mono-Phonic	Stereo-Phonic	Stereo-Surround	Fully Replicated → Resolution

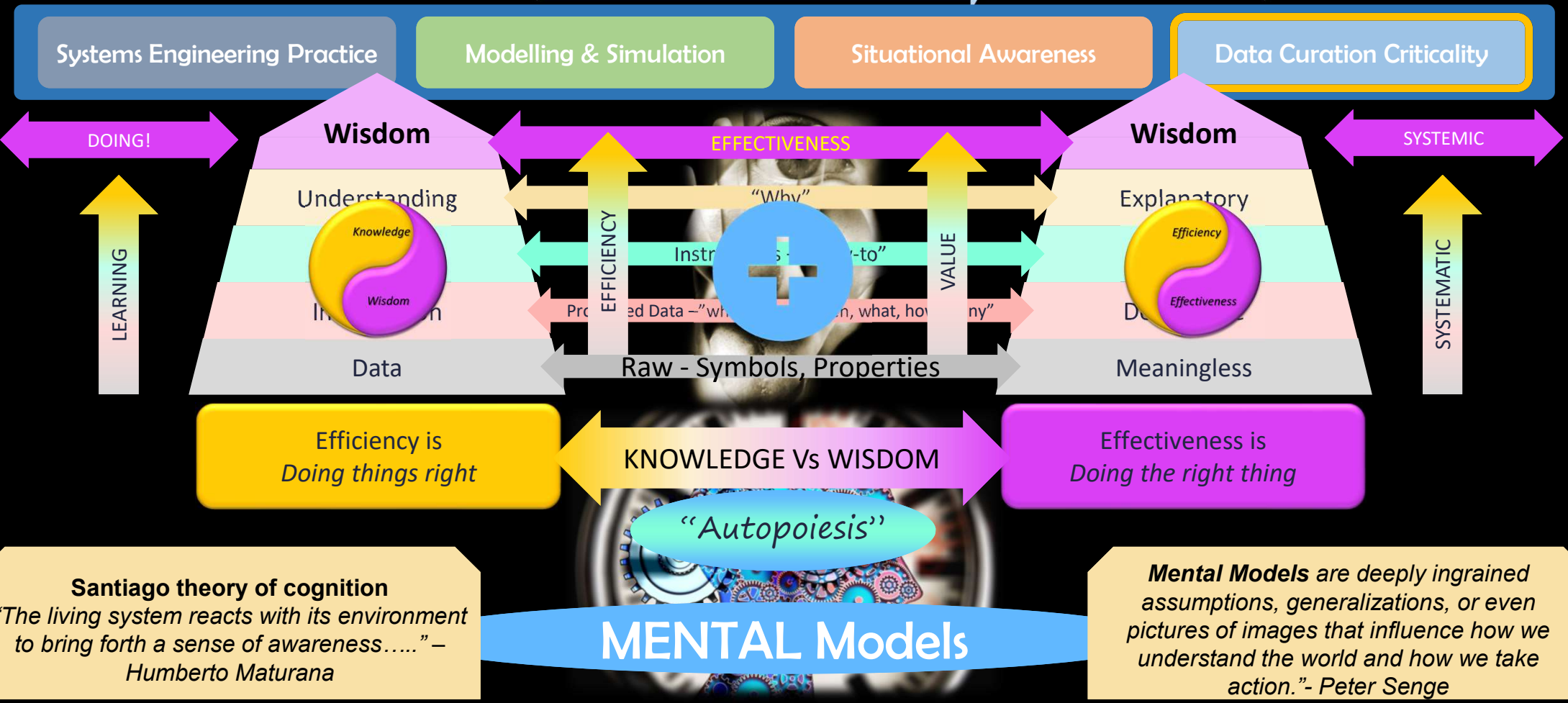
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**Santiago theory of cognition**  
"The living system reacts with its environment to bring forth a sense of awareness....." – Humberto Maturana

**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

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*

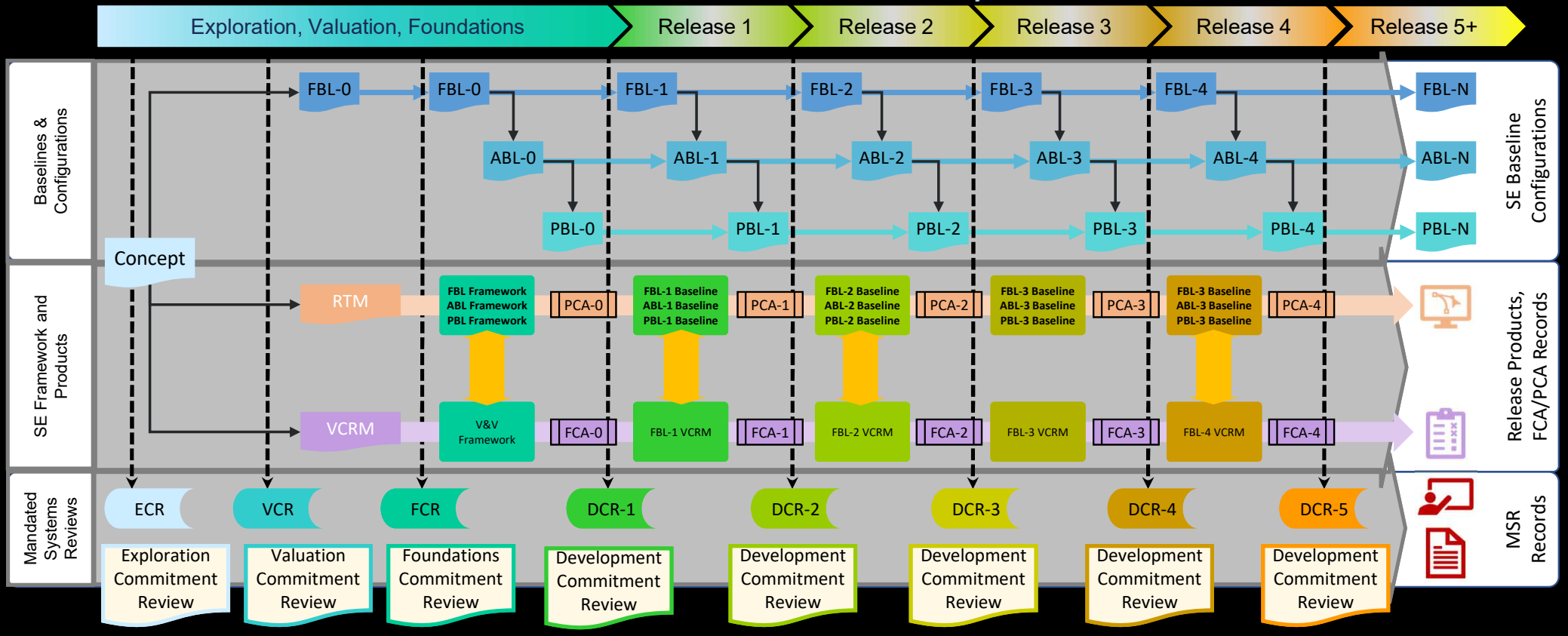
KNOWLEDGE Vs WISDOM

Effectiveness is  
*Doing the right thing*

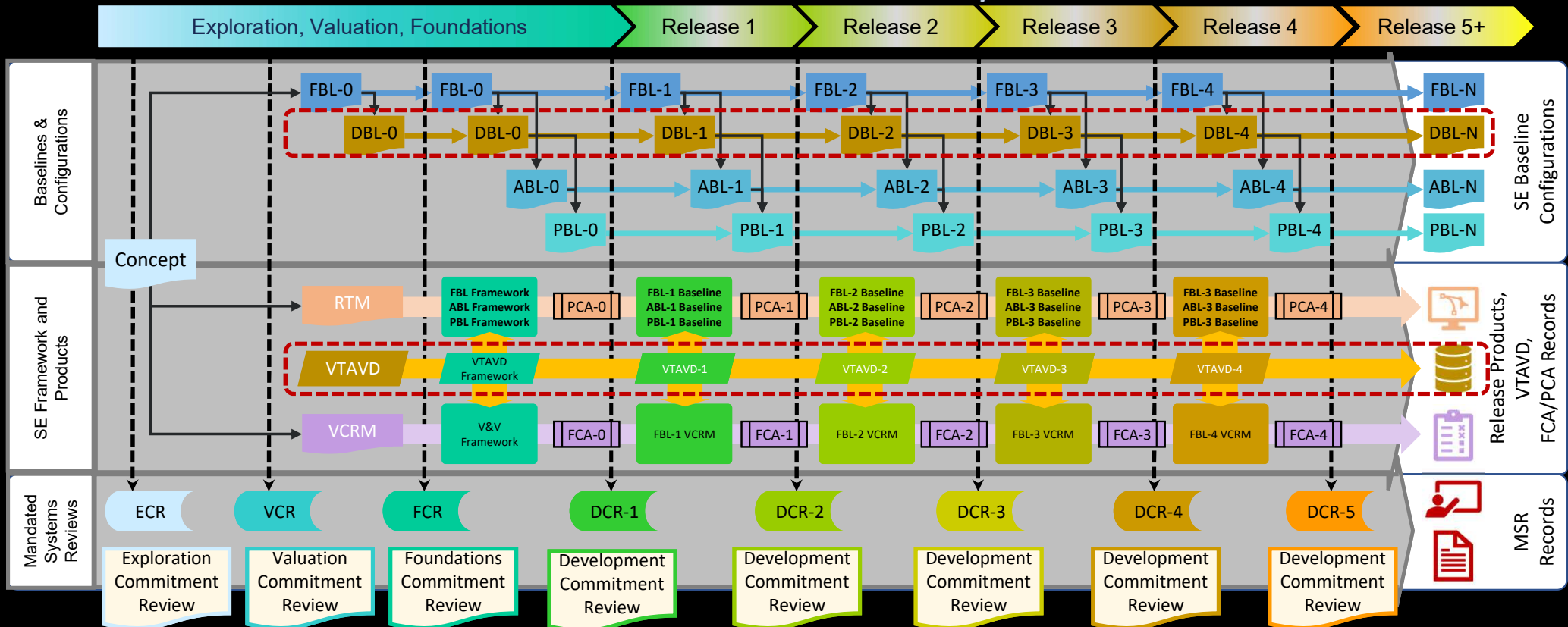
“Autopoiesis”

*Mental Models are deeply ingrained*

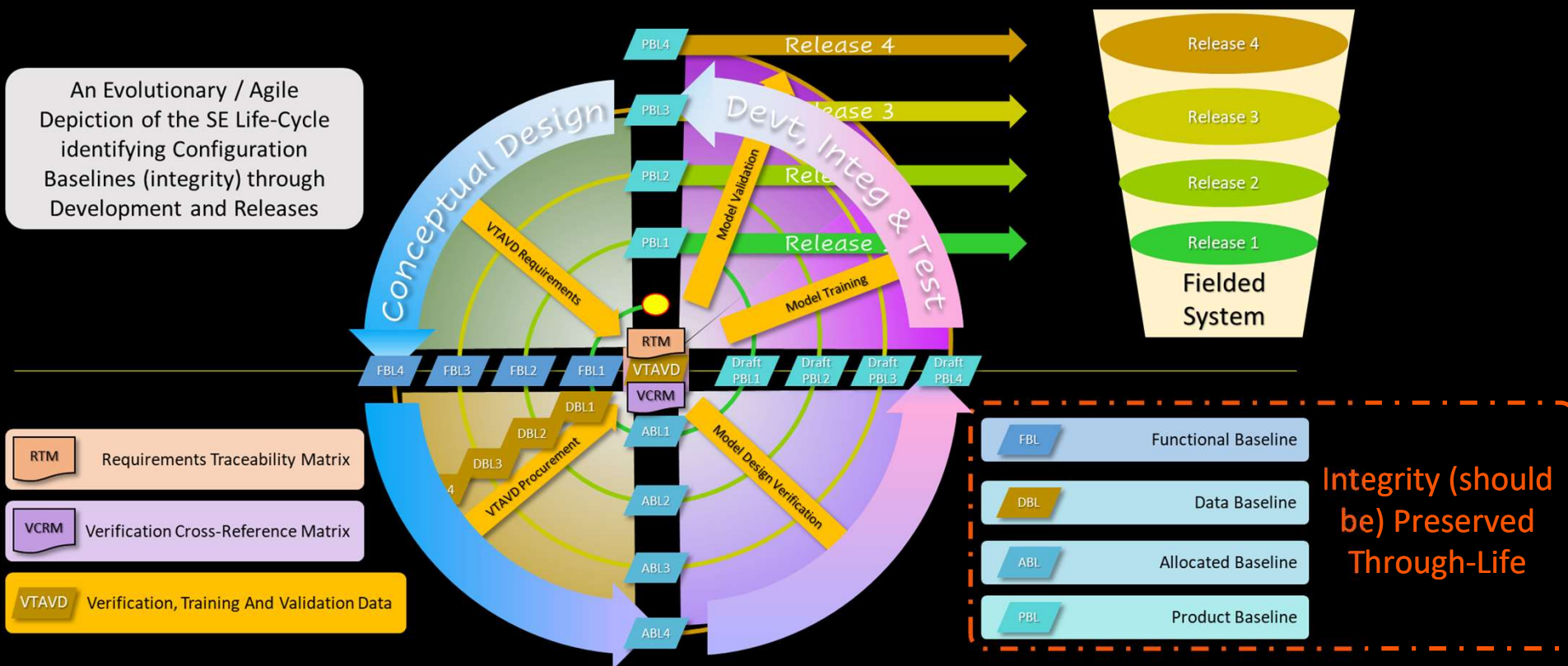
The curation of data for ML model development is therefore fundamental to ensuring their design integrity and assurance of their operational suitability.



## 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.

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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.



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*.

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**”.

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.

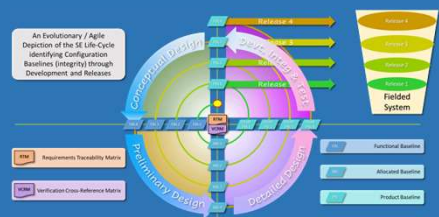
This paper has considered the challenge of SE of AI-Intensive Systems with a particular focus on the end-to-end curation of reference data used as a basis for ML model **design verification**, **model-training**, and **model-validation**.

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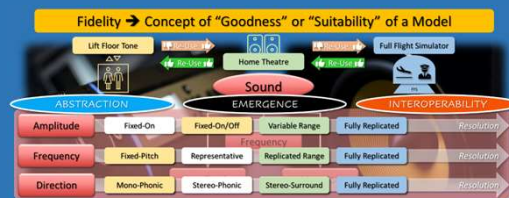
## AI Development Approaches

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 dependency/explainability.

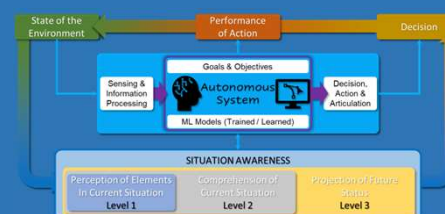
### Systems Engineering Practice



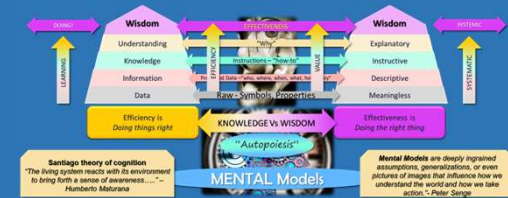
### Modelling & Simulation



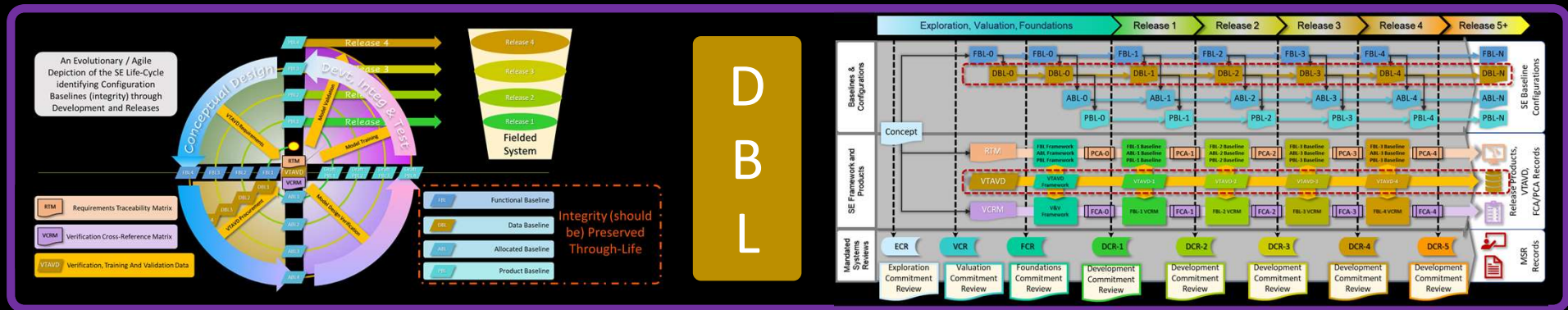
### Situational Awareness



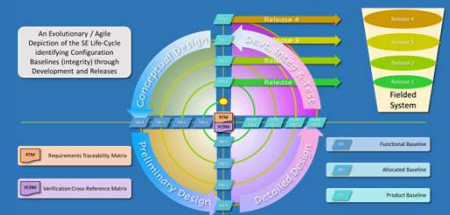
### Data Curation Criticality



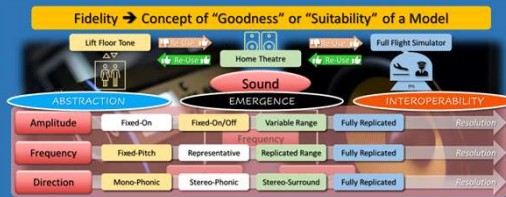
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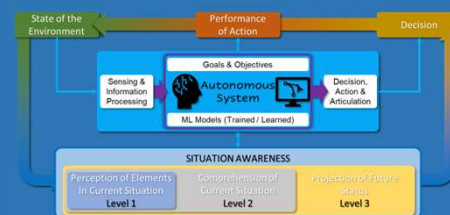
## Systems Engineering Practice



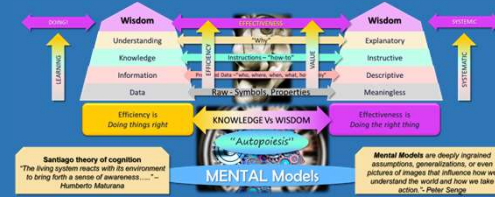
## Modelling & Simulation



## Situational Awareness



## Data Curation Criticality





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Problem Identification  
Introduction  
Paper Scope & Focus

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

Key Points  
Conclusion  
References



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