GE AEROSPACE RESEARCH

2023 DAYTON DIGITAL TRANSFORMATION SUMMIT
May 10 - 12, 2023 | Sinclair College

Digital Literacy for the Engineer of the Future

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Co-chair U.S. Council on Competitiveness Advanced Computing Roundtable

AIAA Digital Engineering Integration Committee, CAE/HPC/AI Working Group Lead

DOE Office of Science Advanced Scientific Computing Advisory Committee
Exascale Computing Project (ECP) Industry Council Technical Liaison

Public-Private Partnering

Engineering Test Facilities
Leadership Computing (HPC) Facilities

Software & Methods (Models & Data)
Science & Engineering Collaborations as "Fellow Travelers"

Industrial Research Perspective

Every minute:

Power Generation
1/3 of world's electricity

Jet Propulsion
30 airline takeoffs

Health Care
over 16,000 scans

GE Separations 2022-2024

Every minute:

Power Generation
1/3 of world's electricity

Jet Propulsion
30 airline takeoffs

Health Care
over 1a6,000 scans

GE VERNOVA

GE Aerospace

GE HealthCare

GE RESEARCH


GE Aerospace
GE Propulsion Test Platform

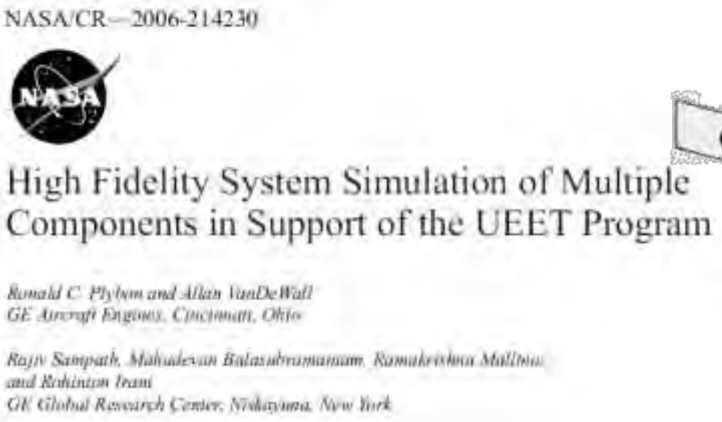
GE RESEARCH


GE Global Research

April 2006
Vision for NPSS

How are we doing on … ?

- ❑ **INTEGRATION** (multi-component)
- ❑ **ZOOMING** (multi-fidelity)
- ❑ **COUPLING** (multi-physics)


NASA/CR—2006-214230

NASA

High Fidelity System Simulation of Multiple Components in Support of the UEET Program

Ronald C. Plybon and Allan VanDeWall
GE Aircraft Engines, Cincinnati, Ohio

Rajiv Sampath, Mahadevan Balasubramaniam, Ramakrishna Mallina and Rohinton Irani
GE Global Research Center, Niskayuna, New York

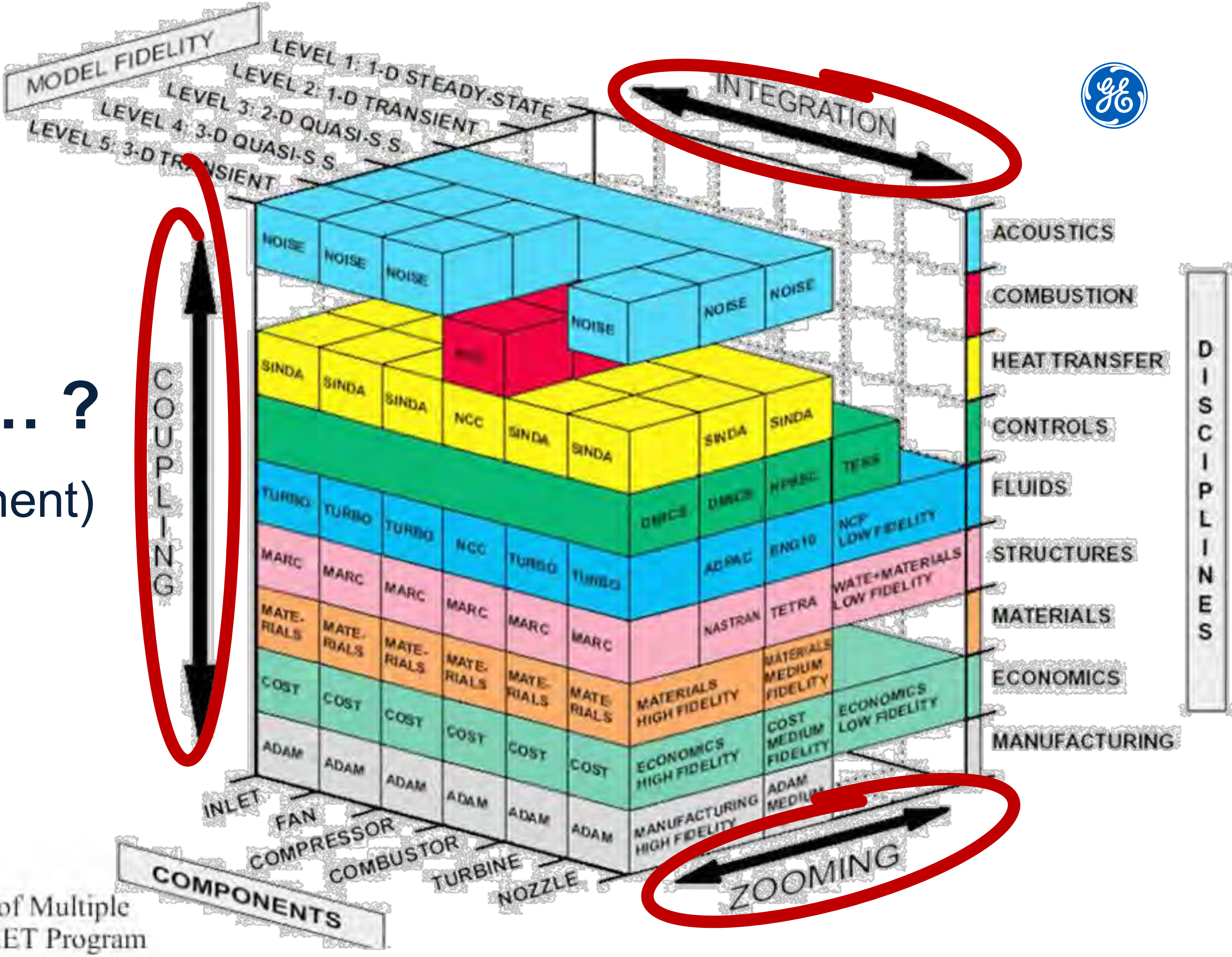


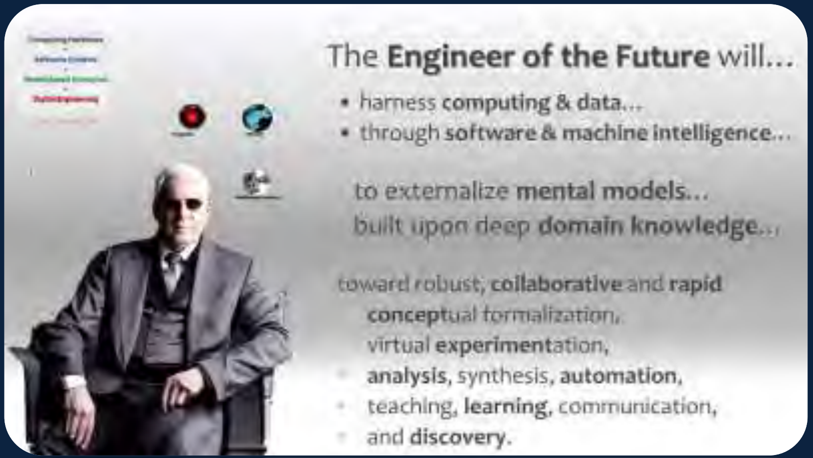
Figure 1.—NPSS simulation cube.

Topics

I. Digital Literacy Rubric
II. Digital
III. Literacy
IV. (for) *Modeling* Literacy
V. (for) Engineer of the Future

Key Points

1. Modeling Literacy
2. Entry-to-*Executive*
3. Continual Workforce Development
4. Human-machine Collaboration
5. Mental models enable cross-disciplinary collaborations



Digital Literacy : Rubric for Digital & Computational Technical Expertise

*The **digitally literate engineer of the future** will have the knowledge and ability to apply the power of computing hardware and computational methods to create and understand products and systems composed of and designed by data and models.*

Awareness — Learn

Models & Data
- Precision, accuracy & uncertainty
- Quality, integrity, & resolution
- Lifecycle (*capture, storage, access*)
- Security, privacy, & integrity
- Correctly apply (*implement, verify*)

Tools (*referenced by Do/Guide/Shape*)
- **Software**
  - Agile & DevOps productivity
  - Integration / interoperability
  - Usability (UX) & Maintainability
  - Testing/validation & QA
  - Configuration & version control
- **Computing Hardware**
  - Architecture (*edge to enterprise*)
  - Processing (*CPUs, accelerators*)
  - Data (*communications & storage*)
  - Sensors, controls & robotics
- **Systems Thinking / Co-design**
  - Performance instrumentation
  - Digital + Physical / **Digital Twin**
  - Integration / **Digital Thread**
  - Security, integrity & robustness

Literacy & Composition — Do

Literate Model & Data Composition
- Derive digital model from mental model
- Structure model Applicability & Credibility
- Codify system dynamics & transforms
- Communication of solution alternatives
- Sensitivity & main effects analysis

Build & apply tools to model and improve
- Problem definition & characterization
- Robustness & performance optimization
- Assessment of confidence bounds & risk
- Data analysis, visualization & info synthesis

Systems productivity, performance & quality
- Searchability & annotation (*metadata*)
- Automation (*for productivity & consistency*)
- Co-design collaboration (*numerical/SW + architecture/HW + domain expertise*)
- Durability to change (*portable, flexible*)

Document & Measure
- Performance profiling & analysis
- Decision Provenance (*assumptions, known unknowns, limitations, evaluation criteria*)

Comprehension Proficiency — Guide

Proficient Model Composition & Comprehension
- Knowledge synthesis from analysis & learning
- Assertible competence (*assumptions, limits, explanation, applicability, credibility, VVUQ*)
- Sensitivity to sources of error, bias, unknowns
- Assess digital vs. physical strategy trade-offs

Advance ecosystem/toolchain capabilities
- Solution capacity/scale & performance
- Model Maturity & VVUQ (*verification, validation & uncertainty quantification*)
- Systems integration (*digital thread driven*)

Improve decision-making speed & accuracy
- Physical measurement to validate confidence
- Employ inclusive collaborative workflows
- Mitigate failure and unexpected results
- Scan decision provenance vs. new information
- Contingency plans & triggering conditions

Evaluate & leverage **emerging technology**
- Computing / network / storage platforms
- Non-von Neumann systems / analog devices
- Augmentation via machine collaboration

Fluent Vision & Strategy — Shape

Invent, innovate & synthesize tools toward
- Breakthrough solution scale/capabilities
- Adaptive systemic uncertainty reduction
- Model applicability & robustness
- Skill-based human-machine collaboration

Inspire investment pursuit to new value
- Innovative Products & Services
- Align strategies & collaborative workflows spanning business silos, supply chain, & customers
- Innovative / disruptive business models
- Challenge traditional limitations (*process, regulatory, certification, design, thinking*)
- Solution trade-off space exploration

Identify/Envision novel solutions vs. gaps
- Enabling tech breakthrough opportunities (*never before seen, built, tried, imagined*)
- Physical Measurement vs. Synthetic Data
- Human expertise development & insight
- Intellectual debt and scientific discovery

SPANNING CAREER FROM ENTRY-LEVEL TO EXECUTIVE DECISION-MAKER ROLES

(We will revisit this rubric throughout…)

Digital Literacy

Digital *breaks the rules* (vs. physical)

near-infinite, near-free, perfect *replication*
near-instantaneous, near-free *transportation*
tasks can be *automated* and *continually* monitored
problems can be decomposed and analyzed *concurrently*
approaching effectively infinite *memory*,
with essentially perfect recall (*search*) and growing *synthesis* capabilities (GPT)

Digital

ABUNDANT & AFFORDABLE

Storage + Compute + Network

= Computational (Literacy)

*"The **Digital** Trinity*

digital engineering and management,

agile software, and

open architecture

is the true successor to stealth… Rather than just building better systems, it builds systems better — opening doors to faster design, seamless assembly, and easier upgrades."

- Dr. Will Roper (in 2020 as Assistant Secretary of the Air Force for Acquisition, Technology and Logistics)

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Modeling

DTO — About | Priorities | Team | Digital Guide

Back to Digital Guide Home

Digital Maturity Assessment

Robert Bond | January 4, 2023

Category	Metric	Component
Infrastructure	Model Environment	• Tool Access and Governance • Interoperability
	Collaboration	• Capability • Security
Modeling / Analysis	Quality	• Authoritative Sources of Truth (ASOT) • Metrics • Model-Based Verification and Validation (V&V)
Process / Policy	Model Management	• Digital Management Strategy • Model-Based Systems Engineering • Configuration Management • Process Verification and Validation (V&V)
	Data Management	• Innovative Technical Processes • Technical Management Processes • Analysis, User Interface (UI) and Visualization
Workforce / Culture	Workforce	• Digital User Skills • Common Digital Understanding
	Adoption	• Digital Artifact Use • Reference Architecture Implementation • Milestone, Program, and Technical Reviews; Audits

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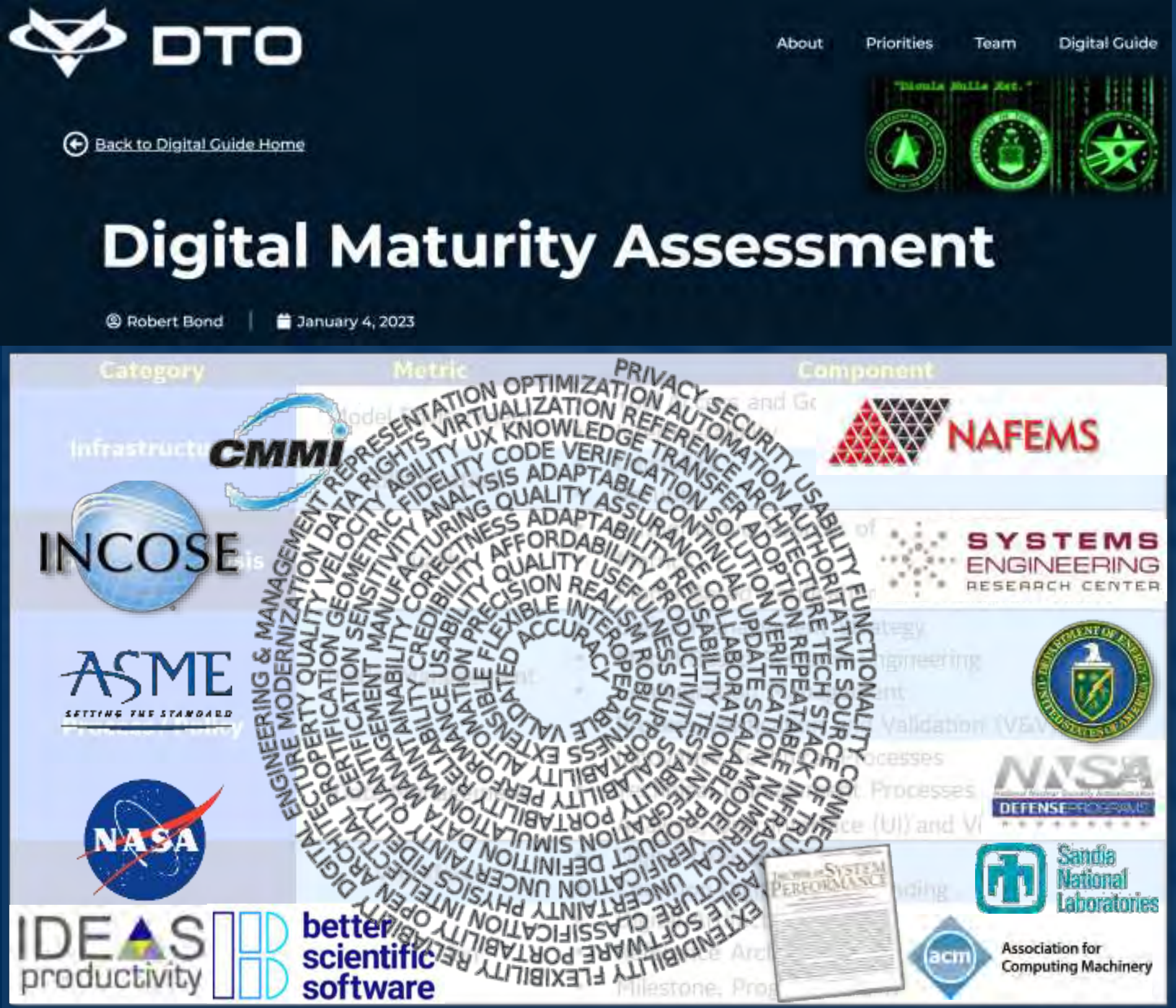
Modeling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Digital Maturity Assessment
Robert Bond
January 4, 2023
Category
Metric
Component
CMMI
INCOSE
ASME
SETTING THE STANDARD
NASA
NAFEMS
SYSTEMS
ENGINEERING
RESEARCH CENTER
DEFENSE PROGRAMS
Sandia
National
Laboratories
IDEAS
productivity
better
scientific
software
Association for
Computing Machinery
acm

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Modeling, Data & Tools

Object – precious & strategic **RAW MATERIAL**

- *Invest* to curate & protect
- *Value* from knowing, learning, & exploiting

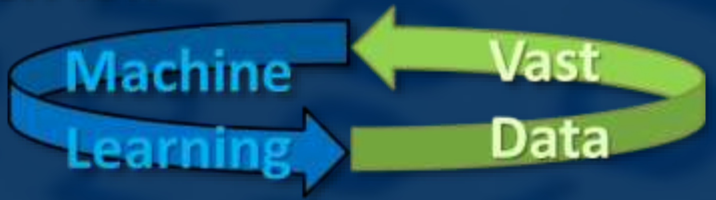
Data

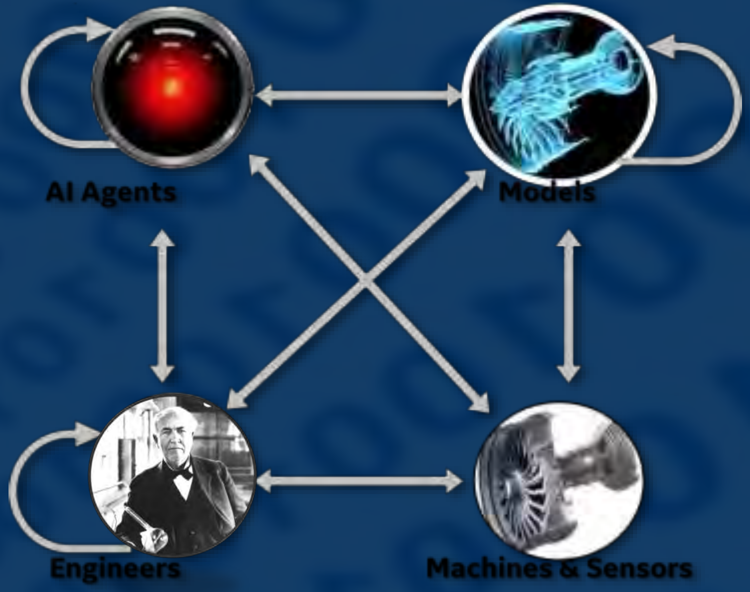
Digital

OpenAI ChatGPT4.0

TensorFlow

PyTorch





Object – precious & strategic **RAW MATERIAL**

- *Invest* to curate & protect
- *Value* from knowing, learning, & exploiting

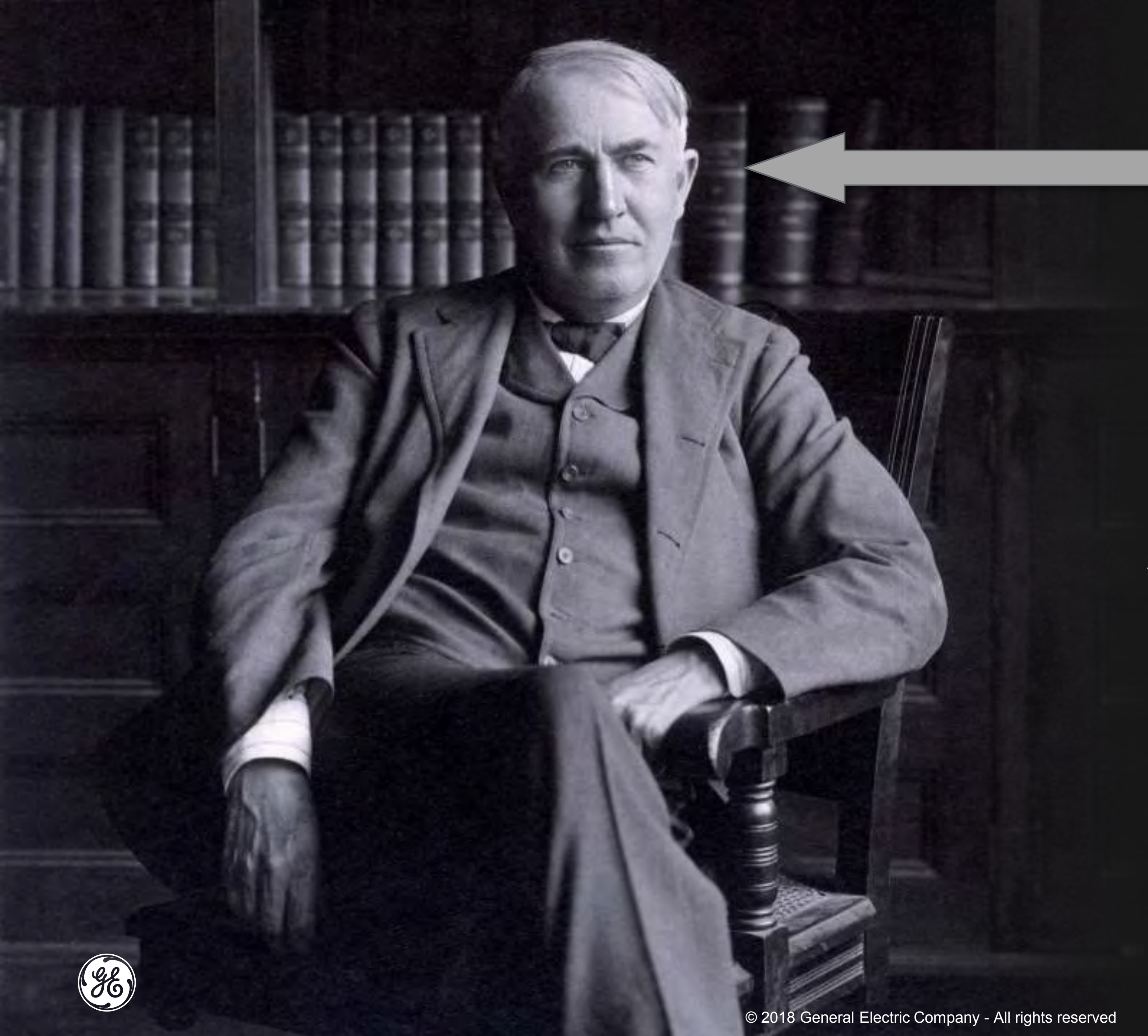
Data + Tools

Verb – empowering to **ACT**

- Perception & Cognition
- Automation & Communication

Digital

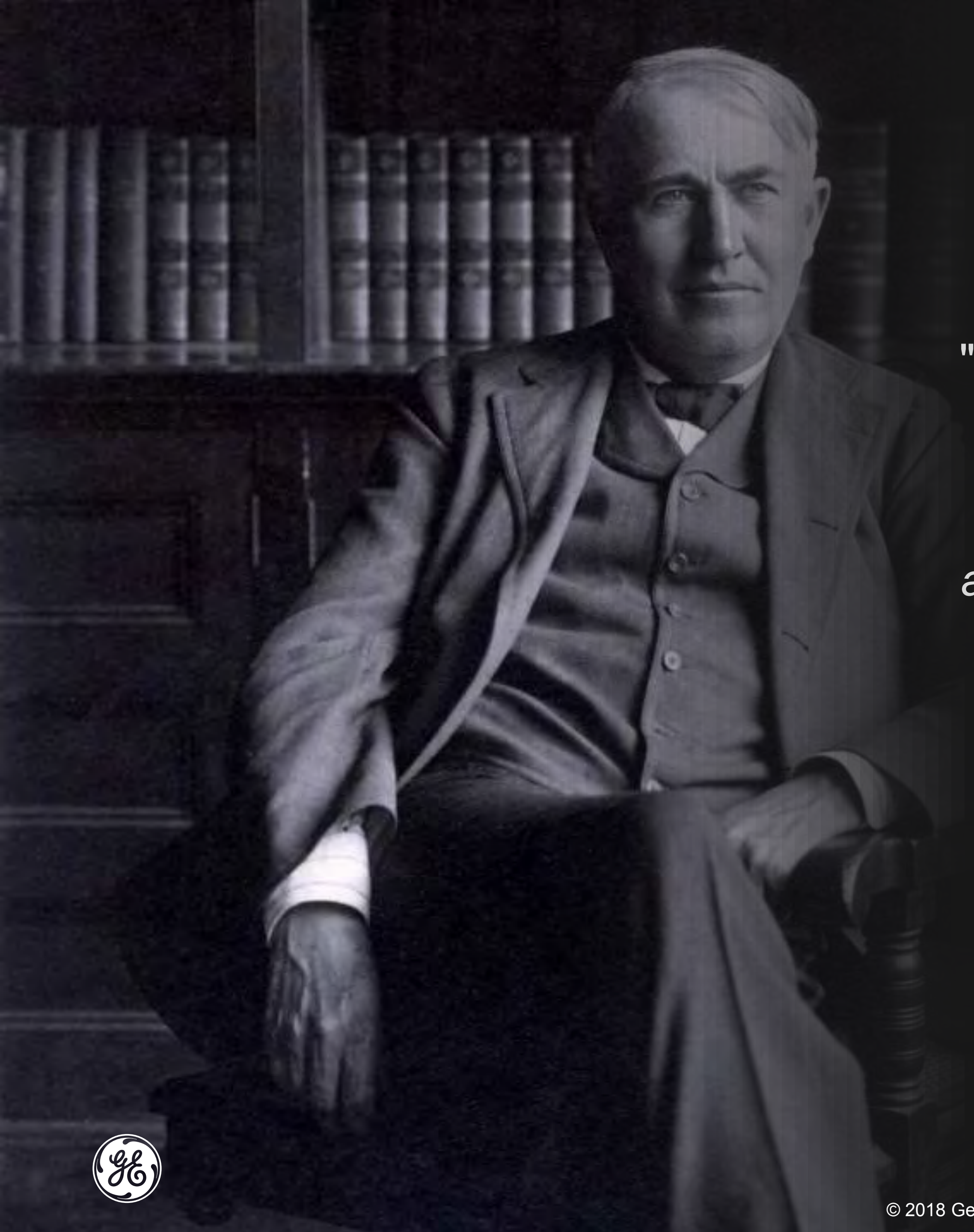
Digital Literacy



Digital Illiterate

The ***Edisonian approach*** to invention is characterized by **trial and error** discovery rather than a systematic theoretical approach.

wikipedia.org



Inventor Nikola Tesla is quoted as saying:

"[Edison's] *method was* *inefficient in the extreme*, *for immense ground had to be covered to get anything at all* *unless blind chance intervened* *and, at first, I was almost a sorry witness of his doings, knowing that* *just a little theory and calculation* *would have saved him 90 percent of the labour*"

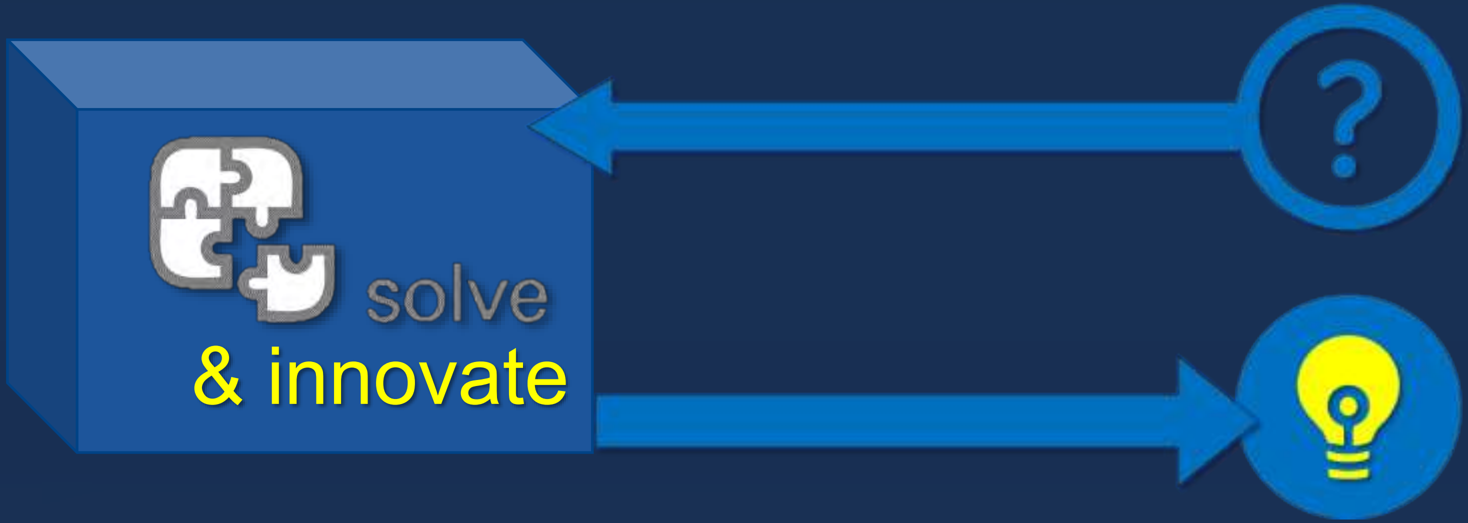
The ***Edisonian approach*** to invention is characterized by **trial and error** discovery rather than a systematic theoretical approach.

wikipedia.org

RESARCH & DEVELOPMENT (R&D)

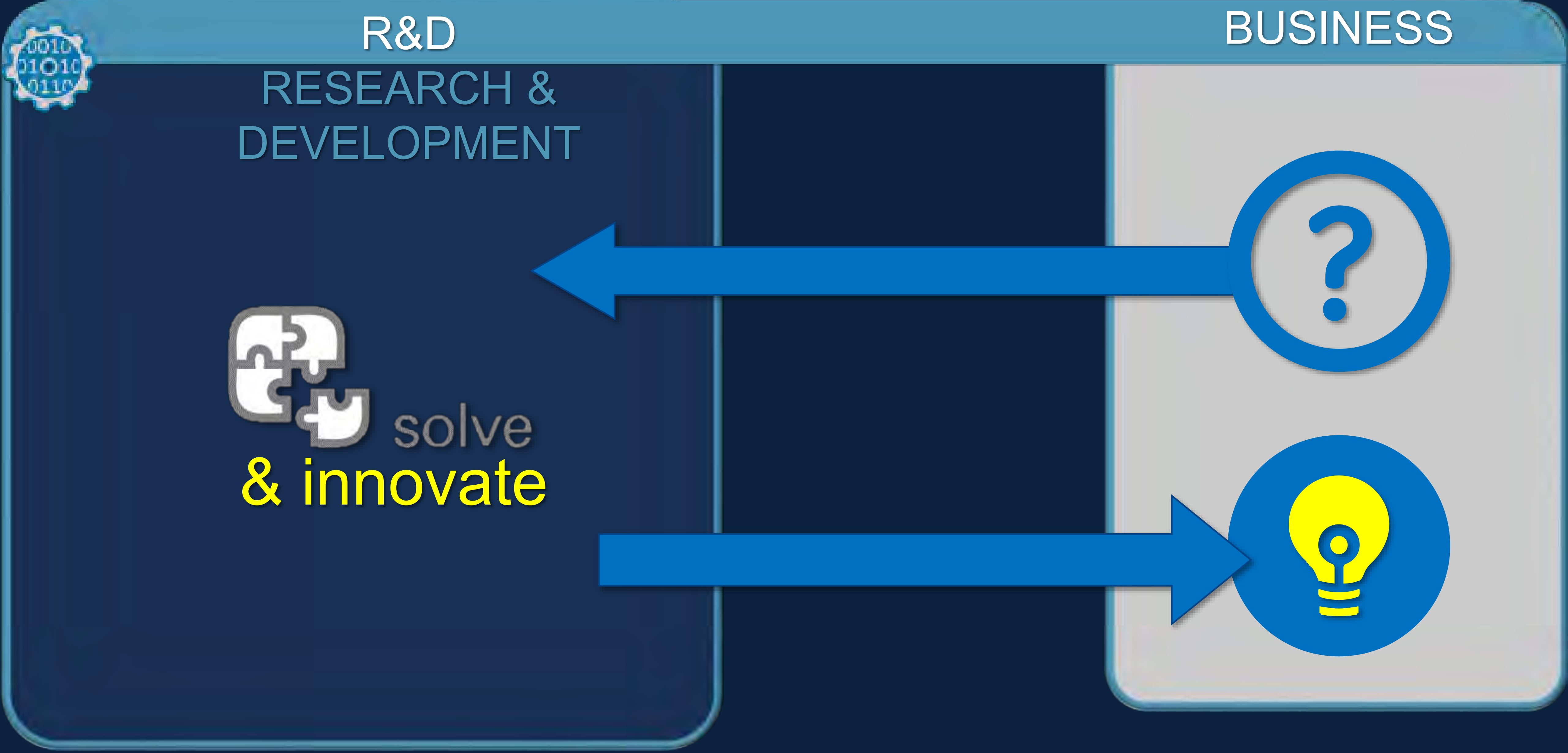
PRE-DIGITAL LABORATORY

R&D LABORATORY AS PROBLEM-SOLVING ENGINE

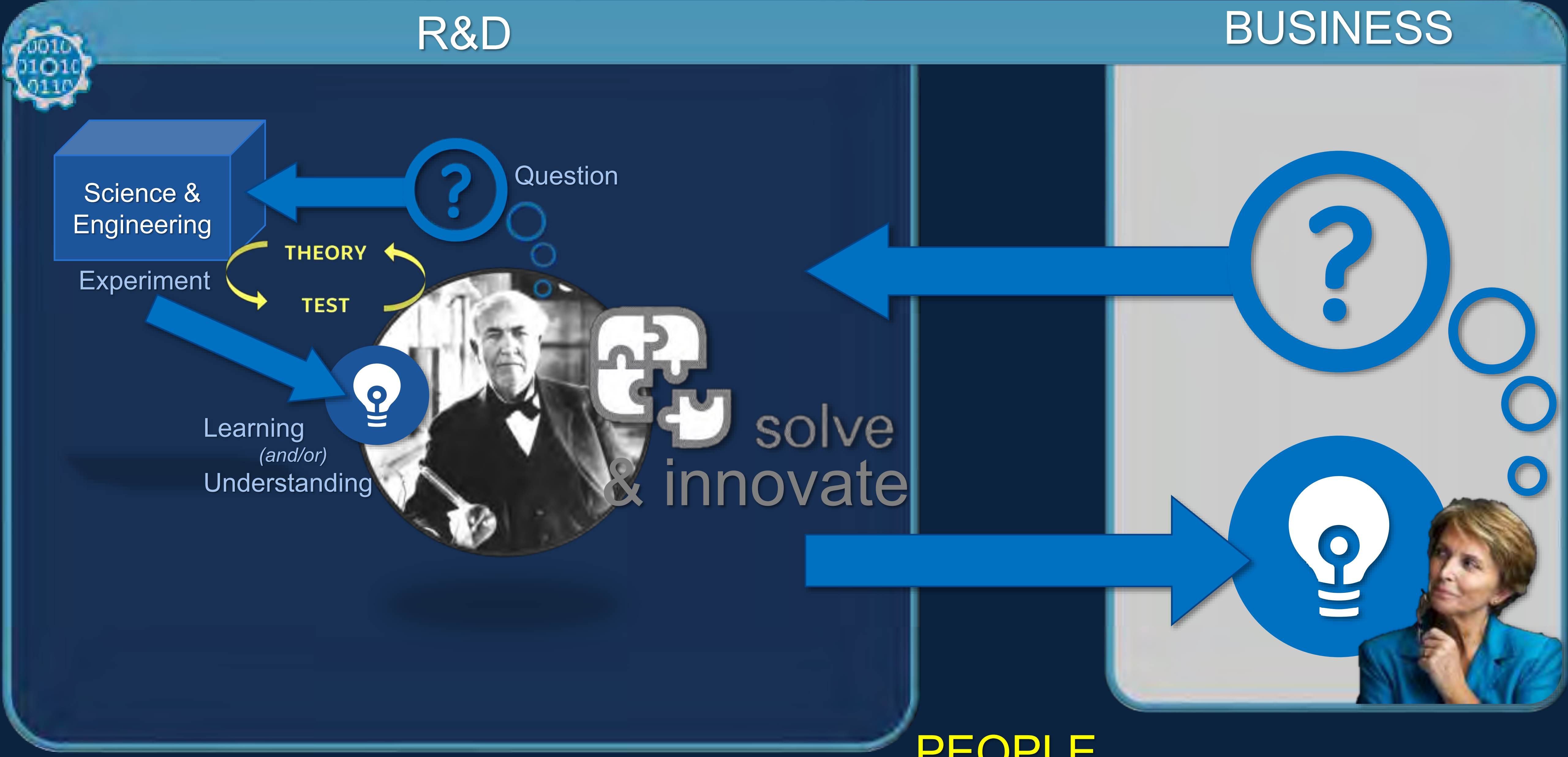


reliably, consistently, powerfully, opportunistically innovate and solve problems

The *(not-so-humble)* Aspiration

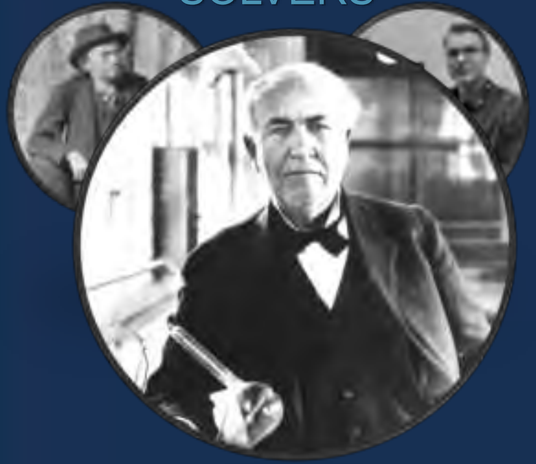


PROBLEM-SOLVING ENGINE



PROBLEM-SOLVING ~~ENGINE~~ PEOPLE

R&D
PROBLEM-
SOLVERS



(*Traditional*)

Scientific Method

THEORY

TEST

Math

Experimentation

THEORETICAL MODEL

EMPIRICAL EXPERIMENTAL OBSERVATION

EDISONIAN
("trial & error")

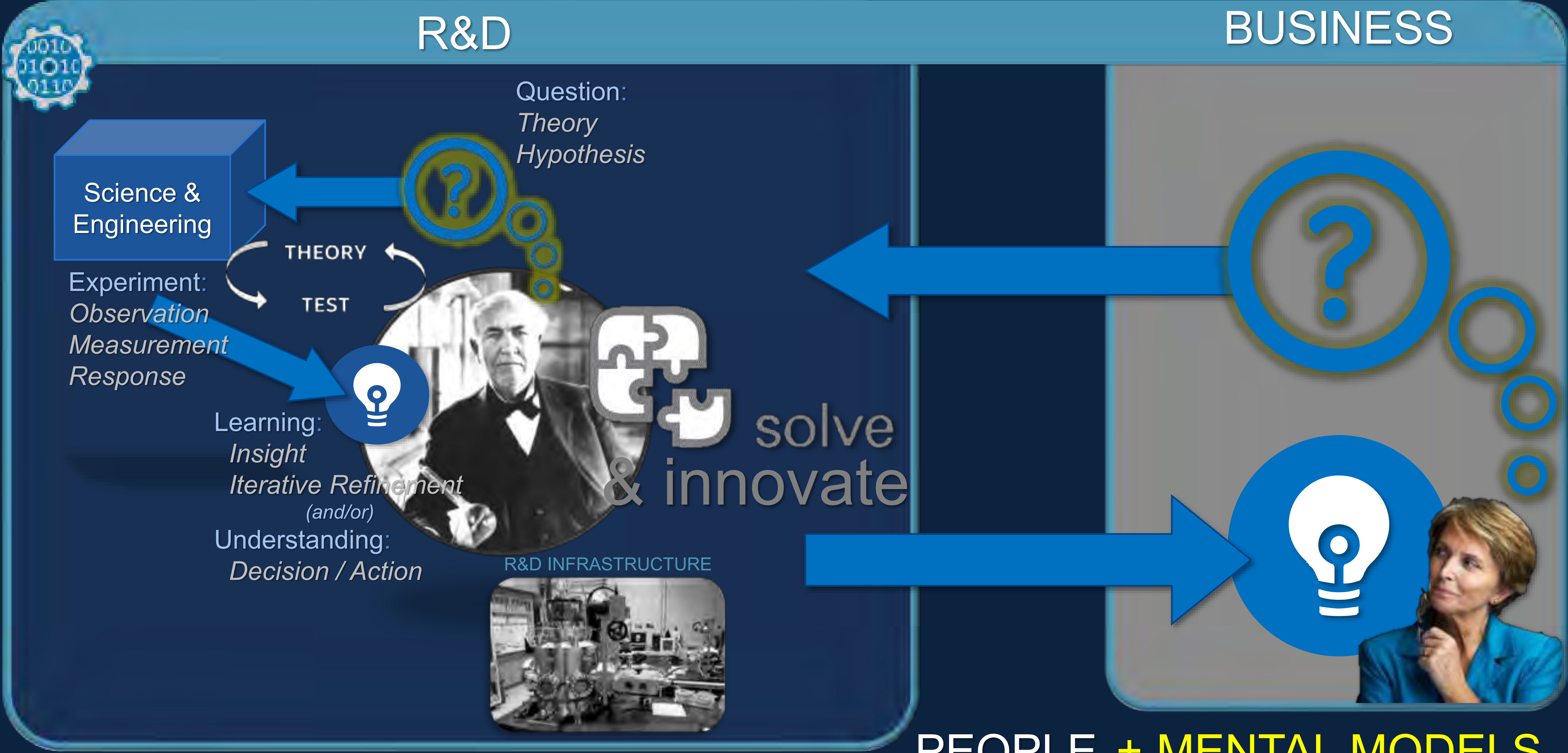
BUSINESS
DECISION-
MAKER

Pose **Problem**

solve

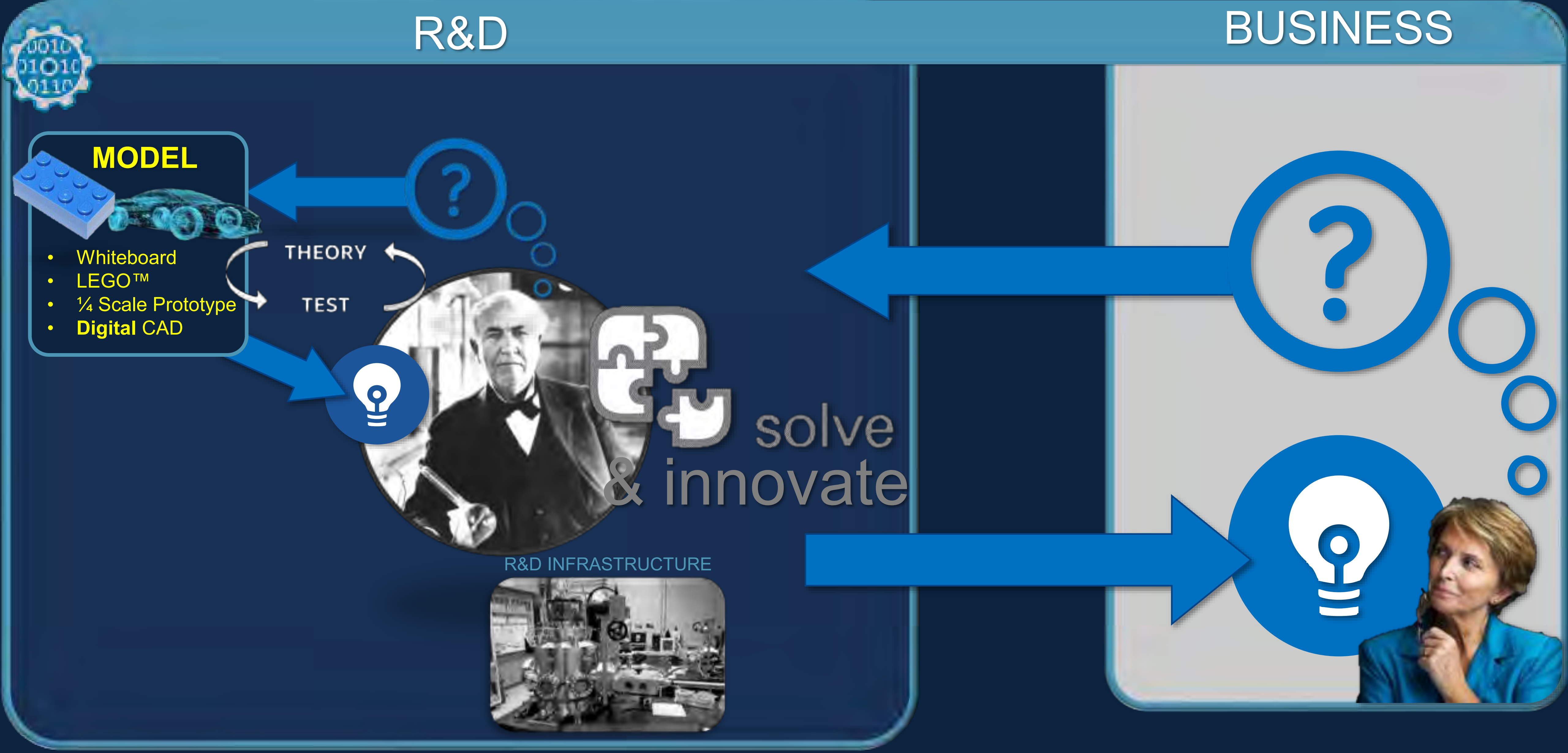
Communicate **Solution**(s)

R&D INFRASTRUCTURE



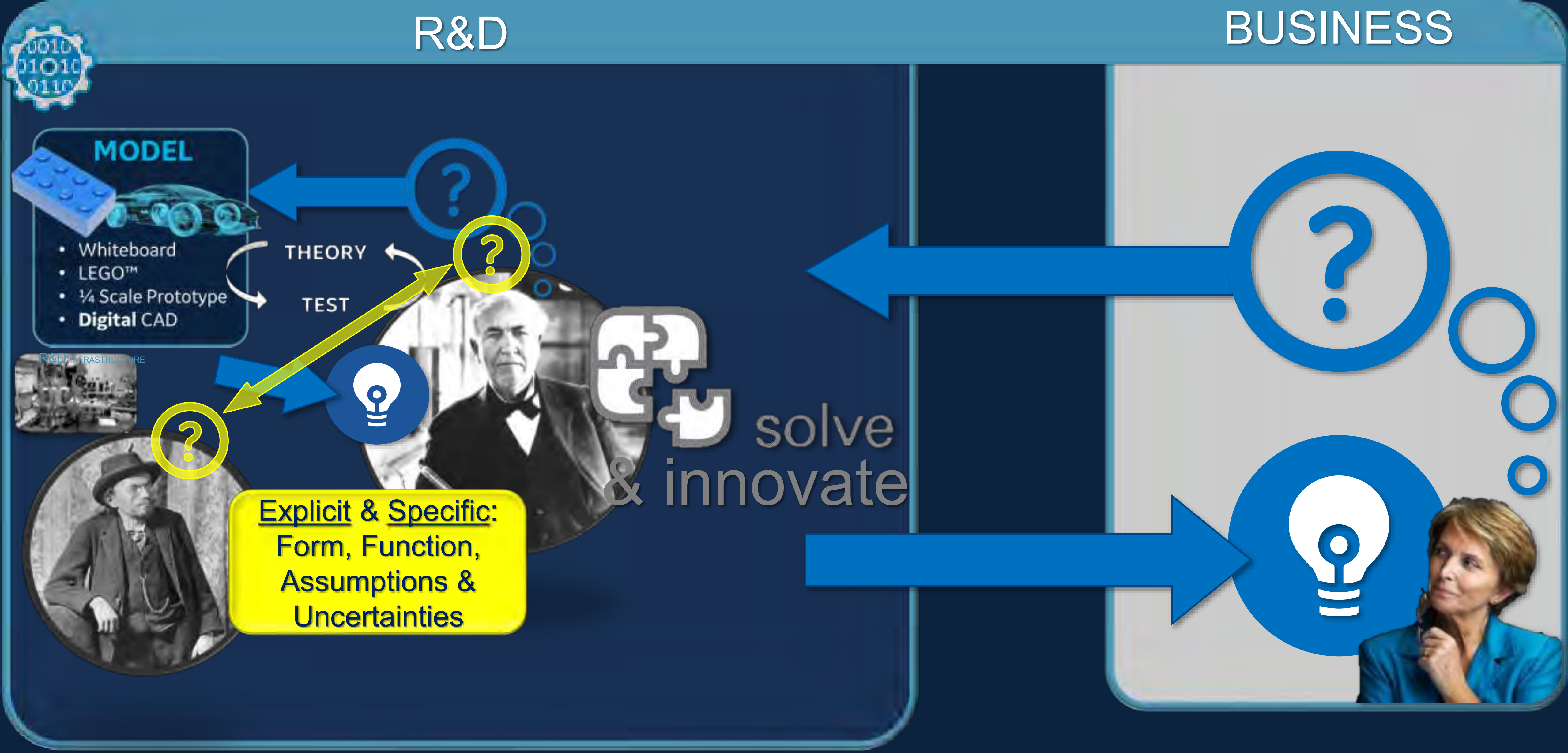
PEOPLE + MENTAL MODELS

PROBLEM-SOLVING ~~ENGINE~~



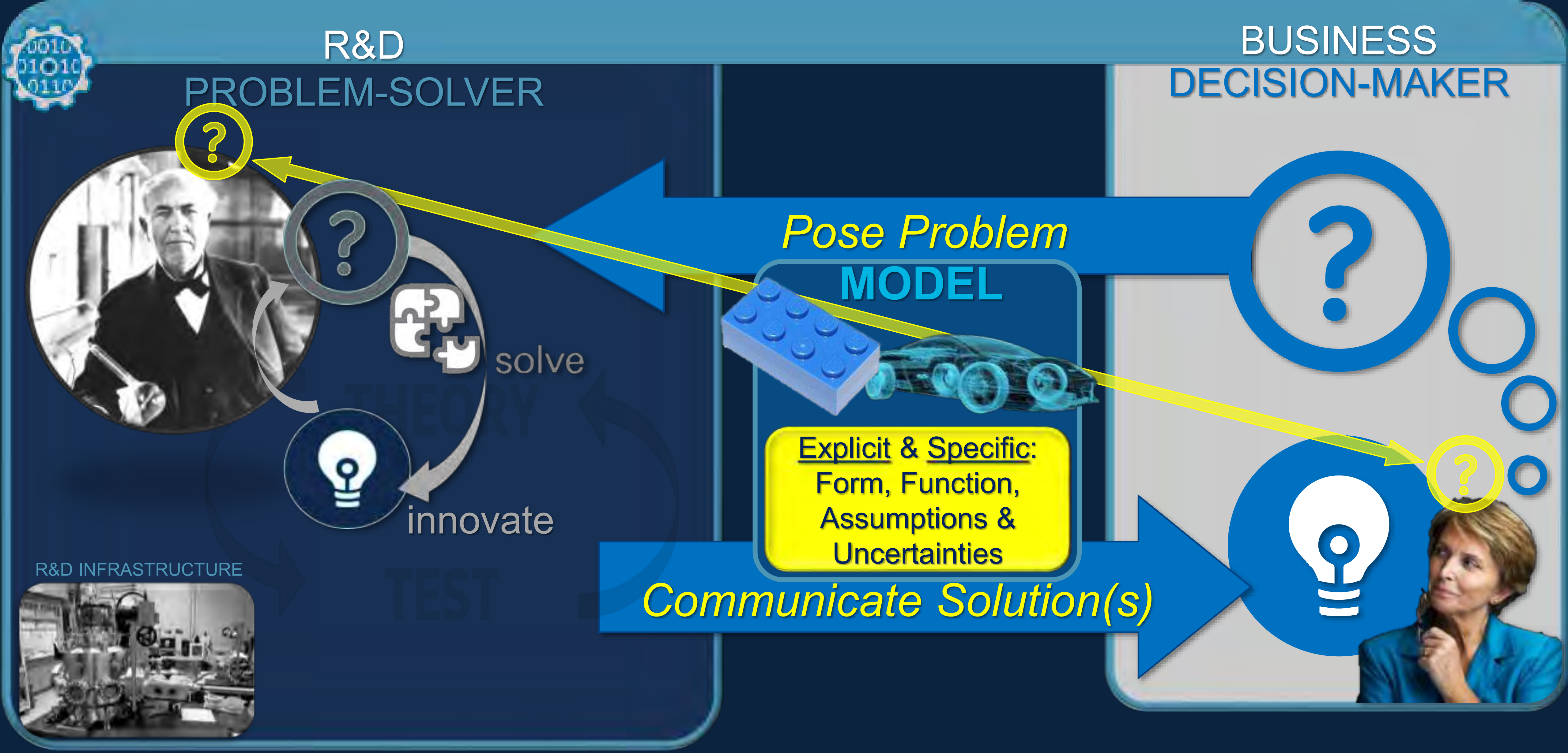
All *problem-solving* employs **models** (even if "merely" MENTAL MODELS)

Credit: Chris Granger, "*Coding is not the New Literacy*"



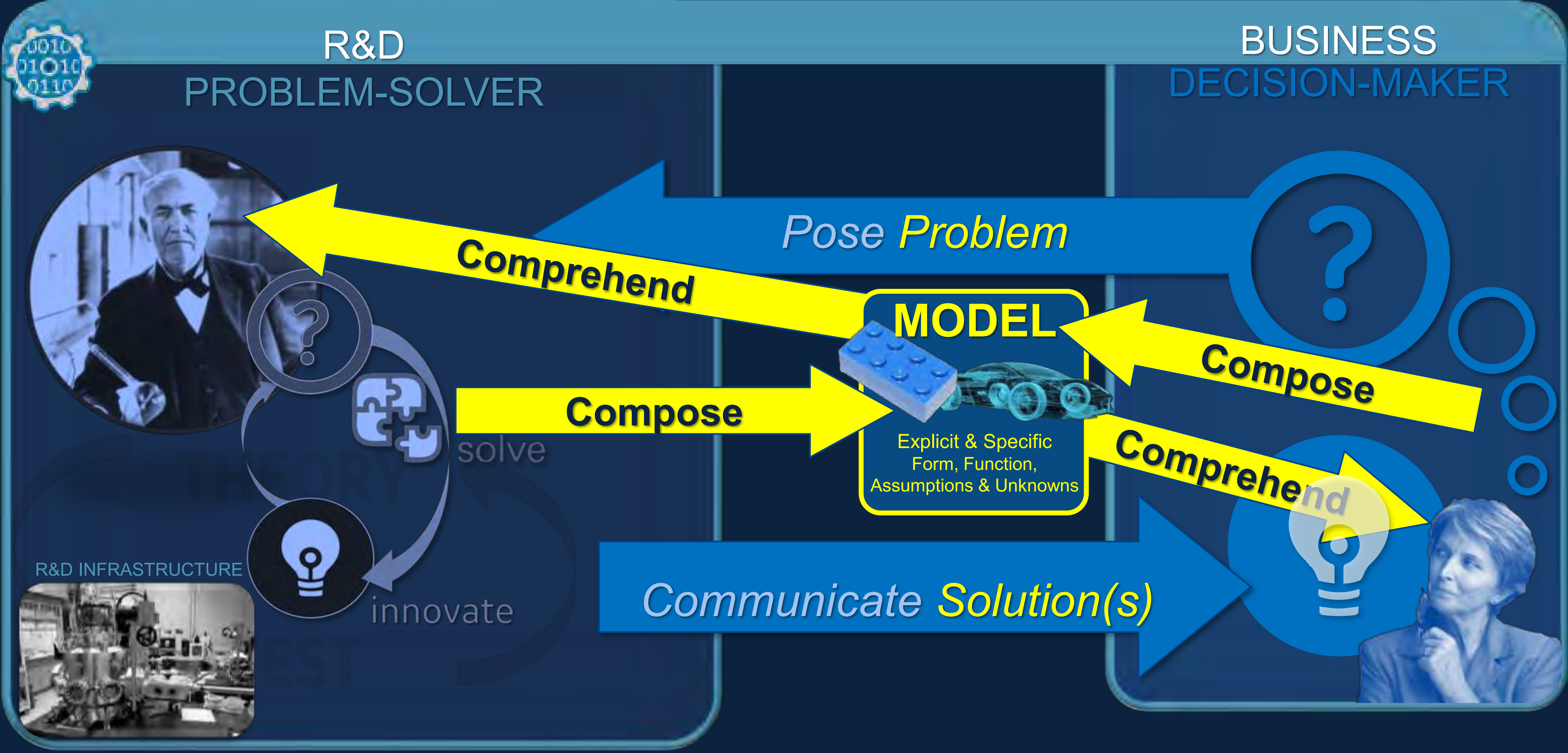
Collaboration requires externalizing details of mental models

Credit: Chris Granger, "*Coding is not the New Literacy*"



Express problem and solution through model

Credit: Chris Granger, “*Coding is not the New Literacy*”



Aptitude in modeling requires skill in Composition and Comprehension

Credit: Chris Granger, "*Coding is not the New Literacy*"

R&D
PROBLEM-SOLVER

BUSINESS
DECISION-MAKER

Pose Problem

Compose

Digital Literacy: Rubric for Digital & Computational Technical Expertise

The digitally literate engineer of the future will have the knowledge and ability to apply the power of computing hardware and computational methods to create and understand products and systems composed of and designed by data and m

Awareness (Learn)	Literacy = Composition (Do)	Comprehension Proficiency (Guide)	Fluent Vision & Strategy
Models & Data	Model & Data **Composition**	**Composition & Comprehension** of Model Ecosystem	
Tools • Software • Computing Hardware • Systems Thinking • Co-design • Digital Twin • Digital Thread	Build & apply tools Systems productivity, performance & quality Document & Measure	Advance infrastructure/toolchain Improve speed & accuracy of decision-making Assess & leverage new technology	Invent, innovate & synthesize tools Inspire investment & Align strategy Identify & envision novel solutions vs. gaps

Knowledge & skill expectations for data & computational engineering literacy, proficiency & fluency.

R&D IN

MODEL

Explicit & Specific
Form, Function,
Assumptions & Unknowns

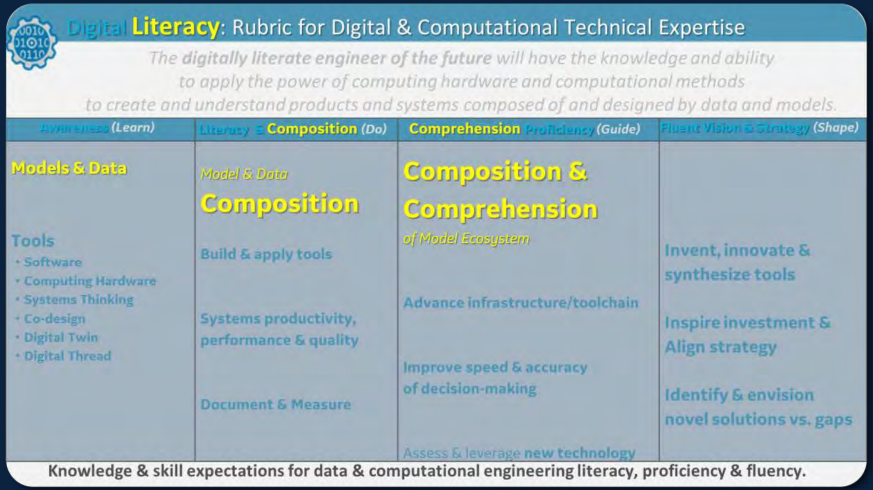
e Solution(s)

Comprehend

Composition + Comprehension = **Literacy**

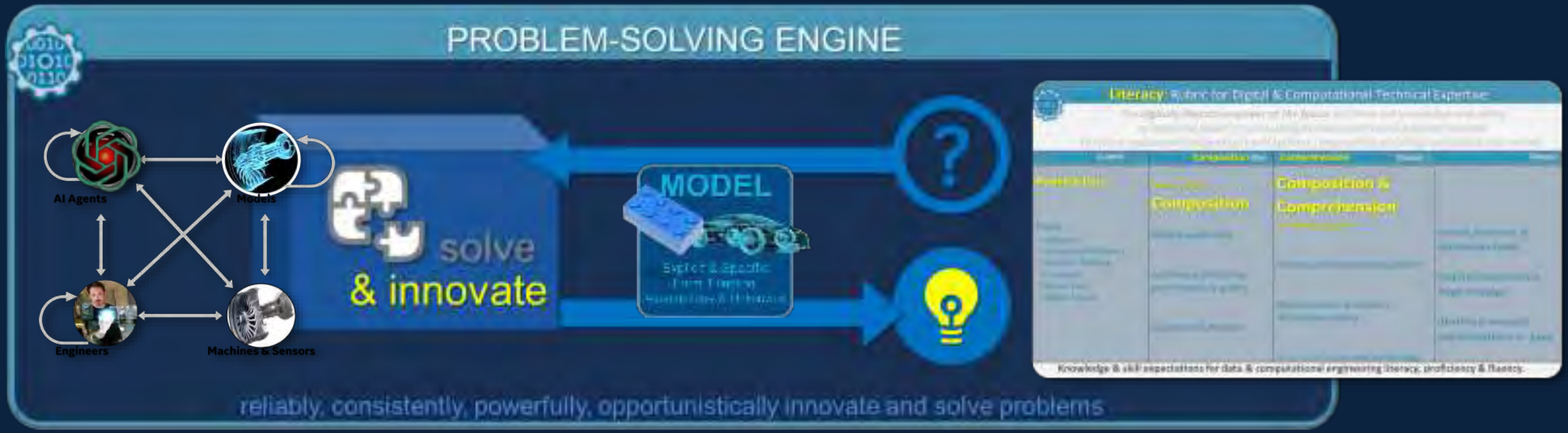
Digital Literacy

Modeling
Data & Tools



Modeling Literacy

Digital
Data & Tools



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Knowledge & skill expectations for data & computational engineering literacy, proficiency & fluency.

What is a Model?

NAFEMS INCOSE

A simplified version of a concept, phenomenon, relationship, structure or system

- (such as) a graphical, mathematical or physical representation
- (often) an abstraction of reality by eliminating unnecessary components

The objectives of a model include:

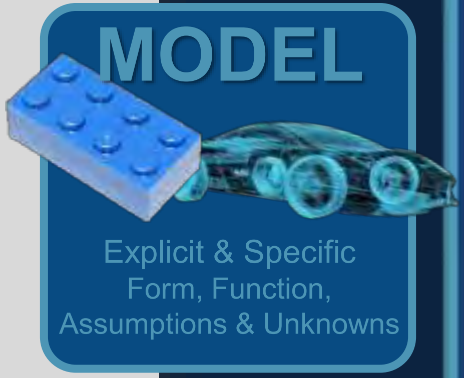
- to facilitate understanding
- to aid in decision making
  (such as) assessing *'what if'* scenarios
- to explain, control, & predict events.

(Defined in Systems Engineering context)

R&D INFRASTRUCT

BUSINESS
DECISION-MAKER

roblem



Compose

Solution(s)

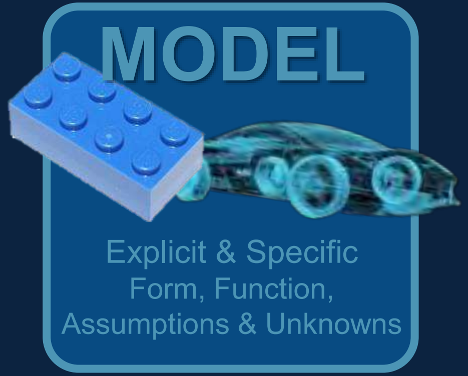
Comprehend

to Understand, Decide, Explain, Predict, …

ALL MODELS ARE WRONG, BUT SOME ARE USEFUL.

- GEORGE E. P. BOX

Types of Models



Wrong and ***Useful***

"A model is a lie that helps you see the truth"

Howard Skipper (Oncologist)

Types of Digital Models

ALL MODELS ARE WRONG, BUT SOME ARE USEFUL.

- GEORGE E. P. BOX

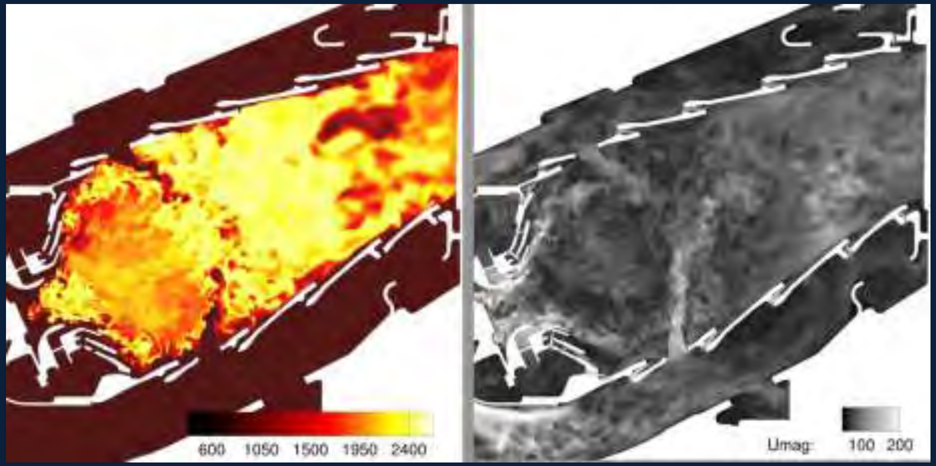
DATA

Visualization of TLC GPS Data

TLC = NYC Taxi & Limousine Commission
Source: NYU Center for Urban Science+Progress

SIMULATION

CFM56 Combustor



RULES

Package Shipping Cost

Model Limitation: **Incompleteness (*Epistemic* Uncertainty)**

Wrong: what your model does not know

(such as lack of knowledge about the modeled process, or absence / sparsity of validation data for the parametric region of inquiry)

DATA

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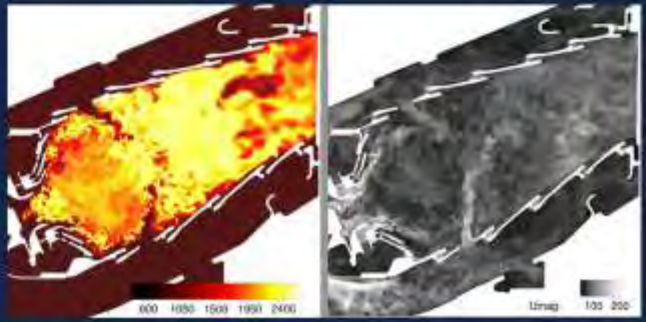
SIMULATION

CFM56 Combustor



GE Combustion Simulation on CFM56 Engine

RULES

One strategy to **fix:**
more and more and more data
(E.g., increase direct V&V/observation of region of inquiry)

One strategy to **detect:**
train/use many models, note discrepancies
(E.g., Bayesian methods applied to models trained from dropout sampling)

TLC = NYC Taxi & Limousine Commission
Source: NYU Center for Urban Science+Progress

Data-derived Models (Modern Machine Learning)

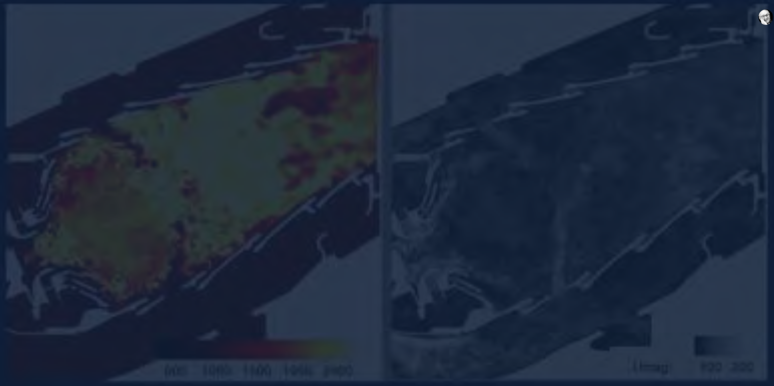
"Over the past decades, computers have broadly automated tasks that programmers could describe with clear rules and algorithms.

DATA

Visualization of TLC GPS Data

SIMULATION

CFM56 Combustor



RULES

Modern machine learning techniques now allow us to do the same for tasks where describing the precise rules is much harder."

\- Jeff Bezos

Letter to shareholders, 2017

Formulaic Models ("*clear rules and algorithms*")

Wrong: Express our best *approximation* of what we understand

DATA

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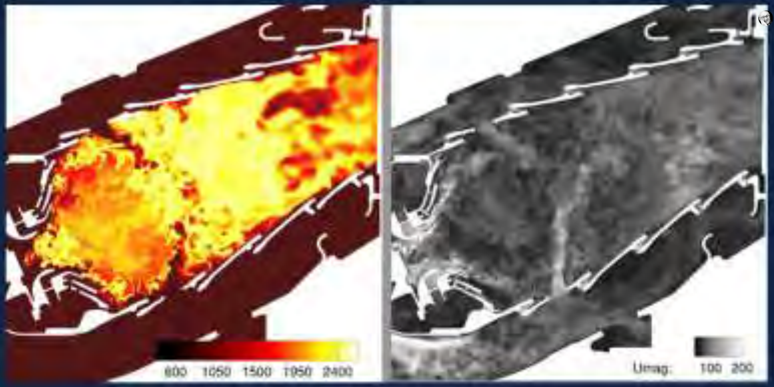
SIMULATION

CFM56 Combustor



GE Combustion Simulation on CFM56 Engine

RULES

Useful: Can ***extrapolate*** outside of direct experience, assuming the same rules apply.

Machine Learning (“*data-derived models*”)

Useful: where “describing precise rules is difficult”

DATA

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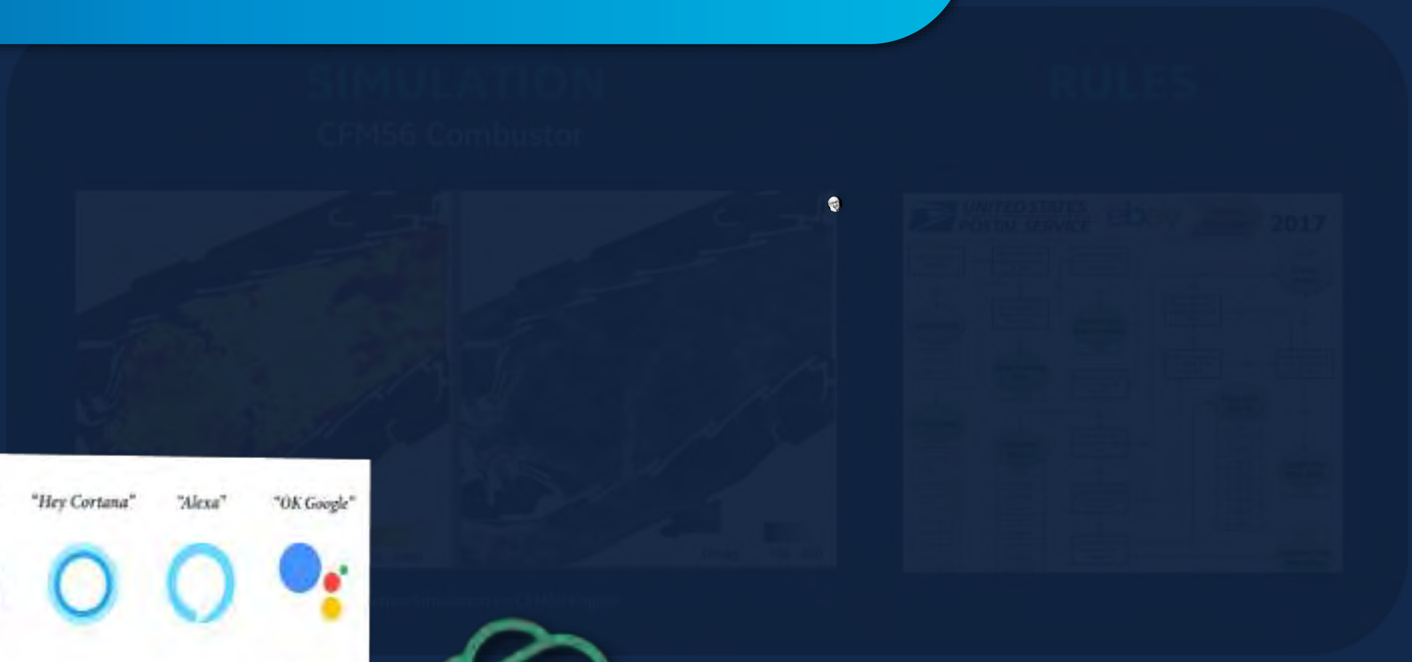

OpenAI
ChatGPT **4.0**

Wrong: numerous limitations and liabilities apply

Data-derived Models

Wrong: numerous limitations and liabilities apply

DATA

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- **Bad Data** (incorrect measurement, miscalibrated sensor, malicious source, …)
- **Missing Data** (unclear where to look/sample, expense to capture or compute, …)
- **Region of Competence** (cannot *Extrapolate* beyond, unclear how to assert)
- **Opacity** (difficult/impossible to *Explain*)
- **Intellectual Debt** (understanding underlying fundamentals is a payment due)

Useful: where "describing precise rules is difficult"

Data-derived Models

Wrong: what you cannot understand from the data
e.g., natural randomness / sensor quality / learnable but not reducible

DATA

Visualization of TLC GPS Data

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***Aleatoric* Uncertainty**, including sensing & measurement limitations

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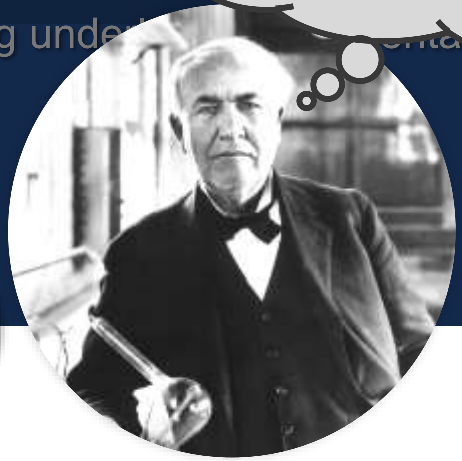
Garbage In
Garbage Out

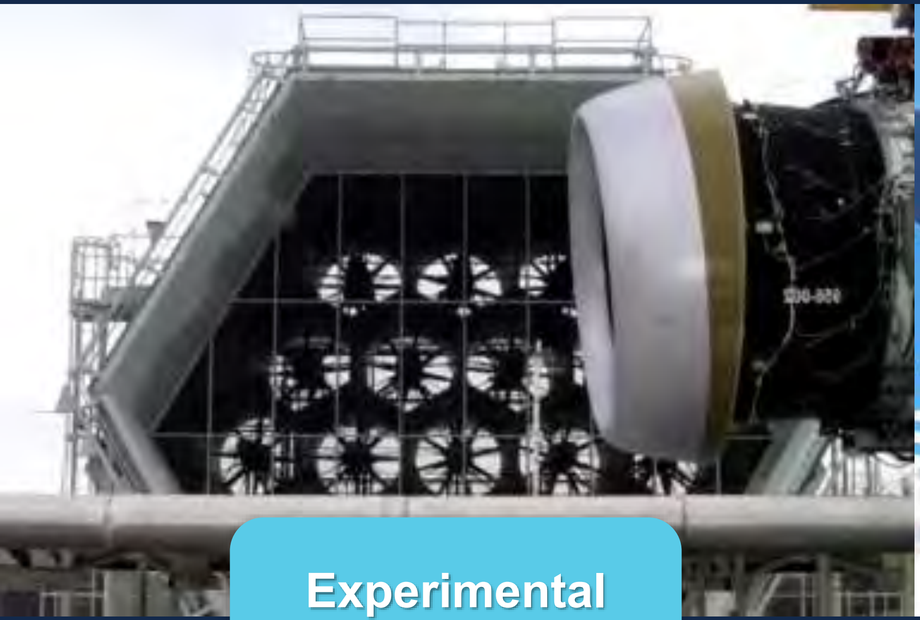


Useful: where "describing precise rules is difficult"

Physical validation of predictive ACCURACY

"RIG" TEST

DIGITAL TWIN



Experimental Measurement

Targeted Field Sampling

VERIFICATION & VALIDATION

CALIBRATION & UNCERTAINTY QUANTIFICATION

Garbage In Garbage Out

is critical to trust model results & bound CONFIDENCE

Data-derived Models

Wrong: numerous limitations and liabilities apply

(including *Epistemic* Uncertainty)

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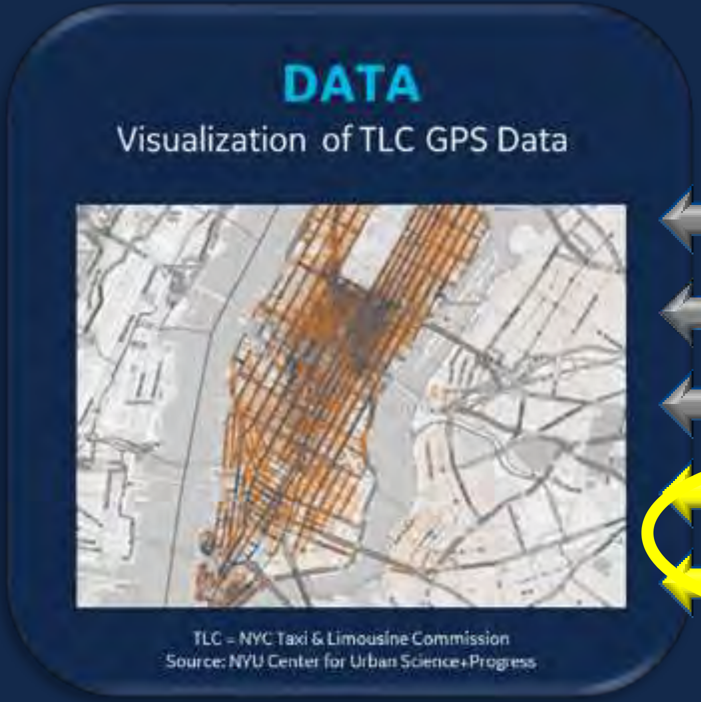
- Intellectual Debt (understanding underlying fundamentals is a payment due)

Useful: where "describing precise rules is difficult"

Data-derived Models

Wrong: numerous limitations and liabilities apply



- Bad Data (incorrect measurement, miscalibrated sensor, malicious source, …)
- Missing Data (unclear where to look/sample, expense to capture or compute, …)
- Region of Competence (cannot *Extrapolate* beyond, unclear how to assert)
- Opacity (difficult/impossible to *Explain*)
- Intellectual Debt (understanding underlying fundamentals is a payment due)

Useful: where "describing precise rules is difficult"

Data-derived Models

Technical debt *arises when systems are tweaked hastily, catering to an immediate need to save money or implement a new feature, while increasing long-term complexity. […] When something stops working, this technical debt often needs to be paid down as an aggravating lump sum.*

Explainability & Understanding (to humans)

Intellectual Debt: With Great Power Comes Great Ignorance

Jonathan Zittrain, Jul 24

This kind of discovery — ***answers first, explanations later*** — I call "intellectual debt."

We gain insight into what works without knowing why it works. We can put that insight to use immediately, and then tell ourselves we'll figure out the details later [debt to be paid in the future].

https://blog.usejournal.com/from-technical-debt-to-intellectual-debt-in-ai-e05ac56a502c

- Bad Data (incorrect measurement, miscalibrated sensor, malicious source, …)
- Missing Data (unclear where to look/sample, expense to capture or compute, …)
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- Intellectual Debt (understanding underlying fundamentals is a payment due)

~~Digital~~ → Modeling Literacy: Rubric for Digital & Computational Technical Expertise

*The **digitally literate engineer of the future** will have the knowledge and ability to apply the power of computing hardware and computational methods to create and understand products and systems composed of and designed by data and models.*

Awareness	Literacy & Composition	Comprehension Proficiency	Fluent Vision & Strategy
Models & Data •Precision, accuracy & uncertainty •Quality, consistency, & resolution •Lifecycle (*capture, storage, access*) •Security, privacy, & integrity •Policy & rights compliance •Implementation (*requirements, V&V*)	**Literate Model & Data Composition** •Derive digital model from mental model •Structure model applicability & credibility •Codify system dynamics & transforms •Communication of solution alternatives •Sensitivity & main effects analysis •Apply governance policy & procedures	**Proficient Model Composition & Comprehension** •Knowledge synthesis from analysis & learning •Assertible competence (*assumptions, limits, explanation, applicability, credibility, VVUQ*) •Sensitivity to sources of error, bias, unknowns •Assess digital vs. physical strategy trade-offs •Assert governance, data rights, derive & protect IP	
Tools (*referenced by Do/Guide/Shape*) • **Software** • **Computing Hardware** • **Systems Thinking** • **Co-design** • **Digital Twin** • **Digital Thread**	**Build & apply tools** to model and improve **Systems productivity, p** **Document & Measure**	**Advance ecosystem/toolchain** capabilities	**Invent, innovate & synthesize tools** **Inspire investment** **Envision novel solutions vs. gaps**
Learn	***Do***	***Guide***	***Shape***

Successful implementation of **modeling** requires the ability to assert a ***Region of Competence*** for a given model

where its use is numerically stable (**ROBUSTNESS**)
with minimal simplifying constraints (**REALISM**) and
quantifiably bounds uncertainties (**CONFIDENCE**)
of results with validated predictive **ACCURACY**.

R&D
PROBLEM-SOLVERS

\+ **INFRASTRUCTURE**

Pose **Problem**

solve

innovate

MODEL

Explicit & Specific
Form, Function,
Assumptions & Unknowns

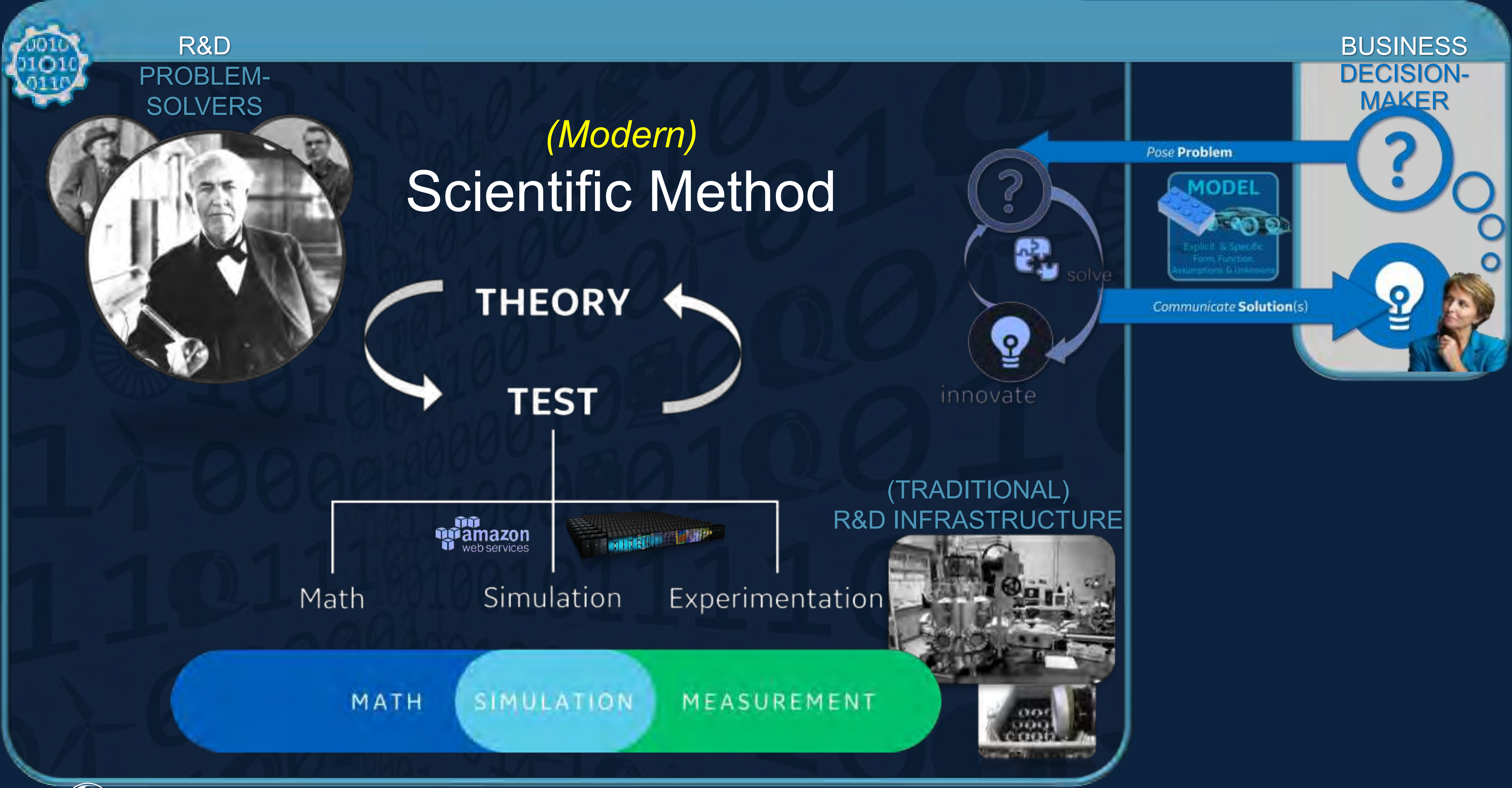
Communicate **Solution**(s)

BUSINESS
DECISION-MAKER

R&D LABORATORY INFRASTRUCTURE

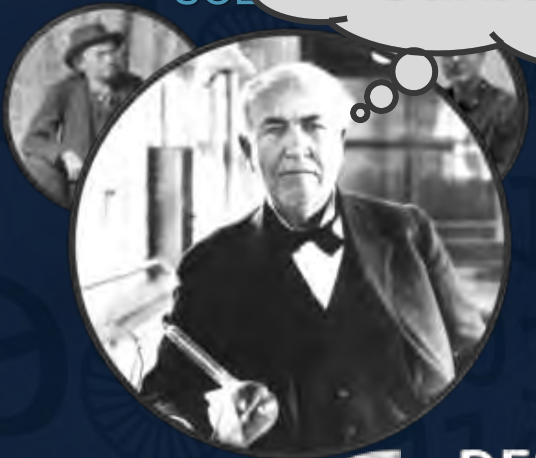
amazon
web services

DIGITAL + TRADITIONAL

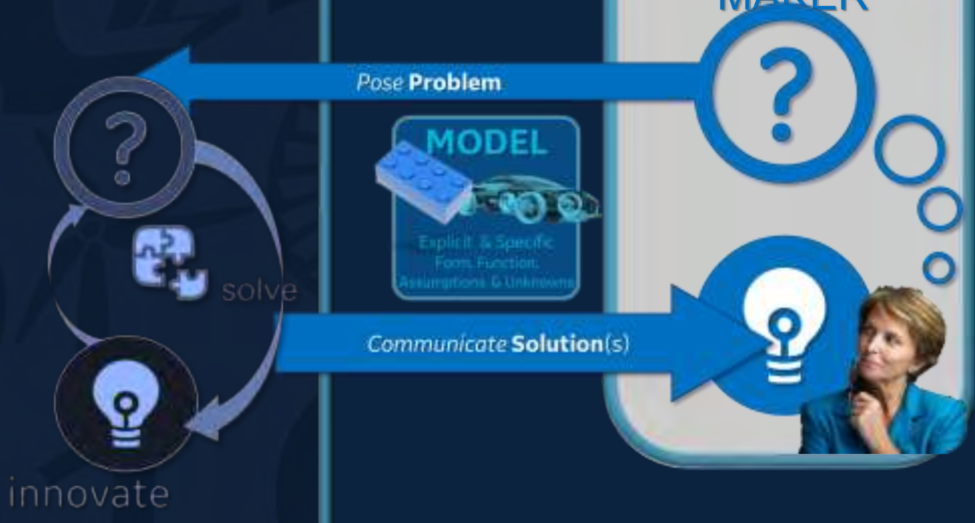

R&D
PROBLEM-
SOLVERS
(Modern)
Scientific Method
THEORY
TEST
amazon web services
Math
Simulation
Experimentation
MATH
SIMULATION
MEASUREMENT
(TRADITIONAL)
R&D INFRASTRUCTURE
solve
innovate
BUSINESS
DECISION-
MAKER
Pose Problem
MODEL
Communicate Solution(s)

R&D
PRO
SOL

Garbage In
Garbage Out



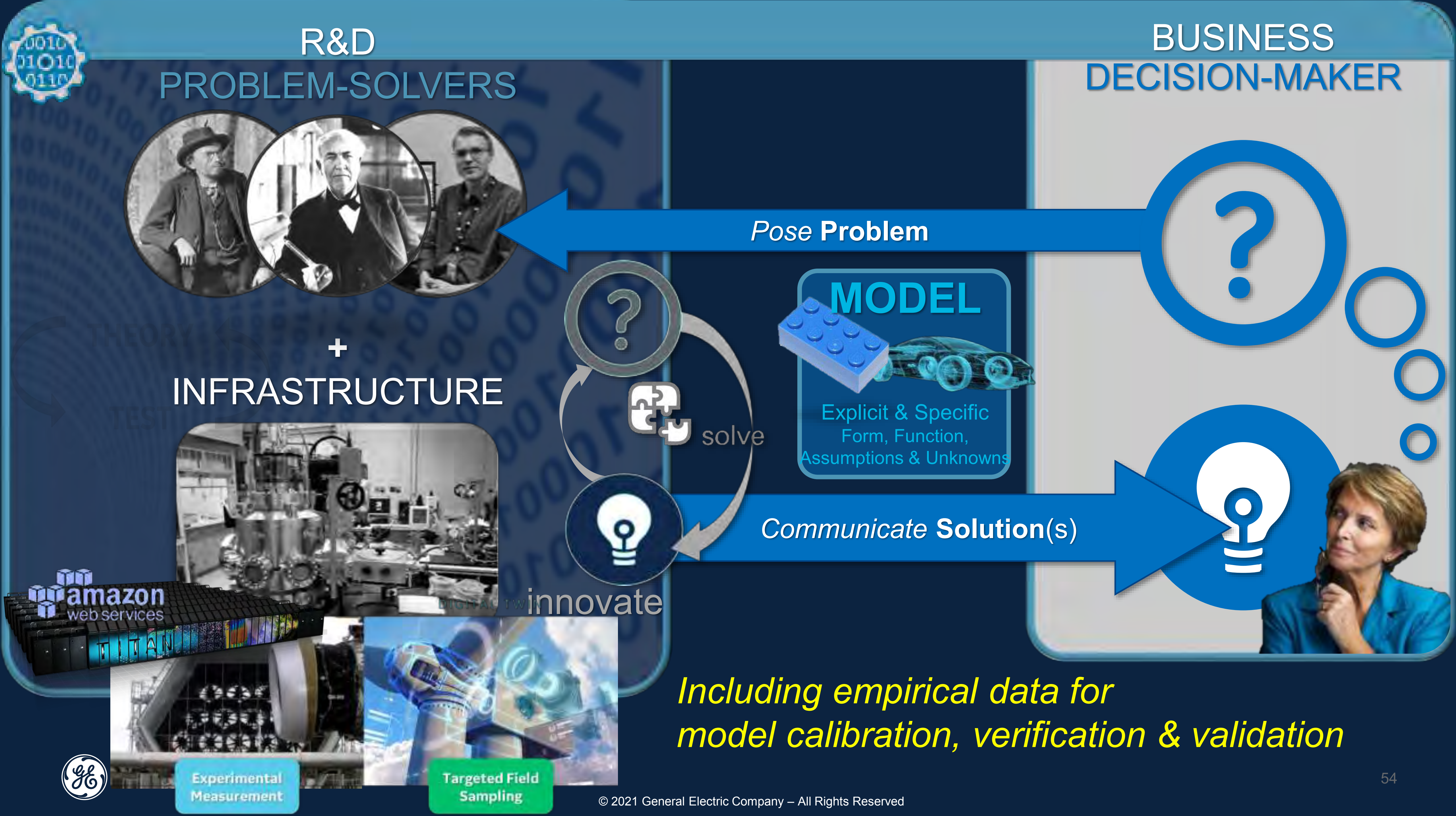
Critical Infrastructure Justifies Conservatism



(PHYSICAL + DIGITAL)
R&D INFRASTRUCTURE

GE Legacy Products:

- are highly complex &
- high value assets, with
- safety-critical components,
- consequential downtime,
- and long field life



R&D
PROBLEM-SOLVERS
+
INFRASTRUCTURE
amazon web services
TITAN
innovate
solve
Experimental Measurement
Targeted Field Sampling
BUSINESS
DECISION-MAKER
Pose Problem
MODEL
Explicit & Specific
Form, Function,
Assumptions & Unknowns
Communicate Solution(s)
Including empirical data for
model calibration, verification & validation

Digital Engineering Infrastructure

Computing Hardware

Software Systems

Model-based Enterprise **Digital Engineering**

OMG SYSTEMS MODELING LANGUAGE SysML

fmi Functional Mock-up Interface

openMDAO

dcp Distributed Co-Simulation Protocol

OpenMBEE

Digital Engineering Infrastructure

Hardware economies of Moore's Law:
- abundant & affordable computing
- abundant & affordable storage
- abundant & affordable network

deliver capability and capacity to drive advancement of **Software Systems**.

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Software Systems enable:
- abstract symbolic representation
- numerical formalization
- concurrency and automation

leading to prominence of **Model-based Enterprise** and **Digital Engineering**.

OpenAI ChatGPT4.0

Digital Thread and **Model-based Enterprise**
- interoperability of software
- interchange of data
- connective workflows

across the enterprise
(sales, design, manufacturing, operations, service)
as well as externally
(customers, partners, supply chain, and regulators),
enhancing Collaboration, Productivity and Innovation.

fmi Functional Mock-up Interface
OMG Systems Modeling Language SysML
dcp Distributed Co-Simulation Protocol
openMDAO
OpenMBEE

Digital Engineering leveraging Digital Thread and MBE enables:
- rapid virtual experimentation
- cross-discipline collaboration
- reduction of design iteration and mapping of trade-off spaces
- automated analysis of anomalies and contradictions *(as-designed vs. as-built vs. as-operated vs. as-serviced)*
- upstream learning, model recalibration & opportunity discovery *(from manufacturing, installation, operation, and field service data)*.

GE Research

~~Digital~~ → Modeling Literacy: Rubric for Digital & Computational Technical Expertise

*The **digitally literate engineer of the future** will have the knowledge and abi*
to apply the power of computing hardware and computational methods
to create and understand products and systems composed of and designed by data a

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Awareness *(Learn)*	**Literacy & Composition** *(Do)*	**Comprehension Proficiency** *(Guide)*	**Fluent Vision & Strategy** *(Shape)*
Models & Data	**Model & Data Composition**	**Composition & Comprehension of Model Ecosystem**	
Tools • **Software** • **Computing Hardware** • **Systems Thinking** • **Co-design** • **Digital Twin** • **Digital Thread**	**Build & apply tools** **Systems productivity, performance & quality** **Document & Measure**	**Advance infrastructure/toolchain** **Improve speed & accuracy of decision-making** Assess & leverage **new technology**	**Invent, innovate & synthesize tools** **Inspire investment & Align strategy** **Identify & envision novel solutions vs. gaps**

~~Digital~~ → Modeling Literacy: Rubric for Digital & Computational Technical Expertise

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to *apply the power of computing hardware and computational methods*
to create and understand products and systems composed of and designed by data a

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Awareness	Literacy & Composition	Comprehension Proficiency	Fluent Vision & Strategy
Models & Data	**Literate Model & Data Composition**	**Proficient Model Composition & Comprehension**	
Tools (*referenced by Do/Guide/Shape*) **Software** •Agile & DevSecOps productivity •Standards/interoperability (SysML, FMI) •Usability (UX) & Maintainability •Testing/validation & QA •Configuration & version control **Computing Hardware** •Architecture (*edge to enterprise*) •Processing (*CPUs, accelerators*) •Data (*communications & storage*) •Sensors, controls & robotics **Systems Thinking / Co-design** •Performance instrumentation •Digital + Physical / **Digital Twin** •Integration / **Digital Thread** •Security, integrity & robustness •Automation & machine learning	**Build & apply tools** to model and improve •Problem definition & characterization •Robustness & performance optimization •Assessment of confidence bounds & risk •Data analysis, visualization & info synthesis **Systems productivity, performance & quality** •Searchability & annotation (*metadata*) •Automation (*for productivity & consistency*) •Co-design collaboration (*numerical/SW + architecture/HW + domain expertise*) •Durability to change (*portable, flexible*) **Document & Measure** •Performance profiling & analysis •Decision Provenance (*assumptions, known unknowns, limitations, evaluation criteria*) •Sources of error & uncertainty	**Advance ecosystem/toolchain/workforce** •Communicate lessons learned and promote continual education •Solution capacity/scale & performance •Model Maturity & VVUQ •Systems integration (*digital thread driven*) **Improv** Evaluate	**Invent, innovate & synthesize tools** • Breakthrough solution scale/capabilities • Adaptive systemic uncertainty reduction • Model applicability & robustness • Human-machine collaboration

Employ modern ***Software Engineering and Computational Methods*** (including AI/ML) discipline and tools to

promote efficient workflows (**PRODUCTIVITY**),
reduce waste and improve quality (**SUSTAINABILITY**).

Implement the model with an ***Architecture*** that

performs capably on HPC hardware (**SCALABILITY**)
and is interoperable and extensible (**FLEXIBILITY**).

Learn ***Do***

Framework to Assess MODEL MATURITY

Assert a ***Region of Competence*** for a given model

where its use is numerically stable (**ROBUSTNESS**)
with minimal simplifying constraints (**REALISM**) and
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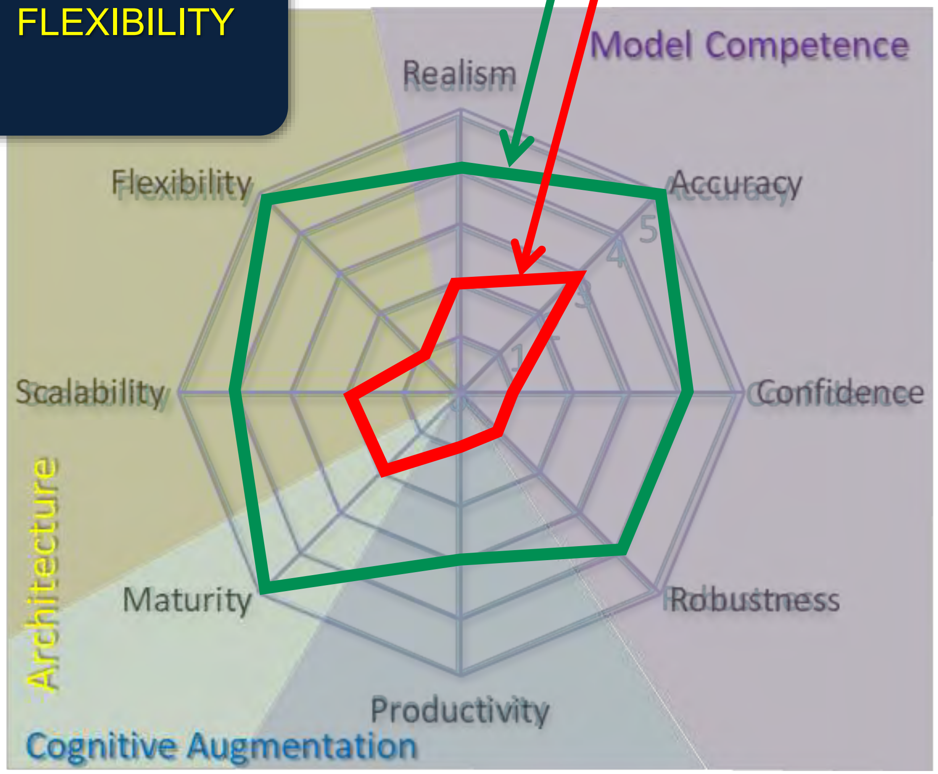
MODEL

REALISM
ACCURACY
CONFIDENCE
ROBUSTNESS
SUSTAINABILITY
PRODUCTIVITY
SCALABILITY
FLEXIBILITY

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Good (outward)

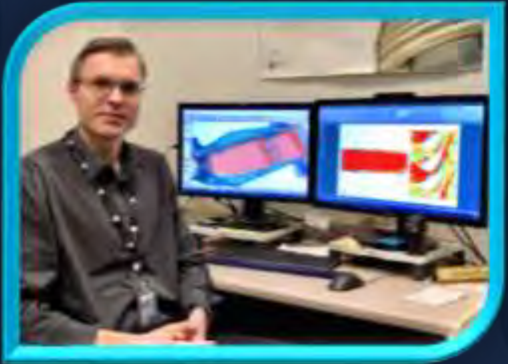
Bad (inward)



See also
richardarthur.medium.com/co-design-web

COMPUTATIONALLY FLUENT

PROBLEM-SOLVER



imagine

+

CRITICAL SUPPORT INFRASTRUCTURE

MODEL

Discover & Compose Problem *through model*

Advise Decision/Action
Explain Observation
Answer Question

solve

Communicate-to-Comprehend Solution(s) *through model*

Insight Discovery
Trade-off Analysis
Mapped Decision Space

DIGITALLY LITERATE

DECISION-MAKER

lead

build

~~Digital~~ Modeling Literacy: Rubric for Digital & Computational Technical Expertise

Decision-Makers Guiding and Shaping

Awareness	Literate Composition	Comprehension Proficiency	Fluent Vision & Strategy
Models & Data **Tools** • **Software** • **Computing Hardware** • **Systems Thinking** • **Co-design** • **Digital Twin** • **Digital Thread**	**Literate Model & Data Composition** **Build & apply tools** **Systems productivity, performance & quality** **Document & Measure**	**Proficient Model Composition & Comprehension** **Advance ecosystem/toolchain** capabilities **Improve decision-making speed & accuracy** •Physical measurement to validate confidence •Employ inclusive collaborative workflows •Mitigate failure and unexpected results •Scan decision provenance vs. new information •Contingency plans & triggering conditions •Clarify roles & responsibilities to create, manage, improve support tools & processes Evaluate & leverage **emerging technology** •Computing / network / storage platforms •Augmentation via machine collaboration	**Invent, innovate & synthesize tools** **Inspire investment pursuit** to new value •Innovative Products & Services •Align strategies & collaborative workflows spanning silos, supply chain, & customers •Innovative / disruptive business models •Challenge traditional limitations (*process, regulatory certification, design margins*) •Solution trade-off space exploration •Promote digital mindset inclusive culture **Identify/Envision novel solutions vs. gaps** •Enabling tech breakthrough opportunities (*never before seen, built, tried, imagined*) •Physical Measurement vs. Synthetic Data • Human expertise development & insight •Intellectual debt and scientific discovery
Learn	**Do**	**Guide**	**Shape**

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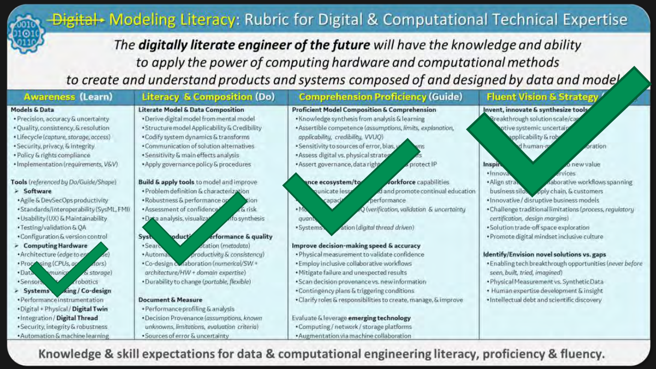
Knowledge & skill expectations for data & computational engineering literacy, proficiency & fluency.

See: Digital Literacy

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Digitally Illiterate / Fluent



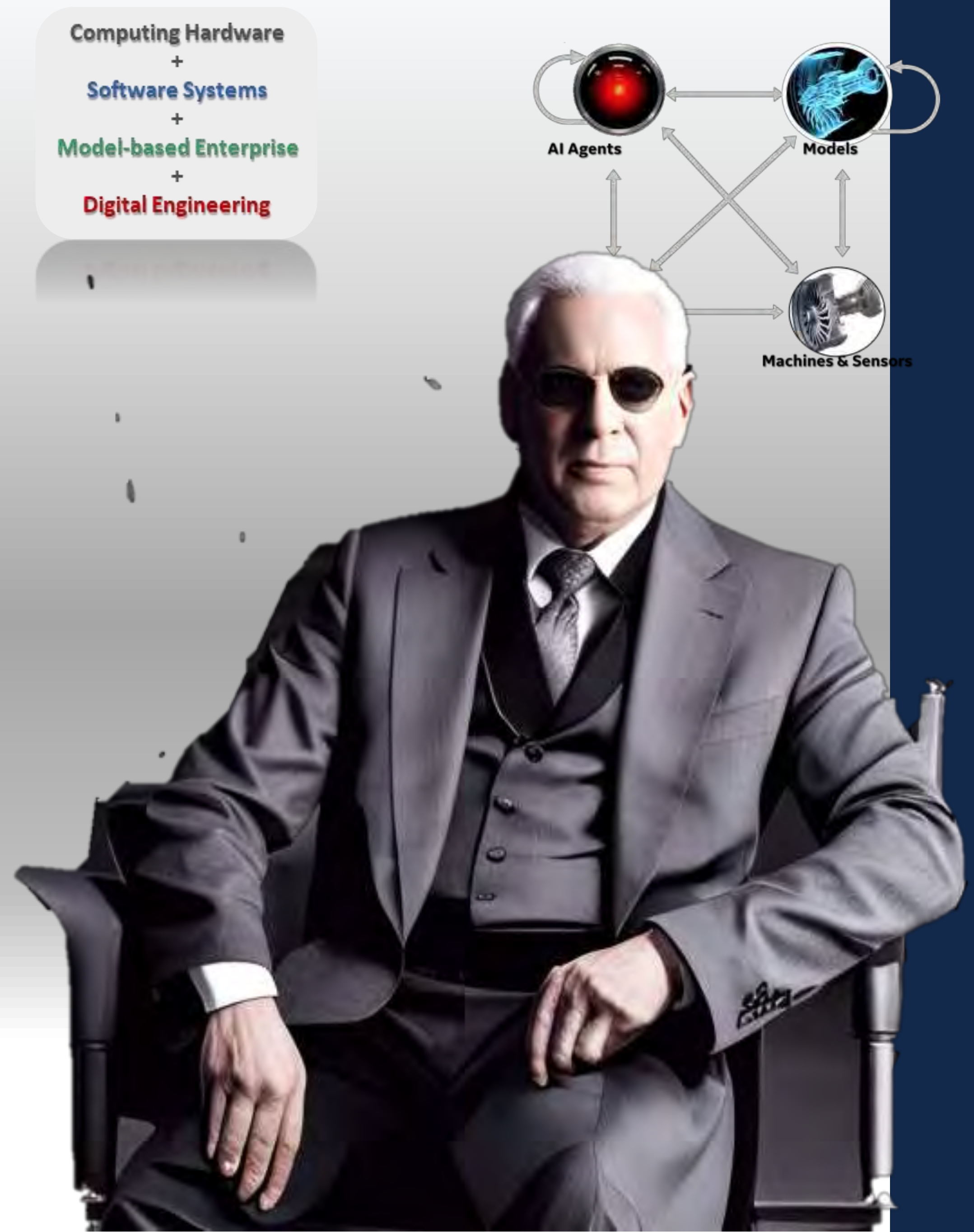
Thank you

STABLE DIFFUSION

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

Engineer of the Future

https://www.youtube.com/watch?v=T0eCJqEVKNQ



The **Engineer of the Future** will…

- harness **computing & data**…
- through **software & machine intelligence**…

to externalize **mental models…**
built upon deep **domain knowledge…**

toward robust, **collaborative** and **rapid**

- **concept**ual formalization,
- virtual **experiment**ation,
- **analysis**, synthesis, **automation**,
- teaching, **learning**, communication,
- and **discovery**.

Mindfulness vs. Uncertainty: *Plan* as a Verb (not a Noun)

Advantage: Human Mind

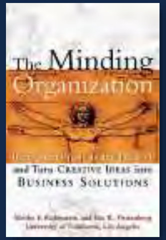
Coherent frame of reference to act, recognizing realities of:

- incompleteness of knowledge in the present (+ *unknowability*)
- emergent change in the future – discovery and learning (*sense* & *adapt*)

Decision-making focuses on a choice based on the merits of alternatives.

Framing shapes "the menu" of alternatives from which to choose, applying:

- Causal Reasoning (inference for understanding & explainability)
- Counterfactuals (sensitivity & hypothesis testing of imagined future "what-ifs")
- Constraints (pragmatic bounding of counterfactuals to focus & prioritize)

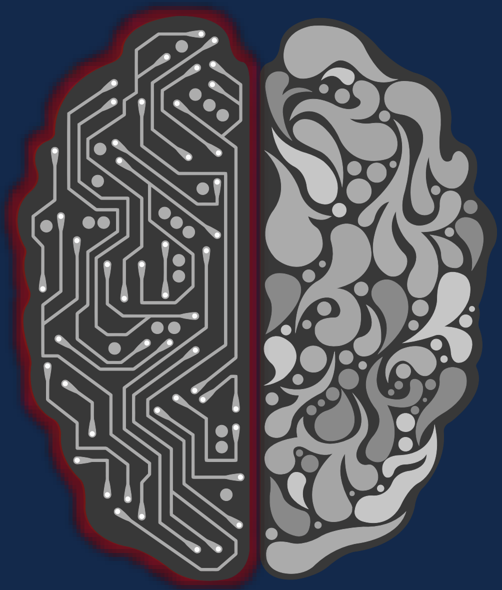


The Minding Organization: *Bring the Future to the Present and Turn Creative Ideas into Business Solutions*
by Moshe F. Rubinstein, Iris Rubinstein Firstenberg

https://framers-book.com/
Kenn Cukier (Sr. Editor, The Economist),
Viktor Mayer-Schönberger (U Oxford/Harvard U)

Machine-Augmented Mindfulness: *Perception, Cognition, & Productivity*

Machine-augmented Mind



Situation Assessment (C4I, Digital Thread/Twins)

Knowledge Curation (enterprise insight and coherence)

Alternative Exploration

- parametric trade-off space mapping
- generative design / inverse design / convergent design

Sophisticated Automation (tedious & complex activities like meshing)

Continuum Mindset (temporal coherence vs. emergent change)

Machine-augmented Mindfulness

The Awakened Enterprise: Part 2

Employing the "magic" of digital technology toward systemic awareness across the space of the enterprise and the continuum of operational time.

Medium: Machine-augmented Mindfulness

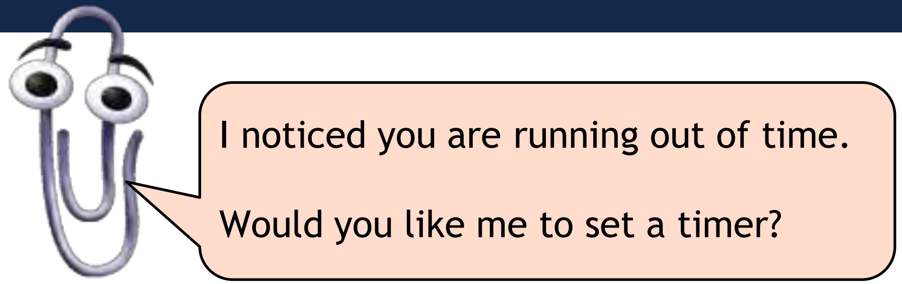
Augmented Cognition: *Tool becomes Collaborator*

You learn the tool

- (Passive) Human-directed Tools →
- (Generative) Automated Design Space Analysis Tools →

The tool learns you

- (Intuitive) Human-aware Tools Anticipate & Assist →
- (Empathic) Understand Intent and Collaborate



Autodesk CTO (Jeff Kowalski) Vision (2016)

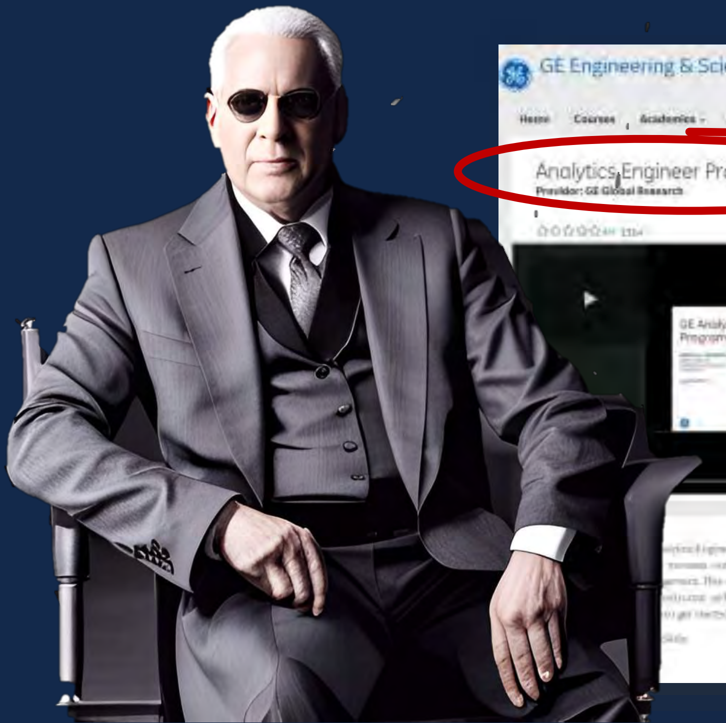
GE Analytics Engineer Program

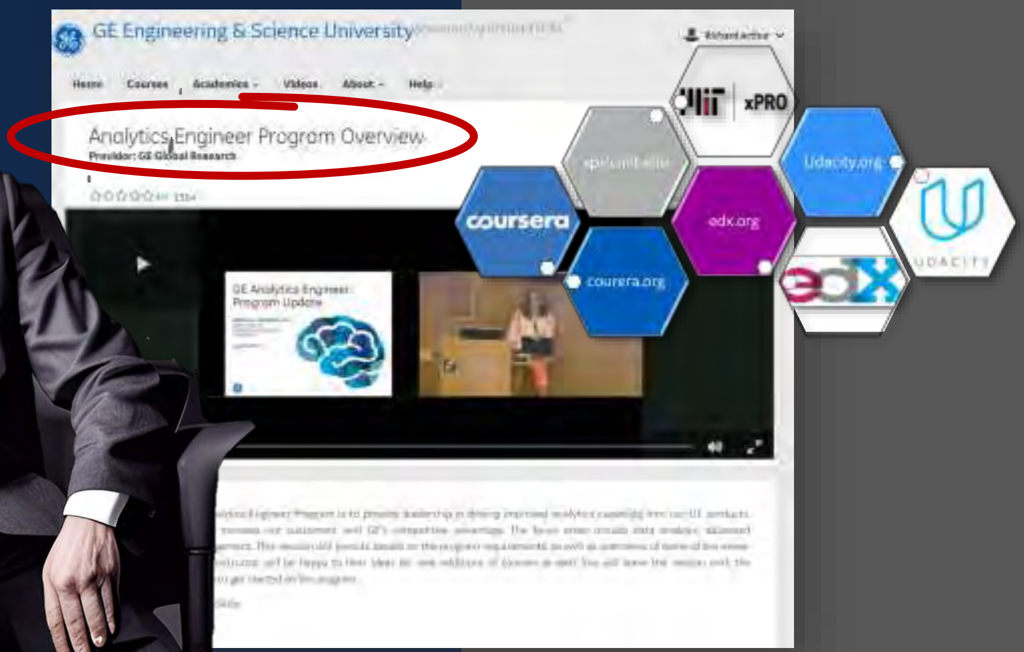
Over 100 pre-approved courses.
Participants select 2+ interest areas

- Data Analysis
- Advanced Algorithms
- Data Management

(additional areas in development including skills & knowledge within the Digital Literacy rubric)

Program completion requires a peer-reviewed case study (and participating as a peer in reviews of other studies)

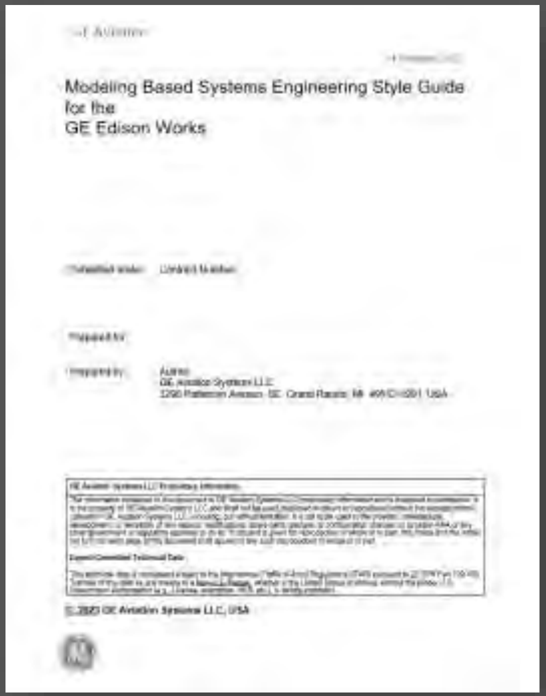




GE BrilliantYOU®

Science & Engineering University

Internal and remote-learning content



MBSE Training

GE Systems Design Fundamentals

- Model-based Systems Engineering
- Digital Thread
- Digital Systems Model
- Digital Twin


CLEARED
For Open Publication
Mar 31, 2023
DOD
CYBER WORKFORCE
STRATEGY
2023-2027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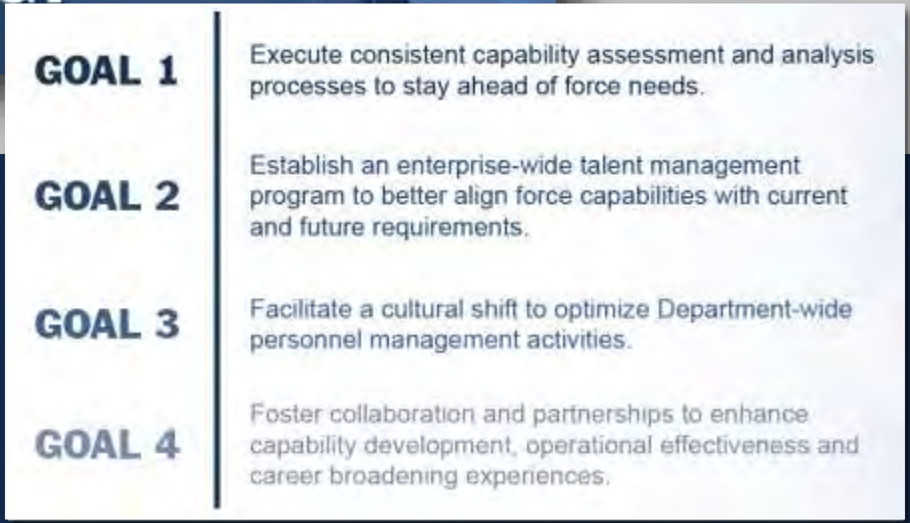
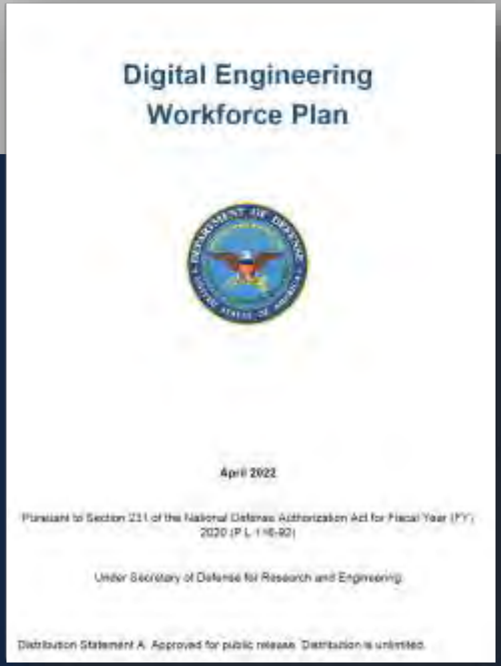
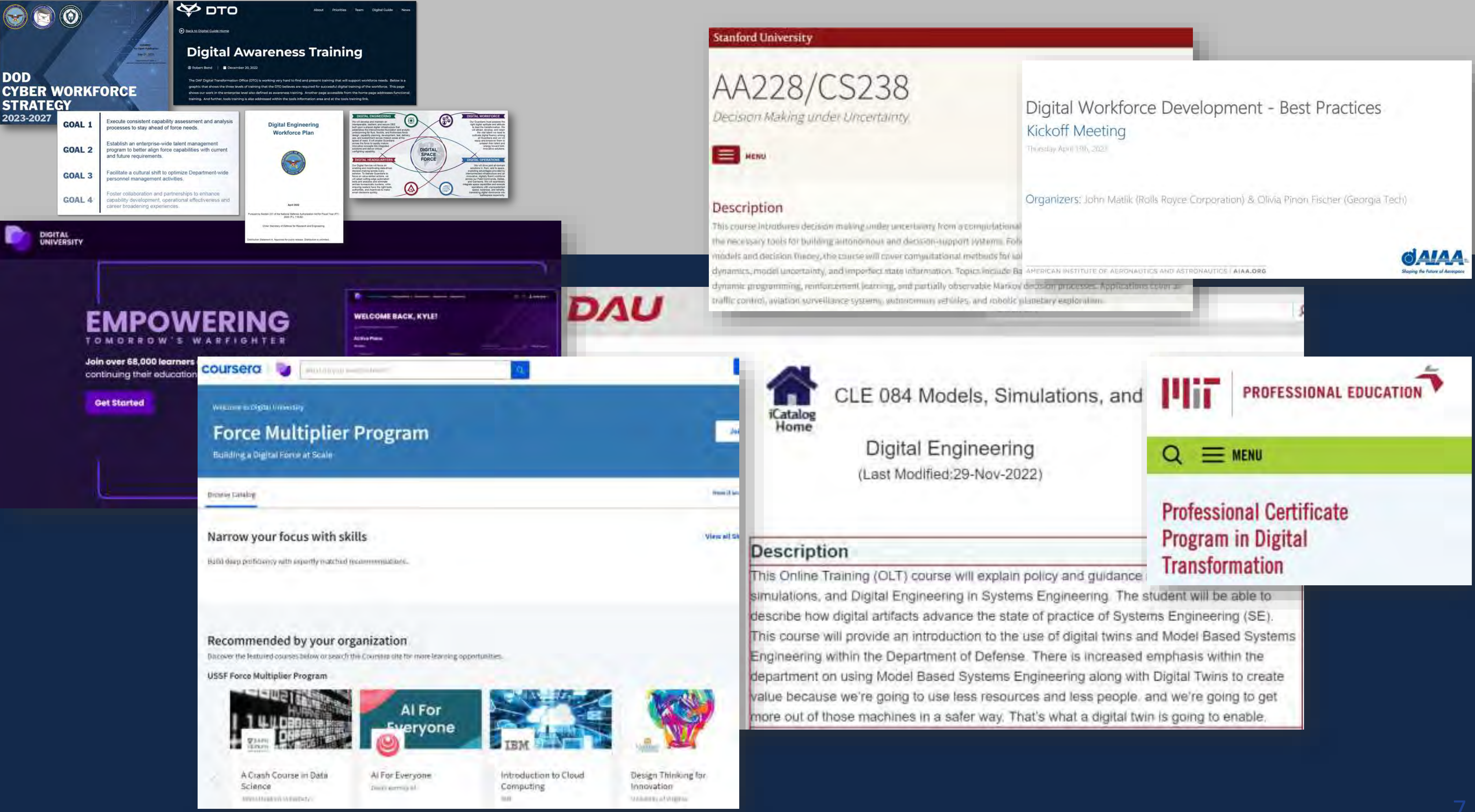
Digital Awareness Training
Robert Bond
December 20, 2022
The DAF Digital Transformation Office (DTO) is working very hard to find and present training that will support workforce needs. Below is a graphic that shows the three levels of training that the DTO believes are required for successful digital training of the workforce. This page shows our work in the enterprise level also defined as awareness training. Another page accessible from the home page addresses functional training. And further, tools training is also addressed within the tools information area and at the tools training link.


GOAL 1
Execute consistent capability assessment and analysis processes to stay ahead of force needs.
GOAL 2
Establish an enterprise-wide talent management program to better align force capabilities with current and future requirements.
GOAL 3
Facilitate a cultural shift to optimize Department-wide personnel management activities.
GOAL 4
Foster collaboration and partnerships to enhance capability development, operational effectiveness and career broadening experiences.


Digital Engineering
Workforce Plan
April 2022
Under Secretary of Defense for Research and Engineering
Distribution Statement A. Approved for public release. Distribution is unlimited.


DIGITAL ENGINEERING
DIGITAL WORKFORCE
DIGITAL SPACE FORCE
DIGITAL HEADQUARTERS
DIGITAL OPERATIONS


DOD
CYBER WORKFORCE
STRATEGY
2023-2027
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DTO
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Priorities
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Digital Guide
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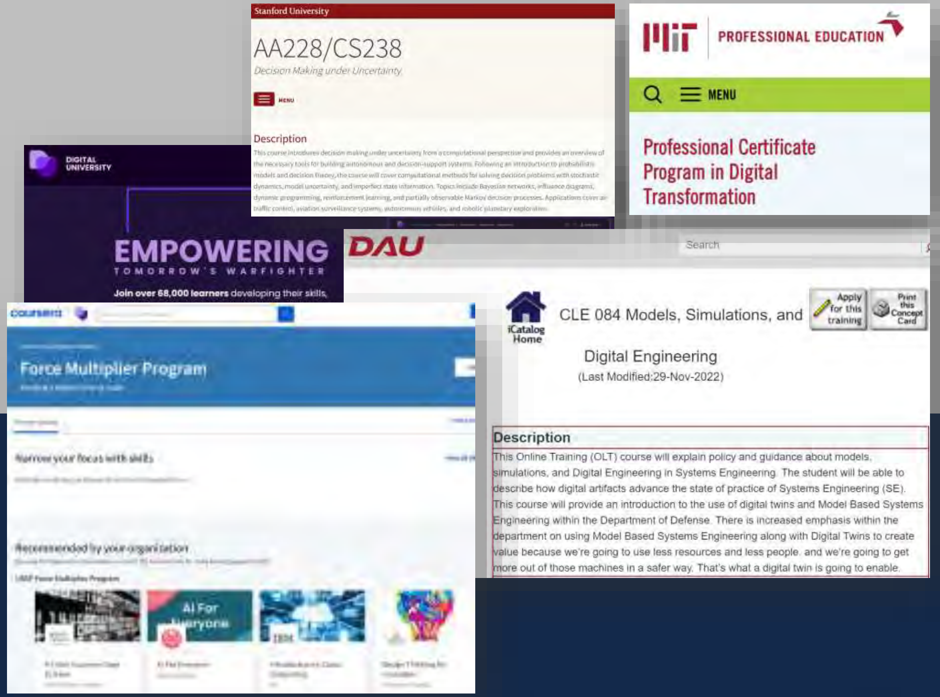
Digital Awareness Training
Digital Engineering Workforce Plan
DIGITAL SPACE FORCE
DIGITAL UNIVERSITY
EMPOWERING
TOMORROW'S WARFIGHTER
Join over 68,000 learners
continuing their education
Get Started
WELCOME BACK, KYLE!
coursera
Force Multiplier Program
Building a Digital Force at Scale
Narrow your focus with skills
Recommended by your organization
USSF Force Multiplier Program
AI For Everyone
IBM
A Crash Course in Data Science
AI For Everyone
Introduction to Cloud Computing
Design Thinking for Innovation
Stanford University
AA228/CS238
Decision Making under Uncertainty
MENU
Description
Digital Workforce Development - Best Practices
Kickoff Meeting
Organizers: John Matlik (Rolls Royce Corporation) & Olivia Pinon Fischer (Georgia Tech)
AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS | AIAA.ORG
AIAA
DAU
iCatalog Home
CLE 084 Models, Simulations, and
Digital Engineering
(Last Modified:29-Nov-2022)
Description
This Online Training (OLT) course will explain policy and guidance
simulations, and Digital Engineering in Systems Engineering. The student will be able to describe how digital artifacts advance the state of practice of Systems Engineering (SE). This course will provide an introduction to the use of digital twins and Model Based Systems Engineering within the Department of Defense. There is increased emphasis within the department on using Model Based Systems Engineering along with Digital Twins to create value because we're going to use less resources and less people. and we're going to get more out of those machines in a safer way. That's what a digital twin is going to enable.
MIT PROFESSIONAL EDUCATION
MENU
Professional Certificate Program in Digital Transformation

Great Work!

(Now don't stop at MBSE
(1D / SysML)
onward to
MBE 3D Multiphysics!)



and...
support / engage/ adopt
from our next speakers

Key Points

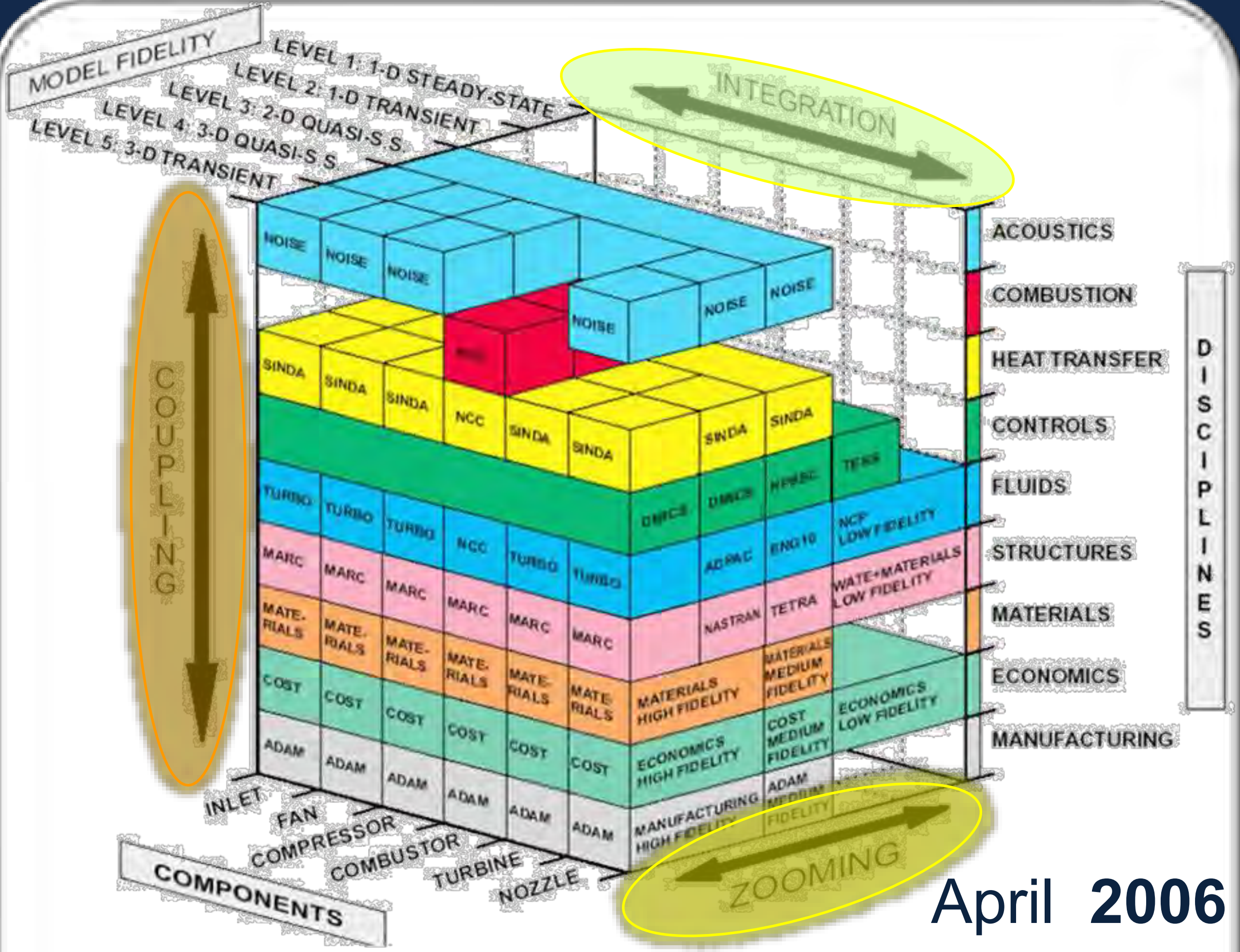
1. <u>Modeling</u> Literacy

2. Entry-to-*<u>Executive</u>*

3. <u>Continual</u> Workforce Development

4. Human-machine <u>Collaboration</u>

5. *Mental* models crucially enable <u>Cross-disciplinary</u> Collaborations



April 2006

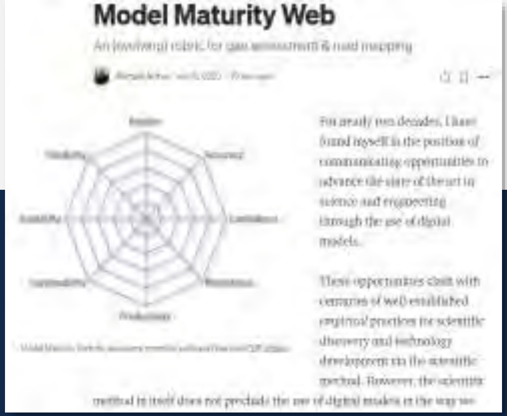
How are we doing on … ?

- **INTEGRATION** (multi-component)
- **ZOOMING** (multi-fidelity)
- **COUPLING** (multi-physics)

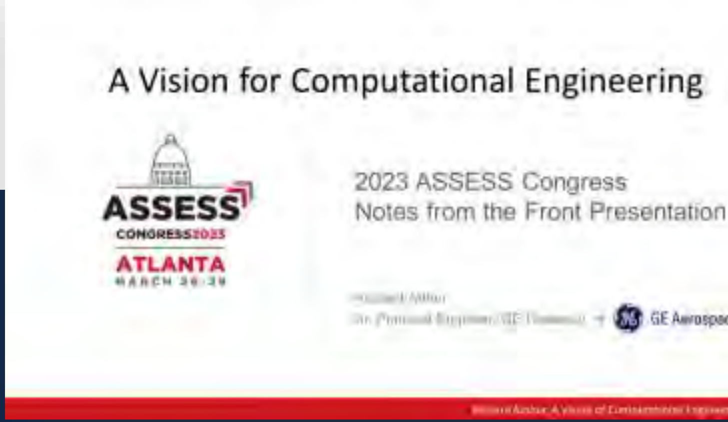
See also:

https://richardarthur.medium.com/provenance-for-decision-making-bf2c89d76ec2

https://richardarthur.medium.com/machine-augmented-mindfulness-e844f9c54985



https://richardarthur.medium.com/co-design-web-6f37664ac1e1



https://drive.google.com/file/d/1Jqg5nsf5iCf4R18zKAFJ0y6-o9RY7Wol/view?usp=share_link

https://richardarthur.medium.com/irresponsible-caution-315097ba9328

Richard Arthur

Sr. Principal Engineer, GE Aerospace Research

@arthurrge

RichardBArthur

richardarthur.medium.com

Thank You!

Richard Arthur

Sr. Principal Engineer, GE Aerospace Research

@arthurrge

RichardBArthur

richardarthur.medium.com

Appendix

Reflecting on Digital Campaign Aspirations

Examples of questions leaders should be asking (or designate someone to think about them)

- What are the most pressing issues to de-risk to which we might apply automation and/or virtualized physics-based analysis?
- What level of confidence is required for what high-value decisions? (How close are we to that now?)
- How do we then (sensibly/correctly/affordably) apply uncertainty quantification rigor?
- How are we assessing the readiness of virtualized / computational models to key systems of interest?
- What data am I missing that have significant value in the digital model future for my business?
- What collection mechanisms are in place vs. need to be developed to get those data? How are we positioned on data rights?
- Who is driving those strategies/roadmaps to allocate investments appropriately across (non-legacy) approaches?
- Who is driving a future-ready architecture for needed scalability and interoperability?
- What is the competitive landscape for the state of the art in practice of differentiating knowledge/skills/modeling capabilities?
- What are the cultural or process changes necessary to get the benefits from these investments? Who is driving these?
- What present organizational or process-based contradictions / inefficiencies create waste collaborative workflow can reduce or eliminate?
- What regulatory certification costs can be reduced? Who has the prioritized list for cost-reduction opportunities for physical testing in general?
- In addition to cost, what additional factors could be improved through virtualization (turnaround time, reproducibility, etc.)?
- What are the historic sources of error or sensitivities limiting our ability to computationally model? How are we addressing these?
- Where models have historic limitations in realism, confidence, etc. who is developing capabilities in conjunction with the exponentially-growing computing capabilities to capture that potential?
- …

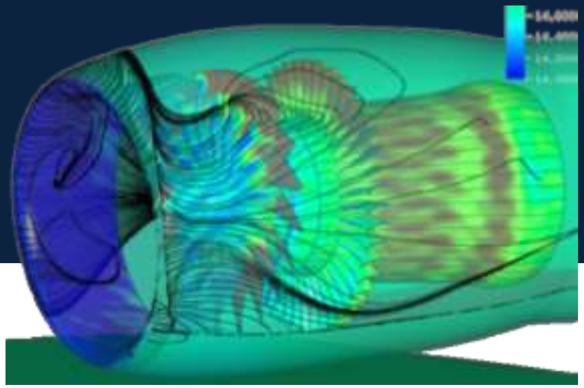
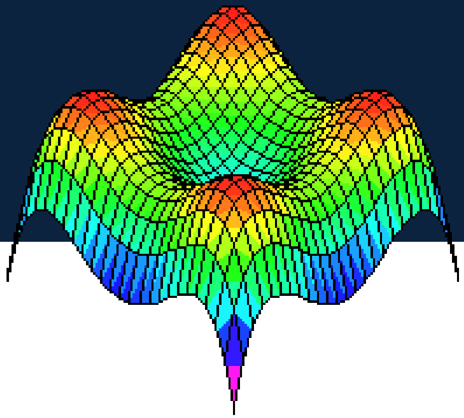
Computational Methods as *Scientific Instrument*



MICROSCOPE
Interrogate extreme detail

MACROSCOPE
Perceive system-wide interactions

CAMPAIGN
Explore vast alternatives

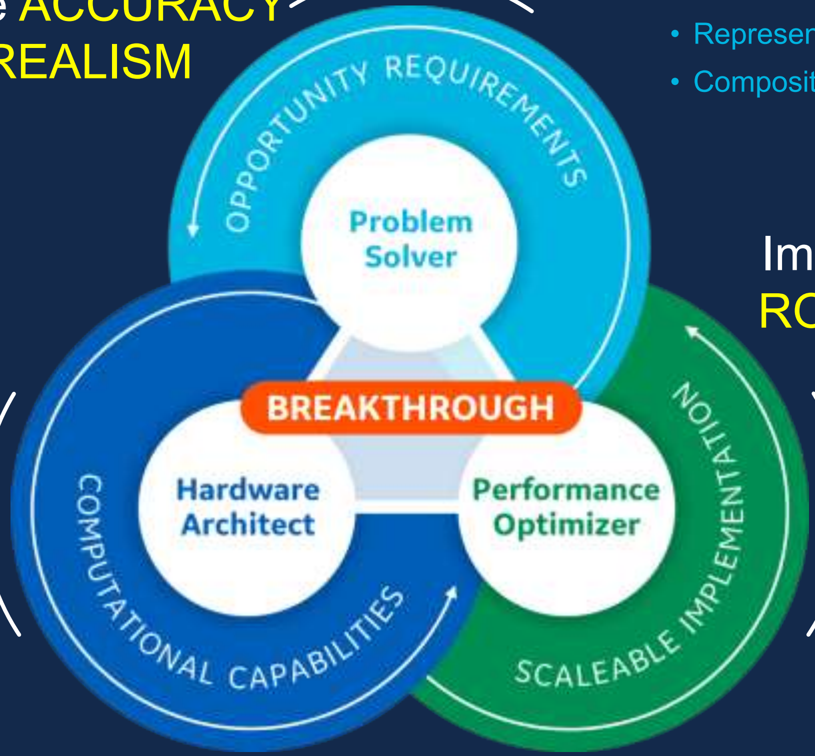




Systems Co-Design Practice

Decision-sufficient CONFIDENCE
Validated predictive ACCURACY
Physical Systems REALISM

SCIENCE & ENGINEERING

- Domain Expertise
- Representation Fidelity
- Composition & Comprehension



Implementation
ROBUSTNESS

SYSTEMS ENGINEERING

- Vendor Partnerships
- Procurement & Lifecycle
- Infrastructure Tuning

COMPUTATIONAL SCIENCE

- Numerical Methods & Confidence Bounds
- Algorithms & Data Structures
- Productivity & Usability

Performance, problem size & affordable SCALABILITY
Interoperable & extensible FLEXIBILITY

Workflow PRODUCTIVITY
Software & system MATURITY

Computing Hardware
+
Software Systems
+
Model-based Enterprise
+
Digital Engineering

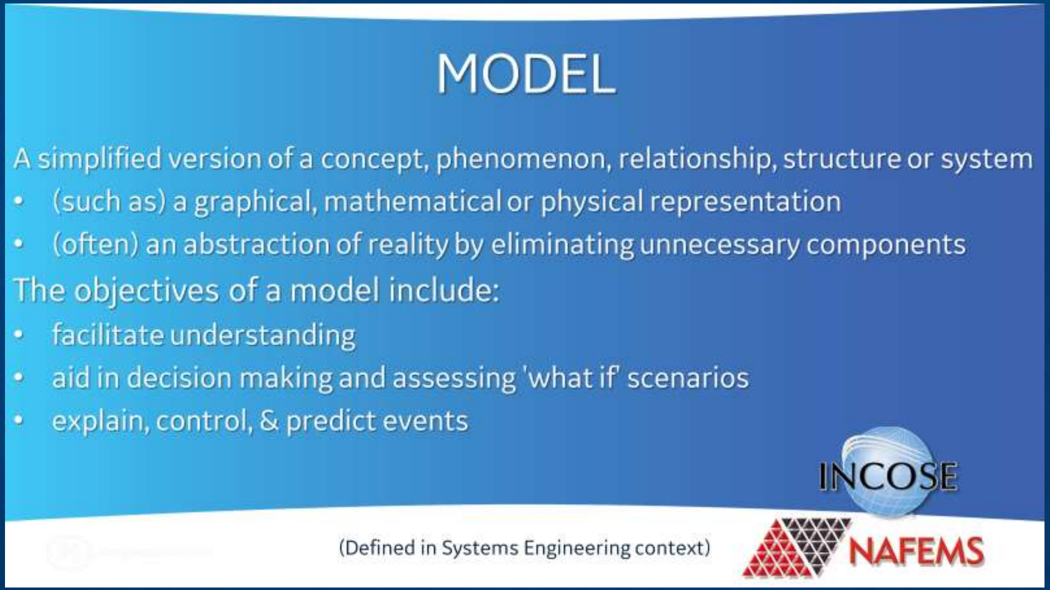
Rethinking how we think… mental models as frames

framers-book.com

Kenn Cukier (Sr. Editor, The Economist),
Viktor Mayer-Schönberger (U Oxford/Harvard U)

- Falsely attribute success to the final moment of choosing, when in fact we achieve our goals by *shaping the choices* from which we decide and act
- *Mental models* guide interactions with the world, learn, adapt, and imagine futures
- Success results from *skill in constructing, selecting and using models*
  - Beyond sensing + memory
  - Framing for problem-solving
  - Curate diverse frame repertoire
  - Successful when applicable, correct, effective, insightful

- Understanding (*Causal Reasoning*)
- Assess what-ifs (*Counterfactuals*)
- Critical focus (*Bounding Constraints*)



- Scientific frames are highly effective due to explicitness and disciplined refinement
- AI "miracles" often downplay critical roles of human-conceived constraints
- Computers are not adept at linking causality or creating counterfactuals

Collaboration between **Machines** & People

Machine-as-Collaborator: Productivity, reproducibility, completeness, confidence

MACHINE STRENGTH	Task Characteristics	HUMAN LIMIT
TIRELESS / DIGITAL	**Continual & Repetitive**	BORING / FATIGUE / ERROR
FORMALIZED RULES & PROCESS	(Task-to-Task) **Consistency**	BIAS / SUBJECTIVITY
PARALLEL ARCHITECTURE	**Concurrent** Execution	DIMINISHED SELECTIVE ATTENTION
BEYOND HUMAN PERCEPTION	**Complex** to Interpretation	SCALE / VELOCITY / DIMENSIONALITY
PRECISION & TURNAROUND SPEED	(Rapid/fine-grained) **Control**	MANY AREAS AT DEFICIT (*)

(* several areas remain superior to machines however)

The Cognitive Era: Machine + Human

MACHINE STRENGTH	HUMAN STRENGTH
DIGITAL KNOWLEDGE	EXPERTISE
LARGE-SCALE MATH	DIRECTED GOALS
PATTERN RECOGNITION	COMMON SENSE
STATISTICAL REASONING	VALUE JUDGMENT

(From SC|17 Keynote: [Katharine Frase (IBM) - Cognitive Computing](#))

Toward Digital Transformation & Adoption

List of enterprise success factors from the survey analysis

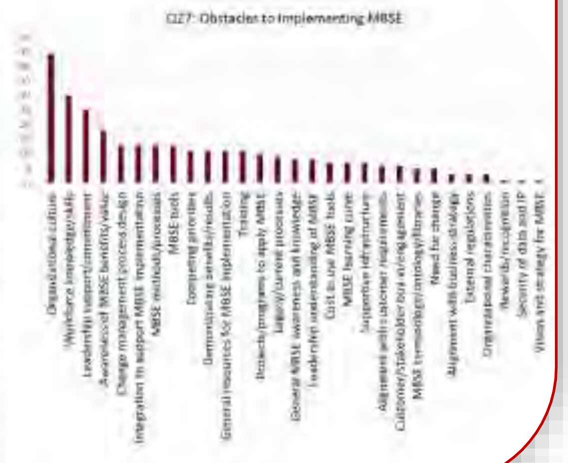
Category	List of Success Factors		
Leadership	Leadership support/commitment	Leadership understanding of MBSE	
Communication	Awareness of MBSE benefits/value	Communicating success stories/practices	Need for change
Resources	Cost to use MBSE tools	General resources for MBSE implementation	
Workforce	General MBSE awareness and knowledge	People willing to use MBSE tools	Teamwork
	MBSE learning curve	People in SE roles	Training
	Workforce knowledge/skills		
Change Processes	Champions	Competing priorities	Legacy/current processes
	Change management process design	Integration to support MBSE implementation	Vision and strategy for MBSE
	Community of practice	Demonstrating benefits/results	
MBSE Processes	MBSE methods/processes	MBSE tools	Security of data and IP
	MBSE terminology/ontology/libraries	Projects/programs to apply MBSE	
Organizational Environment	Alignment with business strategy	Organizational culture	Success metrics
	Organizational characteristics	Rewards/recognition	Supportive infrastructure
External Environment	Alignment with customer requirements	Customer/stakeholder buy-in/engagement	
	External regulations	Use in SE community	

Source: SERCuarc.org

Analysis of Survey Responses: *Obstacles*

- There were 166 respondents providing comments to the question on obstacles, parsed into 303 unique response comments.

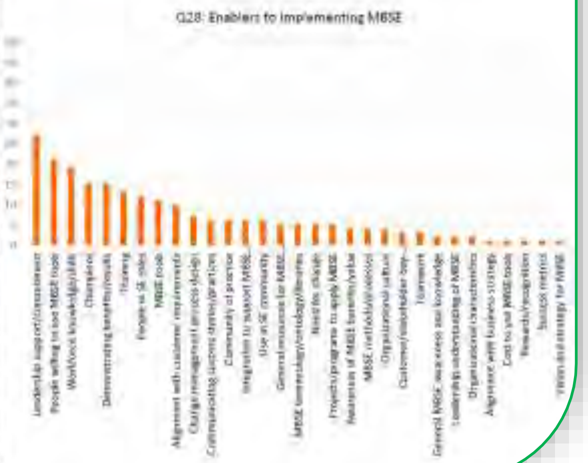
Code	# Comments Obstacles
Organizational culture	44
Workforce knowledge/skills	30
Leadership support/commitment	25
Awareness of MBSE benefits/value	18
Change management process design	13
Integration to support MBSE implementation	13
MBSE methods/processes	13
MBSE tools	13
Competing priorities	11
Demonstrating benefits/results	11
General resources for MBSE implementation	11
Training	11
Projects/programs to apply MBSE	10
Legacy/current processes	9
General MBSE awareness and knowledge	8
Leadership understanding of MBSE	8



Analysis of Survey Responses: *Enablers*

- There were 156 respondents providing comments to the question on enablers, parsed into 223 unique response comments.

Code	# Comments Enablers
Leadership support/commitment	27
People willing to use MBSE tools	21
Workforce knowledge/skills	19
Champions	15
Demonstrating benefits/results	15
Training	13
People in SE roles	12
MBSE tools	11
Alignment with customer requirements	10
Change management process design	7
Communicating success stories/practices	6
Community of practice	6
Integration to support MBSE implementation	6
Use in SE community	6



"To recruit and retain the most talented workforce, we must advance our institutional culture and reform the way we do business. The Department must attract, train and promote a workforce with the skills and abilities to tackle national security challenges, creatively and capably, in a complex global environment."

— Mr. Lloyd Austin, III,
Secretary of Defense

DOD CYBER WORKFORCE STRATEGY

2023-2027

GOAL 1	Execute consistent capability assessment and analysis processes to stay ahead of force needs.
GOAL 2	Establish an enterprise-wide talent management program to better align force capabilities with current and future requirements.
GOAL 3	Facilitate a cultural shift to optimize Department-wide personnel management activities.
GOAL 4	Foster collaboration and partnerships to enhance capability development, operational effectiveness and career broadening experiences.

The four pillars provide a unifying direction to accomplish the mission, vision and goals laid out in this strategy. The four pillars are defined as:

Identification: The processes of determining workforce needs or requirements and the potential or incumbent workforce to meet them.
Recruitment: Identifying & attracting the talent needed to meet mission requirements & the process of evaluating the effectiveness of recruiting efforts.
Development: Understanding & providing the necessary opportunities & resources to satisfy individual & team performance requirements.
Retention: The incentive programs the Department employs to retain talent and the process of evaluating the effectiveness of the incentive programs.

Department-wide challenges:

- Lack of common criteria regarding cyber workforce requirements (**Identification**).
- Need for targeted identification of candidates based on skills to fill capability gaps (**Recruitment**).
- Limited availability of capability assessment and enhancement programs (**Development**).
- Attrition of highly skilled personnel within an already limited pipeline of talent (**Retention**).

"To address the numerous workforce challenges DoD faces, we must take a unified and coordinated approach that takes meaningful action to reduce the talent pipeline gap, increase the quality and diversity of our cyber workforce, and prioritize the personal and professional needs of our cyber practitioners."

— Mr. John Sherman,
DoD CIO

(DEIC) Digital Engineering Integration Committee

SHAPING THE FUTURE OF AEROSPACE

AIAA DEIC Chair

David Kepczynski

Chief Information Officer &
Digital Engineering Leader,
GE Research
brunon.kepczynski@ge.com

AIAA DEIC Vice-Chair

Natalie Straup

Chief Engineer & Digital
Transformation Leader,
Northrop Grumman
natalie.straup@ngc.com

AIAA DEIC Secretary

Dr Olivia Pinon Fischer

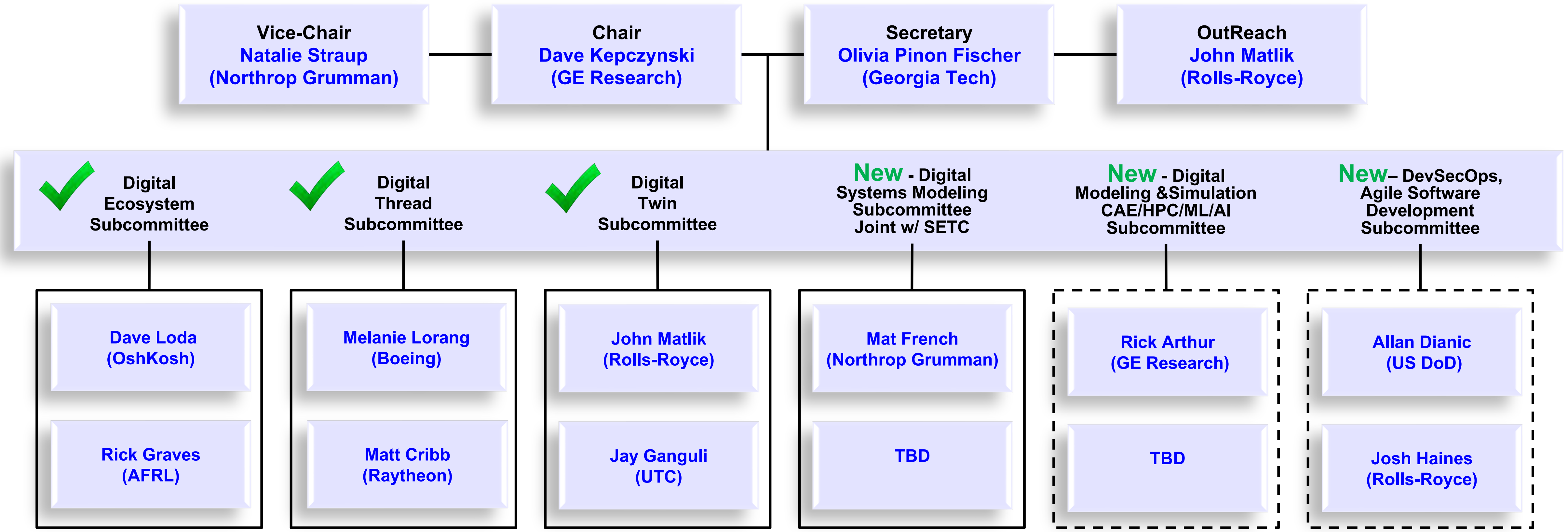
Senior Research Engineer & Chief,
Digital Engineering Division,
Aerospace Systems Design
Laboratory, Georgia Institute of
Technology
olivia.pinon@asdl.gatech.edu

AIAA DEIC Outreach

Dr John Matlik

Chief of Capability – Digital Engineering,
Rolls-Royce Defense
john.f.matlik@Rolls-Royce.com

DEIC – Steering & Subcommittees



6th committee is the steering committee

DEIC – 2022 Summary Report

Group Overview

Integration Steering Committee: David Kepczynski - GE Research (Chair)
- Natalie Straup - Northrop Grumman (Vice-Chair)
- Olivia Pinon Fischer - Georgia Tech (Secretary)
- John Matlik - Rolls-Royce Defense (Outreach)

Emails: brunon.kepczynski@ge.com, natalie.straup@ngc.com, olivia.pinon@asdl.gatech.edu, john.f.matlik@rolls-royce.com

Number of Members: 82 As of: Jan 2023
- Industry, 57 (70%)
- Government, 13 (16%)
- Academia, 12 (14%)

Top Accomplishments

Continuing development and publication of industry-leading position papers (definition & value) and implementations papers (reference model, case-studies, and recommendations) - - -

1. **Digital Twin Position Paper (Published with AIA 2020)**
2. **Digital Twin Implementation Paper - Case Studies (Released!)**
3. **Digital Thread Position Paper (Publishing!)**

- Digital Ecosystem Position (framing, publishing in 2024)
- Digital System Model (targeting AIAA Domain Focus 2024)

Forum Support

SciTech 2022
- 4 panel sessions, 4 technical paper sessions

Aviation 2022
- 3 panel sessions, 2 technical paper sessions

AA&S 2022
- 1 panel session, 1 technical paper session

Ascend 2022
- 22 abstracts, 18 accepted. 10 paper sessions in DEIC, 8 other

SciTech 2023
- 4 panel sessions, 17 technical paper sessions

Aviation 2023
- 2 Panels, 4 technical paper sessions

SciTech 2024
- Begin planning now

Partnered Collaborations Ongoing
- AIA, NAFEMS, INCOSE, OMG-DTC, ICME, SETC, ISTC, STEM K-12, DSI

DEIC – Operational Framework

POSITION PAPER (What and Why) – Definition, Value

Building Technical Content and Sessions, Panels, Outreach

IMPLEMENTATION PAPER (How and Outcomes) – Reference Model and Case Studies

Building Technical Content and Sessions, Panels, Outreach

Adding future PROCESSES & TECHNOLOGIES

WORKFORCE DEVELOPMENT – Training, Development, Reference Materials (concepts, position and implementation papers, case studies), Curriculum, Education, Digital Engineering Book of Knowledge, Digital & Computational Literacy. Add to this, create taxonomy, becomes our DEIC BOK

ADVOCACY, FEEDBACK, & VERSIONING

STANDARDS

DEIC – Recognitions

✓ Released!

Great job John, Olivia, Jay and entire team!!!

[DEIC Digital Twin Implementation Paper 2023]

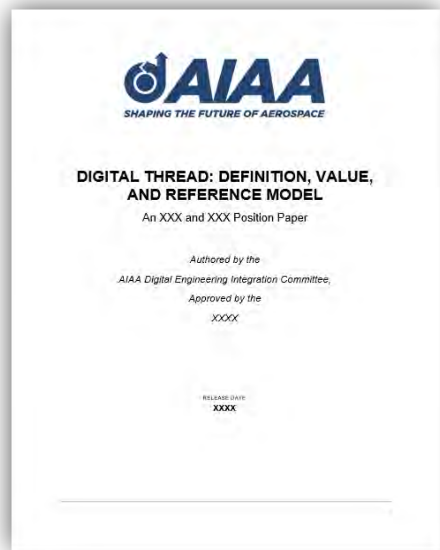
Jay Ganguli
Raytheon
Co-Chair

Dr Olivia Pinon Fischer
Georgia Tech
Co-Chair

Dr John Matlik
Rolls-Royce
Co-Chair

[DEIC Digital Twin Position Paper 2020]

✓ Publishing!


AIAA
SHAPING THE FUTURE OF AEROSPACE

DIGITAL THREAD: DEFINITION, VALUE, AND REFERENCE MODEL
An XXX and XXX Position Paper

Authored by the
AIAA Digital Engineering Integration Committee,
Approved by the
XXXX

RELEASE DATE
XXXX

Great job Matt, Melanie, Bill, Rick, Olivia and entire team!!!

[DEIC_Digital Thread Position Paper 2023]

Matthew Cribb
Anduril Industries
Co-Chair

Melanie Lorang
Boeing
Co-chair

New Stand Ups!

Digital Systems Modeling
Joint with Systems Engineering TC

CAE/HPC/ML/AI
Joint with CFD 2030 TC

Dev/Sec/Ops/Agile
Joint with Information Systems TC

DEIC - Digital Twin


Jay Ganguli
Raytheon
Co-Chair

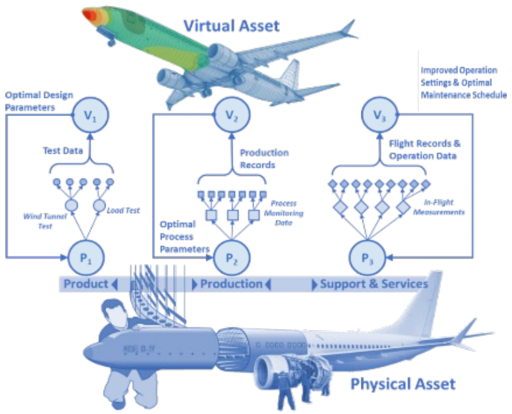

Dr Olivia Pinon Fischer
Georgia Tech
Co-Chair


Dr John Matlik
Rolls-Royce
Co-Chair

Jan`22	Feb'22	Mar`22	Apr'22	May '22	Jun '22	Jul '22	Aug '22	Sept '22	Oct '22	Nov '22	Dec '22	Jan '23	Feb '23	Mar '23
SciTech				Qtrly		Aviation	Qtrly	AA&S		Qtrly	SciTech Prep	SciTech		

Overview

A **Digital Twin** is a virtual representation of a connected physical asset and encompasses its entire product lifecycle.



A Digital Twin's value stems from the ability to shift work from a physical environment into a virtual or digital environment enabling to verify and/or predict asset conditions by leveraging the digital model. This leads to significant improvements in capabilities, productivity, quality, delivery, and cost when designing, producing, and sustaining aerospace assets. The Digital Twin Position Papers 1) provide the Aerospace community with a common definition of the Digital Twin, 2) illustrate Digital Twin capabilities through a number of applications and value examples, 3) discuss the alignment between the Department of Defense (DoD) Digital Engineering Strategy and aerospace industry's viewpoint of the Digital Twin, and 4) identify future focus areas and activities for accelerating value realization from the use of Digital Twins. We recommend establishing a Digital Twin "Center of Excellence" for collaboration between Academia, Industry, the United States Government, and relevant Certification Authorities to tackle the business, technical and cultural needs, gaps, and challenges identified.

Priorities

✔ **POSITION PAPER – Definition, Value**
- ✓ Sessions – SciTech21, Aviation21
- ✓ Panels – SciTech21
- ✓ Outreach – AIA, ASME

✔ **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
- Sessions – SciTech22, Aviation22, Asc
- Panels – SciTech 22
- Outreach – AIA, ASME, DTC, NA... INCOSE, AA&S, TETS

- **WORKFORCE DEVELOPMENT (Including traini... & support off future Digital Engineering Book)**

DEVELOPING

- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

Launch Digital Engineering Book
- Establish core editorial team
- Draft initial proposed outline
  - Chapter topics based on subcommittees (for now)
  - Confirm committed & passionate authors
- Begin drafting 'strawman' of Chapter content to promote alignment & integration
- Initiate appropriate AIAA publication processes & protocols

Agree "Top 2" Focus Areas (for 2023-2024)
- Revisit Digital Twin Implementation Paper recommendations
- Agree Industries 'next 2 big focus areas' for realizing value

DEIC - Digital Thread

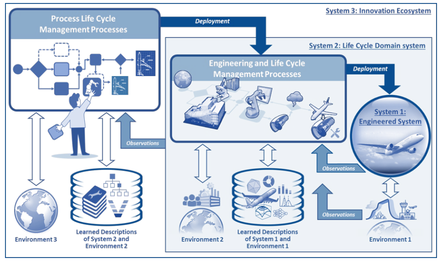
Matthew Cribb
Anduril Industries
Co-Chair

Melanie Lorang
Boeing
Co-chair

Jan`22 — SciTech
Feb`22
Mar`22
Apr`22
May '22 — Qtrly
Jun '22
Jul '22 — Aviation
Aug '22
Sept '22 — Weekly Meetings
Oct '22
Nov '22
Dec '22 — SciTech Prep
Jan '23
Feb '23 — SciTech
Mar '23

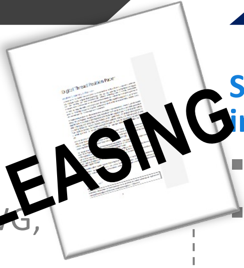
Overview

A **Digital Thread** is A linked set of digital artifacts whose consistency is actively managed over the life cycle of a product, process, or system.



A Digital Thread needs to be engineered and constructed to bring value to the organization(s) that develop, support, and maintain it. Traditionally, value is often associated with Return on Investment (ROI), however, herein we are going to take a more expansive viewpoint. At its core, the Digital Thread is one of the foundational technologies for accelerating and facilitating the agile capture, maintenance, and use of models, simulation data, experimental/operational data, and associated metadata throughout the lifecycle. Fujimoto describes three degrees of integration relevant to the Digital Thread: integrability, interoperability, and composability [10]. Integrability encompasses the information technology connectivity of data and models. Interoperability enables the collaborative execution of models. Composability provides combinatorial assembly and execution of simulations from component models. The Digital Thread can similarly be viewed as an implementation of FAIR principles (findability, accessibility, interoperability, and reusability) in an engineering context [11]. Integrability corresponds to findability and accessibility, and composability relates to reusability. Interoperability has a similar meaning in both conceptions. The integration qualities of the Digital Thread enable both the development of multi-fidelity, multi-scale, and multidisciplinary analysis capabilities and the construction of digital system models or Digital Twins to support system qualification, operations, and maintenance.

Priorities



RELEASING

- ✓ **POSITION PAPER – Definition, Value**
  - ✓ Sessions – SciTech23,
  - ✓ Panels – Aviation22
  - ✓ Outreach – AIA, INCOSE Patterns WG, NAFEMS
  - ○ Final Approval – AIAA, AIA, INCOSE Patterns WG, NAFEMS – in progress

DEVELOPING

- **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
- **WORKFORCE DEVELOPMENT (Including training & support off future Digital Engineering Book)**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

Support Digital Engineering Book Development including

- Establish core editorial team
- Draft initial proposed outline
  - Chapter topics based on subcommittees (for now)
  - Confirm committed & passionate authors
- Begin drafting 'strawman' of Chapter content to promote alignment & integration
- Initiate appropriate AIAA publication processes & protocols

Develop Digital Thread Implementation Paper

- Kicking off after SciTech2023!

DEIC - Digital Ecosystem

Rick Graves
AFRL
Co-Chair

David Loda
Oshkosh
Co-Chair

Jan`22 | Feb'22 | Mar`22 | Apr'22 | May '22 | Jun '22 | Jul '22 | Aug '22 | Sept '22 | Oct '22 | Nov '22 | Dec '22 | Jan '23 | Feb '23 | Mar '23

SciTech | **Qtrly** | **Aviation** | **Qtrly** | **AA&S** | **Qtrly** | **SciTech Prep** | **Qtrly** | **SciTech**

Overview

The **Digital Ecosystem** is a group of interconnected information technology resources that can function as a unit, regardless of location and throughout the product lifecycle. It is the digital environment in which the Digital Twin, Digital Thread and Digital Systems Model operate and reside.

The Digital Ecosystem represents the data environment and infrastructure that enables interconnectivity between Digital Twins, Digital Threads and Digital Systems Models for a product as it is designed, manufactured and operated/supported in the field. The technology stack enables data exchanges between multiple digital representations of a product that provides for product evolution over time. This systems architecture is technology agnostic in that specific tools and vendor offerings are interchangeable and are expected to change as new digital capabilities are introduced. Hence, the proper design and management of the Digital Ecosystem architecture is critical to ensuring flexibility and connectivity between all Digital variations of a product across its lifecycle.

Priorities

DEVELOPING

- **POSITION PAPER – Definition, Value**
  - Sessions – SciTech24, Aviation23
  - Panels – SciTech24
  - Outreach – AIA, ASME, INCOSE
- **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech25, Aviation24
  - Panels – SciTech 25
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

- Kicking off Digital Ecosystem Position Paper effort at SCITECH 2022 (January 2022)
- Goal is to publish Ecosystem Position Paper 2024
- Digital Ecosystem Position Paper:
  - Define Digital Ecosystem in prose & model form
  - Define how Digital Engineering elements (e.g. Digital Thread, Digital Twin, etc.) work together
  - Utilize generic reference model tailored to aerospace from INCOSE
  - Provide recommendations and next steps for implementation
- Develop operational rhythms and host technical panel sessions at SCITECH 2024 on Digital Engineering – Aerospace Perspectives

DEIC - DevSecOps

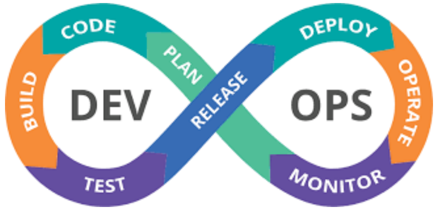
Allan Dianic
US DoD
Co-Chair

Josh Haines
Rolls-Royce
Co-Chair

Jan`23 – SciTech | Feb`23 | Mar`23 | Apr`23 | May '23 – Qtrly | Jun '22 | Aviation | Jul '23 | Aug '23 – Qtrly | Sept '23 | Oct '23 | Nov '23 – Qtrly | Dec '23 | SciTech Prep | Jan '24 | SciTech | Feb '24 | Mar '24

Overview

DevOps is a software engineering culture and practice that aims at unifying software development (Dev) and software operation (Ops).



The main characteristic of the DevOps movement is to strongly advocate automation and monitoring at all steps of software construction, from integration, testing, releasing to deployment and infrastructure management. DevOps aims at shorter development cycles, increased deployment frequency, and more dependable releases, in close alignment with business objectives.

DevOps is NOT ENOUGH! DevSecOps is what must be implemented with the cybersecurity stack built-in into the DevOps pipeline

Reference: *https://software.af.mil/training/devops/*

Priorities

FRAMING

- **POSITION PAPER – Definition, Value**
  - Sessions – SciTech24, Aviation24
  - Panels – SciTech24
  - Outreach – AIA, ASME, INCOSE
- **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech25, Aviation25
  - Panels – SciTech 25
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

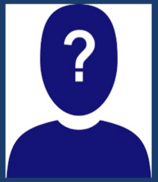
Next Steps

Scope & Launch Subcommittee

1. **Confirm passionate leads (x2) & members.**
2. **Agree scope of focus, i.e.**

- Working practices and Development models for teams
- How DevSecOps/Agile Software Development helps support / realize AI/ML and Digital Engineering efforts
- Any specific tools or working practices specific to the industry that are different from standard tech tooling
- Strategy for how to leverage cloud solutions/platforms to enable secure collaboration
- Best practices working with vendors & platform providers while respecting Export & securing IP
- Tools and Processes which can be shared / open sourced for the greater good of the Defense & Commercial Industrial Base
- Crowd/Open source and hackathon opportunities with help from various vendors.

DEIC – CAE/HPC/ML/AI



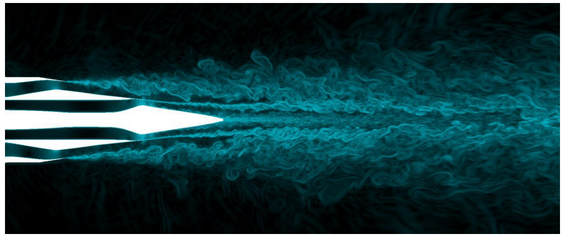
TBD
Co-Chair

Rick Arthur
GE Research
Co-Chair

Jan`23 – **SciTech** · Feb`23 · Mar`23 · Apr`23 · May '23 – **Qtrly** · Jun '22 · **Aviation** · Jul '23 · Aug '23 – **Qtrly** · Sept '23 · Oct '23 · Nov '23 – **Qtrly** · Dec '23 · **SciTech Prep** · Jan '24 · **SciTech** · Feb '24 · Mar '24

Overview

CAE/HPC/ML/AI advancing the future and reality of computer aided engineering (first principle physics, multi-disciplinary physics, at scale, fidelity, and speed), with high performance computing, machine learning, and artificial intelligence with new technology advancements in hardware, software, applications, and integrations.



Enable advanced computing technologies in global infrastructure, architecture, CPU's, GPU's, high speed backbones, and high speed storage capacity for the growing demands of high performance computing to perform advanced computational methods and algorithms for synthesis, analysis, and iterative simulation and optimization on new product technologies resulting in performance, efficiency, regulatory, cost, mass, cycle, quality, reliability, durability, and lifing improvements.

Priorities

FRAMING

- **POSITION PAPER – Definition, Value**
  - Sessions – SciTech24, Aviation24
  - Panels – SciTech24
  - Outreach – AIA, ASME, INCOSE
- **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech25, Aviation25
  - Panels – SciTech 25
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

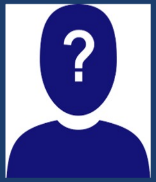
Next Steps

Scope & Launch Subcommittee

1. **Confirm passionate leads (x2) & members.**
2. **Agree scope of focus, i.e.**

- Working practices and Development models for teams
- How CAE/HPC/ML/AI & CFD 2030 help support / realize Digital Engineering efforts
- Any specific tools or working practices specific to the industry that are different from standard tech tooling
- Strategy for how to leverage cloud solutions/platforms to enable secure collaboration
- Best practices working with vendors & platform providers while respecting Export & securing IP
- Tools and Processes which can be shared / open sourced for the greater good of the Defense & Commercial Industrial Base

DEIC - Digital System Model



TBD
Co-Chair

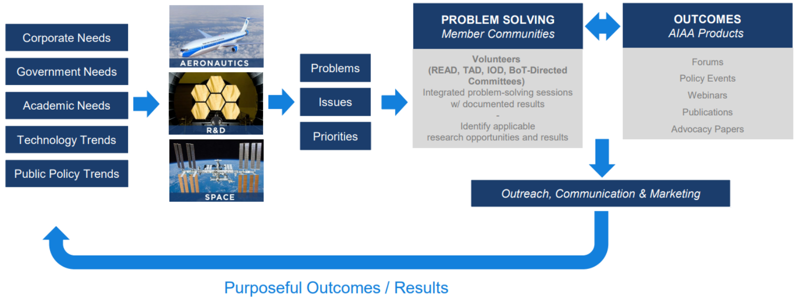
Mat French
Northrop Grumman
Co-Chair

Jan`23 | Feb`23 | Mar`23 | Apr`23 | May '23 | Jun '22 | Jul '23 | Aug '23 | Sept '23 | Oct '23 | Nov '23 | Dec '23 | Jan '24 | Feb '24 | Mar '24

SciTech (Jan`23) | Qtrly (May '23) | Aviation (Jun–Jul '23) | Qtrly (Aug '23) | Qtrly (Nov '23) | SciTech Prep (Dec '23–Jan '24) | SciTech (Jan–Feb '24)

Overview

The Digital Systems Model:



- **Advanced System Engineering Tools & Techniques**
  - Embrace digital twin concepts being inspired by engineered resilient systems and accelerating adoption of model-based systems engineering (MBSE)
  - Create frameworks to incorporate new technologies into system engineering methodologies, such as human-AI teaming and advanced materials more effectively
  - Leverage new digital techniques to reverse the trend of increasing timelines from first flight to initial operational capability

Priorities

- **POSITION PAPER – Definition, Value**
  - Sessions – SciTech24, Aviation24
  - Panels – SciTech24
  - Outreach – AIA, ASME, INCOSE

FRAMING

- **IMPLEMENTATION PAPER – Reference Model, Case Studies, & Recommendations**
  - Sessions – SciTech25, Aviation25
  - Panels – SciTech 25
  - Outreach – AIA, ASME, INCOSE
- **TRAINING & DEVELOPMENT**
- **ADVOCACY, FEEDBACK, & VERSIONING**
- **STANDARDS**

Next Steps

Scope & Launch Subcommittee

1. **Confirm passionate leads (x2) & members.**
2. **Agree scope of focus, i.e.**

- Working practices and Development models for teams
- How Digital Systems Modeling & MBSE (Model Based Systems Engineering) help support / realize Digital Engineering efforts
- Any specific tools or working practices specific to the industry that are different from standard tech tooling
- Strategy for how to leverage cloud solutions/platforms to enable secure collaboration
- Best practices working with vendors & platform providers while respecting Export & securing IP
- Tools and Processes which can be shared / open sourced for the greater good of the Defense & Commercial Industrial Base

AIAA DEIC Subcommittee Activities (2023)

- AIAA / USAF DTO SciTech Digital Transformation Workshop Outcome
  - Digital Workforce Development Working Group
  - Digital Twin/Digital Thread Integration Working Group
  - Digital Maturity Model & Assessment Working Group
- AIAA Aviation 2023
- AIAA Digital Engineering Book (kick-off)
- Other new collaborations:
  - OSD Digital Engineering, Modeling & Simulation Community of Practice
  - RAND Digital Engineering Assessment
  - DSI Digital Engineering for Defense Summit

DEIC – Digital Transformation Workshop

DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC

OFFICE OF THE ASSISTANT SECRETARY

MEMORANDUM FOR THE ACQUISITION ENTERPRISE

SUBJECT: Digital Building Code for the Transformation of Acquisition and Sustainment

In line with the National Defense Strategy, the Department of Defense's Digital Engineering Strategy, and Chief of Staff of the Air Force's Accelerate Change or Lose Paper, the Department of the Air Force (DAF) is implementing a Digital Transformation across the acquisition and sustainment enterprise. This is truly a cultural, business, and technological transformation. As such, it requires the continued support and engagement of the entire community: across all functional domains; from program trenches to headquarters staffs; from freshly hired graduates to seasoned veterans; and with government and industry collaboration. A Digital Transformation is the disruptive enabler we need to overcome our adversaries' rapidly increasing parity. Through this Digital Transformation, and the relentless spirit of Airmen and Guardians across the Department, we can and will transform our acquisition enterprise into one that securely delivers capability at the speed of relevance.

In response, the DAF laid out a strategic vision to improve its acquisition and sustainment practices through a Digital Transformation that includes Digital Engineering and Management, Agile Software Development, and Open System Architectures. This strategic vision promotes digitally enabled processes and replaces the linear, document-centric approach of today with a dynamic, model-centric approach. This new approach places emphasis on evolving and refining models as opposed to updating paper documents; obtaining appropriate intellectual property (IP) rights to prevent vendor-lock during sustainment; and developing and delivering capabilities in rapid, innovative, and agile ways. Implementing the Department's Digital Transformation involves artful execution of this "Digital Building Code." The Digital Building Code is intended to be a living set of best practices that will be updated and to capture lessons learned along the DAF's Digital Transformation journey.

Digital Acquisition and Sustainment hold the key to unleashing the speed and agility we need to field capability at the tempo required to win in future conflicts with peer competitors. The attached tabs give a point of departure for executing programs aligned with the Digital Transformation concept of operations.

Andrew P. Hunter
Assistant Secretary of the Air Force
(Acquisition, Technology & Logistics)

Frank Calvelli
Assistant Secretary of the Air Force
(Space Acquisition & Integration)

Attachments:
1. Digital Building Code for Digital Engineering and Management
2. Digital Building Code for Agile Software
3. Digital Building Code for Open Systems Architecture

DIGITAL BUILDING CODE FOR DIGITAL ENGINEERING AND MANAGEMENT

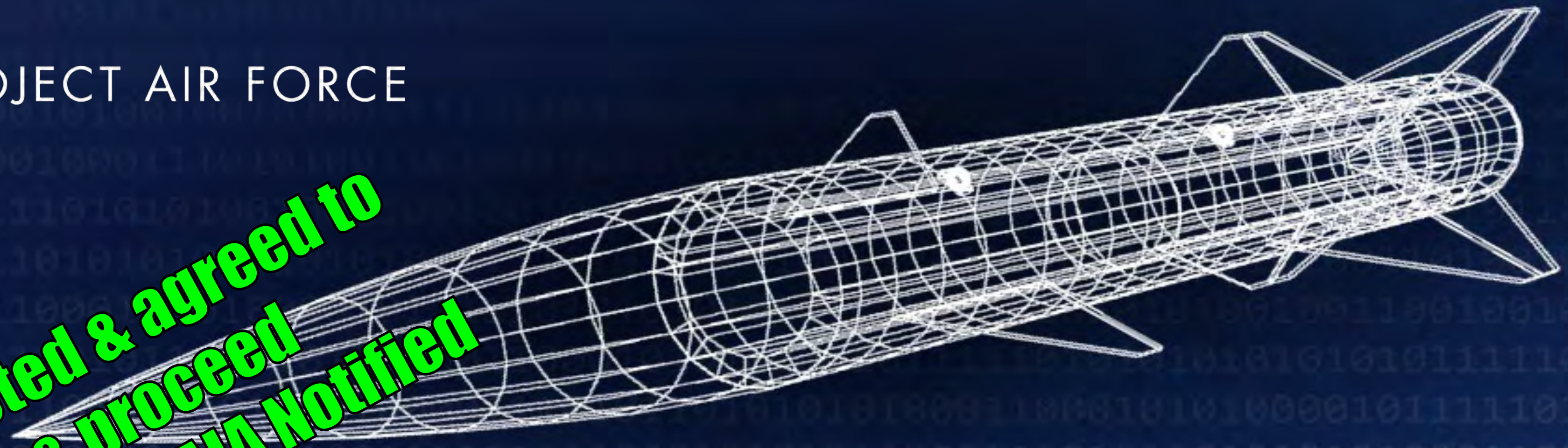
The key to employing Digital Engineering and Management is achieving a measure of authoritative virtualization that automates, replaces or truncates real-world activities. This is how you realize game-changing agility that Digital Acquisition and Sustainment can deliver for your program and our warfighters. In addition, it is also how you will realize the return on investment (ROI) for your digital transformation efforts. The following guidance is provided to assist PEOs/PMs to determine and implement Digital Engineering:

1. Develop digital models of systems
2. Develop a digital twin and digital thread
3. Implement an integrated digital environment
4. Employ a tailored digital strategy for contracting with industry
5. Ensure organizational readiness for Digital Engineering
6. Implement Digital Acquisition

DIGITAL BUILDING CODE FOR AGILE SOFTWARE

1. Implement DevSecOps software development methodology and reference design
2. Leverage PlatformONE and discontinue building new or competing enterprise-wide Continuous Integration/Continuous Delivery (CI/CD) pipelines and DevOps or DevSecOps platforms. PlatformONE is a pay-per-use model which can provide significant cost savings to DAF programs
3. Implement organization staffing, leadership, and training guidance
4. Start tracking performance metrics for software factories and Agile teams

RAND PROJECT AIR FORCE



AIAA DEIC voted & agreed to collaborate & proceed 1/25/23. RAND & AIA Notified

Assessment of Digital Engineering: Implications for Weapon System Programs and Supply Chain Adoption

SciTech Conference Brief

RAND Corporation

January 2023

DEIC – Communications, Aviation 2023

AIAA AVIATION 2023 – San Diego, CA, 12 – 16 June 2023

PROPOSED AVIATION'23 TECHNICAL PANELS & PAPER SESSIONS

Format	Session	Title	Papers
In-person	DGE-01/DE-02	Digital Modeling & Simulation with ML/AI and/or HPC	5
Virtual	DGE-02	Digital Engineering Virtual	4
In-person	DGE-03/DE-03	Digital Ecosystem, Digital Thread and Digital Twin	5
In-person	DGE-04/NDA-	Uncertainty Quantification and Management in Digital Engineering and Digital Twins (joint DGE/NDA)	2
In-person	DGE-05	Digital Innovation & Transformation for Aerospace Product Development and Production	
In-person	DGE-06	Digital Airworthiness and Certification (DAC)	
In-person	DGE-07	Integrated Digital Environments to Accelerate Collaboration Across the Digital Ecosystem	

TECHNICAL PANEL — TECHNICAL PAPER SESSION (16 Technical papers)

AMERICAN INSTITUTE OF
AERONAUTICS AND ASTRONAUTICS

Digital Twin & Digital Thread

A Brief Overview

Olivia Pinon Fischer, Ph.D.

Chief, Digital Engineering Division
Aerospace **S**ystems **D**esign **L**aboratory (ASDL)
School of Aerospace Engineering | **Georgia** Institute of **Tech**nology
E: olivia.pinon@asdl.gatech.edu

2023 Dayton Digital Transformation Summit | Dayton, OH
May 11th, 2023

Georgia Tech | Aerospace Systems Design Laboratory

Georgia Tech

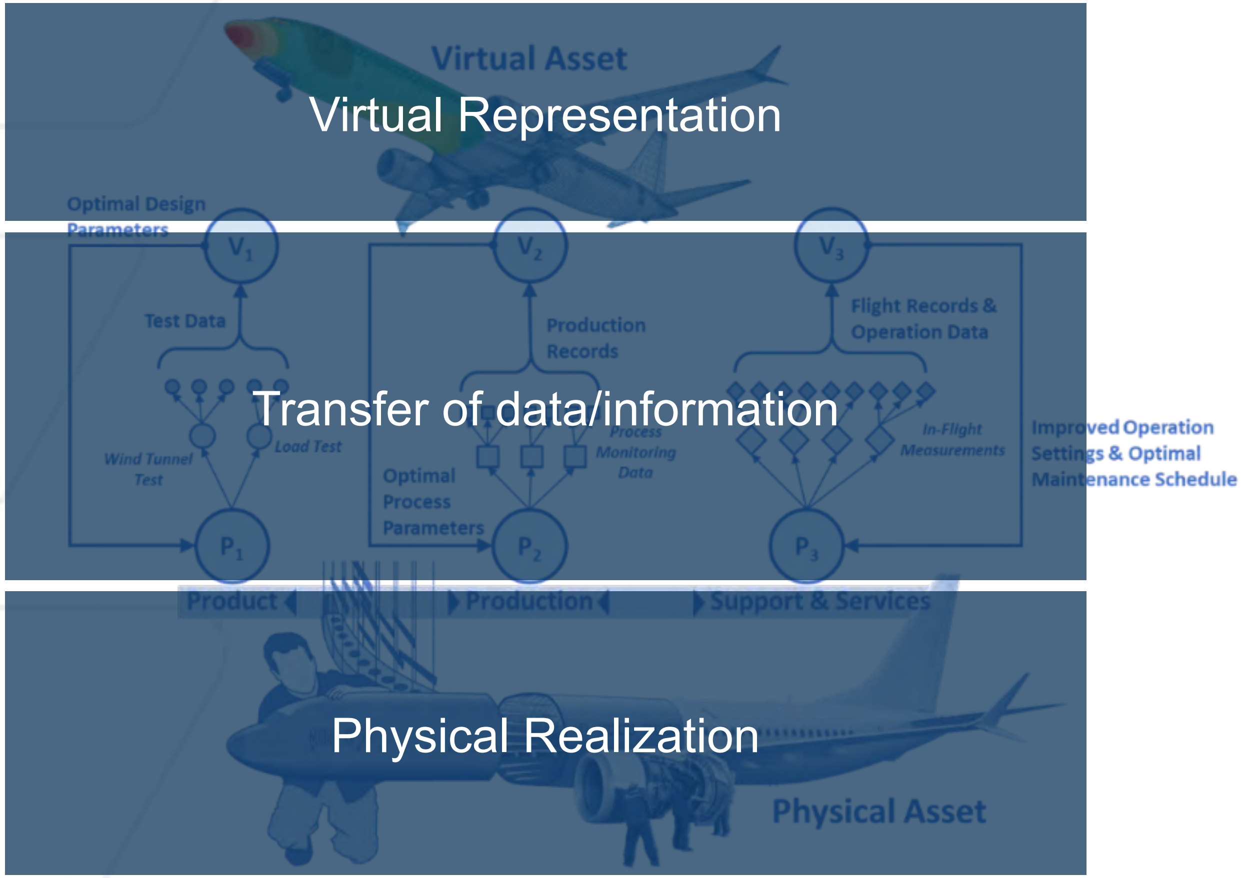
Digital Twin - Definition

- Many competing definitions
- A Digital Twin is [1]….

	Attributes
… a set of **virtual information** constructs	Description
that mimics the **structure, context and behavior**	Content
of an **individual/unique physical asset**,	Association
is **dynamically updated** with data from its physical twin	Transience
throughout its life cycle,	Life Cycle
and **informs decisions**	Function
that **realize value**.	Benefit

Digital Twin - Definition

A Digital Twin is a virtual representation of a connected physical asset



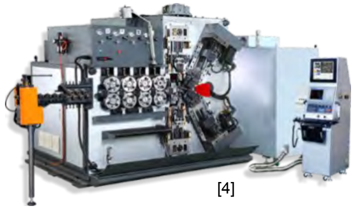
Example representation of the digital twin concept [1]

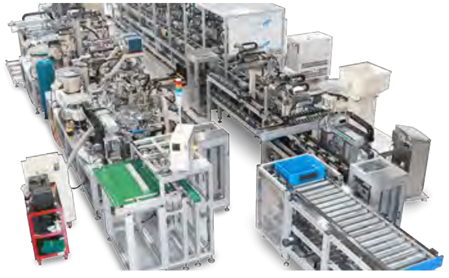
- The “physical asset” can be a product, a process, an object, a system, a subsystem or combinations of those

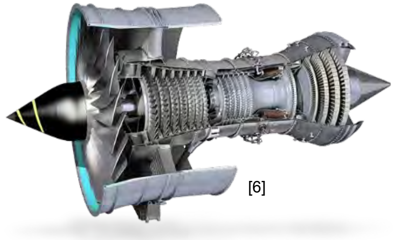

[8]


[3]


[2]


[4]


[5]


[6]


[7]

Olivia Pinon Fischer (olivia.pinon@asdl.gatech.edu)

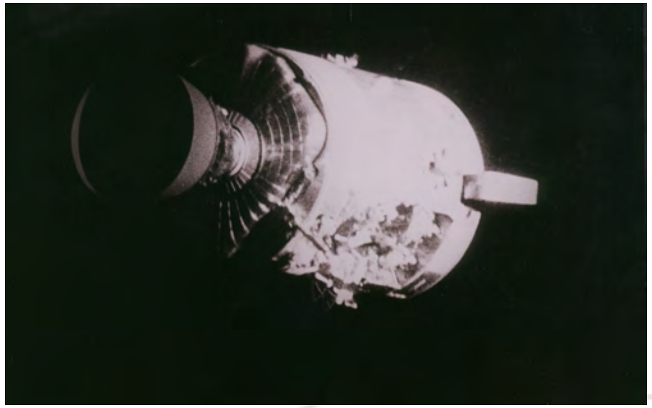
The "Twin" Concept

- Dates back from NASA's Apollo program [9, 10]
- Two identical space vehicles were built, the one remaining on Earth being called the *Twin*
  - Mirrors the conditions of the space vehicle during the mission [2]
  - Used extensively for training during flight preparations [2]
  - Used to simulate alternatives on the Earth-based model [2]

02 07 55 19	LMP	Okay, Houston - -
02 07 55 20	CDR	I believe we've had a problem here.
02 07 55 28	CC	This is Houston. Say again, please.
02 07 55 35	CDR	Houston, we've had a problem. We've had a MAIN B BUS UNDERVOLT.
02 07 55 42	CC	Roger. MAIN B UNDERVOLT.
02 07 55 58	CC	Okay, stand by, 13. We're looking at it.

NASA transcript of the communications with Apollo 13 at the time of the accident

Apollo Command Module Mission Simulator. Image credit: NASA



Damaged Apollo 13 Service Module. Image credit: NASA

Critical to the rescue of the Apollo 13's crew by allowing engineers to test possible solutions from ground level [11]:

- "NASA mission controllers were able to rapidly adapt and modify the simulations to match conditions on the real-life crippled spacecraft, so that they could research, reject, and perfect the strategies required to bring the astronauts home." [12]

Model vs. Digital Twin

- A **validated model** can provide a "snapshot of the behavior of an object **at a specific moment** [13]

vs.

- A **digital twin** provides an "accurate description of object that changes **over time**" [13]

Digital Twin Development – Important Considerations

- The proper definition & development of a Digital Twin require to [32]
  - Identify the **intended users and use** of the Digital Twin.
  - Elicit and document the scope, context, points of view, environment, operational scenarios, major constraints, existing investments in tools and methods, and other key assumptions.
  - Identify Information and data ; **recognize data management and acquisition challenges.**
  - Identify modeling needs and capabilities:
    - ✓ Be aware of the **"agony of abundance"** when it comes to platforms, tools and languages
    - ✓ Understand the implications that modeling tools, languages and platforms has on **usability, scalability, extensibility or maintainability** of the models and Digital Twin
    - ✓ Other considerations: model fidelity, nature of the models and the availability of standards, services and APIs

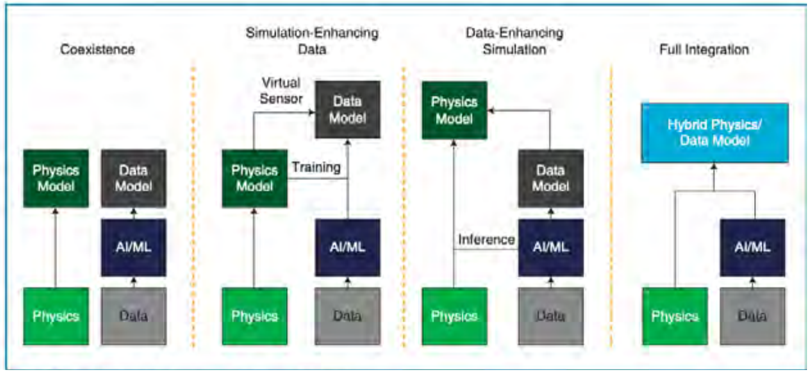
Olivia Pinon Fischer (olivia.pinon@asdl.gatech.edu)

Modeling Approaches to Digital Twins

Purely Physics-based: Models derived directly from the physics of the phenomena under consideration [2] → require a solid understanding of the physics, failure modes, degradation mechanisms, etc. considered

Purely Data driven: "Approach based on the assumption that since data is a manifestation of both known and unknown physics, by developing a data-driven model, one can account for the full physics." [2]

Hybrid techniques
- Integration of both types of modeling approaches (e.g. integration of ML to physical processes)
- Have been demonstrated to give superior performance [2]
- e.g. Use of physics-informed ML



[3]

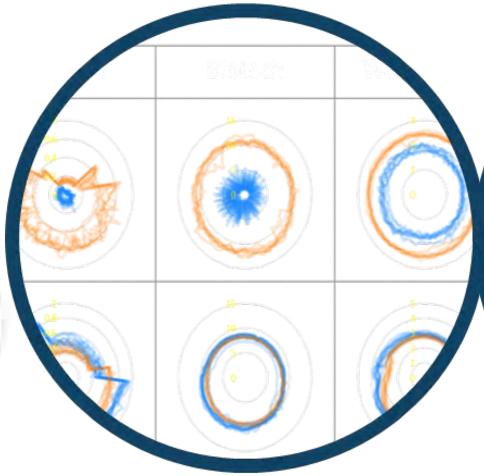
Selection of modeling approaches is dependent on:
- Availability of data to calibrate, verify and validate models
- Time frame the twin is to be updated [1] and decisions about the application need to be made
- What needs to be modeled: specific part vs. complete system [1]
- The needed or required generalizability and explainability of the models.
- Application/purpose of digital twin: driver for accuracy requirement

[1] Wright, L., & Davidson, S. (2020). How to tell the difference between a model and a digital twin. *Advanced Modeling and Simulation in Engineering Sciences*, *7*(1), 1-13.
[2] Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE Access*, *8*, 21980-22012
[3] Adams, M., Li, X., Boucinha, L., Kher, S. S., Banerjee, P., & Gonzalez, J. L. (2021). Hybrid Digital Twins: A Primer on Combining Physics-Based and Data Analytics Approaches. *IEEE Software*, *39*(2), 47-52.

Digital Twin – Analytical Capabilities

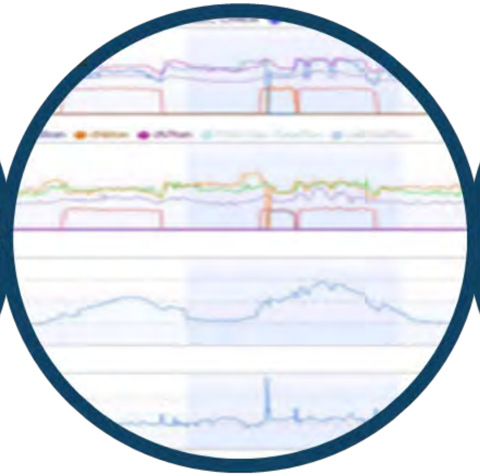
DIGITAL TWIN – ANALYTICAL CAPABILITIES

Descriptive



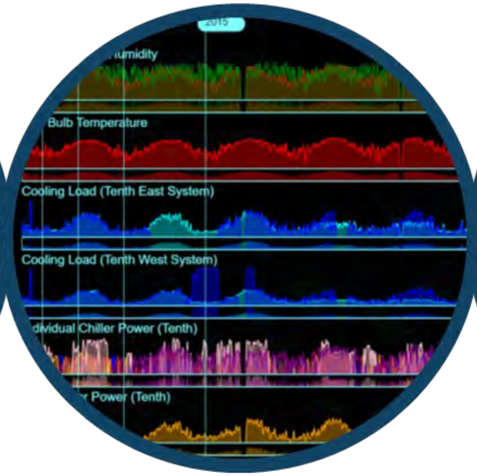
"What happened"
"What is happening?"

Diagnostics



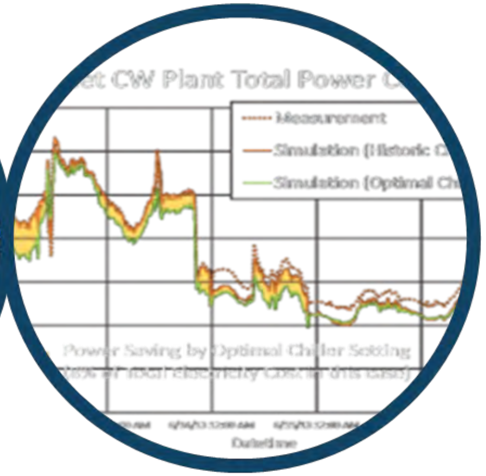
"Why did it happen?"

Predictive



"What is likely to happen?"

Prescriptive



"How to act in response?"

Digital Twin – Challenges to Development & Implementation

- **Tools and Methods**
- **Confidence & Trust**
- **Data/information integrity and authenticity**
- **Availability**
- **Maintainability**
- **Computing power**
- **Culture / Workforce**
- **Cybersecurity**

The Digital Thread

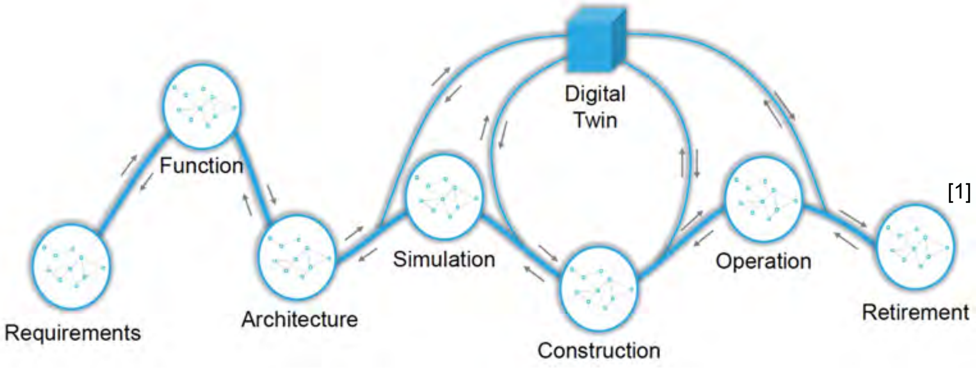
Aerospace Systems Design Laboratory

Digital Thread – Definition & Value

"A linked set of digital artifacts whose consistency is actively managed over the life cycle of a product, process, or system" [4]

- Required to **manage consistency** among the diverse and evolutionary models, data sets, practices, and regulatory requirements across the life cycle.
- Describes the comprehensive linkage of models and related product information, encompasses the entire product life cycle, and includes customers, suppliers, partners, and configuration management.
- Foundational to the development and implementation of valid Digital Twins [2,3]

Illustration of engineering design with Digital Thread [5]



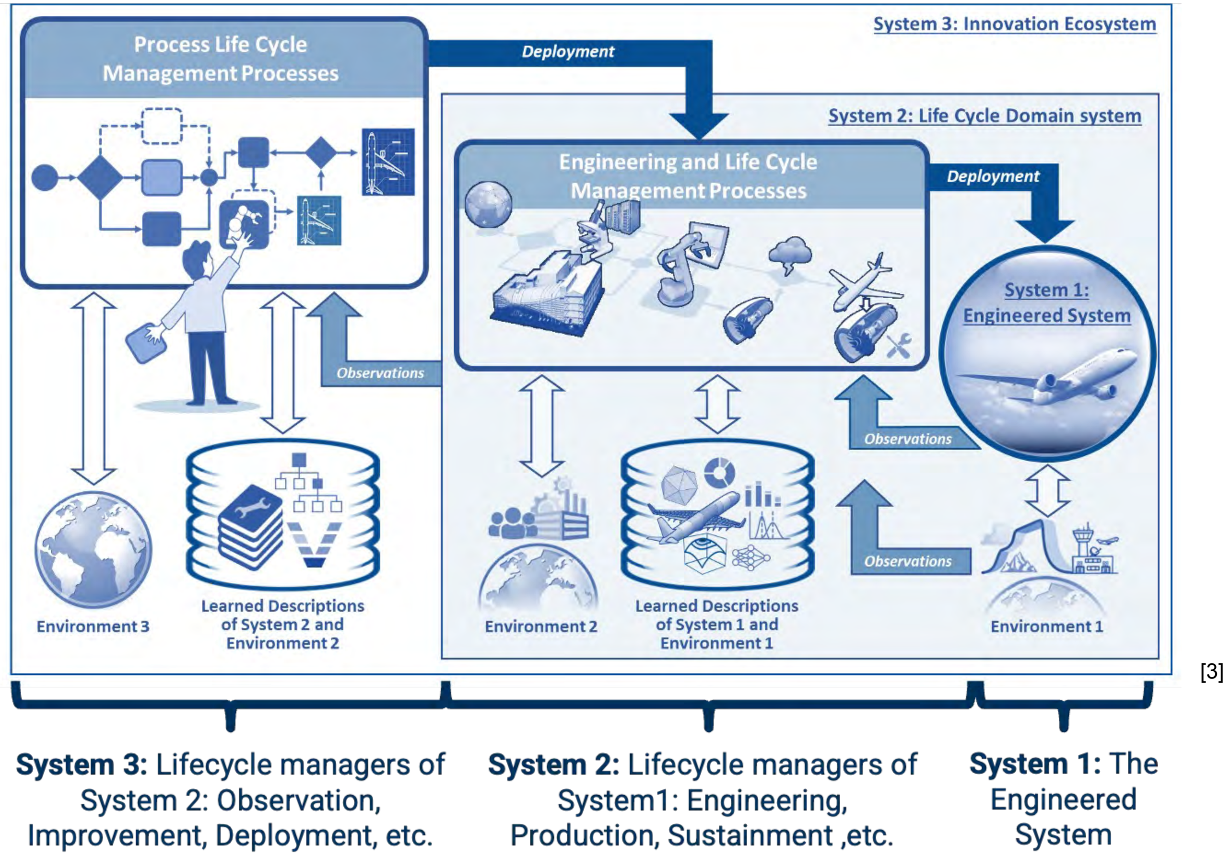
[1]

[1] Montezzo Coelho, M. E., & Browning, L. S. (2022). *INL Digital Engineering: Model-Based Design, Digital Threads, Digital Twins, Artificial Intelligence, and Extended Reality for Complex Energy Systems* (No. INL/CON-22-69247-Rev000). Idaho National Lab.(INL), Idaho Falls, ID (United States).
[2] AIAA Digital Engineering Integration Committee, *Digital Twin: Definition and Value - An AIAA and AIA Position Paper*. 2020, American Institute of Aeronautics and Astronautics (AIAA).
[3] AIAA Digital Engineering Integration Committee, *Digital Twin: Reference Model, Realizations & recommendations,* 2023, American Institute of Aeronautics and Astronautics (AIAA).
[4] AIAA Digital Engineering Integration Committee, *Digital Thread: Definition, Value and Reference Model* (under review), American Institute of Aeronautics and Astronautics (AIAA).
[5] Singh, V. and Wilcox, K., "Engineering Design with digital thread," AIAA Journal, Vol. 56, Number 11, November 2018, https://doi.org/10.2514/1.J057255.

A Digital Thread Generic Reference Model:
The INCOSE Innovation Ecosystem Reference Model

- Describes “the entire ecosystem in which an engineered product is developed, produced, distributed, used, and improved, along with the system of governance and improvement of not just the engineered product but the ecosystem itself.” [3]

- Can be used for “**planning**, **describing**, and **analyzing ecosystems** using or planning Digital Thread capabilities” [3]



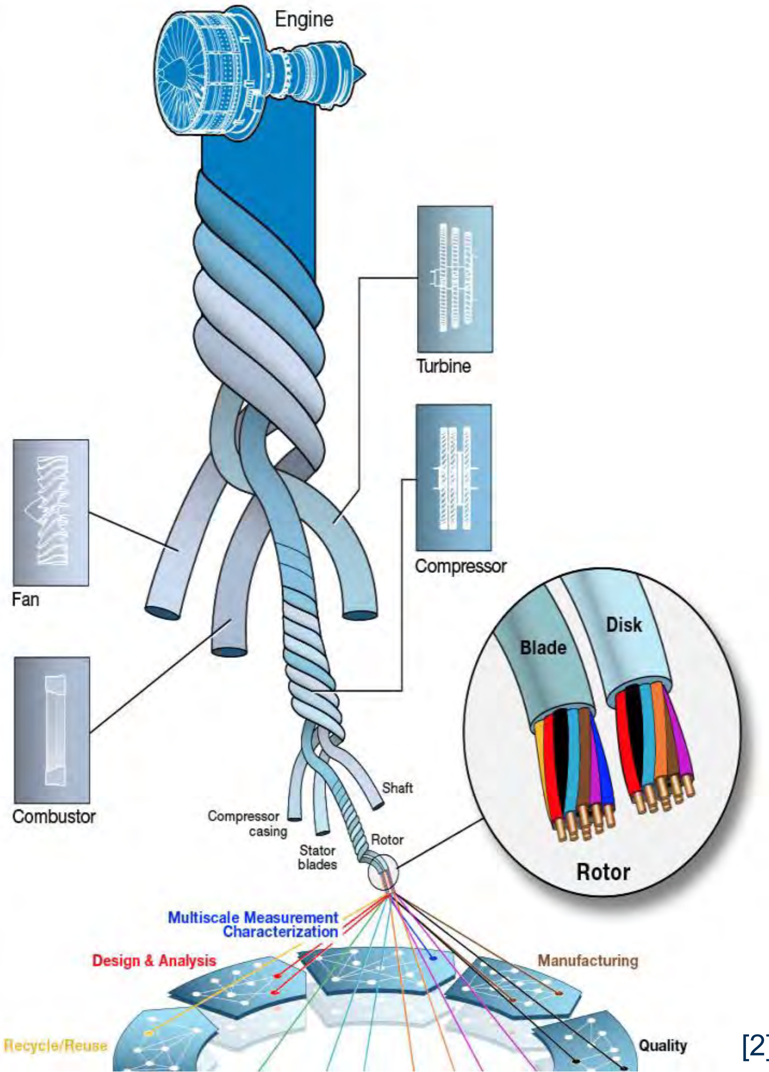
[3] AIAA Digital Engineering Integration Committee. "Digital Thread: Definition, Value & Reference Model - American Institute of Aeronautics and Astronautics (AIAA), To be published in 2023

Digital Thread - Benefits

Bi-directional Traceability: Allows to trace and link
- Data originating from virtual and physical tests to the most up-to-date designs and requirements [1]
- Verification and certification artifacts across all data sources
- Method of compliance requirements to a tested and verified product [1]

Managed Consistency: helps ensure that all authoritative derivative or successor information is fully compatible with its authoritative parent or predecessor information [2]

Increased Communication, collaboration across teams, stakeholders and customers, which contribute to creating a cooperative and trusting relationship with customers and regulatory authorities [1,2]



[2]

[1] Siemens Digital Industries Software, Digital Approach to Airworthiness: A Technical Guide, White Paper, 2021
[2] AIAA Digital Engineering Integration Committee, *Digital Thread: Definition, Value and Reference Model* (under review), Institute of Aeronautics and Astronautics (AIAA).

Digital Thread - Benefits

Workflow automation: opportunity to partly or fully automate [1]:

- The retrieval of authoritative information,
- The translation, transformation, and fusion of that information for input into an analysis activity,
- The collaborative execution of software that produces raw analysis data, and
- Post-processing that visualizes or reduces the analysis data for consumption by analysts or downstream activities

Analytical capabilities: The digital thread provides the foundational basis to many analytical capabilities critical to the ability to quantify risks and uncertainty and make informed decisions over the entire life cycle

Model Reuse: The digital thread allows for the previous exploration of data, knowledge, and models to be available to all designers and decision-makers → Allows for the reuse of information in the development of both current and new design configurations [2]

[1] AIAA Digital Engineering Integration Committee, *Digital Thread: Definition, Value and Reference Model* (under review), American Institute of Aeronautics and Astronautics (AIAA).
[2] Mauery, T., Alonso, J., Cary, A., Lee, V., Malecki, R., Mavriplis, D., Medic, G., Schaefer, J., and Slotnick, J., "A Guide for Aircraft Certification by Analysis." NASA, 2021

Relevance of Digital Thread in Contested Logistics Scenarios

- **Enhanced Situational Awareness:** the Digital Thread helps create a comprehensive picture of the battlefield → improved situational awareness, better allocation of resources and ability to rapidly adapt to changing circumstances.
- **Realistic Asset Representation:** the Digital Thread supports the simulation of real-world conditions and help wargamers understand the capabilities and limitations of these assets in different scenarios.
- **Predictive Analysis and Decision Support:** Ability to simulate potential outcomes of various actions and strategies → helps identify the most effective courses of action
- **Interoperability and Collaboration:** Having a shared virtual environment for joint exercises and planning, helps support communication, coordination, and interoperability across different platforms, systems, and services

The Digital Thread leads to:
- More efficient use of resources
- Reduced downtime
- Better allocation of logistics resources across operations

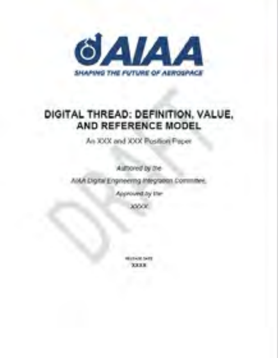
16

Relevant Resources from the AIAA Digital Engineering Integration Committee

- **Digital Twin: Definition & Value - An AIAA and AIA Position Paper**
  - https://www.aia-aerospace.org/report/digital-twin-paper/
  - https://www.aiaa.org/advocacy/Policy-Papers/Institute-Position-Papers

- **Digital Twin: Reference Model, Realizations & Recommendations** Leverages Digital Twin position paper context and recommendations to promote implementation and use of digital twins for value realization across the Aerospace Industry.
  - Collaboration between AIAA, AIA, NAFEMS, INCOSE and the OMG DTC
  - 8 Use Cases across Academia, Industry & Government
  - Available: https://www.aiaa.org/resources/digital-twin-implementation-white-paper/

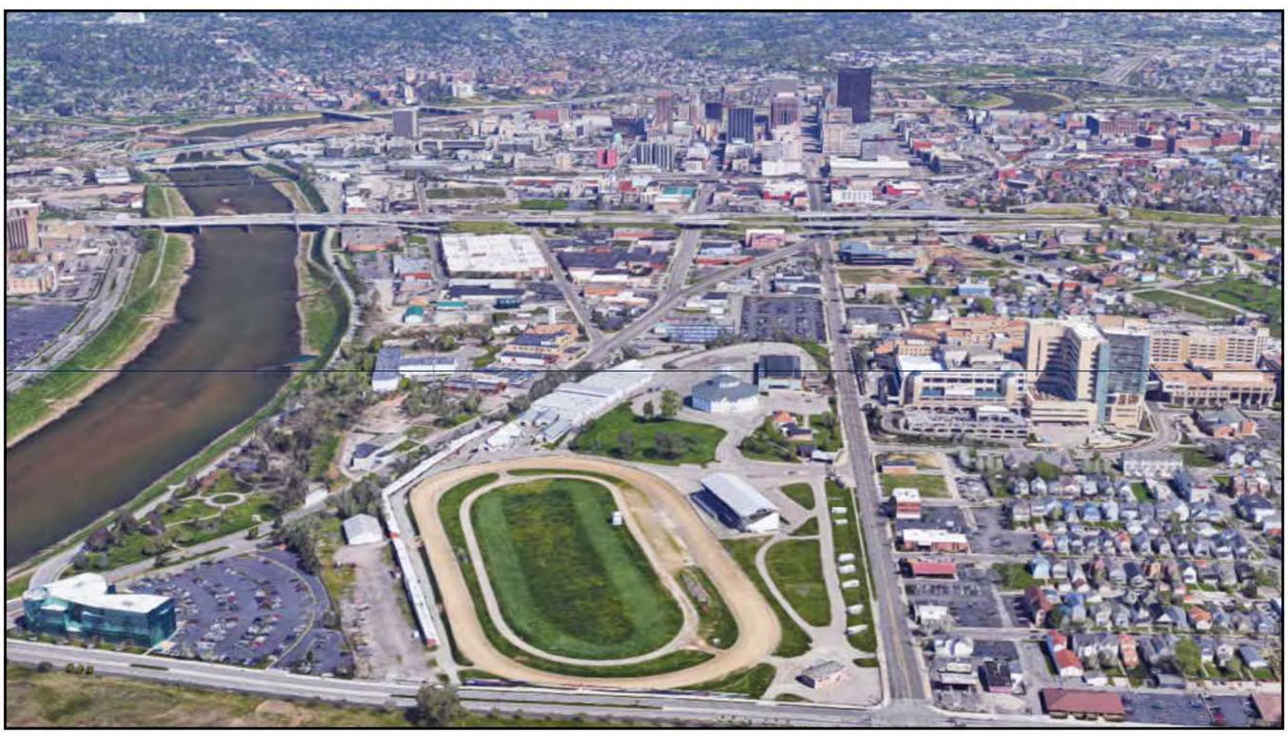
- **Digital Thread Definition, Value, and Reference Model:**
  - Expected to be released: June/July 2023



onMain

Dayton’s Imagination District

onMain



Vision

- **Represent the best of Dayton** as a city of innovation, entrepreneurialism, creativity, sustainability and inclusiveness.
- **Establish a unique platform** to create, build and demonstrate solutions across a range of disciplines from health care, energy, housing, environment, business creation and neighborhood wellbeing.
- **Create a density of ideas, activity and collaborations** that can propel the next wave of businesses and entrepreneurs to bring jobs and opportunity to Daytonians and the Miami Valley.
- **Create a setting that connects people**, neighborhoods, businesses and institutions.
- **Establish a neighborhood** unlike any other in the Miami Valley that demonstrates a new type of walkable urban environment.
- **Establish development standards that reflect the missions and values of the two institutions** by integrating environmental sustainability and wellness into the design.

onMain

Full Build Out

LAND USE	PROGRAM MIX
Employment	750,000 – 900,000 sf
Housing	1,350,000 – 1,500,000 sf 1,350 – 1,500 units
Retail/Active Uses	75,000 – 85,000 sf
Community Use	35,000 sf
Parking	2,500+ spaces
Open Space	Approximately 8 acres
New Streets	1 mile

The estimated **number of jobs** to be created within the district is approximately **3,000**

With an average salary of $50,000, the **annual payroll could be $125-150 million**

onMain's Development Approach

- Set the stage for development and own the underlying land in perpetuity
- Establish the site layout and the design guidelines; construct the "platform" for development
- Seek out developers who share our vision and commitment; enter into long term land leases for the "pads", allowing them to secure financing to construct the buildings

onMain

Master Plan

onMain
Dayton's Imagination District

Shared Street

Where workers and residents meet

onMain

Think Dayton Plaza

A space for Creative Conversations

onMain

Canal Park

Function and Beauty

onMain

Main Street

Creating a seam that connects and supports multiple modes of transportation

onMain

Roundhouse Plaza
The Community's Living Room

onMain

Community Trail
Connecting to the River and Beyond

onMain

The Bluff

Connecting to Downtown

onMain

The Digital Transformation Center at onMain

Digital Transformation

Digital Transformation (DT) will modernize how the Air Force designs, develops, delivers, operates, and sustains weapon systems. New and emerging DT tools will streamline Air Force operations such as contract writing, scheduling maintenance, testing and evaluation by connecting processes and data flows in a seamless data environment.

The Digital Transformation Center

The Digital Transformation Center will be designed to meet the current needs of WPAFB's digital transformation mission and enable the necessary collaboration between Government, Industry and Academia. The Center will also accommodate future expansion of digital operations as this growing field of study and its associated Department of Defense missions evolve and provide a framework to train the future DT workforce.

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Key components of the DTC

Digital Transformation Office

A Department of the USAF office currently located in Dayton. The office supports the Air Force's mandate for digital transformation with a location that links industry experts with Air Force leaders to deliver cutting edge digital transformation programs and products.

Digital Design Studio - hosted by Ohio University

A digital environment to learn and integrate high end tools and demonstrate new capabilities for digital transformation.

Digital Enterprise Applied Learning Center

The DEAL concept is to support upskilling of the workforce for all partners in the Center. Working to close the skills gap in the digital transformation community, the DEAL will connect the Air Force and industry with college interns and coops from regional and national universities and well as community colleges; provide on-site training in toolsets, concepts, and lessons learned; and open doors for non-traditional students to advance their education and earning power while earning a paycheck.

onMain

Why locate the DTC at onMain?

- Location ideal for Department of the Air Force collaboration with Industry on research and systems development.
- Centrally located to large regional college level student population base
- Leverages the start-up ecosystem at the Arcade and the Webster Station areas in downtown Dayton as well as innovation coming out of WPAFB, Kettering Research Park, Dayton Composites Center, and nationally known regional universities
- Off-base collaboration space for the Air Force to train and meet with large and small industry partners working in the digital transformation space
- Grows the opportunity for additional research and employment among the ecosystem of institutions, organizations and companies supporting the USAF's DT mission

onMain

Amenities within the DTC at onMain

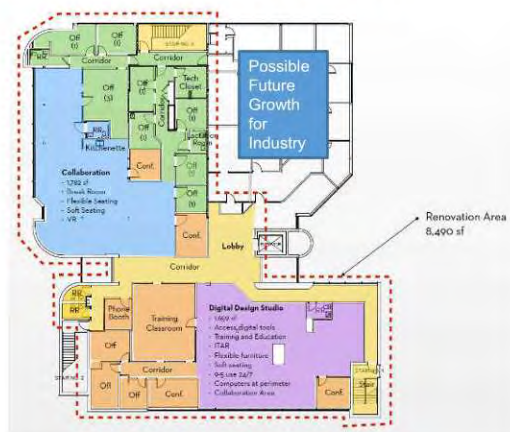
- Intentionally designed shared collaboration space
- Private space
- Training spaces
- Leasable “on demand” SCIF space
- Easy access to intern/co-op housing
- Close proximity to Air Force Digital Transformation Office
- Access to developmental software and industry tools
- Conferences and trainings for upskilling students and the workforce
- Access to students and young talent
- Coffee shop

onMain

onMain
Dayton's Imagination District

Digital Transformation Center: Seedling Space

- Space:
  - Collaboration Space
  - Digital Design Studio Space
  - Industry Space
  - 8,500 sq ft
- Resources / Events
  - Intern/Co-op placement aid
  - DTO technical exchanges
  - DT community social events
  - Training courses
  - Certification Courses
- Opening Fall 2023



University of Dayton

onMain

Collaboration Space

University of Dayton onMain

Digital Design Studio

University of Dayton onMain

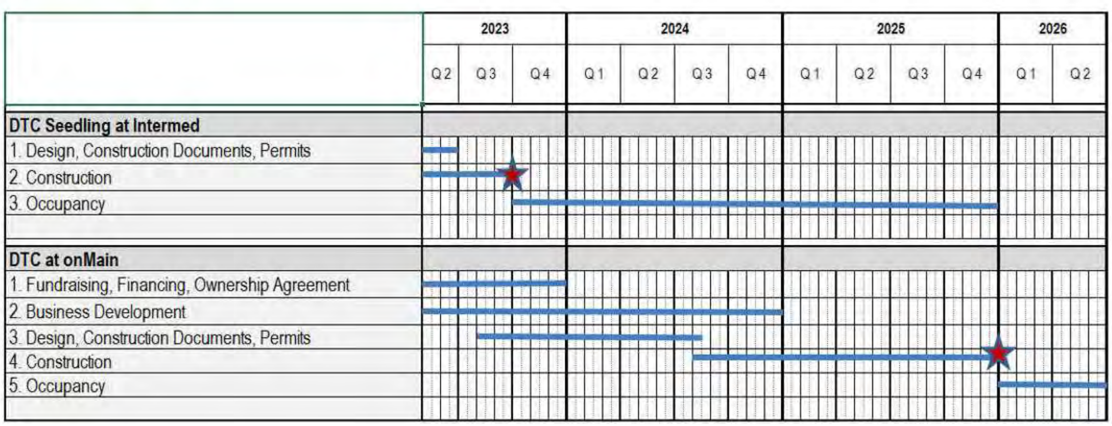
Membership Level Options and annual fees (tentative)

- Premier Plus Membership $12,000
  - All Premier Membership benefits, larger office with a view
  - Prominent naming on partners list near entrance
  - 12 key card member access
- Premier Membership $10,000
  - All Standard Membership benefits
  - Ten total key card member access
  - Reserved, key card controlled office space
  - Office furniture for one professional + one part time (student)
  - Dedicated LAN internet drop
  - Prominent naming on office door
  - Naming on partners list near entrance
- Standard Membership $7,000
  - WIFI internet access
  - Ability to reserve conference rooms
  - Access to break area and hospitality supplies
  - Key card access to all collaborative spaces
  - Access to digital design studio by appointment or standby
  - Three key card member access
- Additional Member $1,000
  - Allows additional keycard for additional employees
- Student Keycard $0
  - Keycard access student employee of a member
- Student Discount $500
  - Discount for fulltime student working in the space
- Digital Design Studio Membership only $4,000
  - 100% virtual access to the DDS. No center access

University of Dayton

onMain

Time line



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Tell us what you think!

onMain

1. What do you like about what's been shared today about the onMain District?

a. Looks like it would be a pretty cool place to work!

b. This is the kind of place that I think would attract young people to choose Dayton as a place to live/work!

c. The ideas around sustainability, equity and inclusion, and uniqueness of place really resonate with me!

d. This is just what Dayton needs!

Choose any and all statements that you agree with

onMain

2. What don't you like about what's been shared today about the onMain District?

a. Looks too "cutesy"

b. The ideas represented here are not really that important to me and or my business

c. Is too dense. Too many uses and ideas crammed into one area

d. I can't see my self living or working at a place like this

Choose any and all statements that you agree with

onMain

3. How well do you think these proposed components of the DTC address the current and future digital transformation needs?

a. Collaboration space for businesses, students and the USAF

b. SCIF space

c. Training

d. Unique flexibles spaces that can serve a variety of uses

e. Coffee Shop!

Rank these with 1 being the highest/most important

onMain

4. How important are the following attributes of proposed DTC to <u>your</u> organization's needs?

a. Access to students
b. SCIF space
c. Training
d. Air Force expertise
e. Digital tools

Rank these with 1 being the highest/most important

5. I think the idea of the DTC Seedling…

a. Provides an good opportunity, on a small scale, to test ideas and relationships that could be considered on a larger scale
b. May be all that is ever needed to address the DT needs
c. May be successful but the ideas and relationships there are not likely to transfer to the larger scale DTC at onMain
d. Is not likely to provide any benefit at all.

Choose the one statement that you most agree with

6. Is there a another place that have you visited or have knowledge of that we could benefit from learning what makes them successful?

Provide one or more responses of your own

onMain

7. Are there other elements or features that we should include in the DTC that have not been mentioned to make sure that collaboration is "baked in" to the DTC right from the start?

Provide one or more responses of your own

onMain

8. If the DTC included _______ , that would make it really special.

Provide one or more responses of your own

onMain

9. I'd like more information about how my organization can become involved in the Digital Transformation Center at onMain.

Company name:

My name:

My email address:

onMain

10. Please contact me about how my organization can become involved in the DTC Seedling.

Company name:

My name:

My email address:

onMain

onMain

Dayton's Imagination District

Brian Heitkamp: BHeitkamp@onMainDayton.com
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Digital Twin Center of Excellence

Digital Twins go to War

11 May, 2023

Dr. Olivia Pinon Fischer
Georgia Institute of Technology
Chief, ASDL Digital Engineering Division

Timothy M. Zadalis
Maj Gen (ret), USAF
Operations Consultant

Digital Twin Center of Excellence (DTCoE) Vision

- Digital Twins offer the opportunity to marry operational simulation with engineering analysis and combine it with real-world data & feedback from the Logistics & Operations Communities.
- This capability will enable the rapid development of new weapons system concepts, tactics & strategies for future conflict scenarios with near peer adversaries.

The Digital Twin Center of Excellence Requirements:

- Operationally Relevant to the Warfighting COCOMs and MAJCOMs
  - Support and Integrate Joint and, Eventually Coalition Partners
- Support Current / Future Operational Constructs
  - Joint All Domain C2, Agile Combat Employment, and Others
- Challenged Digital Twin Thoughts/Concepts with Continuous Experiments, Wargames, and Exercises
- Enhance Collaboration With Industry, Academia and Government

The “Why” For Digital Twins and JADC2

- Command and Control (C2) is Our “Asymmetric” Advantage
  - Joint All Domain Command and Control (JADC2) is the Future … If Done Right!
- Technology, Digital Engineering, and Digital Twin Development is Accelerating
  - Lesson From the Past: SpaceNet 2025– On-Orbit Support
- Agile Transportation 21 ... “Factory to Foxhole” Logistics
  - Technological Advances Left the Original Vision Behind
- My JADC2 Thoughts
  - 5 - 25 Year Journey … or Longer
  - It is “How” We Integrate, Not “What” We Integrate
  - Digital Twins and AI Will Play a Critical Role
  - Requires a ”Grand Strategy” … Not a Strategy

Digital Twin Working Group's Charter

- Consists of Selected Members from Industry, Government, and Academia
  - Supported by AIAA/AIA Digital Engineering Integration Committee and the Dayton Development Coalition
- Tasked to Identify "Operationally Relevant" Use Cases
  - Use Cases Must Nest Into JADC2
  - Identify the Value of Digital Twins in JADC2 Development
  - Identify Validation Methodology for the Use Case Digital Twins
- Develop an Agreed Upon Digital Twin Definition

Working Group Use Case Criteria

- Must Cross Functional Areas
  - Kinetic Ops, Logistics, Mobility, Maintenance, etc.
- Leverage Current / Future Warfighting Constructs
  - Agile Combat Employment (ACE) Selected
- Identified Use Case Digital Twins for Focused Evaluation Via Wargaming
  - "Bites of the Elephant Herd"

Use Case Options

- Aircraft Engine Life-Cycle Monitoring … AFLCMC Developed
  - AFSOC Challenged Conventional Thinking
- “Pit Stop” on Demand … Validating ACE Concepts
- F-35 Wing Battle Damaged Wing … ACC Recommended
  - Shaped Initial Use Case Thinking
- Next Generation Un-Crewed Combat Assets
  - Close Counter Air, Adjuncts, and Loyal Wingman
  - Developing Capabilities Ripe For Digital Twin Sensor Integration

Real World Use Case - AFLCMC Engine Story

- AFSOC is using Digital Twins to Forecast Unscheduled Engine Removals prior to deployment
  - Typical Deployment Required 15 Engine Changes/Year
- Goal Is To Identify "Poor Performers" and Change Engines Prior To Deployments
- Enabled by AFLCMC Developed Software - Deployment Readiness Tool
  - Estimates the Time on Wing (ETOW) of the base's installed engines
  - Deploying unit can replace engines that have a higher probability of failure during deployment
- On 1st Deployment … Only 1 Engine Change Required

Use Case: "Pit Stop" On Demand

- A F-35 4-Ship is Recovering to a Forward Operating Site FOS
  - One F-35 has a Stabilizer Fault Indication … "Land Within 30 Minutes"
  - JADC2 Controllers Quickly Confirm FOS Has Repair Capabilities

- Once On the Ground, In-depth MX Diagnostics Occurs
  - Culprit is the Stabilizer Control … Zero Balance at FOS with 7 Days to Provision
  - Useful Life of Current Control is ~40 Hours

- JADC2 Controllers Coordinate Repair at Main Operating Base (MOB)
  - Aircraft Continues Combat Ops and on 8th Day Recovers to MOB For Repair

Use Case: F-35 Battle Damage (1 of 2)

- International Tensions High as Militarized “Man-Made Atolls” Impede Freedom of Navigation
- Traditional “Shows of Force” Have No Effect
  - US Navy and Air Force “Enhanced” Shows of Force Authorized
- Air Force F-35 4-Ship Begin Conducting Simulated Air Intercepts Over Atolls
- Atoll Commander “Panics” and Fires SAMs at the F-35s
  - One F-35 Sustains Slight Wing Damage Due to Blast Fragmentation
  - Second F-35 Executes Evasive Maneuvers and Over-Gs the Aircraft

Use Case: F-35 Battle Damage (2 of 2)

- The F-35's Sensored Wing Transmits Status to Ground MX and the F-35's Tail Number Specific Wing Digital Twin
- Ground MX Personnel Review DT Data and Prepare For Aircraft Arrival
  - Over-G Aircraft Requires Additional Inspections, the Other Requires More
- Digital Twin of Damaged Aircraft Identifies Potential Damage to a Structural Component
  - Structural Component Replacement Parts … Zero Balance at FOS with 96 Hours to Provision
  - F-35 Engineers in CONUS Use the Digital Twin to Run Dozens of Mission Profiles of the Wing with the Damaged Component
- With Initial Battle Damage Repair the F-35 is Flyable with Minor G Restrictions
  - Combat Ops Shifts the Aircraft's Mission Profile to Accommodate Restrictions
- Aircraft Continues Combat Ops over next 96 hours then Recovers to MOB For Repair

Use Case: Digital Twins for CCA

- A Strike Group of F-35's & Collaborative Combat Aircraft (CCA) fired on by S300 SAM
  - Near miss damages wing of a CCA - another CCA executes high G evasive maneuver
  - All aircraft able to return to the Temporary Contingency Location (TCL) intact

- JFC receives intel that another S300 is being transported to an atoll
  - JFACC assesses the TCL as the most effective response group

- JFACC has live access to the assessed damage via ABMS
  - Combat Operations inputs target mission parameters - 75% likelihood of mission success
  - MX team augments the Digital Twin with visual/inspection information
  - Structural Engineers in CONUS recommend repair
  - Digital Twin re-baselines & assesses that the CCA is at full payload capability, 90% effective range …..Mission success now 90% if identified flight parameters not exceeded

- JFACC authorizes the mission

Strategy Going Forward

- Solidify Use Case Scenarios
  - Develop Digital Twin MVP Roadmaps for Digital Materiel Management Use Cases
- Iterative Wargames To Validate / Improve Concepts
  - Robust AFSIM Capabilities Across Academia, Industry, and Government
- Inform the JCS's JADC2 Cross Functional Team
- Formalize the Digital Twin CoE into a Cross-Functional Capability

CLOUDS: Contested Logistics Operations Using Digital Support

Olivia Pinon Fischer, Ph.D. (olivia.pinon@asdl.gatech.edu)

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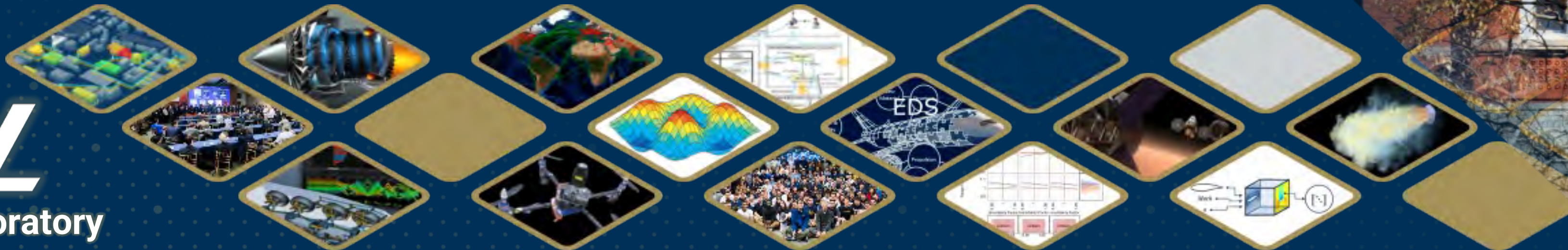
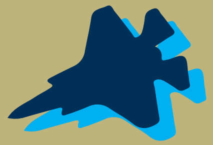


Aerospace Systems Design Laboratory

Summary

To win in a **contested environment**, three distinct components are needed

Internet of Warfighting Things	Digital Environment	Agile Combat Employment
		

Developed a **parametric M&S capability** and **interactive decision-support environment** to help better understand the **synergistic effects** of these elements in a **contested environment**

- Capability enables both top-down and bottom-up approaches
  - **Top-down:** desired outcomes are used to **derive requirements for Digital Twins, IoWT, and ACE**
  - **Bottom-up:** Digital Twin fidelity and accuracy, along with communication capabilities, etc., are used to **quantify key metrics of interest**

Summary (continued)

Examples of Research Questions of Interest

Communications

- Impact of communication capabilities on the outcomes of interest?

Digital Twin

- Impact of Digital Twin fidelity and accuracy on time on shelf and asset's turn around time?
- Impact of a digital environment on mission readiness?

Logistics

- Impact of number of assets / bases on outcomes of interest?

Research Objectives

- Determine the impact of the **Internet of Warfighting Things (IOWT)** on communications
- Assess how IOWT accomplishes logistics in **Agile Combat Employment (ACE)**
- Identify **Digital Environment (DE)** requirements for contested environment operations

Sponsor

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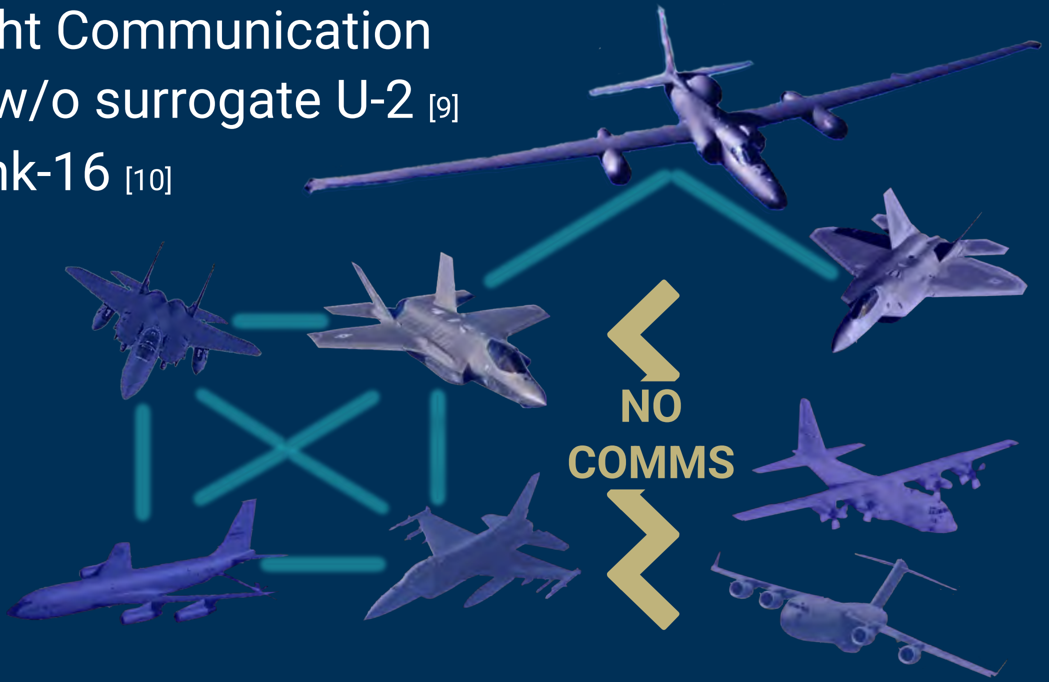
Communication Complications

- Link-16: 0.115 Mbps [8]
  - Current Encrypted Beyond Line-of-Sight Communication
  - F-22 and F-35 cannot exchange data w/o surrogate U-2 [9]
  - Air Mobility aircraft cannot access Link-16 [10]
- Link-22: 4.1 Mbps [11]
- Starlink: 6-800 Mbps [12]
- 5G LTE: 1000 Gbps [13]

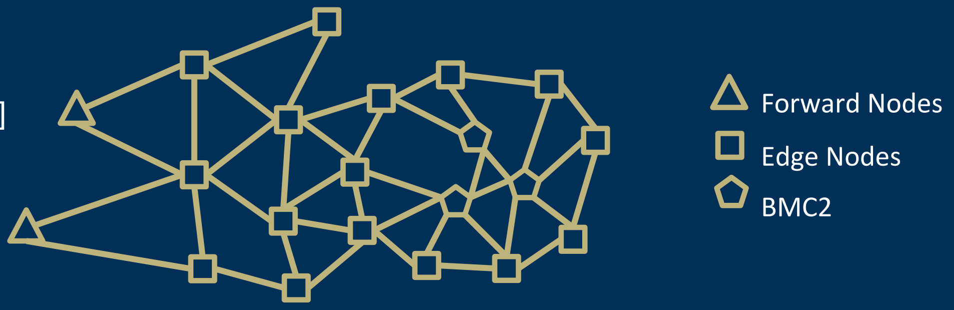


Assumption: No communication limitations between platforms

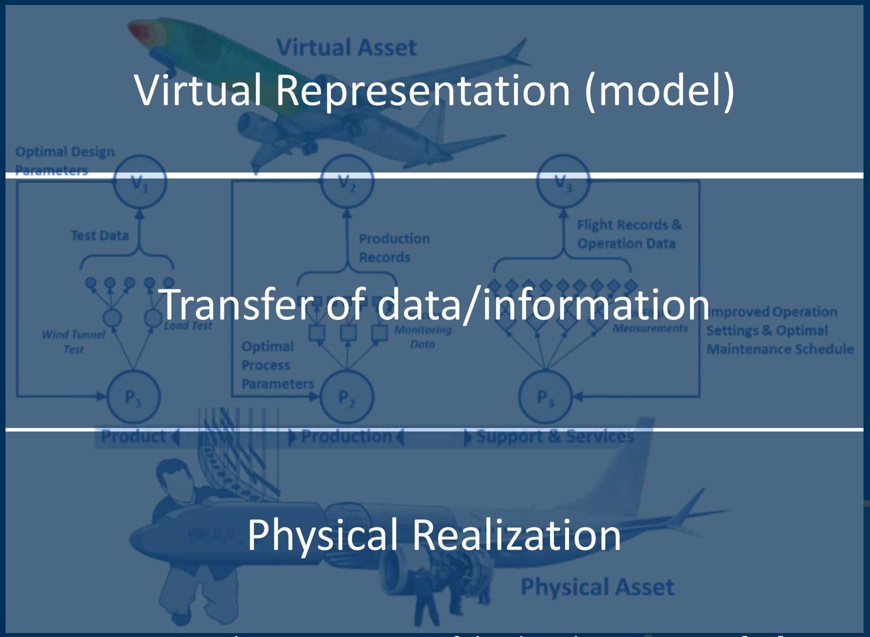
What data rates are **required** to allow **interoperability**?

Digital Environment

- Digital Infrastructure
  - Physical resources that enable use of data, devices, methods, systems, and processes [14]
  - In a contested logistics environment, different types of nodes exist:
    - Forward node
    - Edge node
    - Battle Management Command and Control (BMC2)



- Digital Twin
  - "a virtual representation of a **connected** physical asset" [15]
  - Supports analytical capabilities
    - Descriptive
    - Diagnostics
    - Predictive
    - Prescriptive



Example representation of the digital twin concept [15]

Agile Combat Employment (ACE)

'New' Air Force Doctrine – Expeditionary Force

- "A proactive and reactive operational scheme of maneuver executed within threat timelines to increase resiliency and survivability while generating combat power" [16]
- Contingency locations – large airbases no longer safe
- Maintenance conducted with smaller footprint

Current basing
Buildup *en masse*

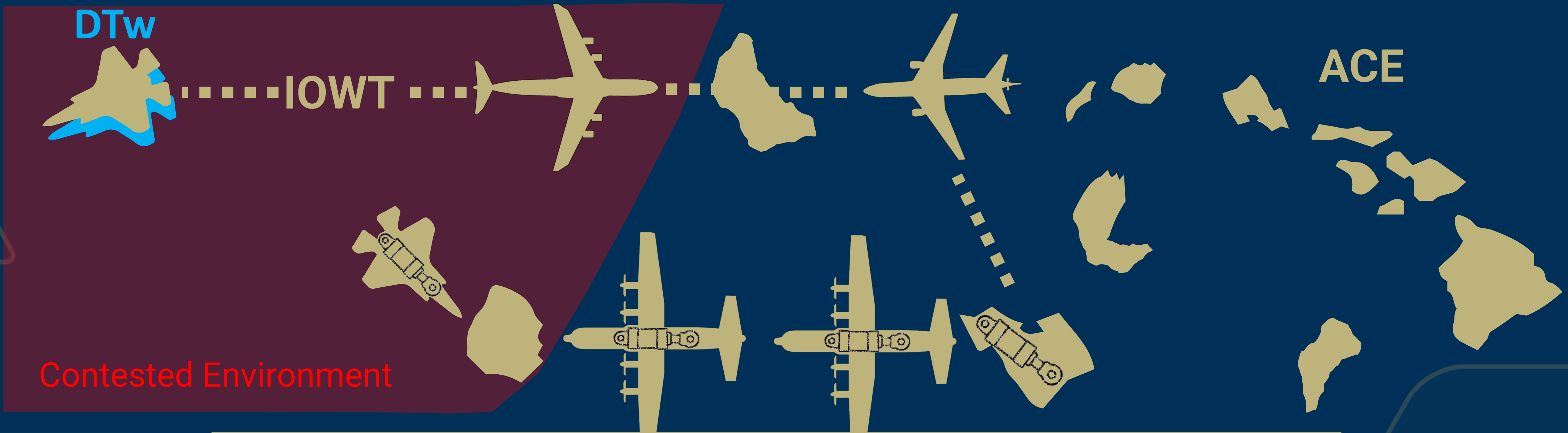
[16]

ACE basing
Operation from Contingency Locations

Assumption: Islands only used with suitable 8,000 ft. runway for F-35A

Operational Vignette

- Initialization: F-35 damaged and lands at Contingency Location (CL) [19]
- Through predictive capabilities of DTw, F-35 sends distress signal to AFB with data (time until failure)
  - Goes through IOWT bandwidth
- After receiving packet, Air Tasking Order (ATO) allocates logistical assets to retrieve part and maintainer for repair at CL

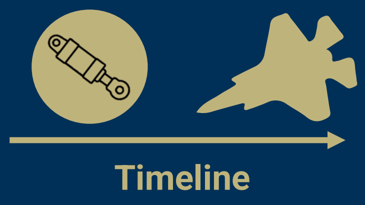


Need to analyze these **three** components in a **parametric fashion**

Establishing Value

- The Mission
- Problem Formulation
- Technical Approach
  - Formulation
  - M&S
- Use Cases
- Conclusions

- Research questions/objectives driven by multiple metrics:



Overall Metrics (hr)

- Time on Shelf
- Turnaround Time
- Total Time Elapsed

Intermediate Metrics (hr)

Communications	Digital Twin	Logistics
F-35 Packet Latency	Predicted Time until Failure	Repair Time
IOWT/Digital Environment	Twin Accuracy	Twin Fidelity

Sufficient **factors** and scenario **simulation** necessary to calculate **metrics**

Modeling and Simulation Methodology

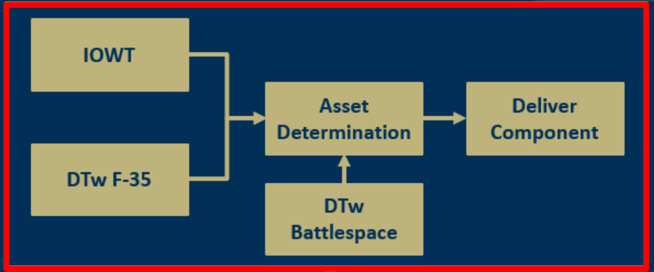
Specify variables for simulation
Comms network, DTw fidelity, number of assets, etc.

Factors and distributions

Batch run

Design of Experiments (DoE)

Input variables

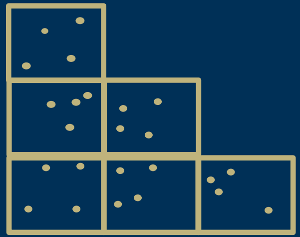


Execute simulation

Response data

Surrogate models
Response = *f(design variables)*
Response = time elapsed, time on shelf, …

Interactive, parametric dashboard/tabletop with surrogates as backend



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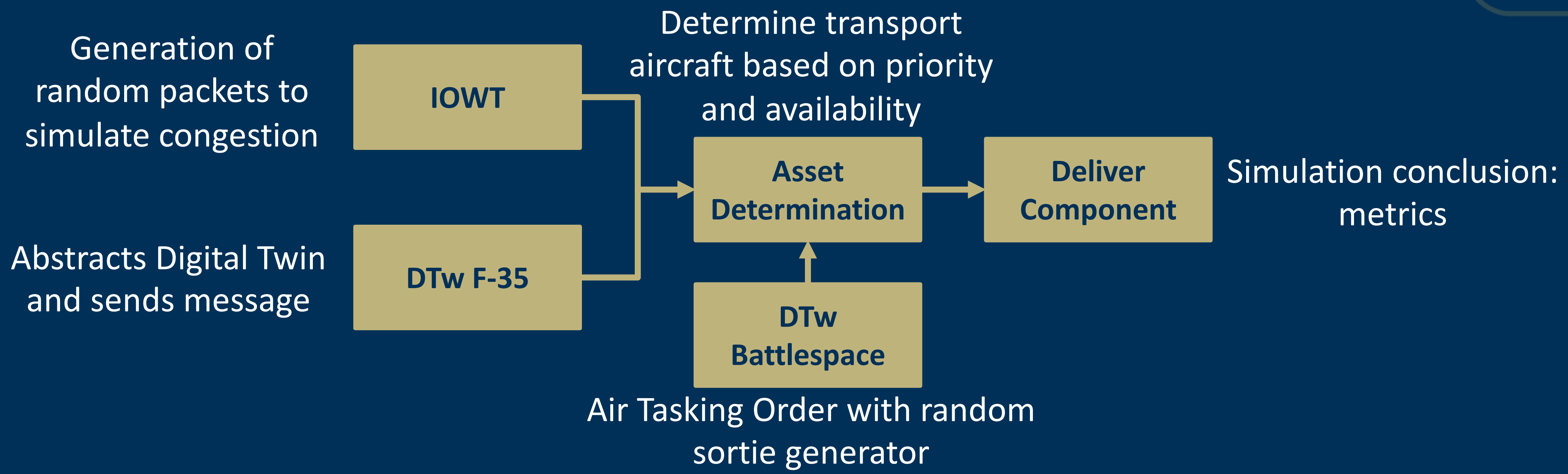
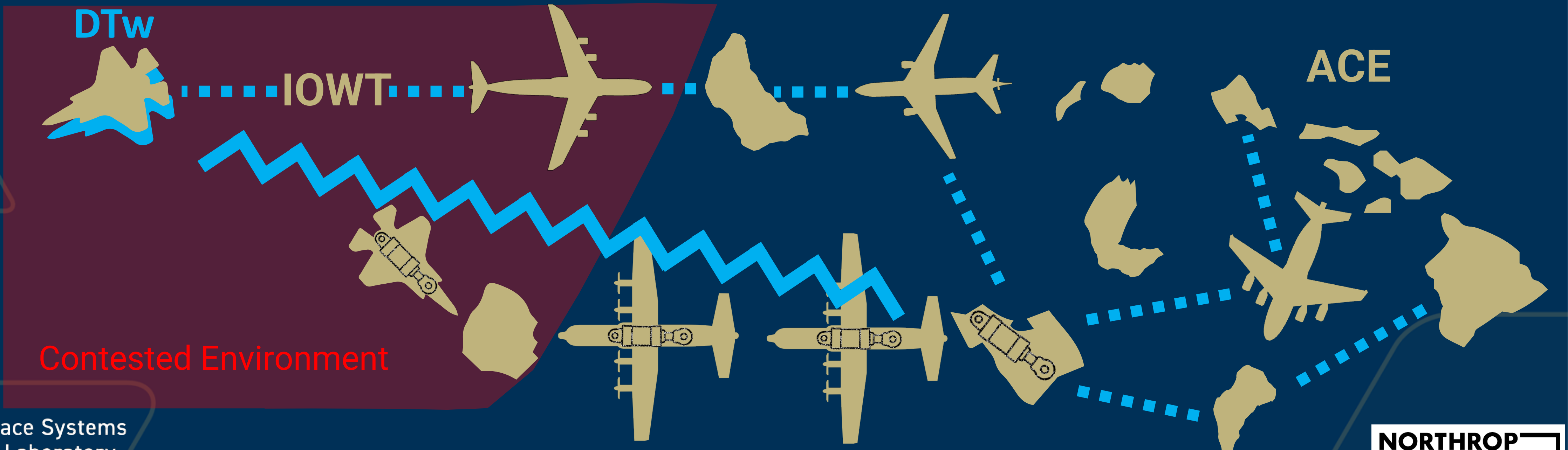
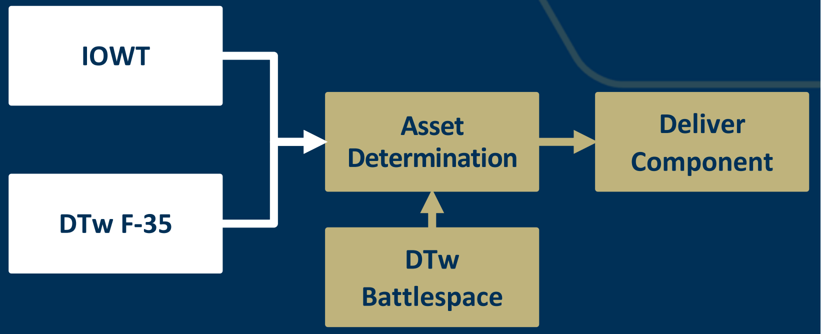
M&S Execution

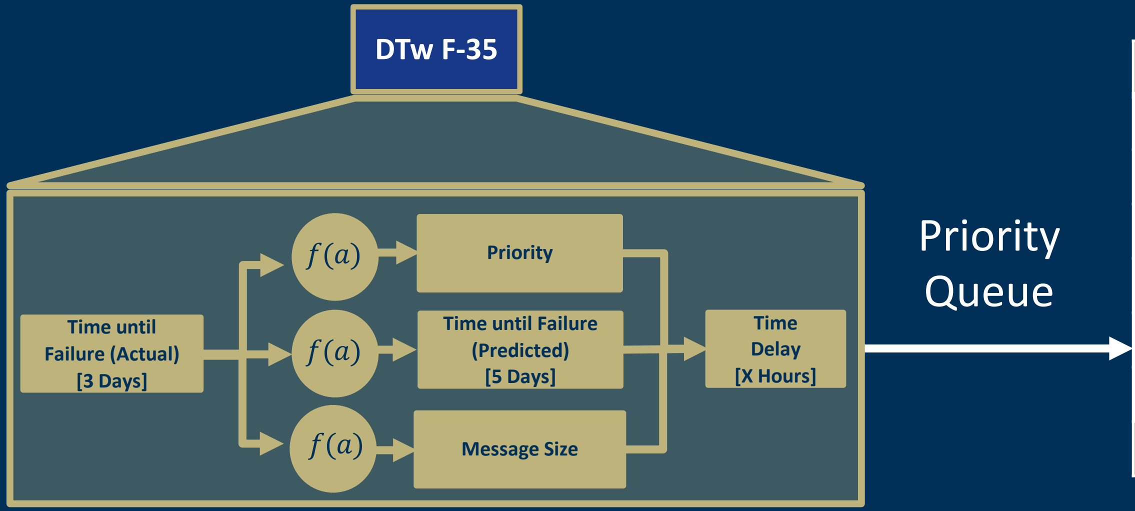




M&S: Communications (Python)



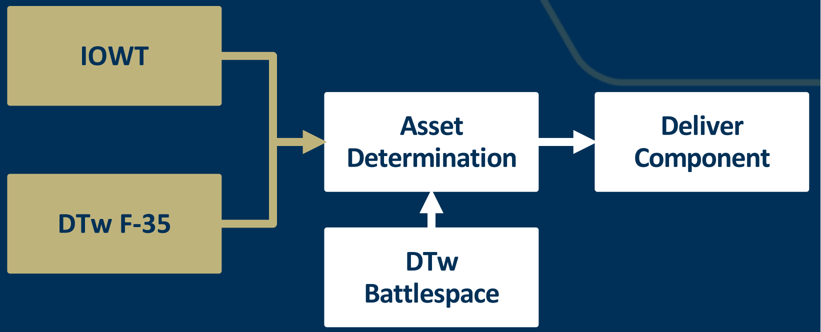
- F-35 Message:
  - **Priority** – function of time until failure
  - **Location** – where F-35 is located
- Priority queue:
  - Packets randomly generated (user defines priority and size distributions)
  - Simulation ends when F-35 leaves General channel



Priority	Size	Type	Time
1	2 KB	Logistics	X/X 0X00Z
1	10 KB	Logistics	X/X 0X00Z
3	5 KB	Comms	X/X 0X00Z
3	6 KB	F-35	X/X 0X00Z
3	8 KB	General	X/X 0X00Z
9	20 KB	Comms	X/X 0X00Z
Random Packet Generator			

- Assumptions:
  - Each channel has same bandwidth
  - Queue size maintained at 10

M&S: Logistics (Simio)



- Air Tasking Order (ATO): updates missions
- Logic:
  - F-35 message priority determines jet allocation
  - Aircraft priority: Only use aircraft below required
  - Aircraft arrives at CL (time on shelf)
    - Golden Window: 2-5 hours*

The Mission
Problem Formulation
Technical Approach
Formulation
M&S
Use Cases
Conclusions

Mission Priority	Current Base	Future Base	Time Available	Asset	Tail Number
5	Okinawa AFB	Yokota AFB	X/X 0X00Z	C-5	K5345
2	Hickam AFB	Guam FOB	X/X 0X00Z	C-17	K3256
10	Midway CL	Adak CL	X/X 0X00Z	C-130	K5359
…	…	…	…	…	
Random Sortie Generator					

- Assumptions:
  - No aircraft downtime
  - All aircraft positions known (complete awareness)

* Notional Range

Modeling and Simulation Methodology

- The Mission
- Problem Formulation
- Technical Approach
  - Formulation
  - M&S
- Use Cases
- Conclusions

IOWT

DTw F-35

Asset Determination

Deliver Component

DTw Battlespace

Specify variables for simulation
Comms network, DTw fidelity, number of assets, etc.

Factors and distributions

Batch run

Design of Experiments (DoE)

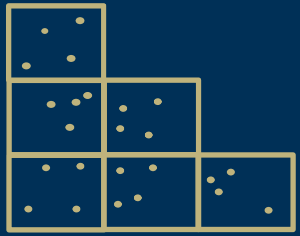
Input variables

Execute simulation

Response data

Surrogate models
Response = *f(design variables)*
Response = time elapsed, time on shelf, …

Interactive, parametric dashboard/tabletop with surrogates as backend

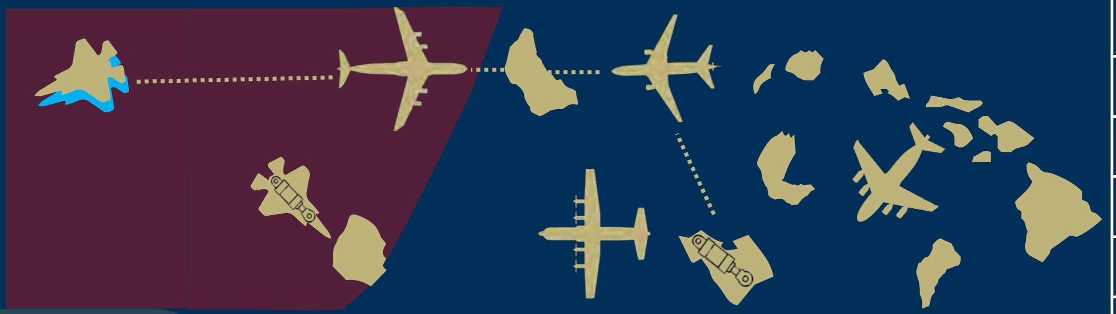


Generating Alternatives

- The Mission
- Problem Formulation
- Technical Approach
  - Formulation
  - M&S
- Use Cases
- Conclusions

- 18 variables
- To run every case: 12.1×10^{24} (septillion) cases

- Design of Experiments (DOE) Approach
  - 4000 cases
    - 100 repetitions IOWT and DE
    - 20 repetitions ACE



Factor	Range
Internet of Warfighting Things Parameters	
Congested Data Size Mean	0.0001– 10 GB
Congested Data Priority Mean	1-9
Congested Data Size Stdev	1-10
Congested Data Priority Stdev	3-10
IOWT Bandwidth	31,600 – 2e10 bps
Digital Environment Parameters	
F-35 Fidelity	0-1
F-35 Accuracy	0-100
F-35 TUF Actual	6 - 336 hrs
F-35 Data Size	0.0001 – 10 GB
F-35 Max Priority Time	24 – 336 hrs
Contestedness	0.5 – 12 hrs
Agile Combat Employment Parameters	
Number of Aircraft	3-15
Number of Bases	3-15
F-35 Location	1-3
Part Location	1-3
Maintenance Priority Mean	1-9
Maintenance Priority Stdev	3-10
Maintenance Package Frequency	6 – 24 hrs

Modeling and Simulation Methodology

- The Mission
- Problem Formulation
- Technical Approach
  - Formulation
  - M&S
- Use Cases
- Conclusions

IOWT → Asset Determination → Deliver Component
DTw F-35 → Asset Determination
DTw Battlespace → Asset Determination

Specify variables for simulation
Comms network, DTw fidelity, number of assets, etc.

→ Factors and distributions →

Batch run

Design of Experiments (DoE)

→ Input variables →

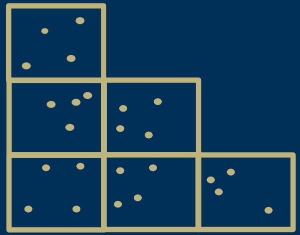
Execute simulation

← Response data ←

Surrogate models
Response = *f(design variables)*
Response = time elapsed, time on shelf, …

→

Interactive, parametric dashboard/tabletop with surrogates as backend



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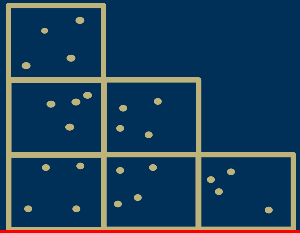
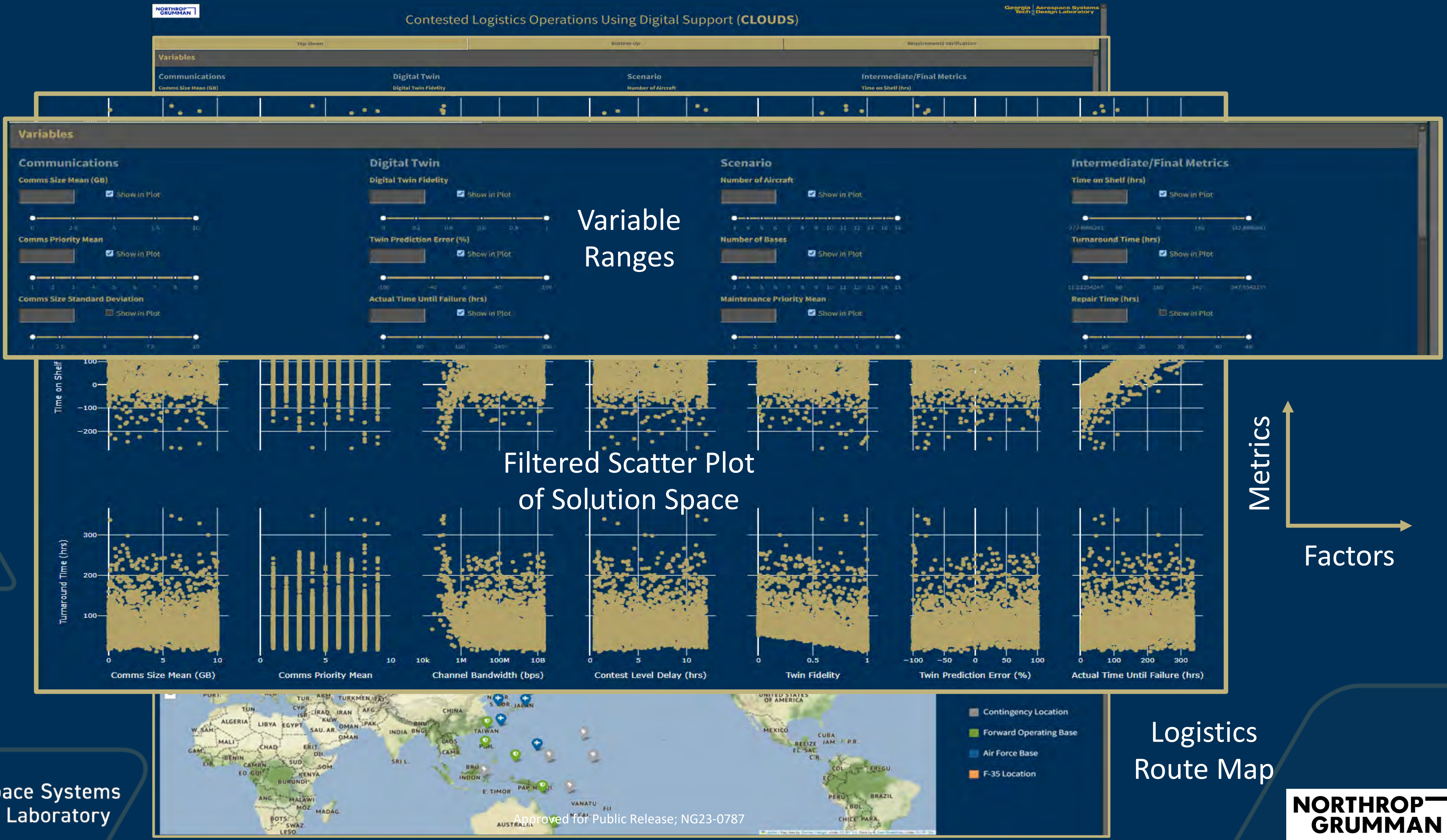


Dashboard: Top-Down Approach



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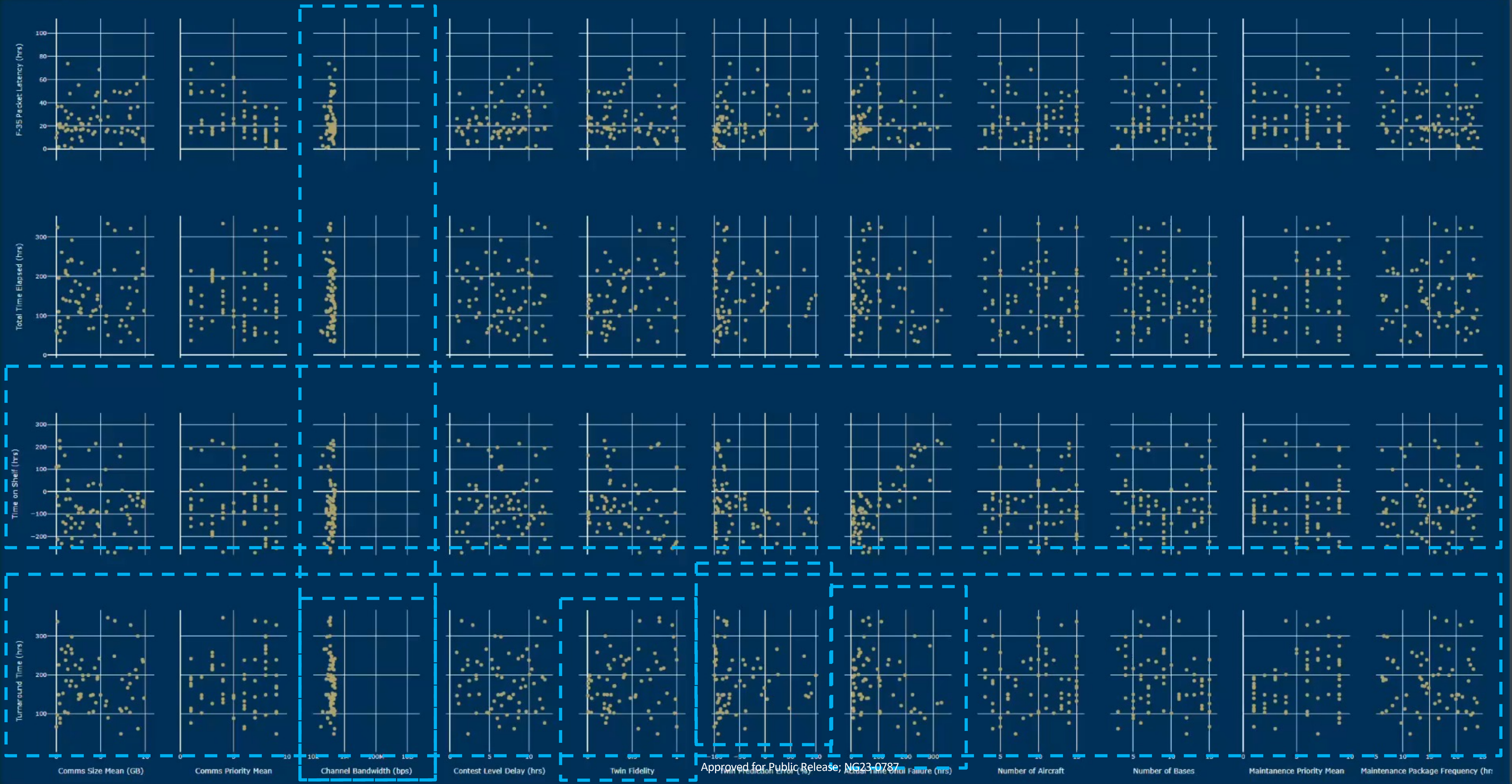
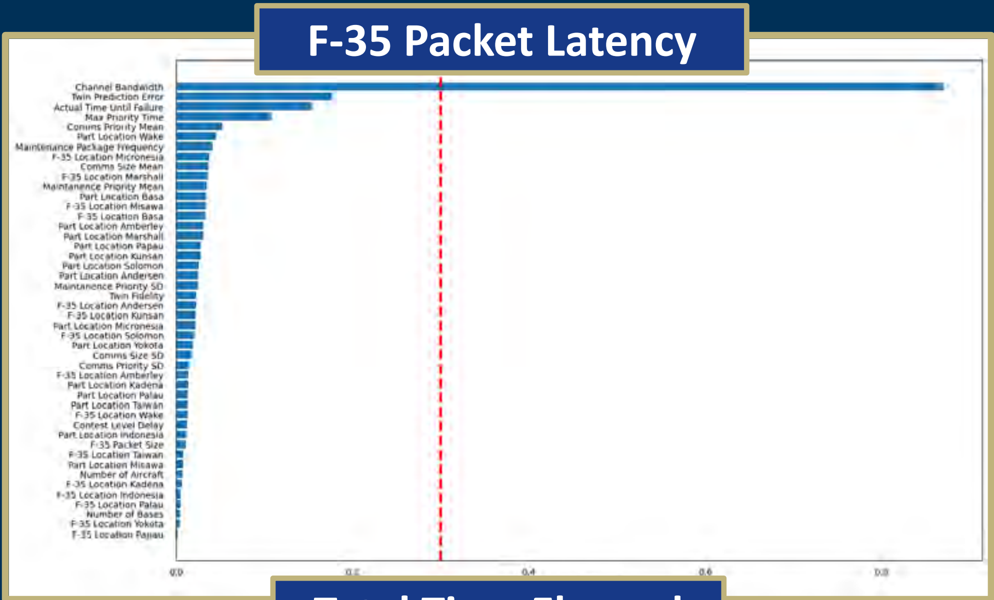
Dashboard: Bottom-Up Approach

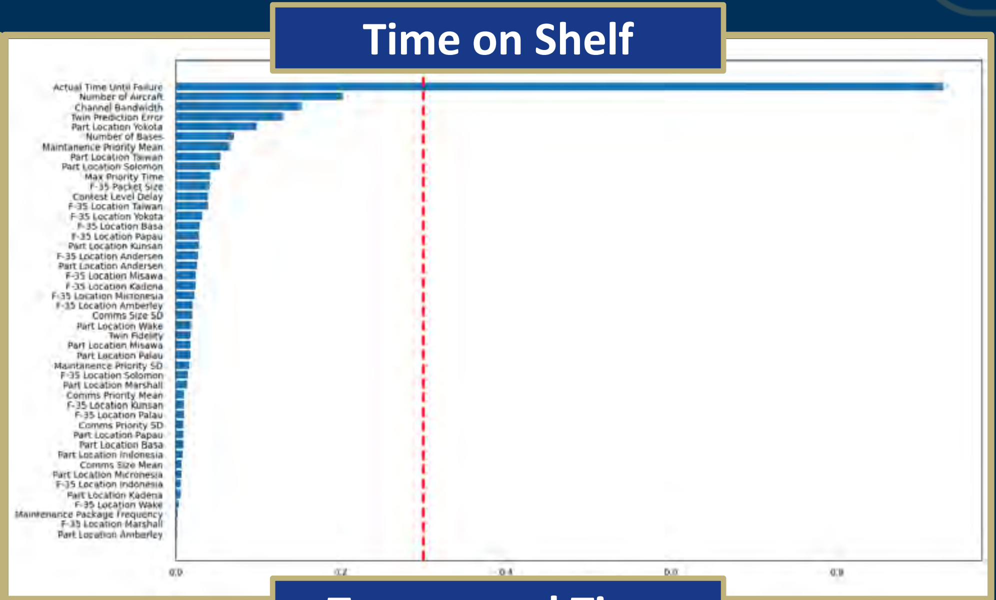
Surrogate Outputs

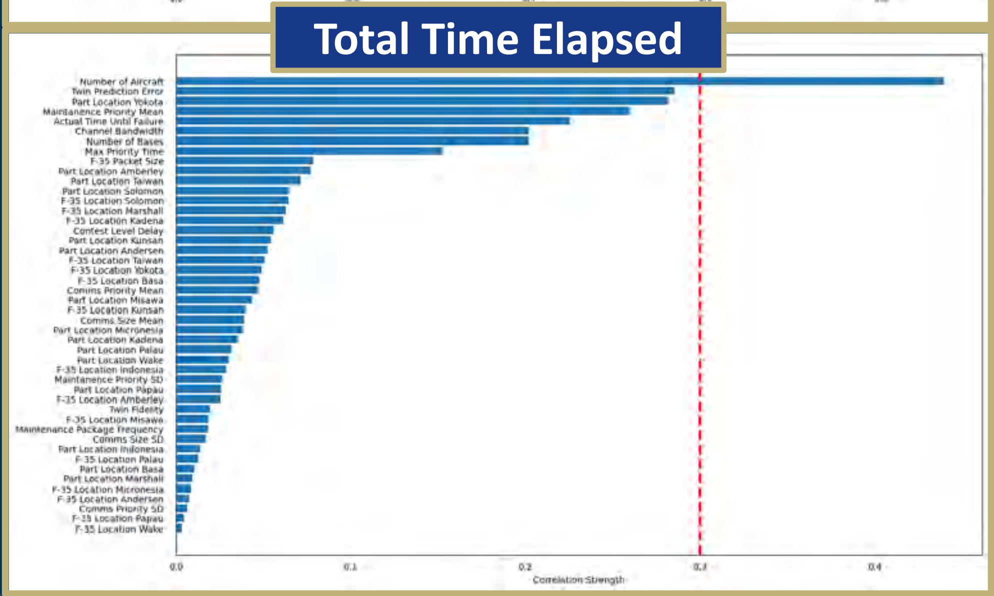
Dashboard Demonstration

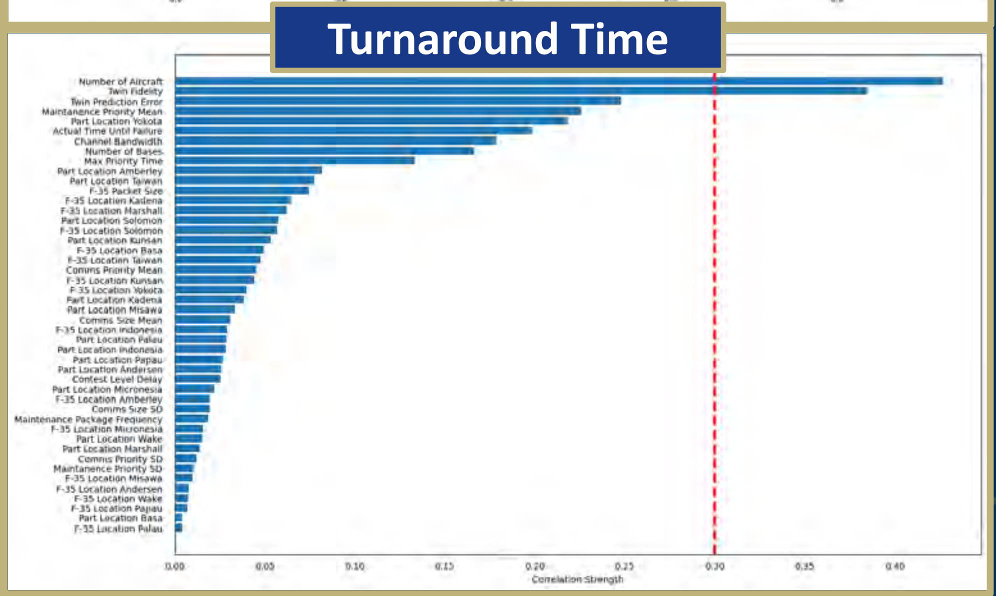


Use Cases: Significance of Factors to Metrics









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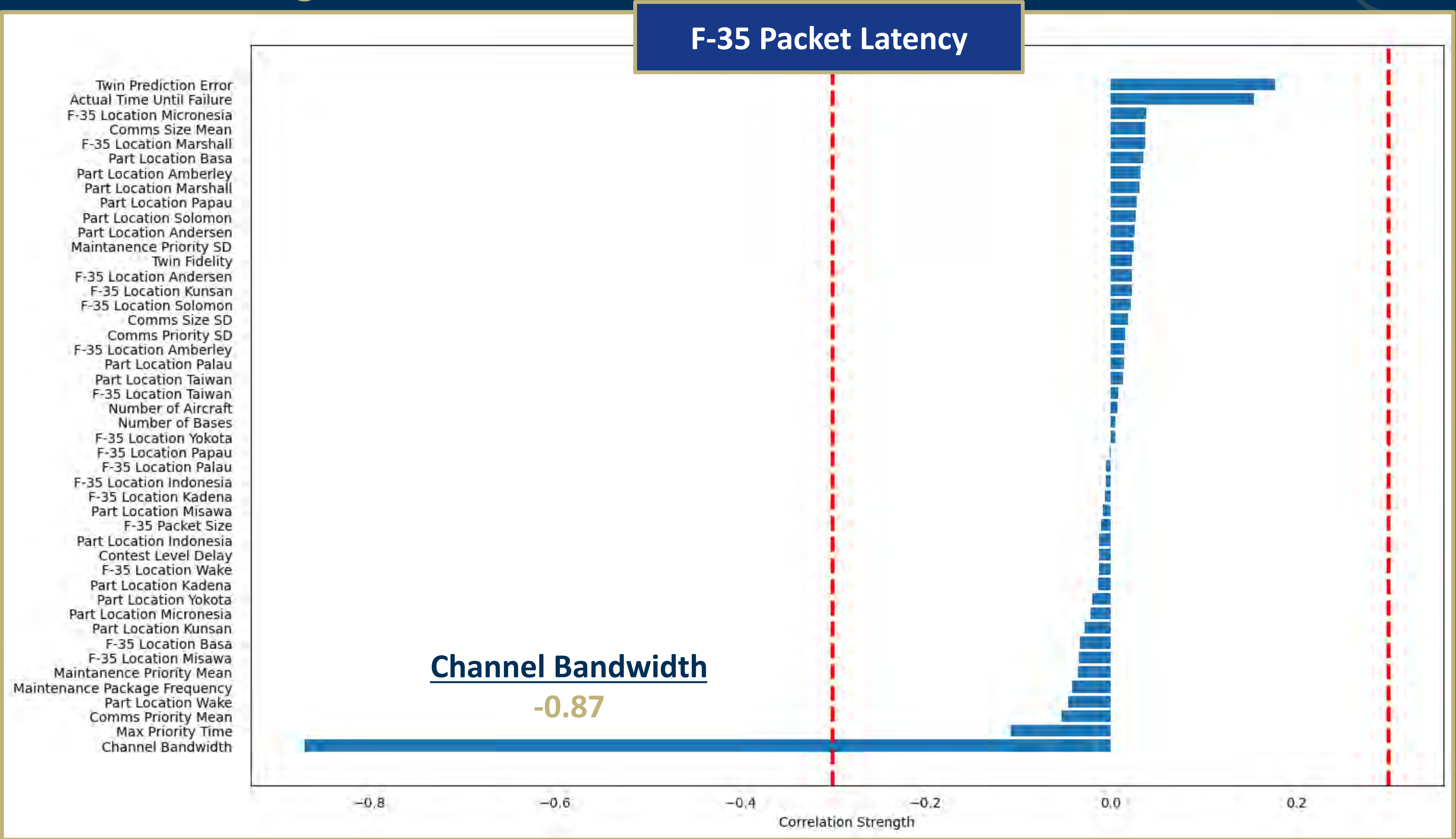

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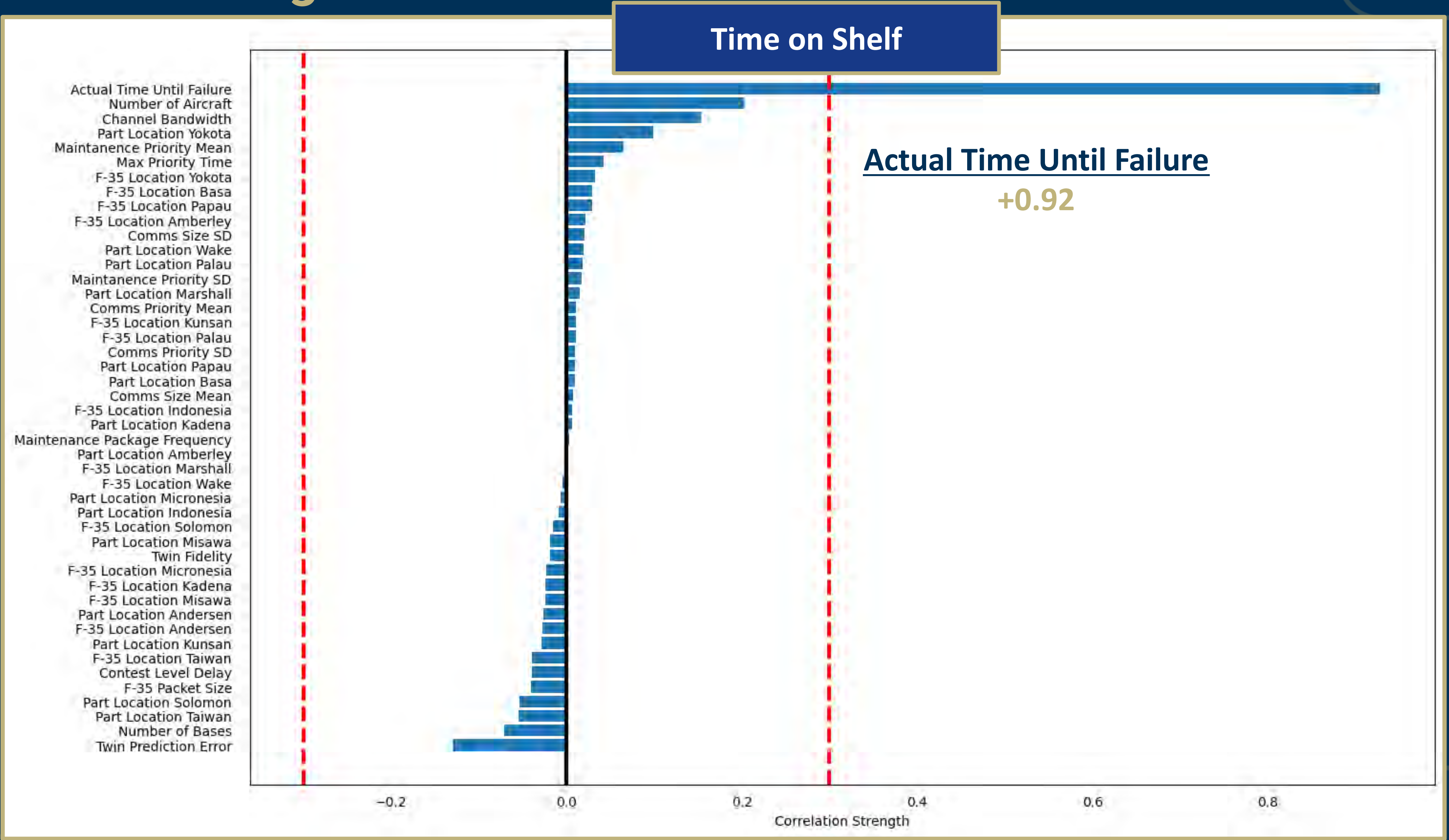
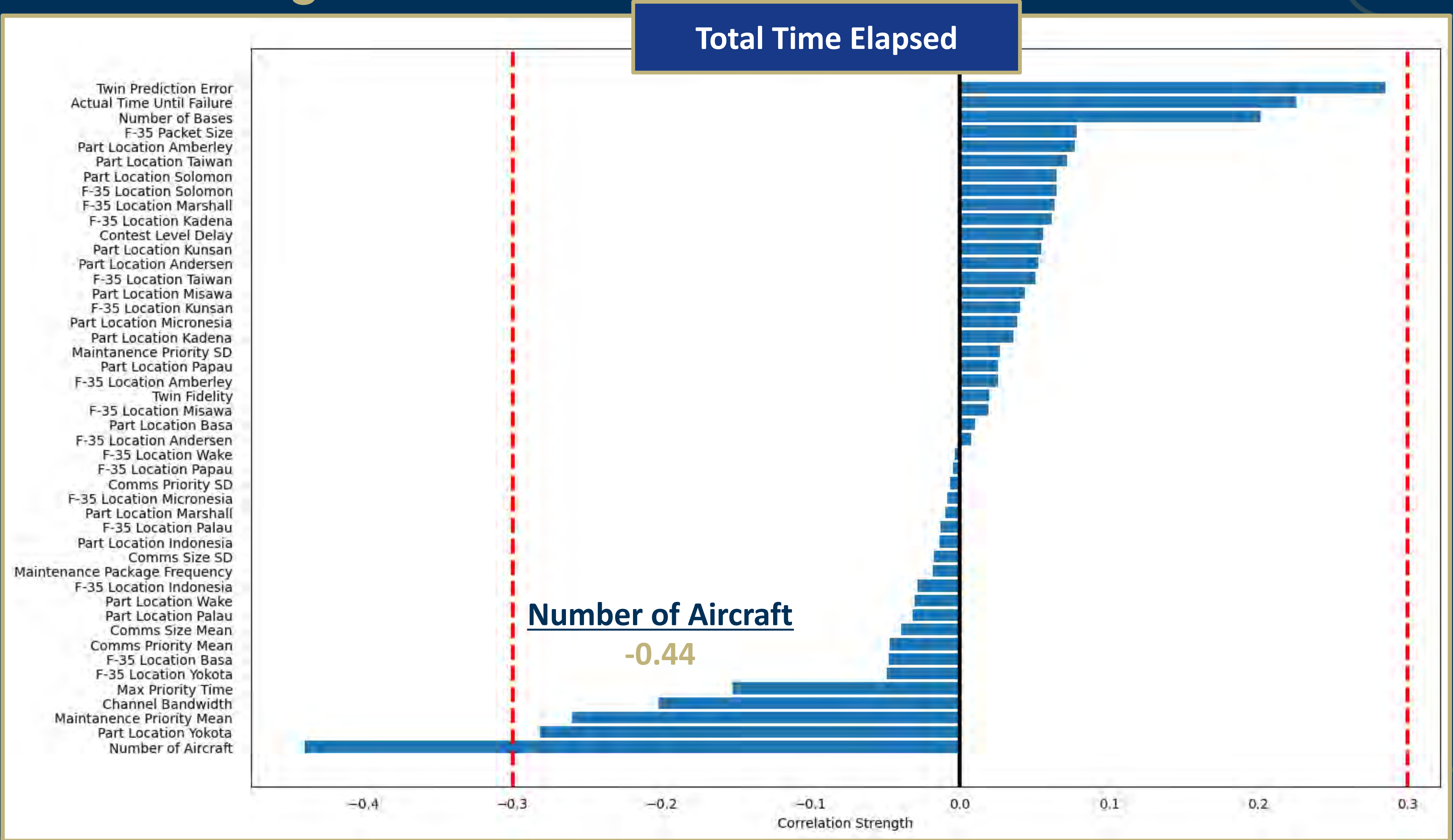


Use Cases: Significance of Factors to Metrics



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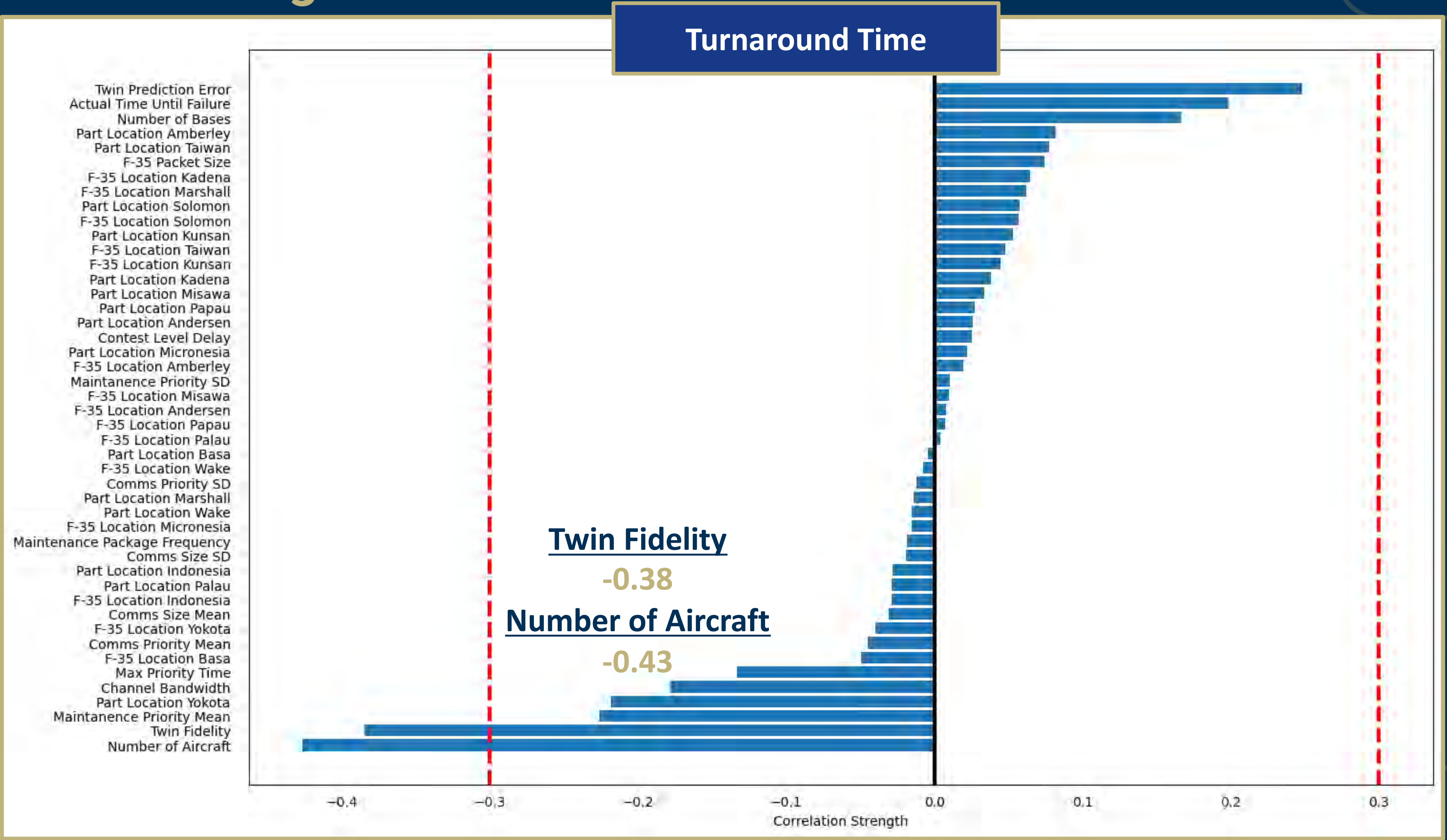


Conclusions

The Mission
Problem Formulation
Technical Approach
Use Cases
Conclusions

- Developed an interactive and parametric environment for **concurrent analysis of the impact of Communications, Digital Twin attributes**, and **Agile Combat Employment** on metrics of interest

IOWT

- For this use case, Link 16 and lower data rate systems **not adequate** in evolving domain
  - Communications bandwidth consistently highly correlated to metrics
    - Larger data rate → better time metrics
    - Composition of other packets (priority and size) not nearly as significant

DE

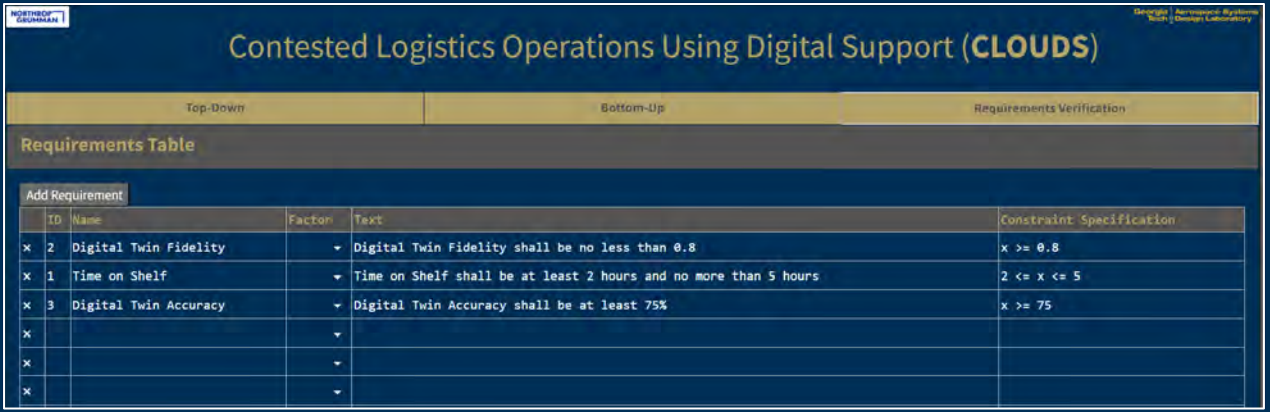
- Digital Twin prediction error (accuracy) **correlated to all metrics**
  - Larger error → more time elapsed and inconsistent predictions (affects time on shelf)
- Higher Digital Twin fidelity → faster F-35 turnaround

ACE

- Number of logistics aircraft **significant** to overall time metrics
  - More aircraft → less time elapsed
- While not as strong, number of bases correlated to time metrics
  - More bases → more time elapsed
- In low data rate situations, size of F-35 distress packet influences mission readiness
- At more demanding turnaround times (mission readiness proxy), larger data rates and Twin fidelity correspondingly required

Future Work

- Integrate Digital Twin capabilities of component (e.g., engine)
  - Dynamic decision-making (DDM) [22]
  - Digital Twin considerations: operational history, performance, health, environment
- Leverage capabilities of Ansys System Toolkit (STK):
  - Dynamic route visualization
  - Information from built-in assets
- Link requirements set to dashboard for verification
- Impact on Digital Environment (compute power required, zero trust)



Contested Logistics Operations Using Digital Support (**CLOUDS**)

Top-Down | Bottom-Up | Requirements Verification

Requirements Table

Add Requirement

	ID	Name	Factor	Text	Constraint Specification
×	2	Digital Twin Fidelity		Digital Twin Fidelity shall be no less than 0.8	x >= 0.8
×	1	Time on Shelf		Time on Shelf shall be at least 2 hours and no more than 5 hours	2 <= x <= 5
×	3	Digital Twin Accuracy		Digital Twin Accuracy shall be at least 75%	x >= 75
×					
×					
×					

Thank you

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School of Aerospace Engineering | Georgia Institute of Technology

Aerospace Systems Design Laboratory

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