SoSECIE Webinar

Welcome to the
2021 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

NDIA National Defense Industrial Association

MITRE

We will start at 11AM Eastern Time

You can download today's presentation from the SoSECIE Website:

https://mitre.tahoe.appsembler.com/blog

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
    - I will start with questions submitted online via the CHAT window in Teams.
    - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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May 4, 2021
OUSD R&E: USD(R&E) Mission Engineering (ME) State of Practice
Elmer L. Roman

May 18, 2021
Application of Probabilistic Graph Models to Kill Chain and Multi-Domain Kill Web Analysis Problems
Jason Baker and Valerie Sitterle

June 1, 2021
Applying an MBSE Approach for Evaluating Shipyard Operations
David Jurkiewicz

June 15, 2021
Implementing a Digital Engineering Environment for Mission Engineering
Jason Anderson and Jeffrey Boulware

https://www.mitre.org/capabilities/systems-engineering/collaborations/system-of-systems-engineering-collaborators

2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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June 29, 2021
Digital Engineering: From Toolchain to Platform
Dr. Aleksandra Markina-Khusid

July 13, 2021
Developing Meta Systems Architectures for Leading Innovation with Complex Societal and Technical Challenges
Dr. Cihan Dagli

July 27, 2021
Advancements Towards a Digital Approach for Mission Engineering
Todd Shayler and Daniel Browne

https://www.mitre.org/capabilities/systems-engineering/collaborations/system-of-systems-engineering-collaborators

Leveraging Set-Based Practices to Enable Efficient Concurrency in Large Systems and Systems-of-Systems Engineering

Brian M. Kennedy
CTO
Targeted Convergence Corporation

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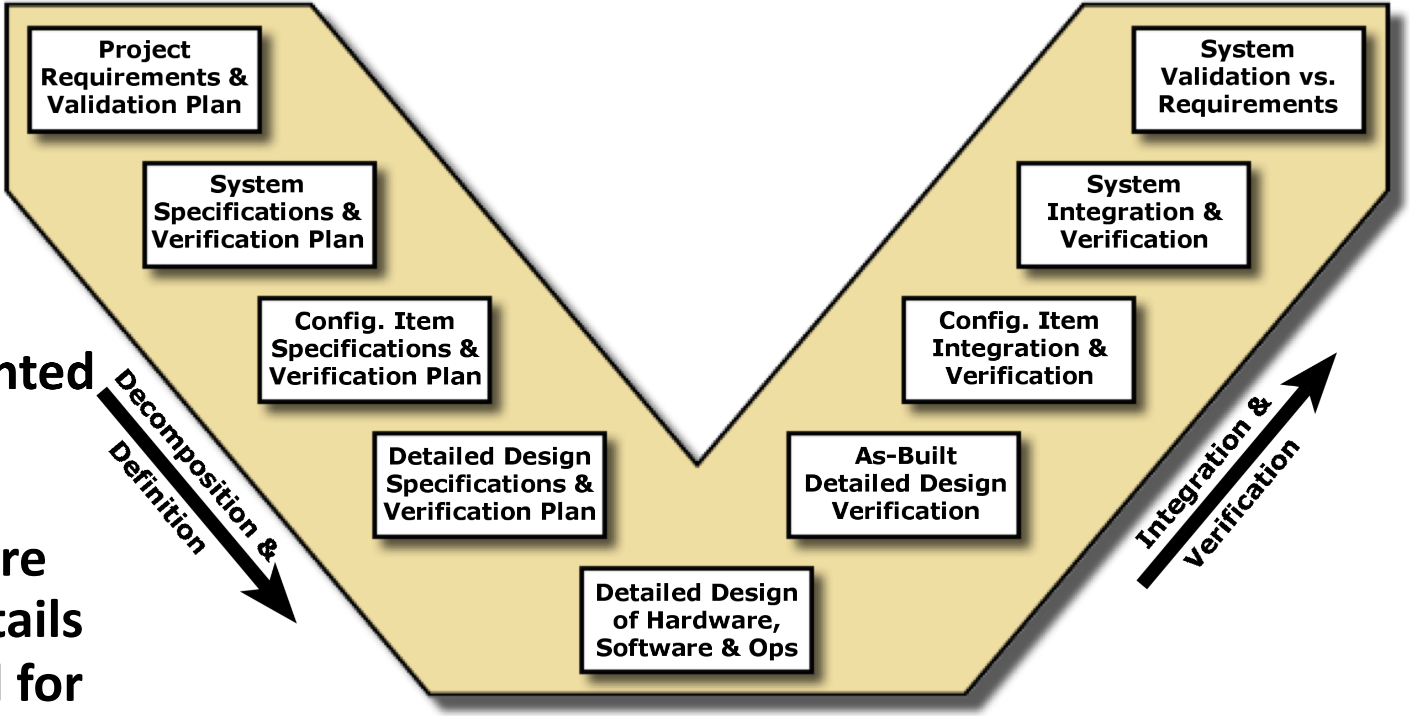
The Systems Development Process is often depicted as a "V"…



… but even the paper that originally presented the "V" model emphasized there were critical details that are needed for this to work…

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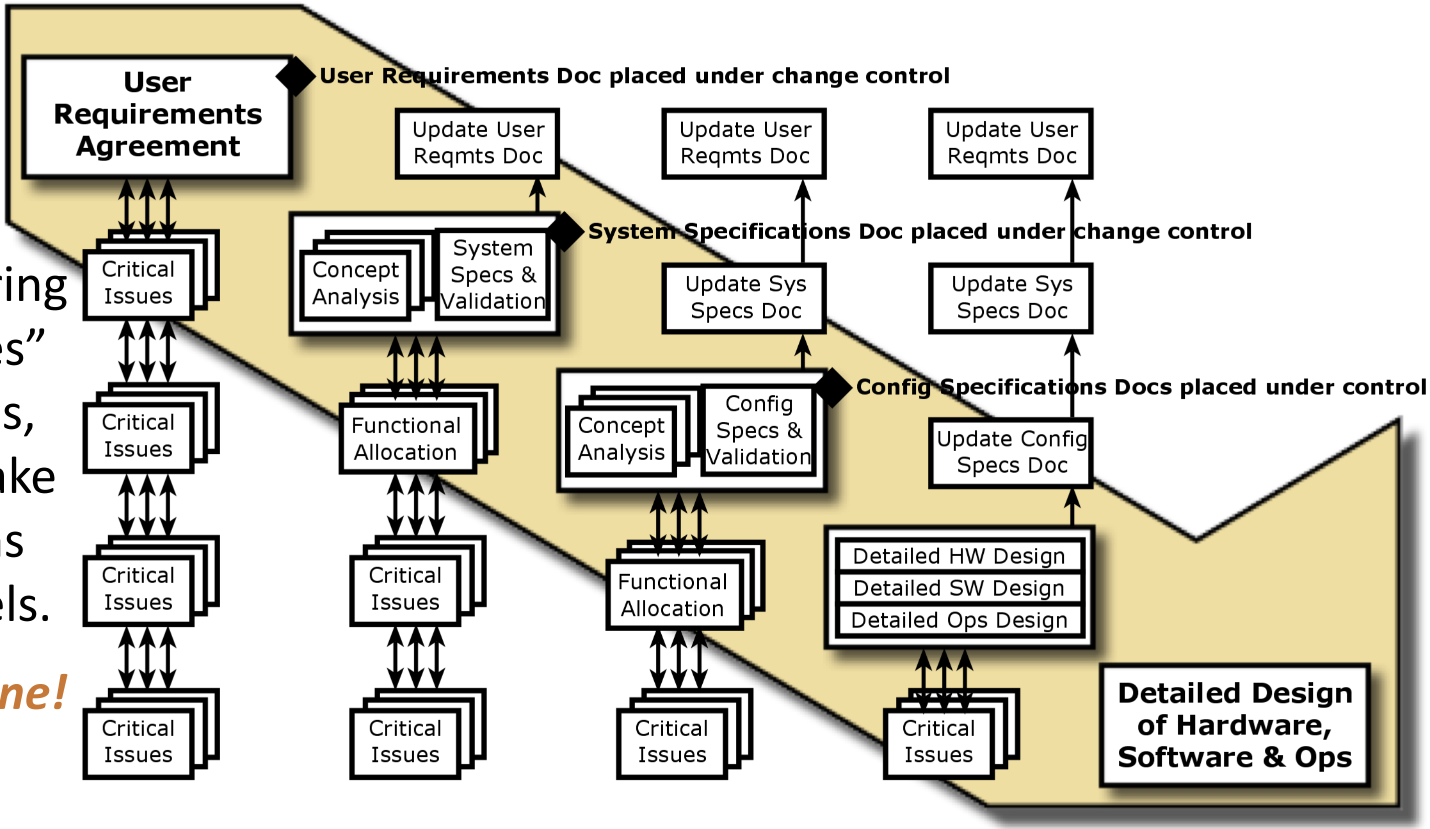
There is critical work that must be done concurrently…



Without considering the "Critical Issues" at the lower levels, you can easily make very bad decisions at the higher levels.

Easier said than done!

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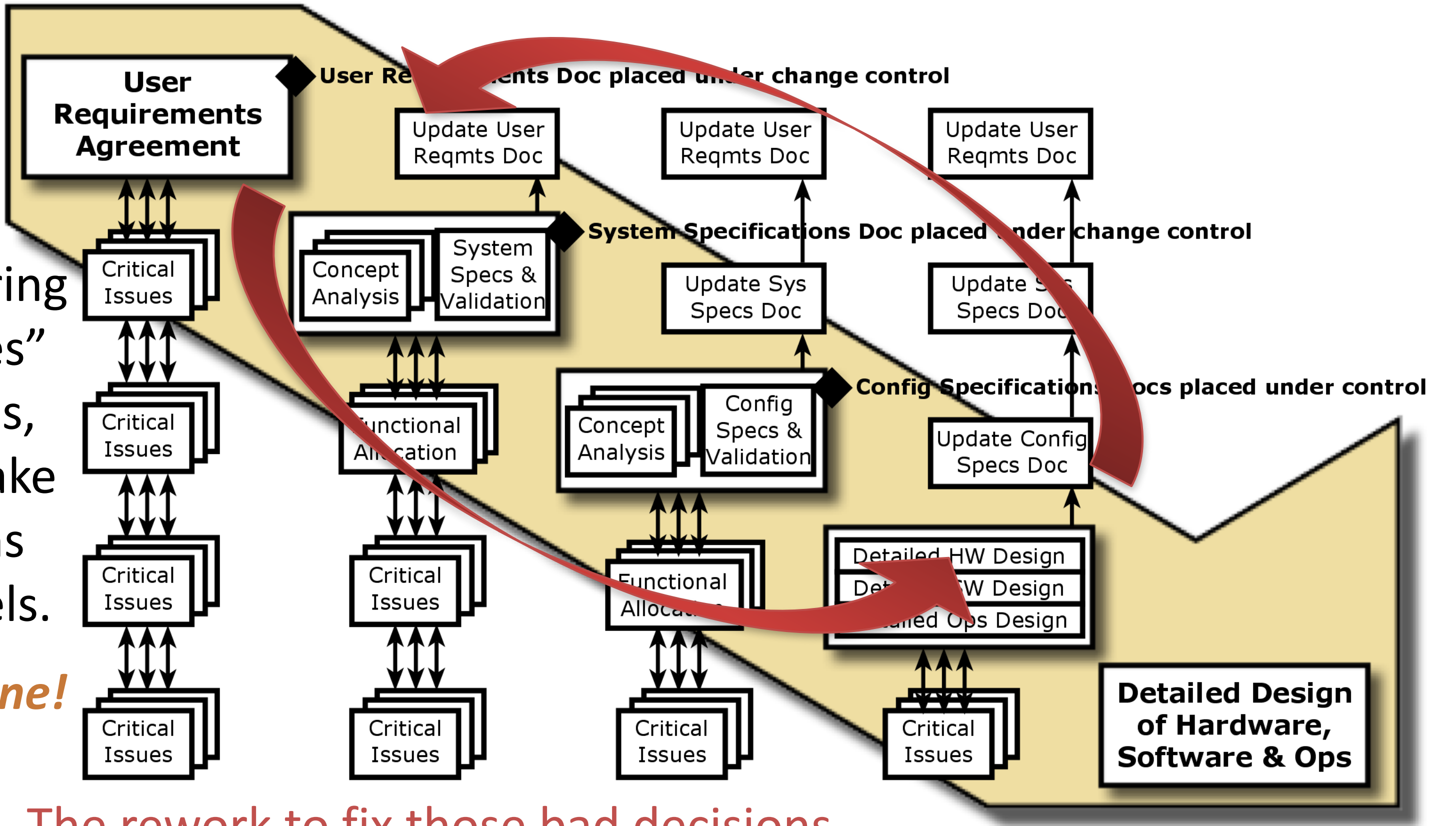
There is critical work that must be done concurrently…



Without considering the "Critical Issues" at the lower levels, you can easily make very bad decisions at the higher levels.

Easier said than done!

The rework to fix those bad decisions tends to be extremely expensive!

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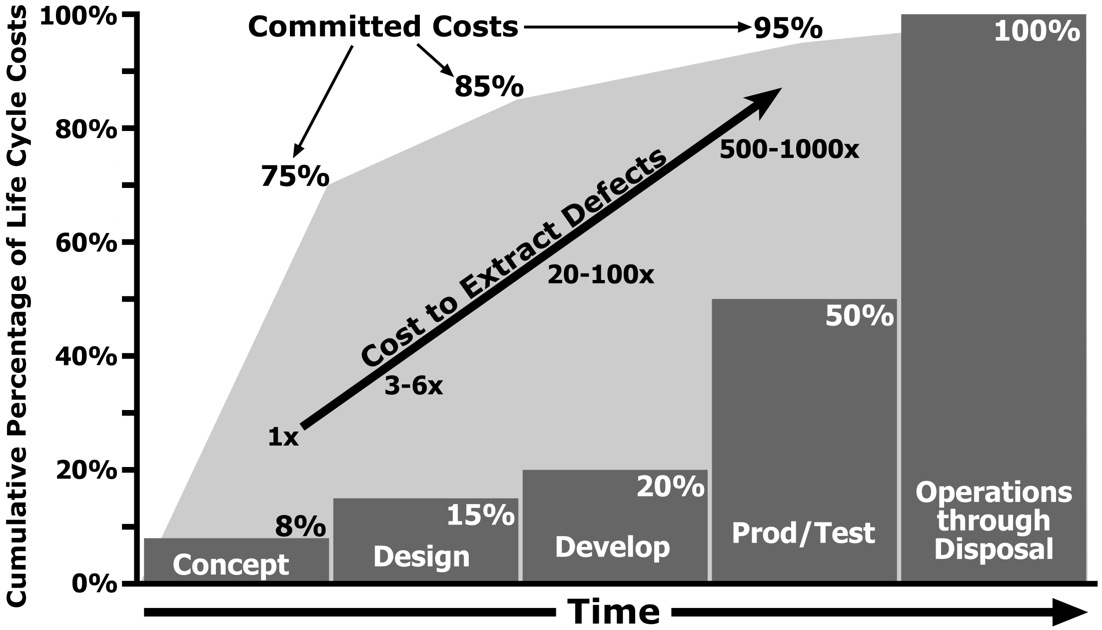
Studies have shown that Rework can Cost 10x, 100x, or even 1000x!

- This chart is from INCOSE's Systems Eng. Handbook (which credits Defense Acq. Univ.)



- Many companies report 65-75% of their engineering capacity is consumed by rework (revising things that they thought were final)
- Just eliminate that alone and you have a 3X-4X productivity boost!

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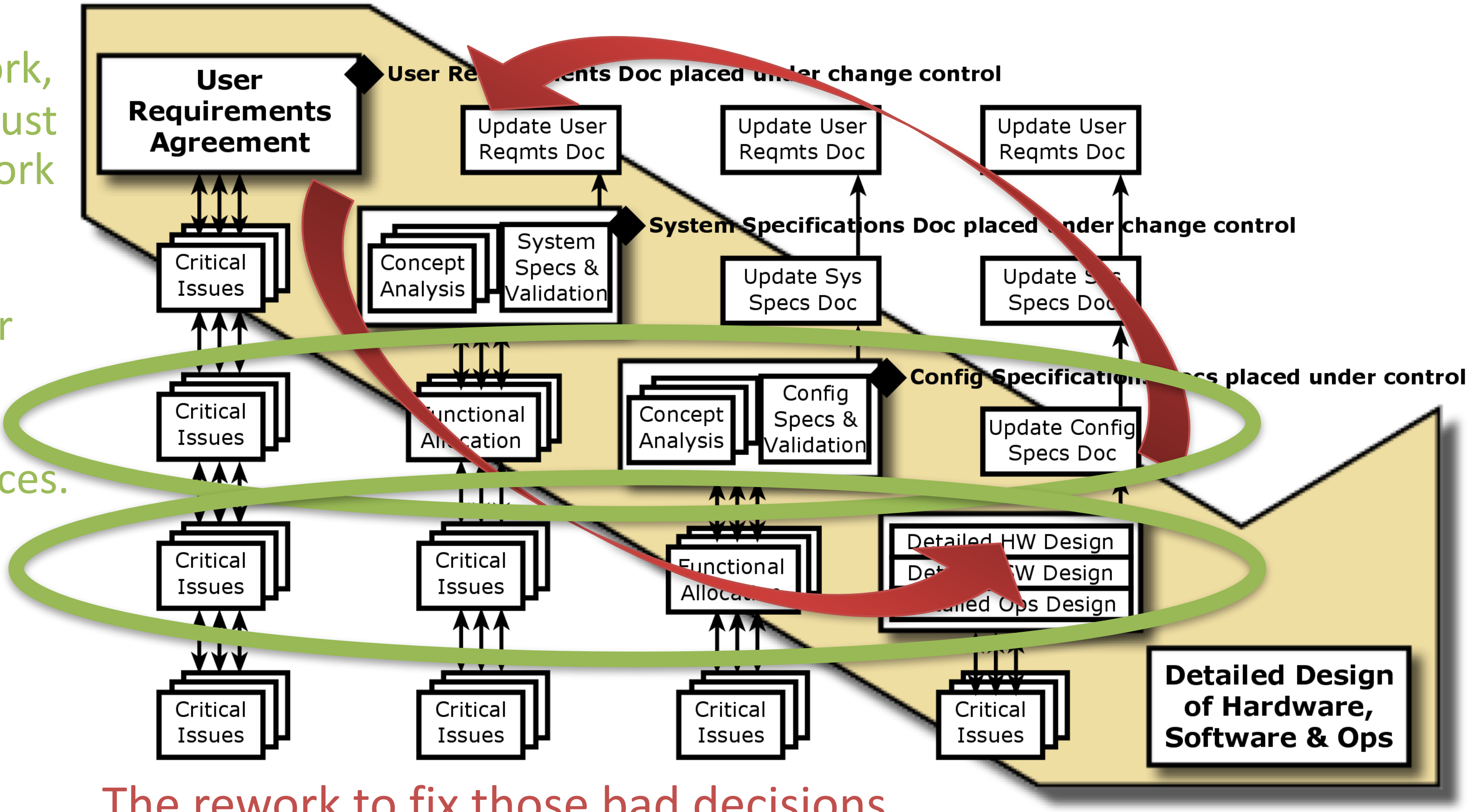
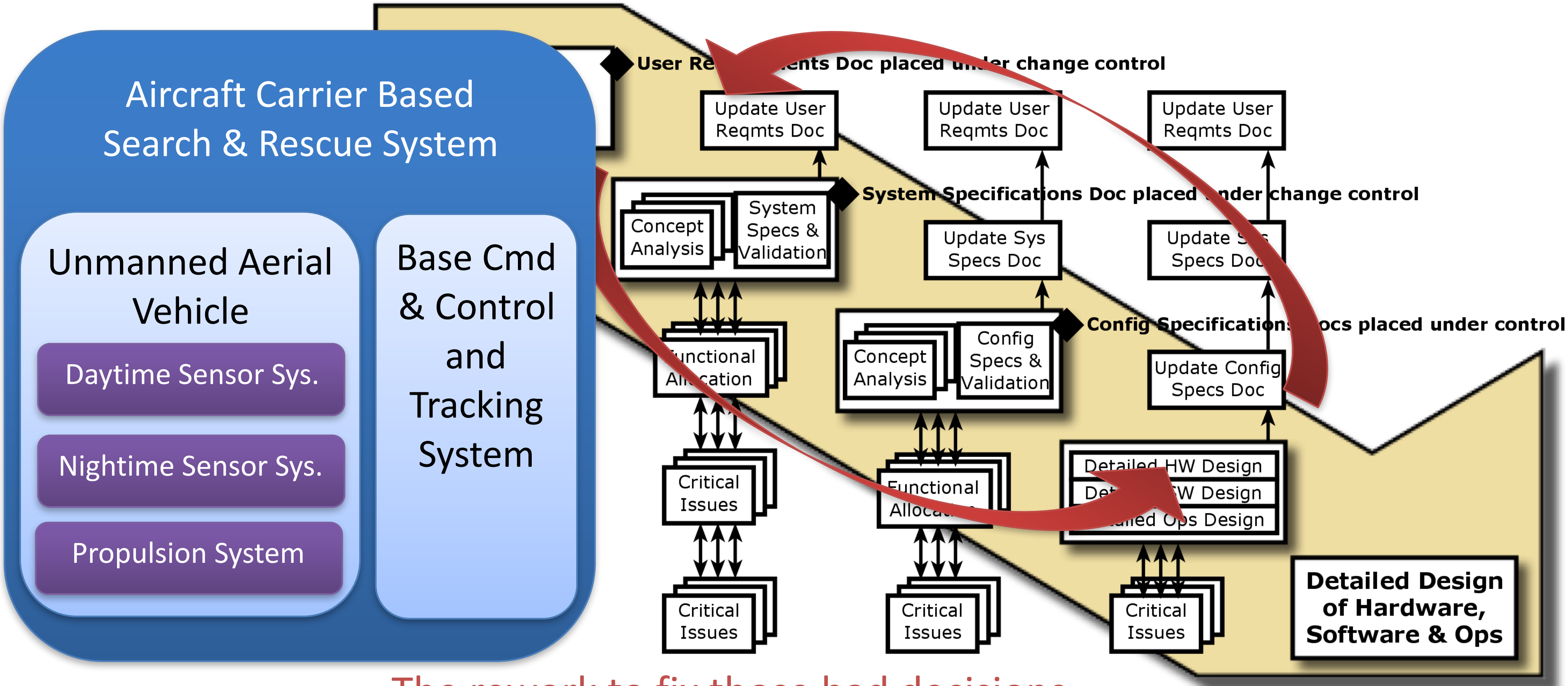
There is critical work that must be done concurrently…

To avoid that rework, the lower levels must do that analysis work with much uncertainty… and hence the need for "Set-Based" Concurrent Engineering practices.



The rework to fix those bad decisions tends to be extremely expensive!

In the case of Systems of Systems…



The rework to fix those bad decisions tends to be extremely expensive!

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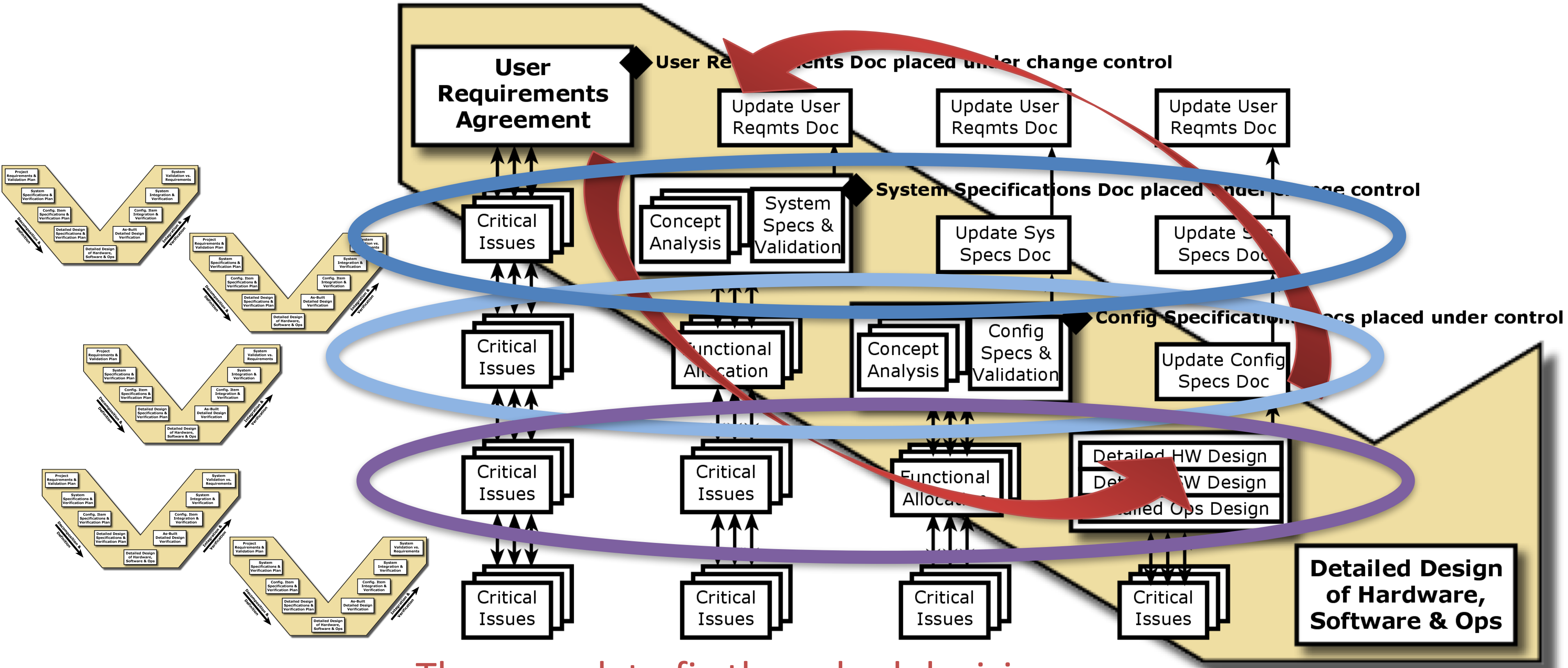
In the case of Systems of Systems, there are “V”s at those lower levels…



The rework to fix those bad decisions tends to be ***even more*** expensive!

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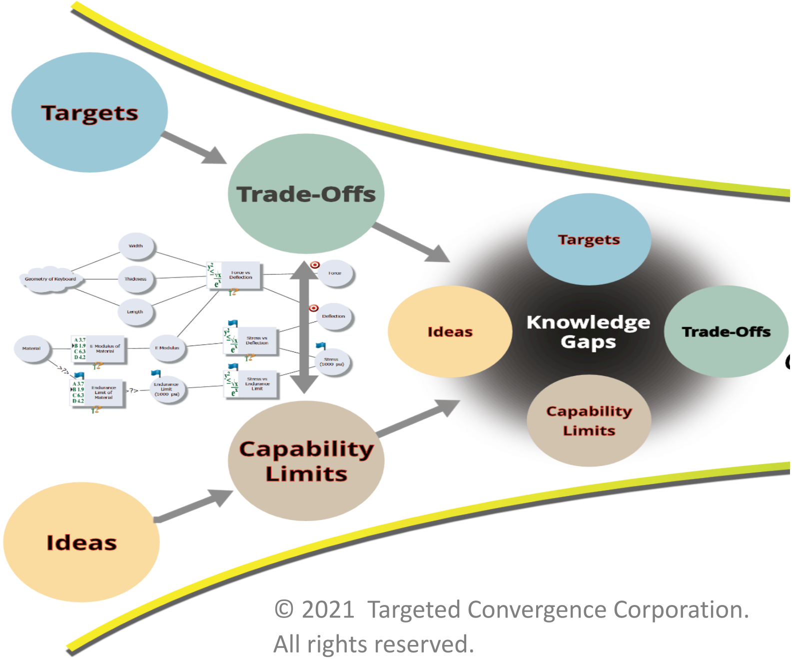
The Set-Based practices start with what we tend to know…

- We start with the Targets… not really "the Requirements" (those are decisions we need to delay until we have all the knowledge)
- Our engineers will have lots of Ideas on how to achieve those Targets
- We then use those Ideas to identify the Capability Limits we will likely run into trying to implement those Ideas in order to satisfy those Targets
- Those Capability Limits will force us to make Trade-Offs between competing Targets
- Knowledge of those Trade-Offs will be needed to make the right decisions on which Ideas and the ultimate Requirements



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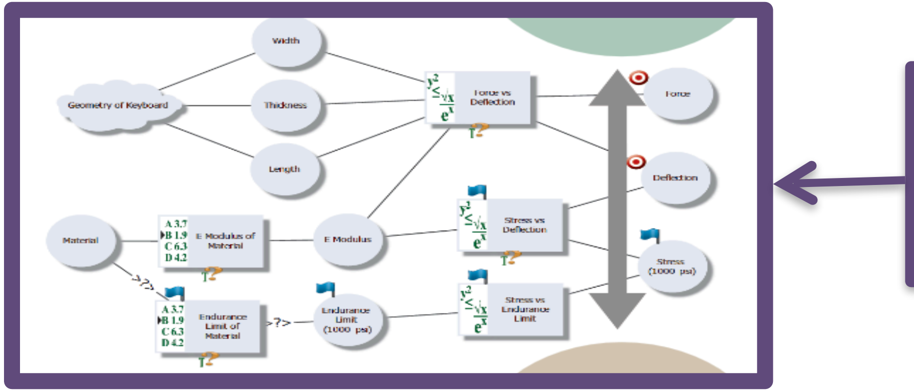
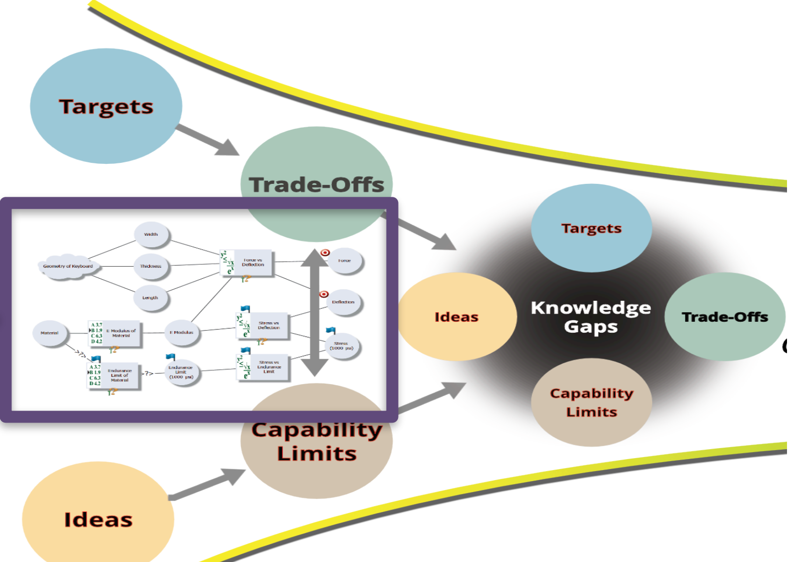
We use Visual Models to Identify the Key Knowledge Gaps…

- To identify those Knowledge Gaps, we use a Causal Map to map out what we know about the Capability Limits to how they impact the Targets, exposing what we need to know to compute the Trade-Offs
- Causal Maps are very simple visual models (just 4 shapes to learn) such that you can pull in experts from many different disciplines with no training





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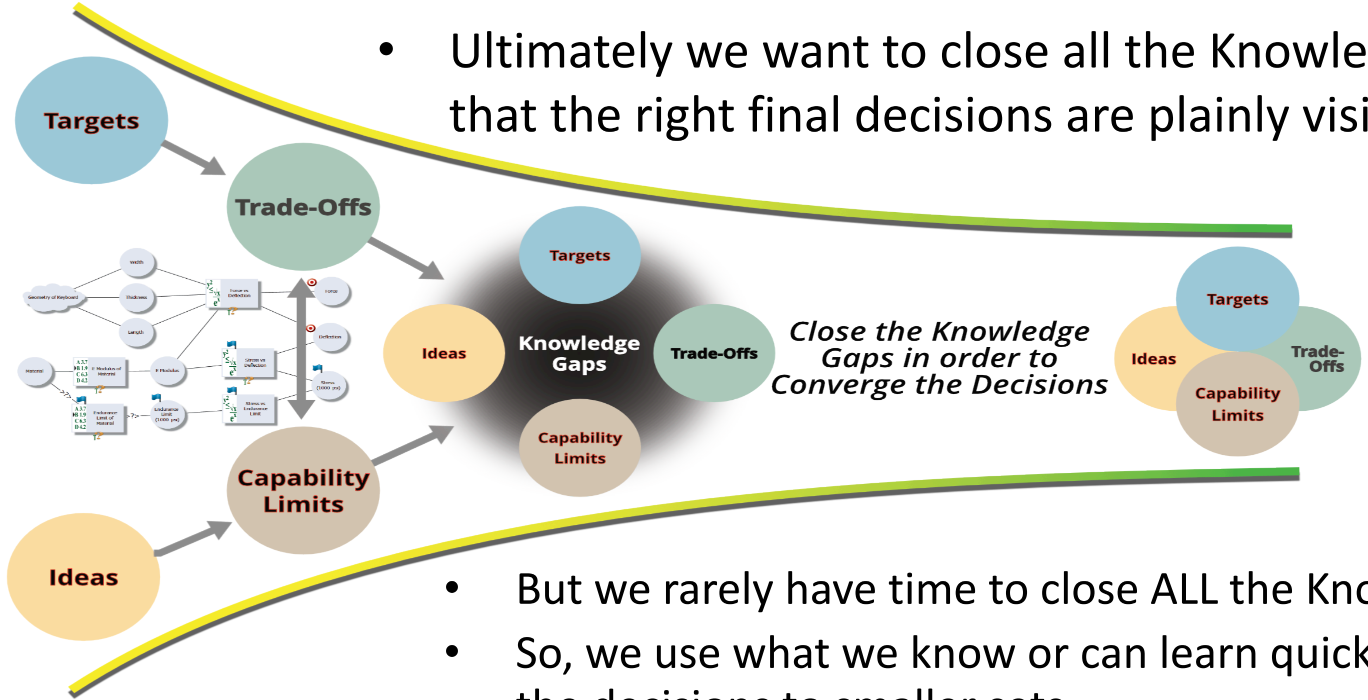
Use the Key Decisions to Prioritize & Pull the Required Knowledge

- Ultimately we want to close all the Knowledge Gaps such that the right final decisions are plainly visible



- But we rarely have time to close ALL the Knowledge Gaps
- So, we use what we know or can learn quickly to converge some of the decisions to smaller sets, …
- And then focus on learning in just that smaller portion of the design space (i.e., efficiency from “eliminating the weak”)

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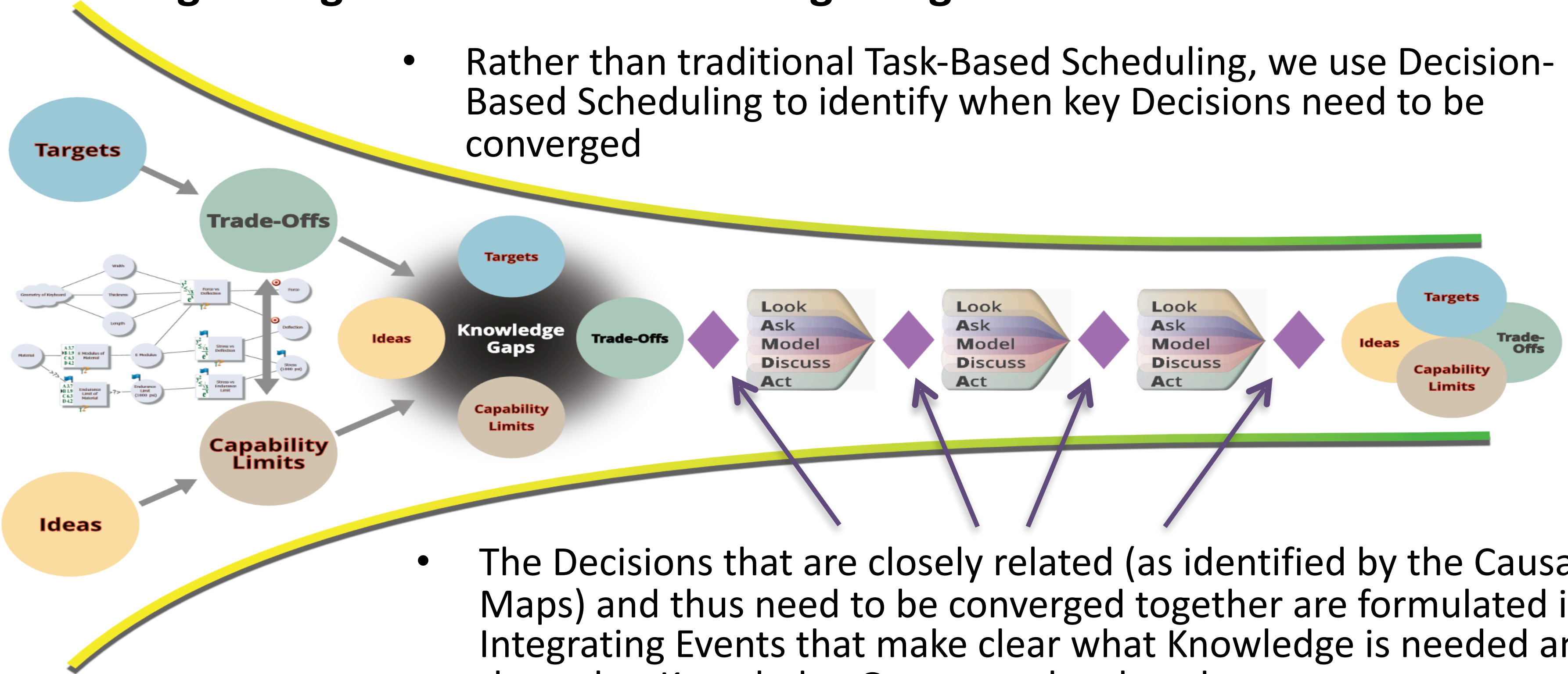
… Organizing the Decisions into Integrating Events…

- Rather than traditional Task-Based Scheduling, we use Decision-Based Scheduling to identify when key Decisions need to be converged



- The Decisions that are closely related (as identified by the Causal Maps) and thus need to be converged together are formulated into Integrating Events that make clear what Knowledge is needed and thus what Knowledge Gaps must be closed

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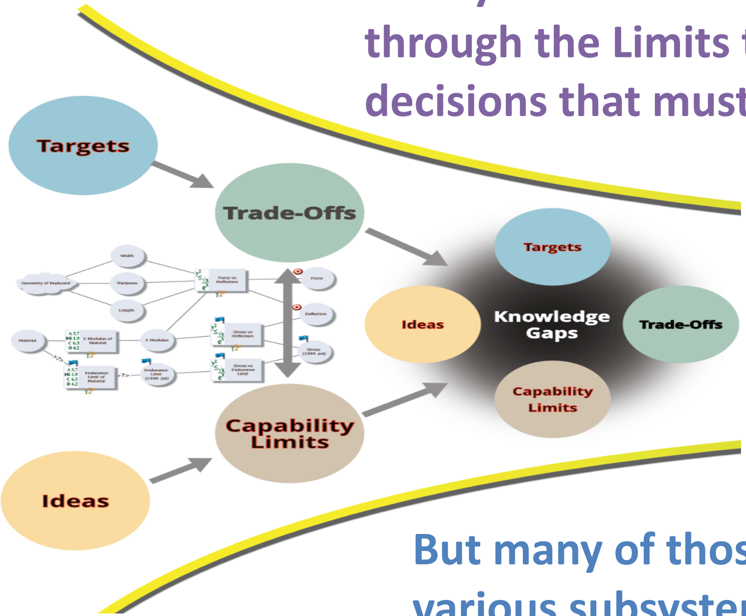
But that must be Coordinated across Subsystem Teams…

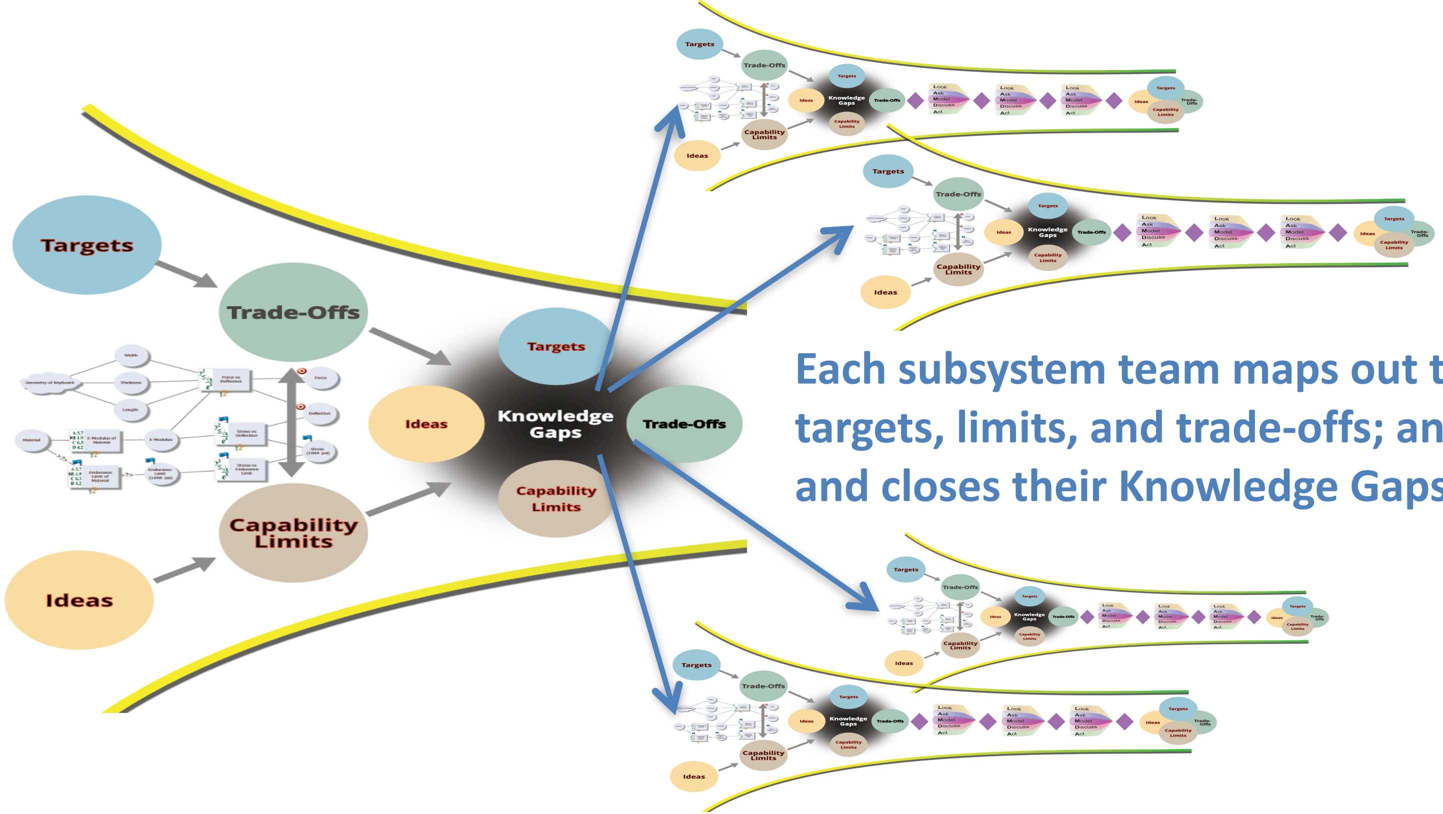
The System team maps the Targets and Ideas through the Limits to identify the Trade-Off decisions that must be made…



and identify the Knowledge Gaps that need to be closed to establish that “Success is Assured”.

But many of those Knowledge Gaps may require the expertise of various subsystem teams (some in suppliers’ organizations)…

But that must be Coordinated across Subsystem Teams…



Each subsystem team maps out their subsystem targets, limits, and trade-offs; and then identifies and closes their Knowledge Gaps.

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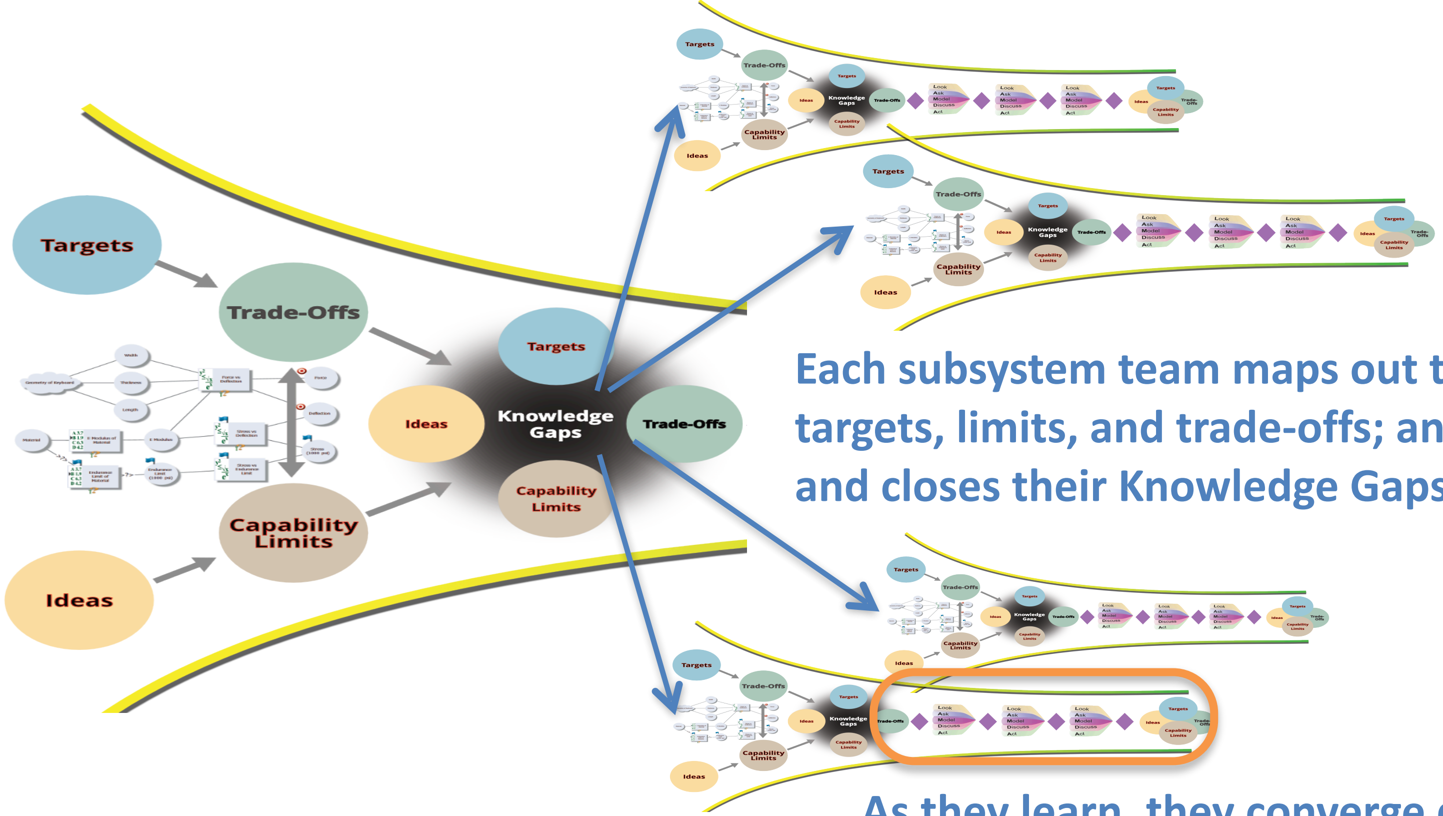
But that must be Coordinated across Subsystem Teams…



Each subsystem team maps out their subsystem targets, limits, and trade-offs; and then identifies and closes their Knowledge Gaps.

As they learn, they converge decisions that may impact others' design spaces.

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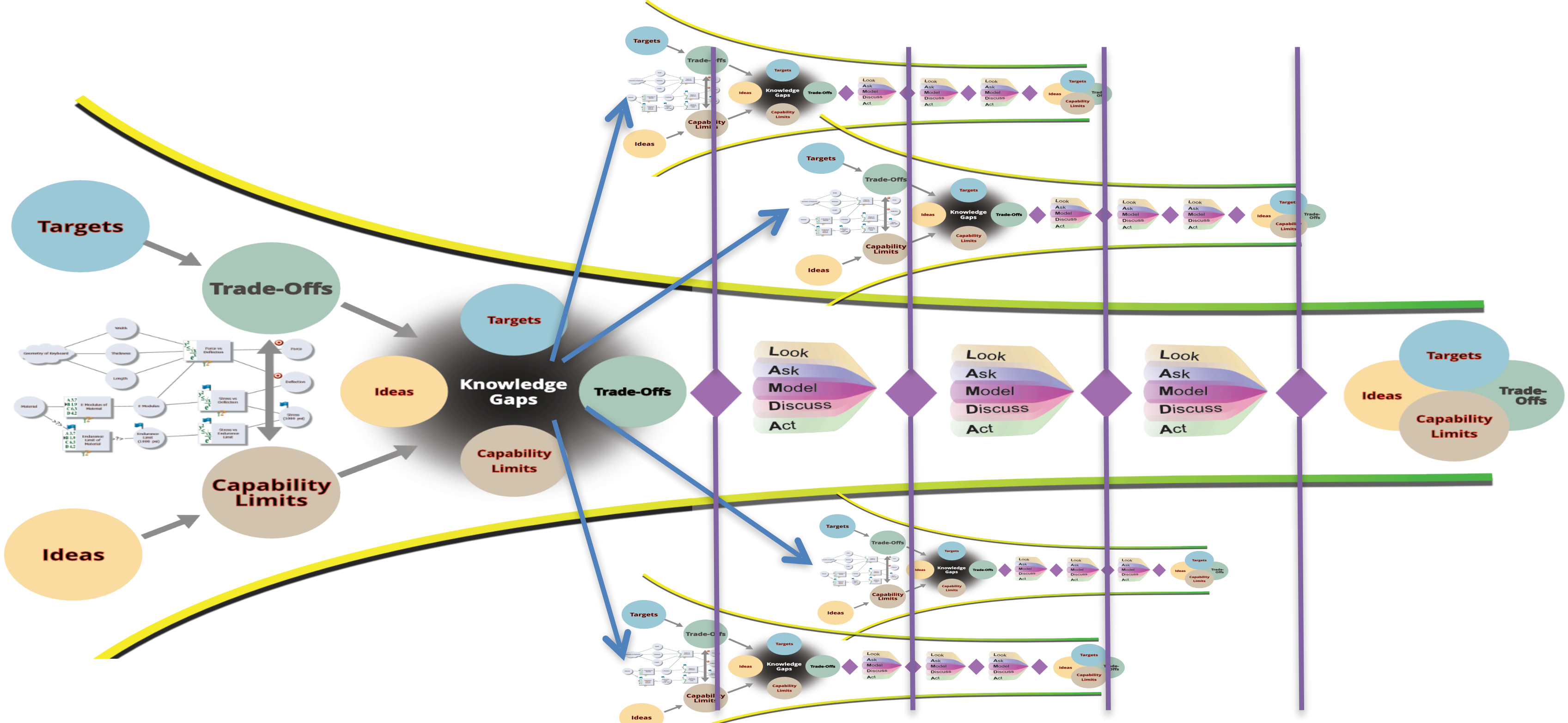
But that must be Coordinated across Subsystem Teams…



The system team collects the learning across the subsystems, makes system decisions, and communicates those to other teams.

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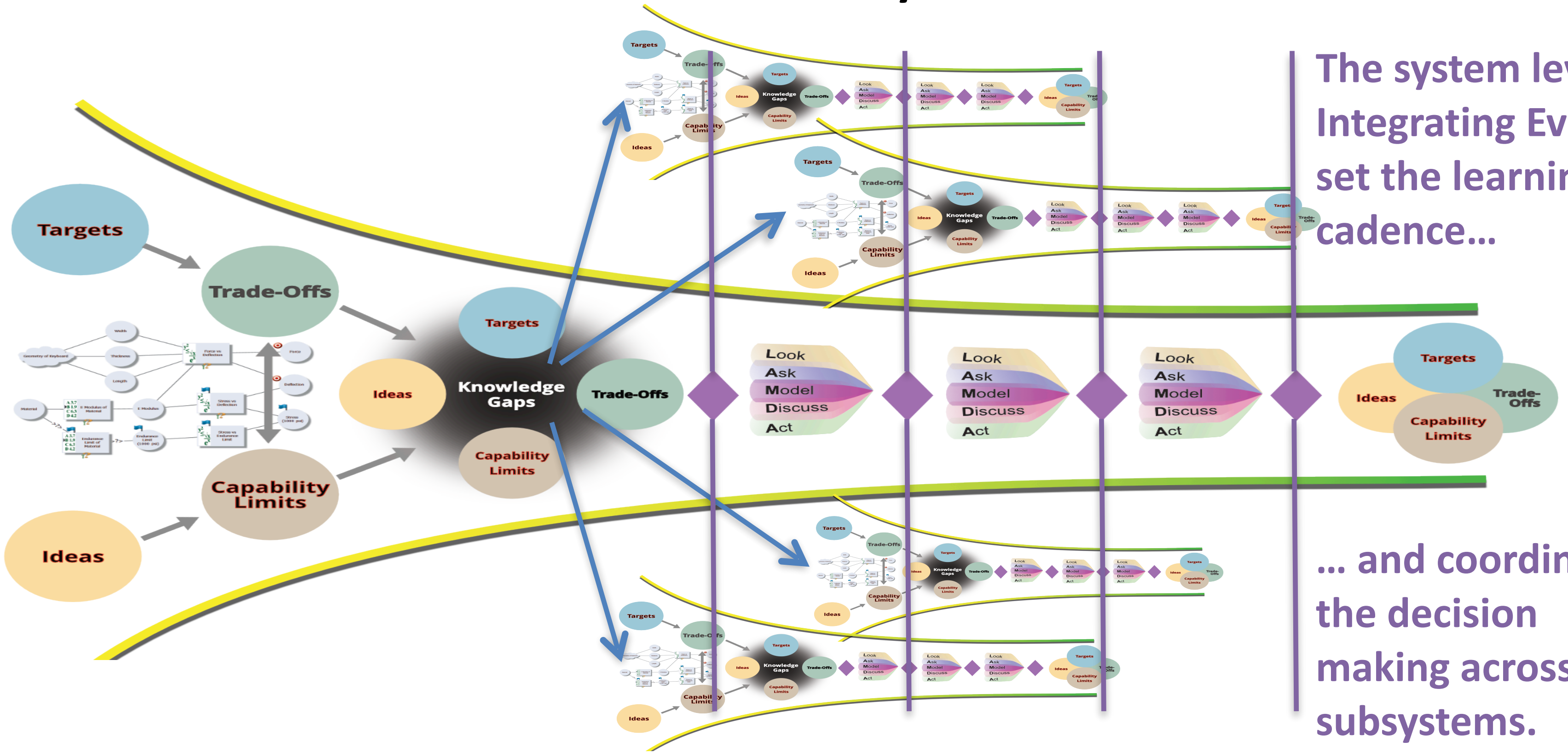
But that must be Coordinated across Subsystem Teams…



The system level Integrating Events set the learning cadence…

… and coordinate the decision making across the subsystems.

** Integrating Events are NOT the same as program milestones, but may be pulled by them.*

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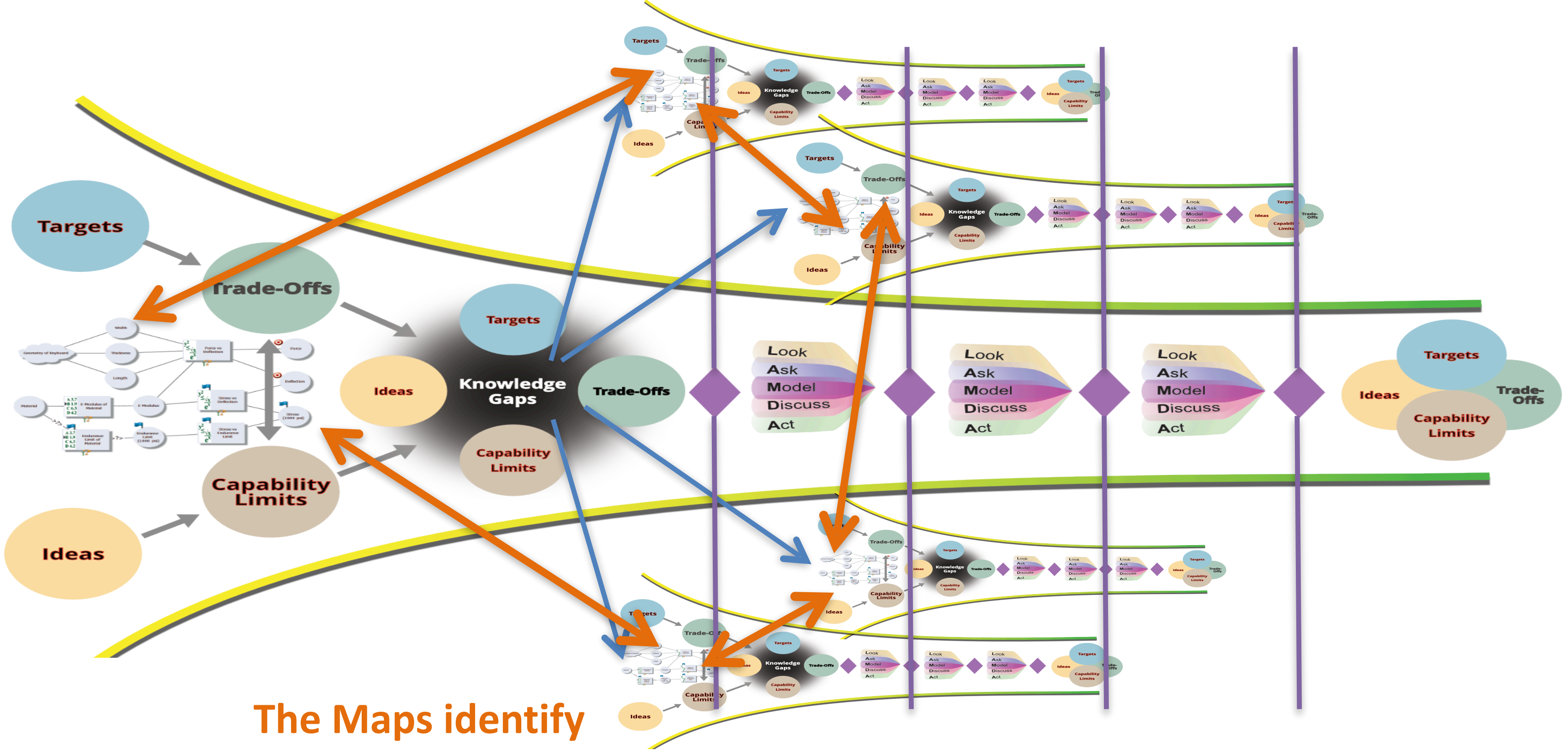
But that must be Coordinated across Subsystem Teams…



The Maps identify
the "Interface Decisions" that are shared
across teams, calling for collaboration.

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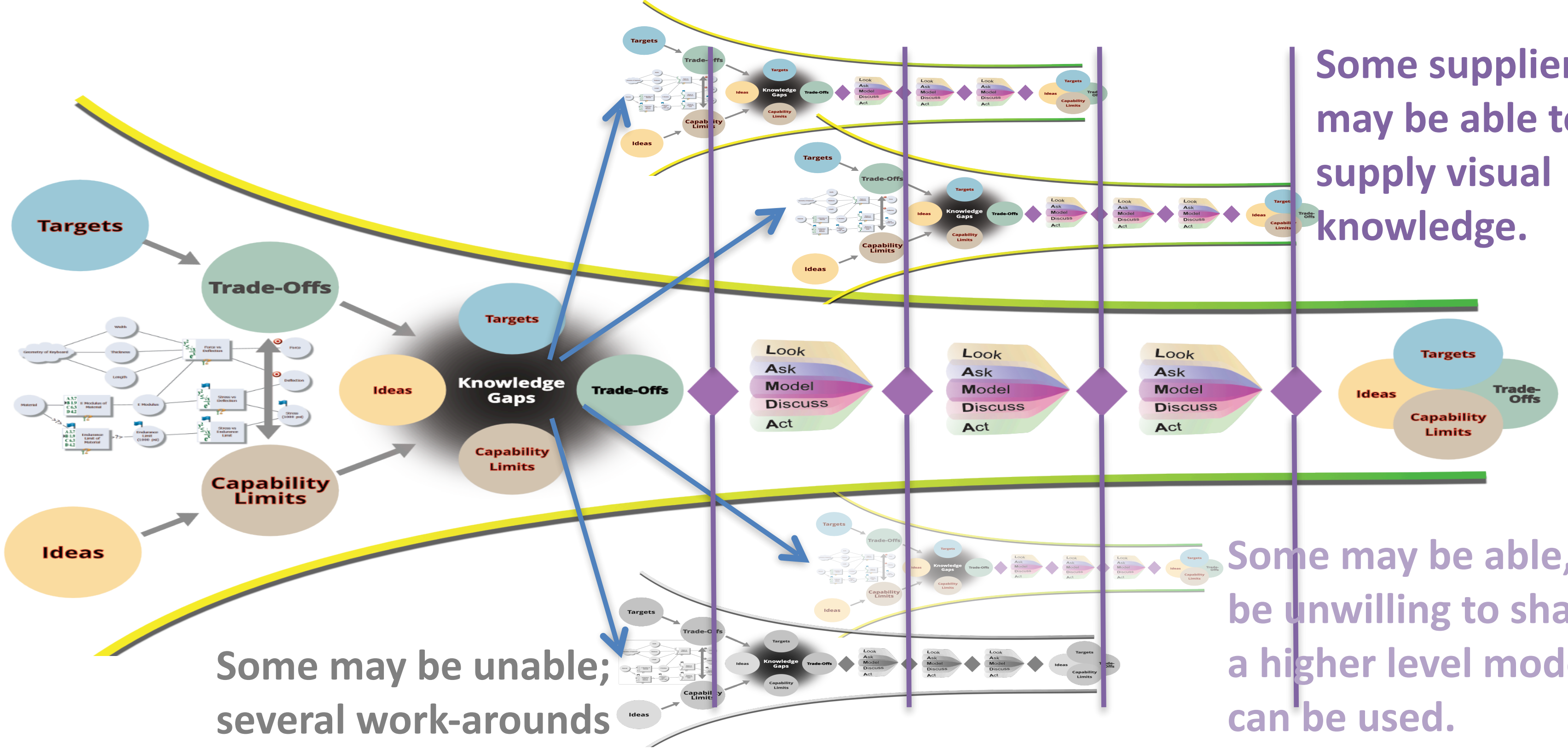
Often Subsystem Teams are in separate Supplier Organizations…



Some suppliers may be able to supply visual knowledge.

Some may be able, but be unwilling to share – a higher level model can be used.

Some may be unable; several work-arounds are possible…

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But in any case, Supplier Collaboration is much richer

- Early on, the Targets (Goal and Veto levels) are provided until the actual program Requirements can be decided (via learning and convergence).
- Rather than simple converging ranges for those Requirements' values, suppliers can provide models that show the design space and the trade-off sensitivities.
- The provided models may be high-level (protecting supplier IP); consider the jet engine model used by the aircraft company in the story in the book *Success is Assured*.
- For less mature suppliers, the system team may create their own model based on historical data or otherwise; consider that the jet engine model actually was a model created by Raymer based on real-world historical data.

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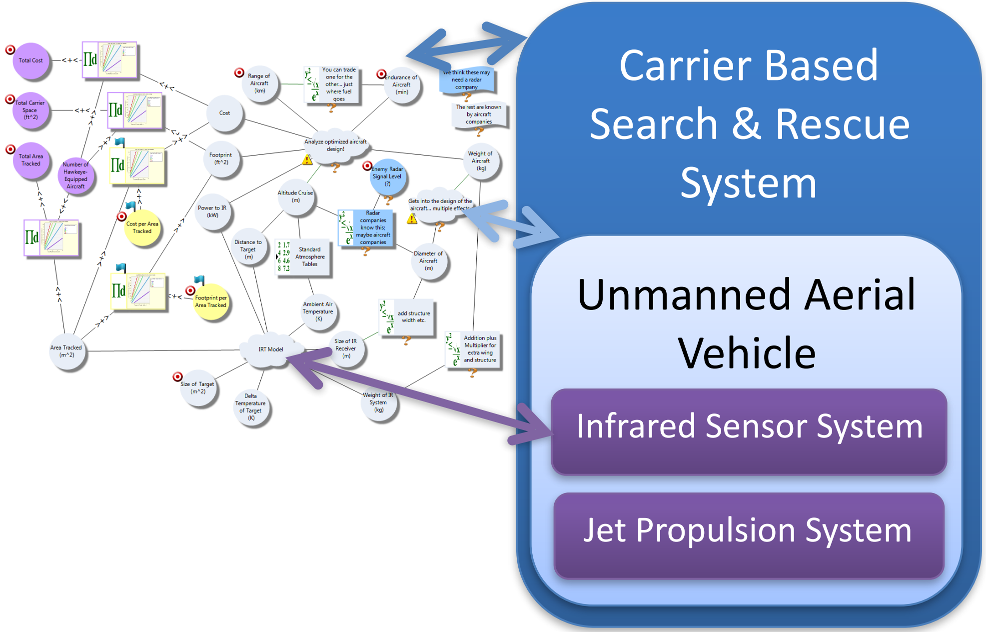
A System-of-Systems Causal Map might look like this…



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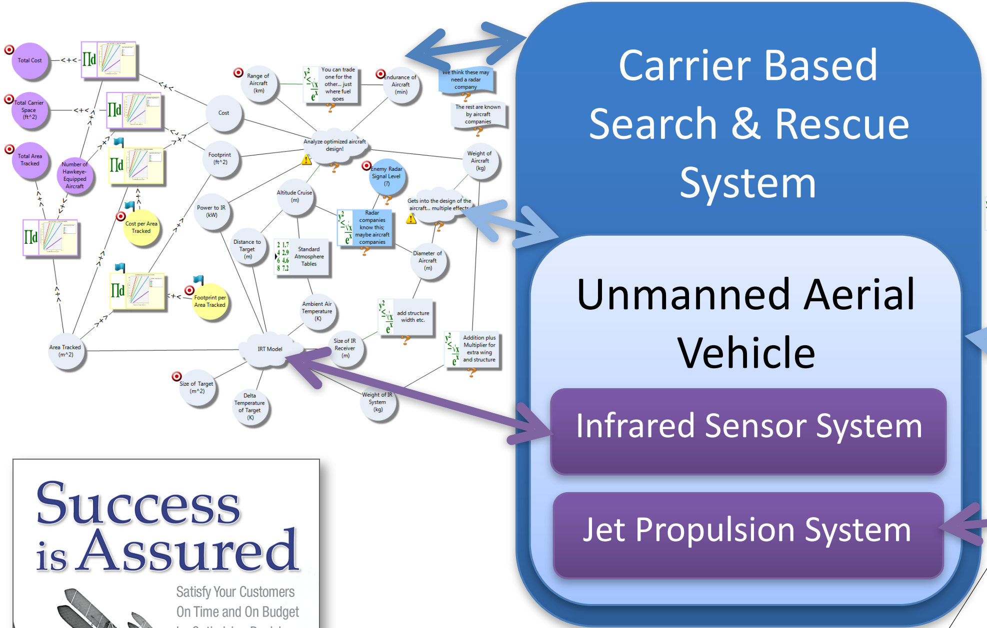

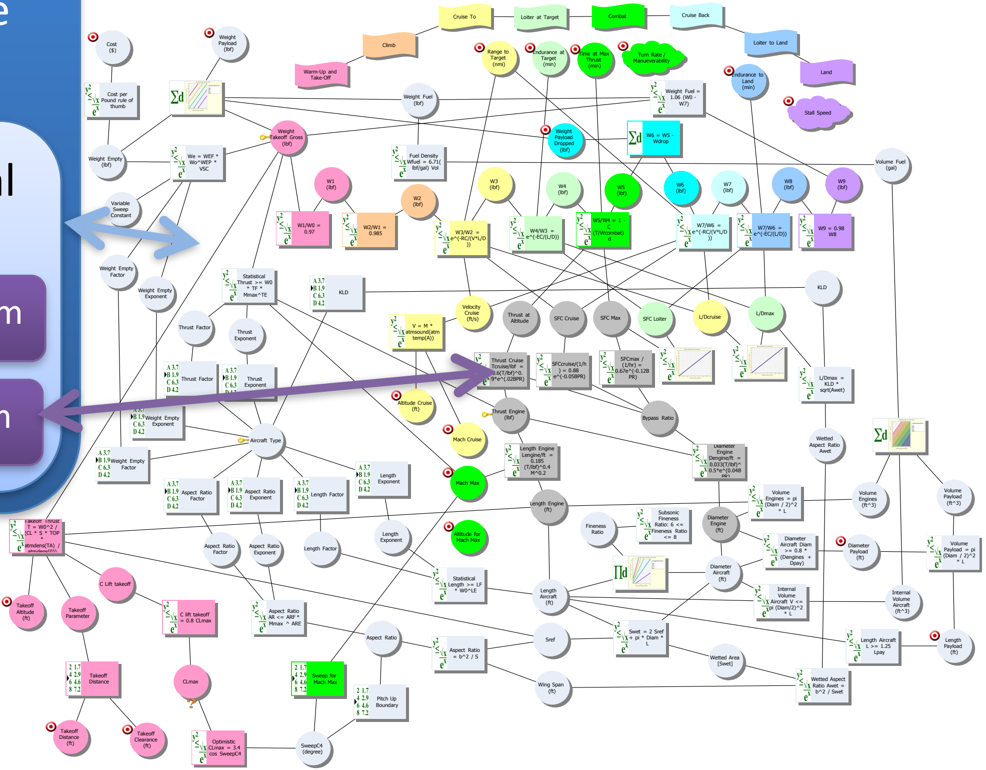

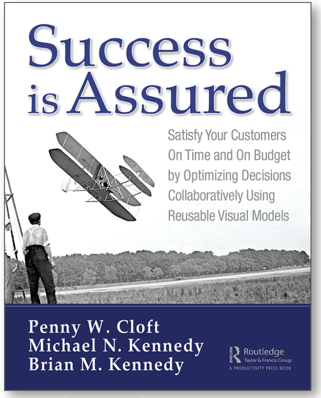

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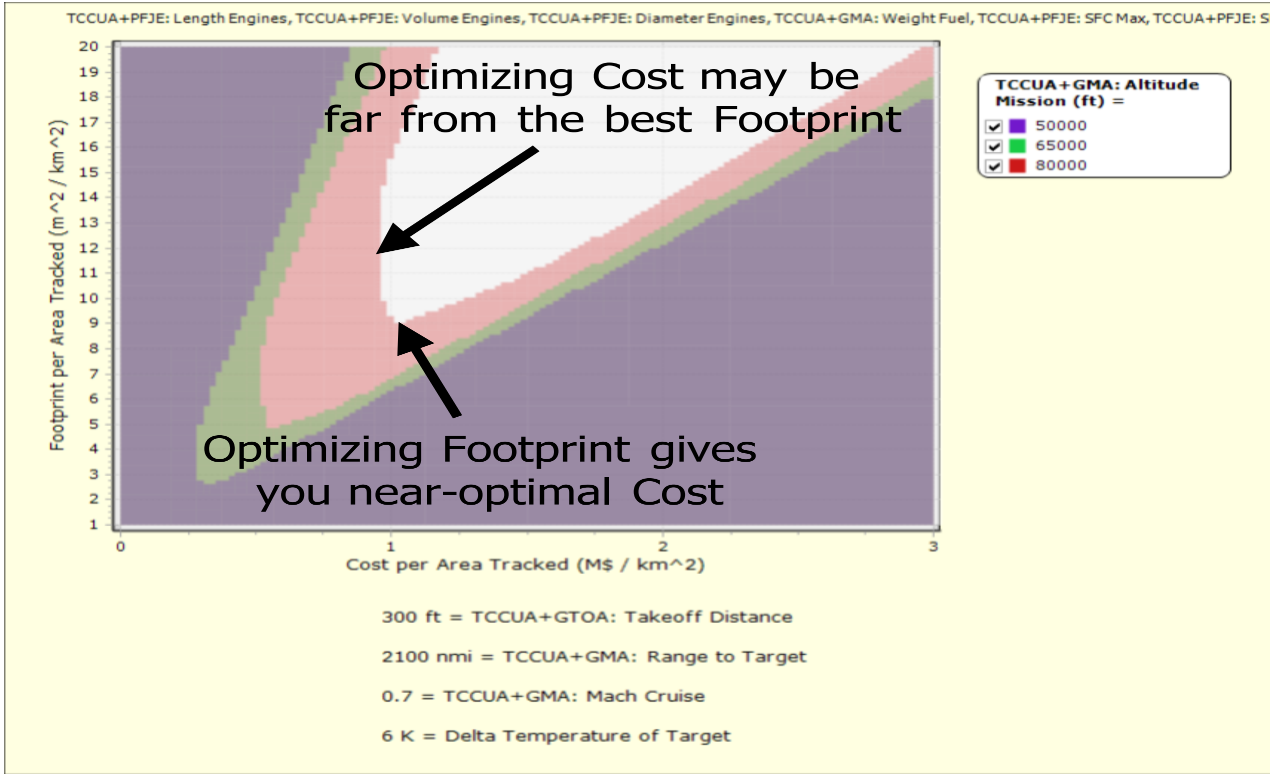
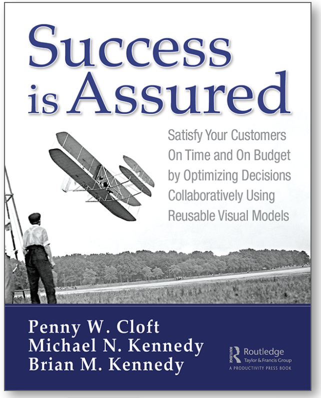
A System-of-Systems Trade-Off Chart might look like this…





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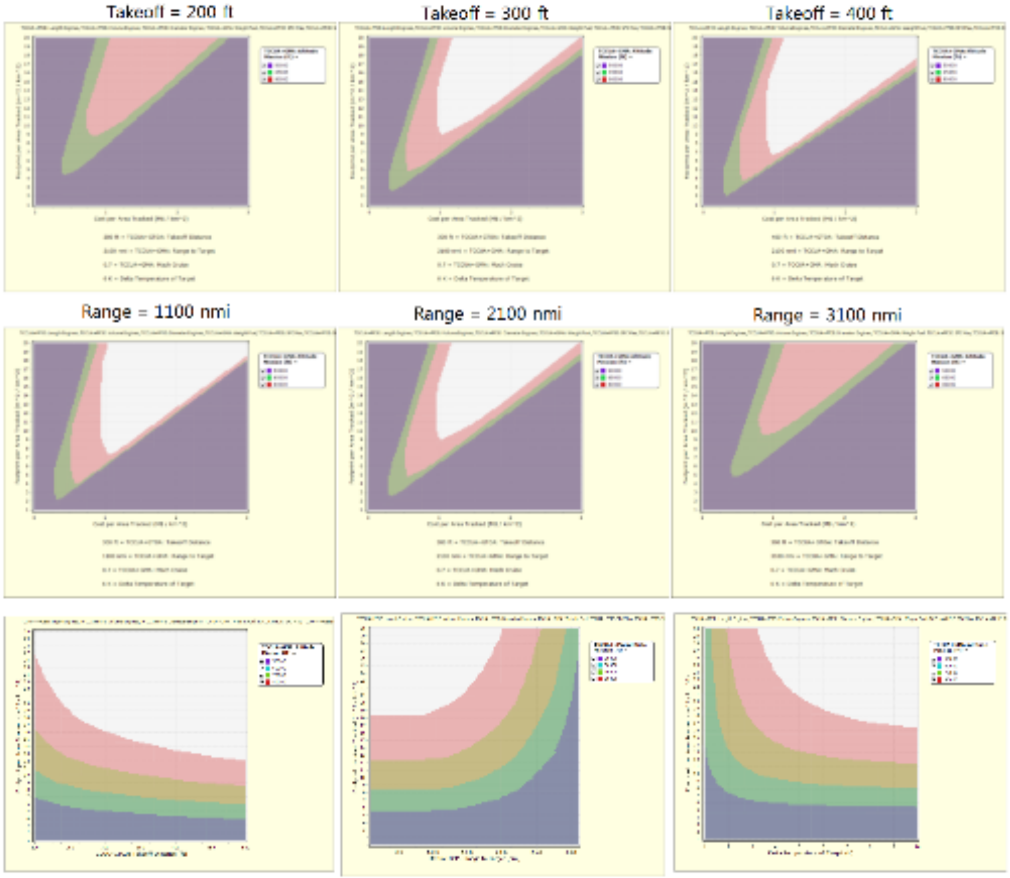
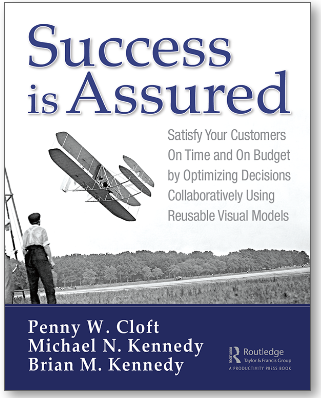
System-of-Systems Trade-Off Charts might look like these…





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K-Briefs organize the Visual Models needed to tell the story that the experts from the different subsystem teams need to Collaborate on

<Information> Help on Understanding the Role of Success Assured™ software in "Success is Assured" Decision Making [54000]

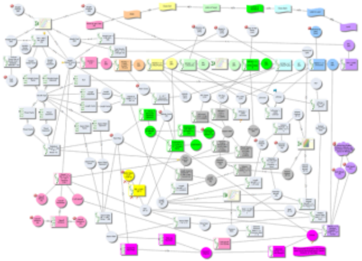
K-Brief | 80 | Multi-Column

A Generic Model of an Aircraft Mission Profile

This Causal Map, the basis for the one developed by the collaboration in the book, was actually developed from the fine book by Daniel Raymer on Aircraft Design. Multiple of our aerospace clients have pointed to that book as "real world", and so we developed this to show the tools applied to real world complexity, but without risk of exposing any of our client's IP. Each node in this can be traced to an equation in Raymer's book (or in a few cases, elementary geometry).

You can see the mission stages in the colored shapes across the top: Takeoff in pink, then Climb, Cruise Out, Loiter at Target, Combat or Avoidance in green, then Cruise Back, Loiter at Landing, and finally Landing in purple.

The shapes below that are then colored to match the stage they are relevant to; the dark gray is the Jet Engine model; the light gray is all the generic decisions regarding the overall aircraft.



When you click on each of those shapes in the software, it is not just a graphical element. The Decision shapes (circles) have fields for Unit of Measure, Min, Max, and Target. You can also describe how it is measured. And you can flag it as a key decision, a customer interest, or a knowledge gap.

The Relation shapes (rectangles) have fields for how they are computed... many will be simple sums or products... others will be more complex equations... often you won't know the equation, but you can collect data points and interpolate the value. In some cases you may need to just draw in the relationship based on the engineers' experience or intuition or rules of thumb.

Key to this process is that as you keep asking:

- "Why?"
- "So what?"
- "How is this calculated?"
- "What else will limit this?"

and breaking things down into their causal elements, you tend to get down to things the engineers know or can more easily test. And if you collect all those pieces known by experts in different areas of expertise, then the tools will let you assemble them back

Success Assured™'s Trade-Off Charts, Maps, and Solvers for Exploring the Multi-Dimensional, Multi-Relational, Multi-Discipline Design Space

With those pieces captured into Decision and Relation K-Briefs forming a computable Decision Map, the Success Assured™ software will allow you to compute three different visual models designed to work together:

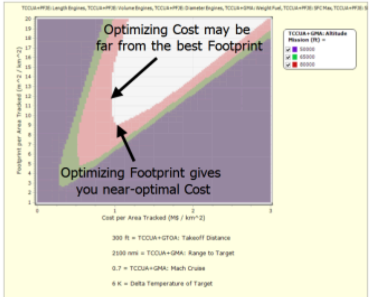
1. Trade-Off Charts
2. Trade-Off Solvers
3. Trade-Off Maps

From each you can compute either of the other two. The Maps show you the connectivity and allow you to setup the Chart in a more intuitive way. The Solvers let you compute the feasible ranges within the larger design space, allowing you to narrow the Charts to the interesting parts of the design space efficiently. The Solver also supports human-in-the-loop optimization processes. The Charts give visibility to the limits of the design space, and to the sensitivities: how one decision affects another, and where the knees in the curves are.

Altogether, they form powerful decision support tools. As such, they become a second layer of reusable knowledge and best practices built on top of the first layer of reusable knowledge, the Decision Map.

For example, built from the Decision Map that is the combination of both the Navy top-level Causal Map and the Aircraft Mission Map above, the following Trade-Off Chart shows the trade-off between Footprint per Area Tracked on the Y axis and Cost per Area Tracked on the X axis.

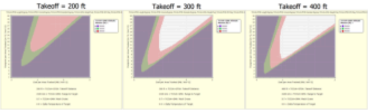
The shaded areas are infeasible; the white is the design space at altitude 80,000 ft. If you turn off the red, the white area inside the green is the design space at 65,000 ft Altitude. The purple at 50,000 ft. In other words, this is showing you a three dimensional design space, where the best cost is the furthest left point in that feasible space, and the best footprint is the furthest down point in that feasible space.



Our brains can only see three dimensions at once. But our problems are always far more than three-dimensions. So, Success Assured™ Trade-Off Charts are designed to use our next strongest sense (eye-hand coordination) to let you see additional dimensions by dragging the sliders along the bottom of the Chart.

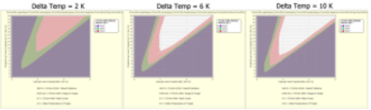
So, the Chart above is actually a 7 dimensional Chart, allowing you to see the impact of changing Takeoff Distance, Range to Target, Mach Cruise speed, and Delta Temperature of the Target.

To illustrate that statically (without opening the live Chart), here is the Chart as you drag Takeoff Distance from 200 ft, to 300 ft, to 400 ft. Notice how the design space doesn't move much going from 400 ft down to 300 ft, but it moves a lot more going from 300 ft down to 200 ft. So, there is some non-linearity.



If you instead drag the Range to Target animator from 1100 nmi, to 2100 nmi, and then to 3100 nmi, you see the design space move like this. Again you see non-linearity as it moves a lot faster as you make Range larger.

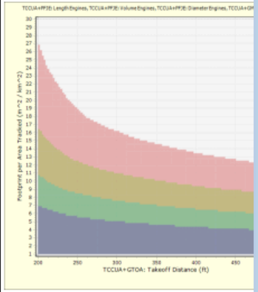
Not surprisingly, Delta Temperature has a similar non-linear effect, but in the opposite direction. There's a knee in the curve at some Delta T... it would be good to know where that it is and stay above it.

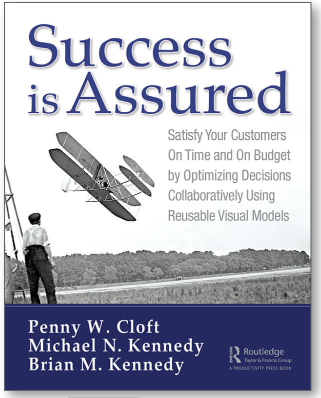


In addition to allowing you to use anim
the multi-dimensional trade space (for
relation Decision Map that crosses mult
the Success Assured™ software is also
it quick and easy to compute very diffe
the same underlying model. Limited to
only 3 dimensions clearly at once, it is
easy as possible for decision makers to
many different 3D slices through their
trade space.

For example, to better see the non-line
Takeoff Distance, you can put Takeoff
X axis such that you can clearly see its
per Area Tracked. Based on this, Take
looks appealing; below that the Footpri
Tracked begins rising more sharply.

(NOTE: This Chart (and the next two) a
Historical Mode because we have not ye
aircraft model to the Help K-Briefs (tha
this is just a "preview".)





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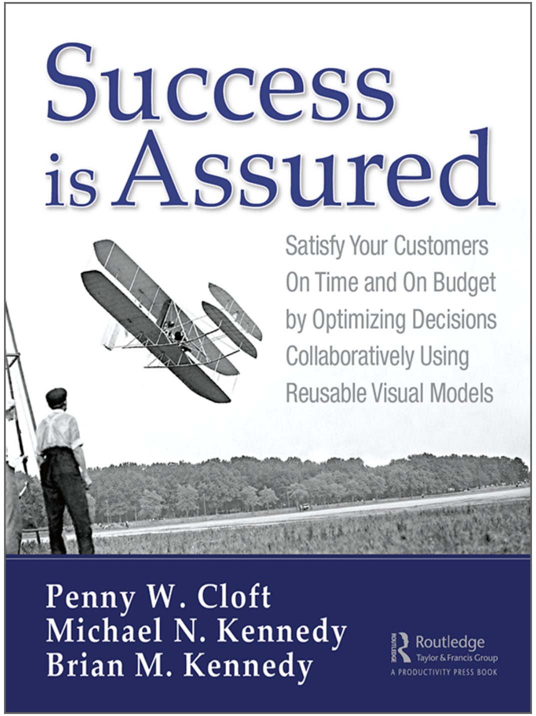
Any Questions??

- There's a short (2-minute) video trailer on our book at:
  http://SuccessIsAssured.com/



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