# WELCOME!

INCOSE Enchantment Chapter Monthly Meeting

We’re glad you’re here.

# We respectfully request:


- Mute your audio when you are not speaking
- *6 toggle or in GlobalMeet left-side, your name

Discussion and questions are encouraged!

Put questions in the chat box or unmute yourself to speak up.

# Meeting Materials

Slide presentations can be downloaded prior to start of the meeting from the Meeting Materials page of our website:

https://www.incose.org/incose-member-resources/chapters-groups/ChapterSites/enchantment/resources/meeting-materials

If recording is authorized by speaker, the video will be posted at the link above within 24 hours.

# SEP Training

CSEP Courses by *Certification Training International:*

CTI currently is offering online course offerings, see
https://certificationtraining-int.com/incose-sep-exam-prep-course/

Our chapter has two SEP mentors:
Ann Hodges alhodge@sandia.gov
Heidi Hahn drsquirt@outlook.com

# Upcoming meetings

- October 13, 2021: Jim Armstrong – “Systems Engineering Evidence in Commercial Kitchens”
- November 10, 2021: Jennifer Russell – “Smart Cities”

# Introductions

- Please type your name, position, and organization in the Chat window


Photo by [Adam Solomon] on [Unsplash]

# Survey

The link for the online survey for this meeting is

- www.surveymonkey.com/r/2021_09_MeetingEval

Your feedback is important!

# Enchantment Chapter Monthly Meeting

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

**Abstract**: This presentation will discuss how Set-Based practices can enable the higher level system to proceed concurrently with its subsystems, coordinating their efforts, and allowing their decision-making to converge together. The presentation will introduce three key enablers of that coordination: Decision-Based Scheduling, Integrating Events, and Causal Mapping.

Download recording from the Library at www.incose.org/enchantment

**NOTE: This meeting will be recorded**

# Speaker Bio

**Brian Kennedy** is an author of the book *Success Is Assured* and is an INCOSE Certified Systems Engineering Professional (CSEP) who has spent more than 25 years designing complex software systems. He was Chief Architect of i2 Technologies' Supply Chain Planner and Demand Fulfillment applications, applying Toyota lean manufacturing, Theory of Constraints, and advanced optimization to the planning and scheduling of the larger supply chain, helping to establish a new market space (Supply Chain Management) and generating billions of dollars of value for i2's customers. Brian was named the first i2 Fellow and holds more than a dozen patents on the inventions that were the basis for those software systems. As co-founder and CTO of Targeted Convergence Corporation, Brian is responsible for the systems engineering of TCC's Success Assured® software and the associated training, which are both designed for superior systems and mission engineering in the early conceptual stages of development.

# 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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## Over the years, companies have developed highly-optimized Product Development and Project Planning processes – staffed with brilliant engineers across all the required Disciplines


But consistently projects:

- take longer than expected
- cost more than expected
- deliver less than expected
- fail to meet customer requirements
- lack the innovation expected
- or the innovations cause other issues

**Why?**

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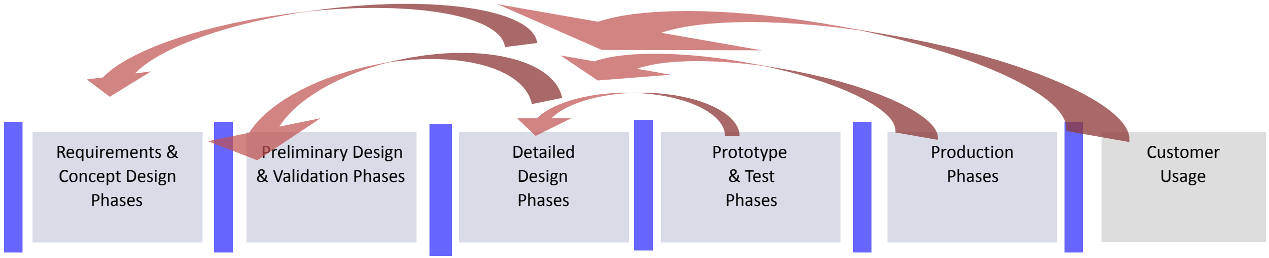
**Over the years, companies have developed highly-optimized Product Development and Project Planning processes – staffed with brilliant engineers across all the required Disciplines**




But consistently projects:

- take longer than expected
- cost more than expected
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- lack the innovation expected
- or the innovations cause other issues

Late process rework has been shown to cost 100X to 1000X more than what it would have cost to do it right the first time.

Late process rework forces compromises, undesirable trade-offs in the final result.

Fear of the unknown and rampant risk mitigation tend to drive out most of the innovative alternatives.

**Why?**

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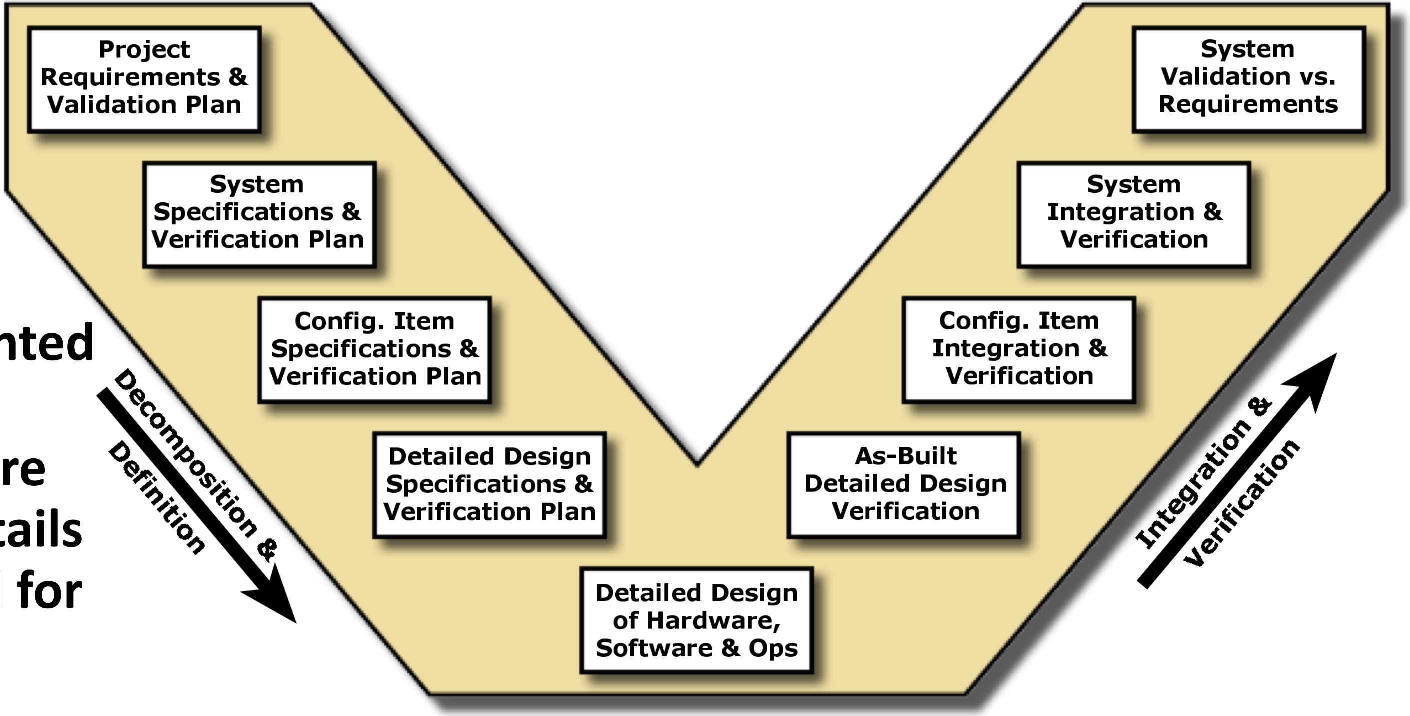
# The Systems Development Process is often depicted as a "V"…

… 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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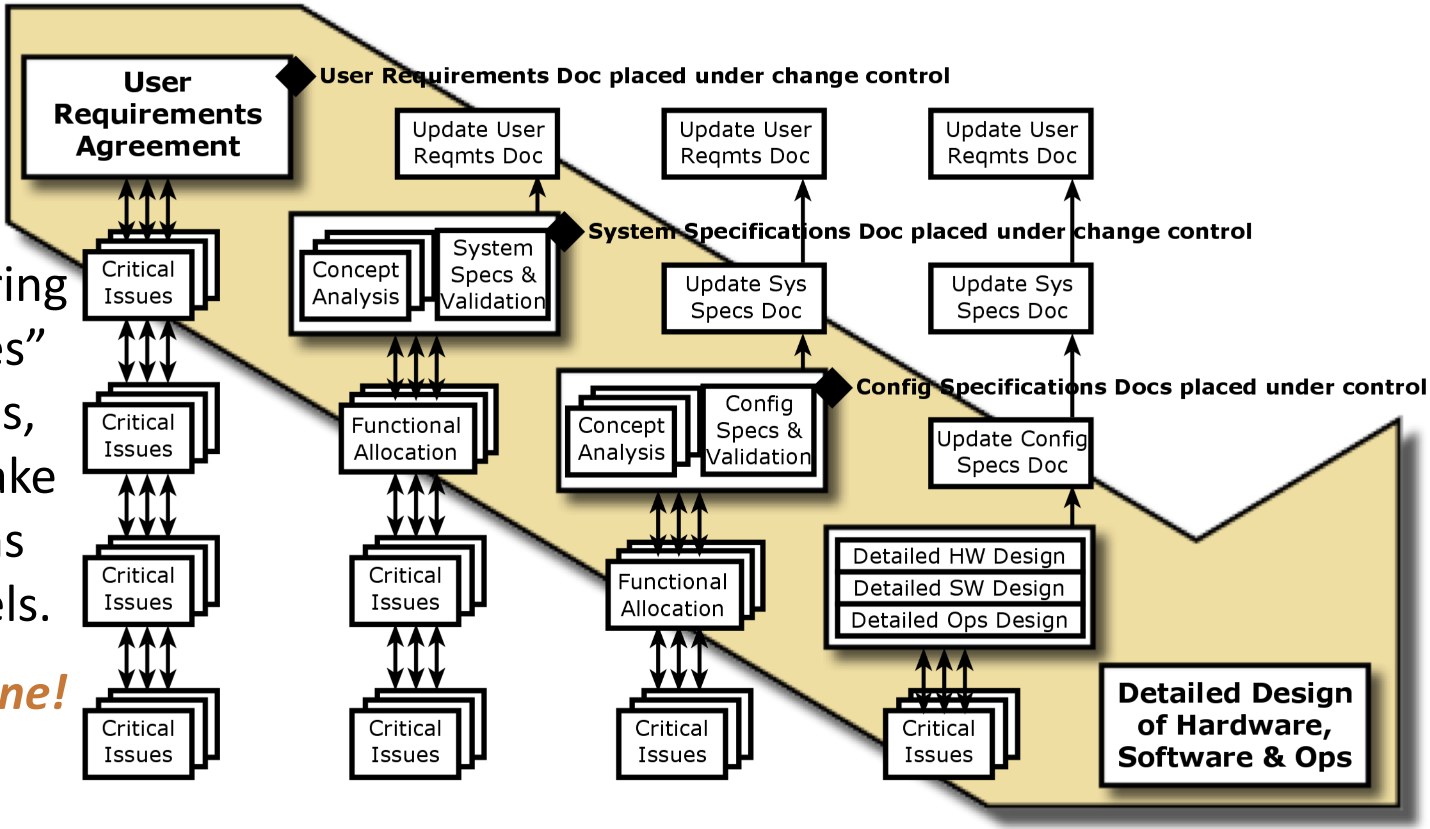
# There is critical work that must be done concurrently…

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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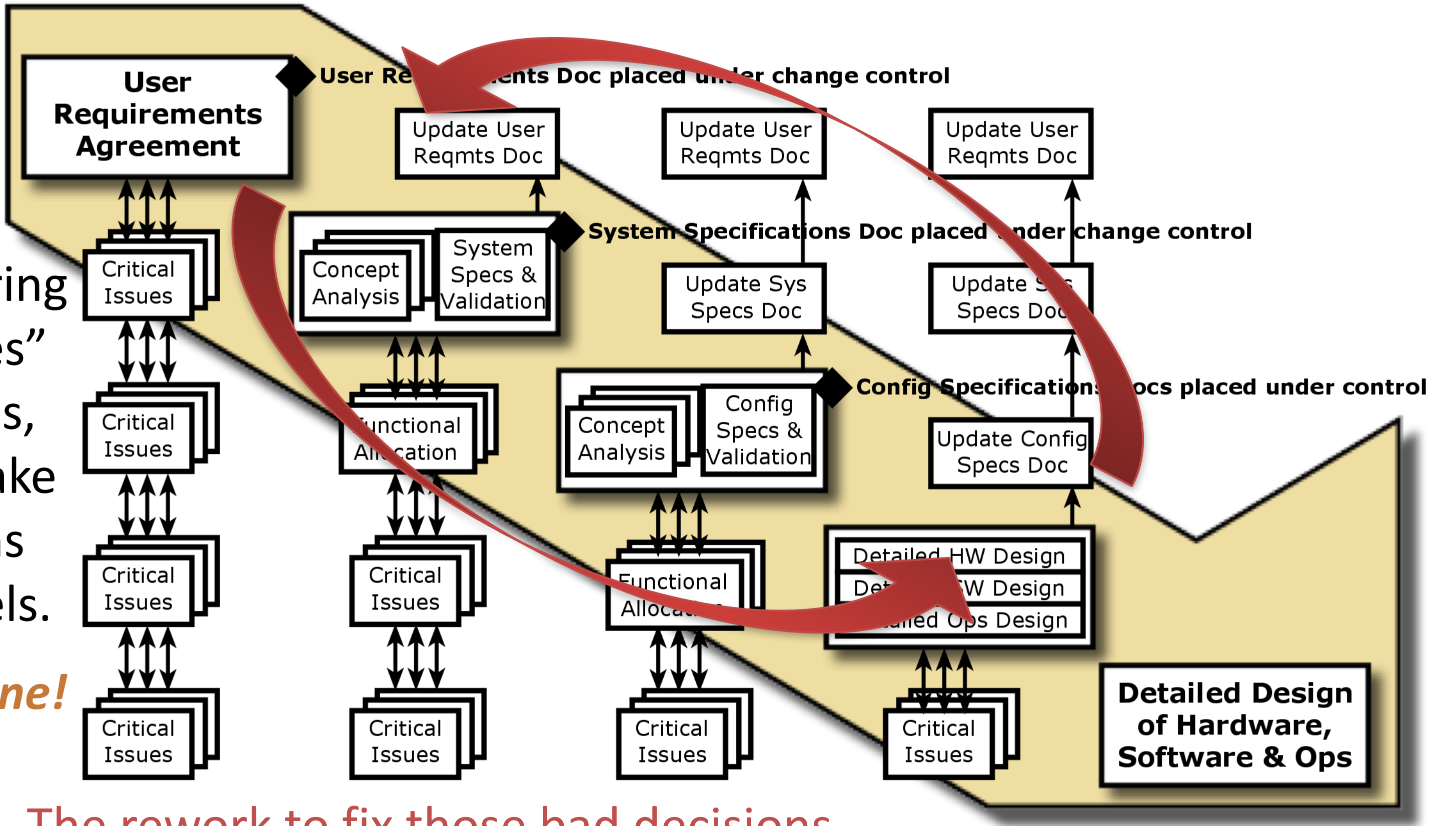


Without considering the “Critical Issues” at the lower levels, you can easily make very bad decisions at the higher levels.

*Easier said than done!*

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

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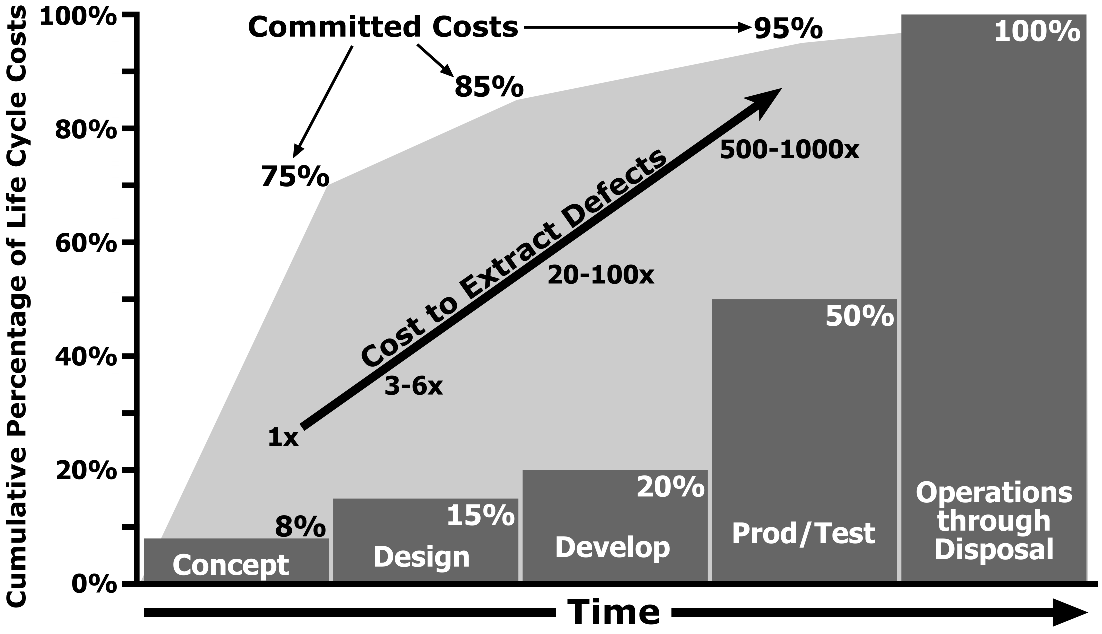
# Studies have shown that Rework can Cost 10x, 100x, or even 1000x!

- 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 in engineering!

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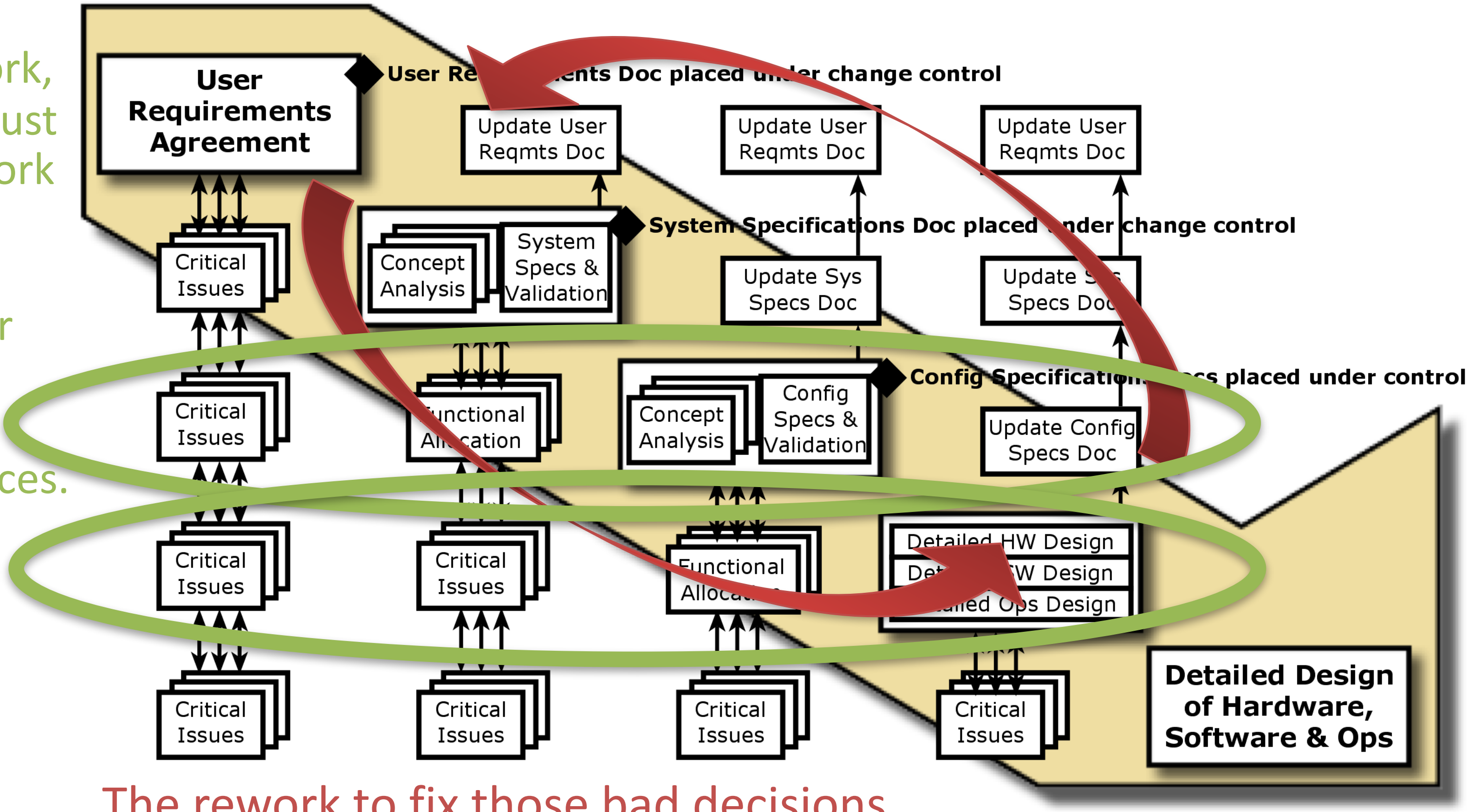
# There is critical work that must be done concurrently…

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!

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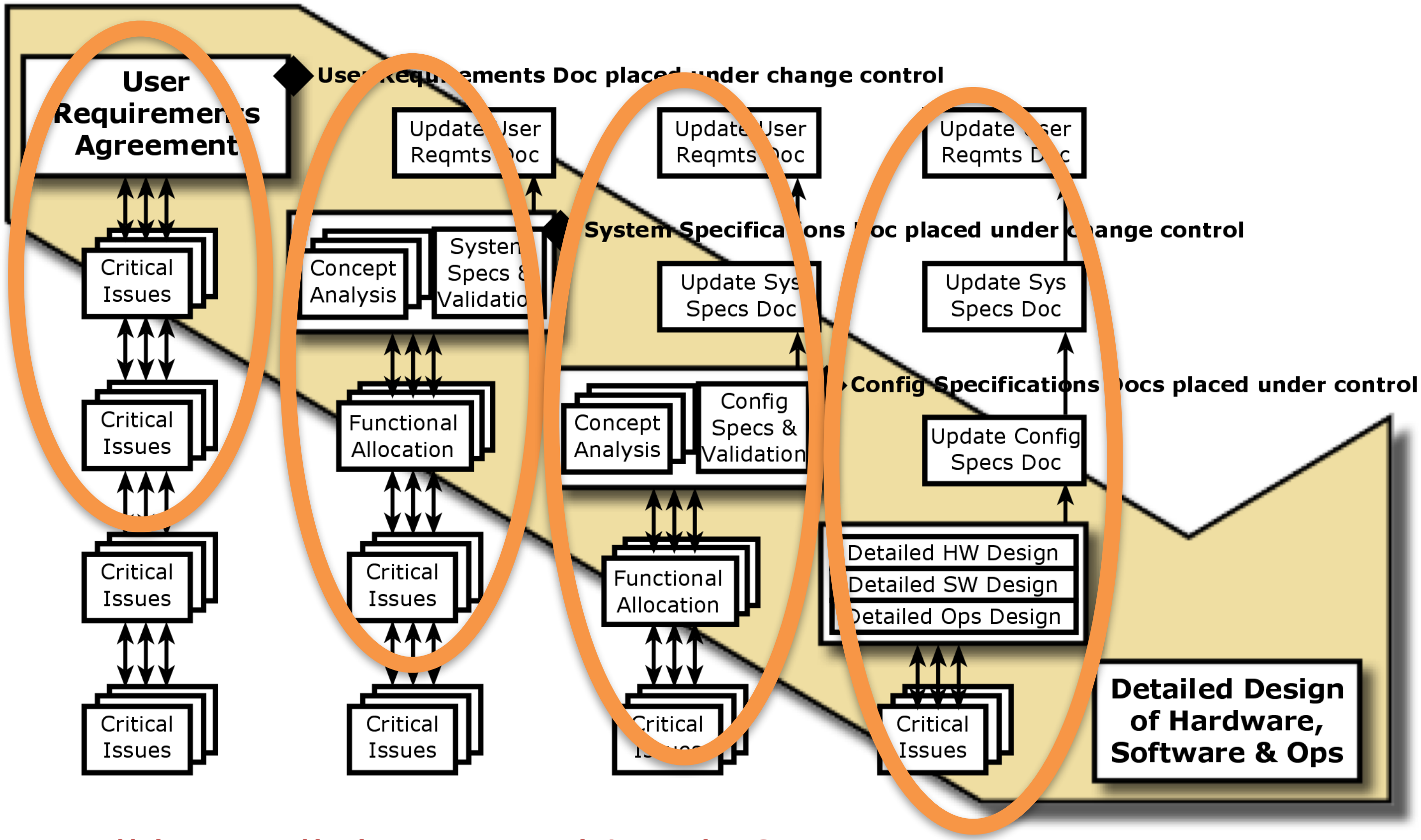
# Traditional Point-Based Design Approach

Traditionally, we try to address those critical issues by doing a quicker low-fidelity analysis on the design, make revisions, then a higher-fidelity analysis, make revisions, and then full detailed design.

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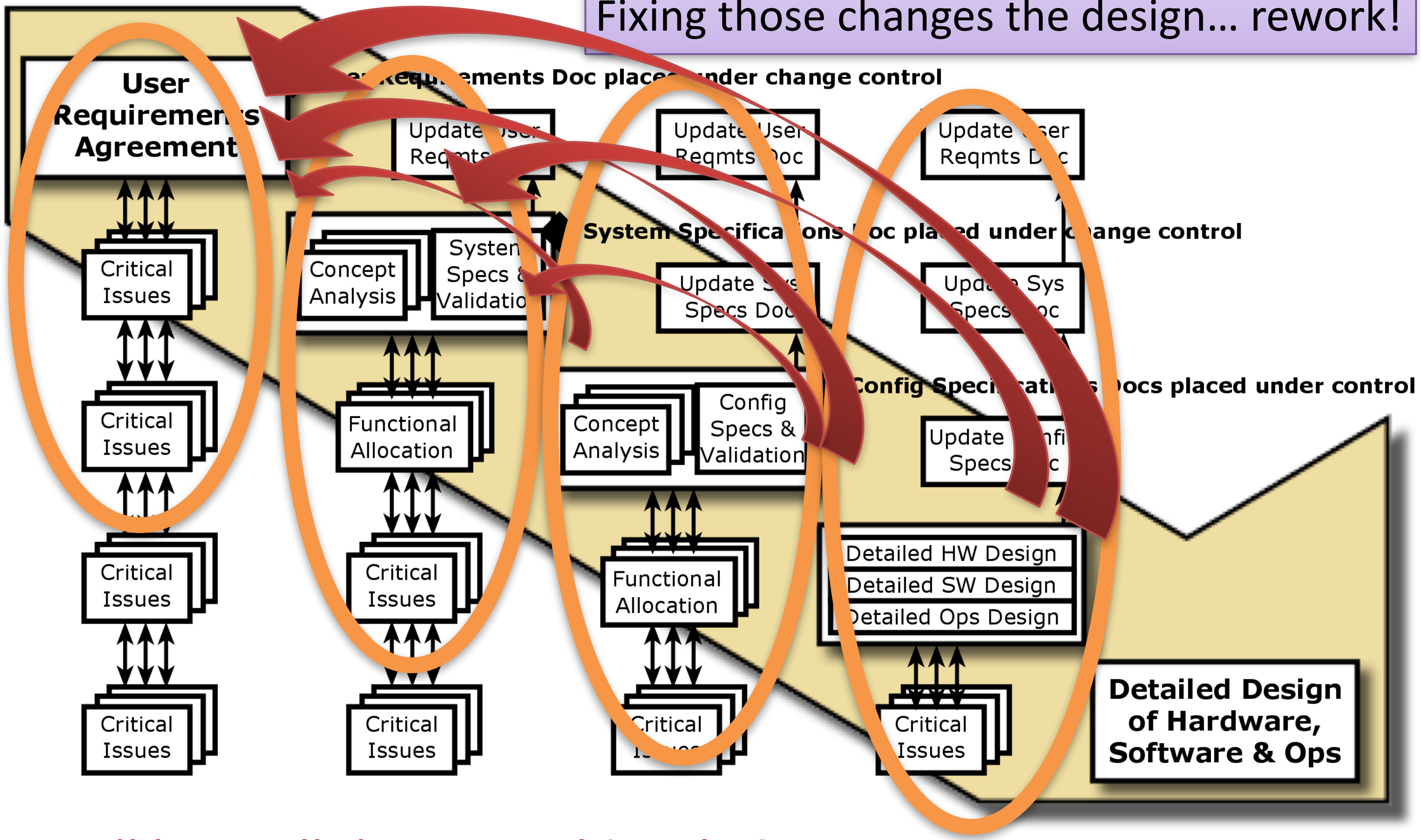
But we still have all that rework! *Why?*

# Traditional Point-Based Design Approach

To do those analyses, we need a design, but that forces premature decisions! Fixing those changes the design… rework!

Traditionally, we try to address those critical issues by doing a quicker low-fidelity analysis on the design, make revisions, then a higher-fidelity analysis, make revisions, and then full detailed design.

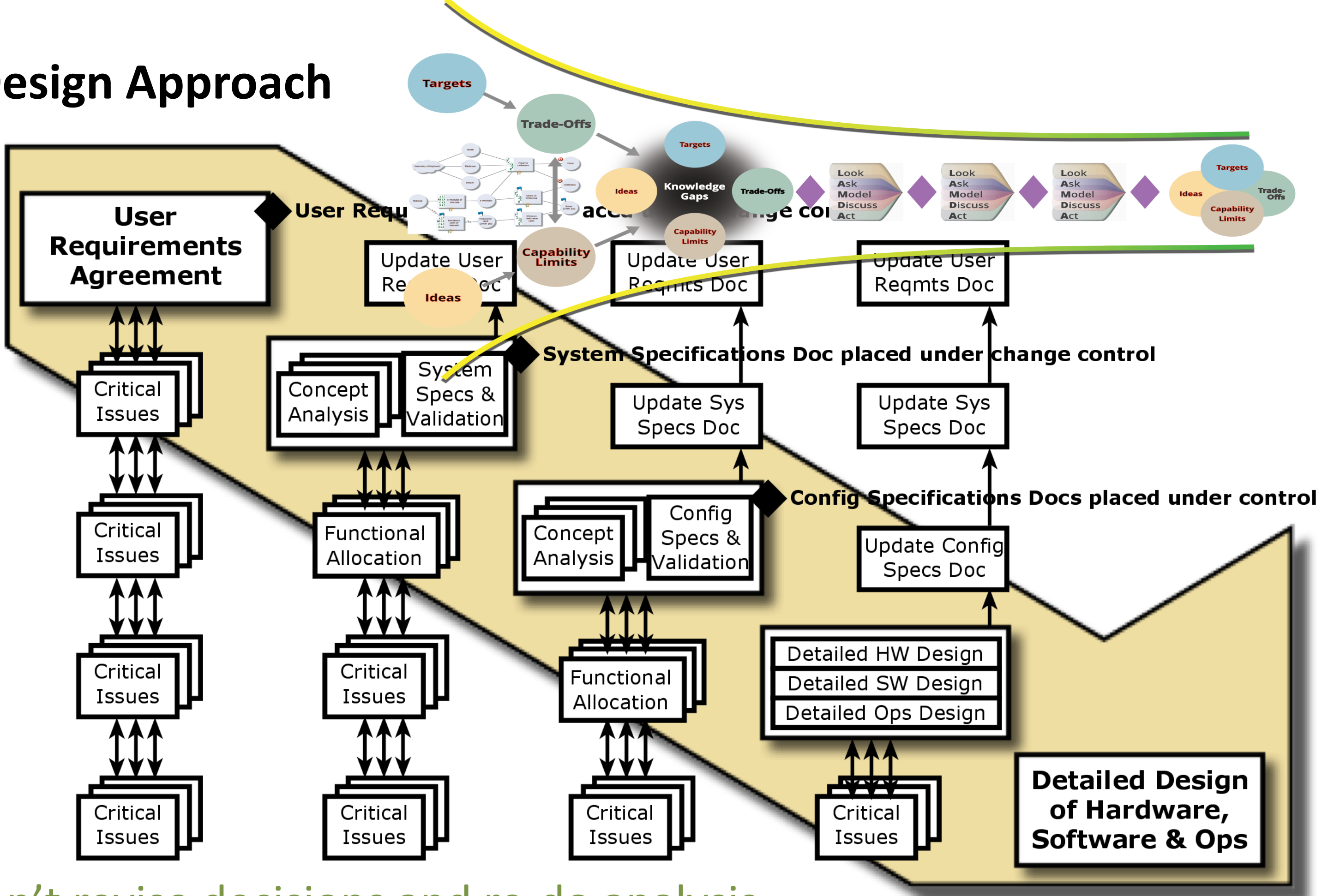



But we still have all that rework! *Why?*

# The Set-Based Design Approach

Rather than analyze a design, we analyze the set of all infinite possible designs… *the whole design space as a whole.*

We deal with the Critical Issues by eliminating the weak parts of that design space.

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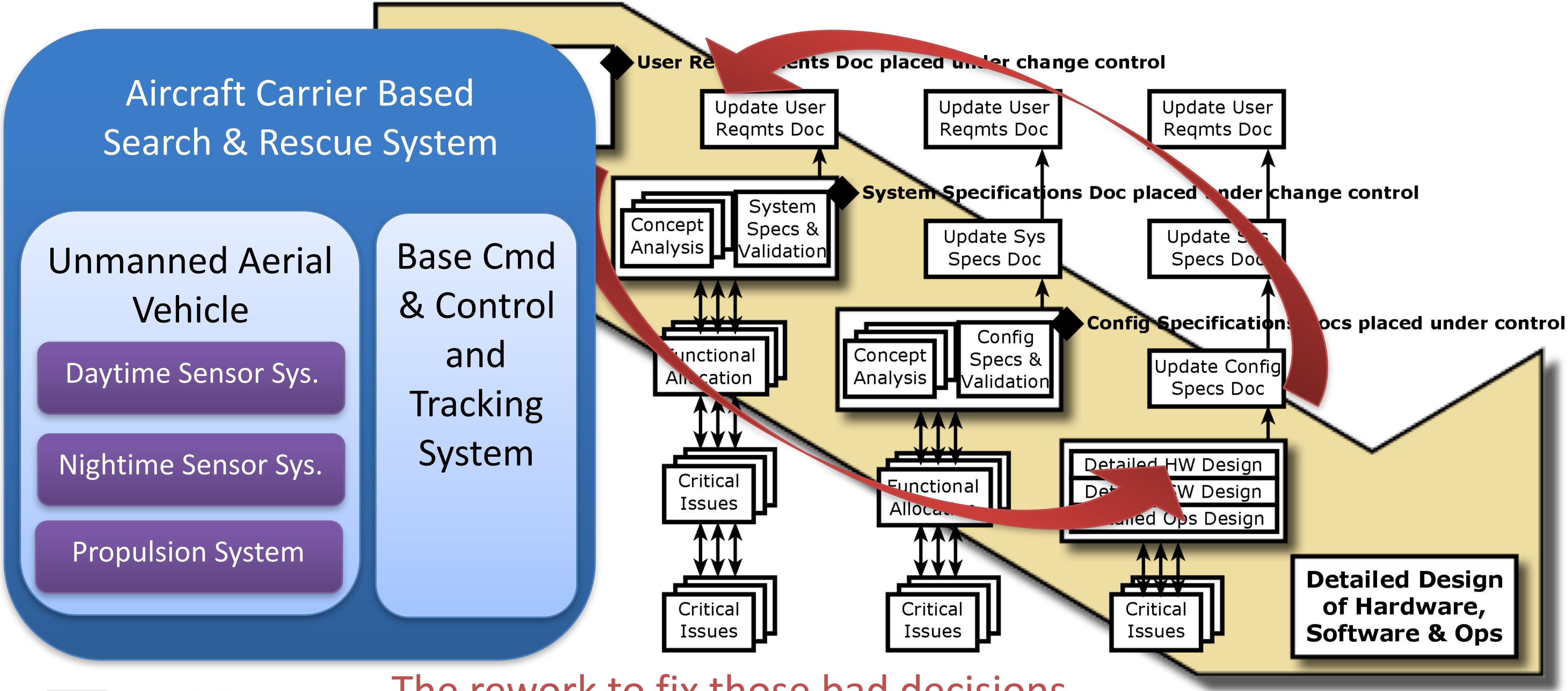
We don't revise decisions and re-do analysis.
Instead we analyze and then narrow decisions.

# In the case of Systems of Systems…




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

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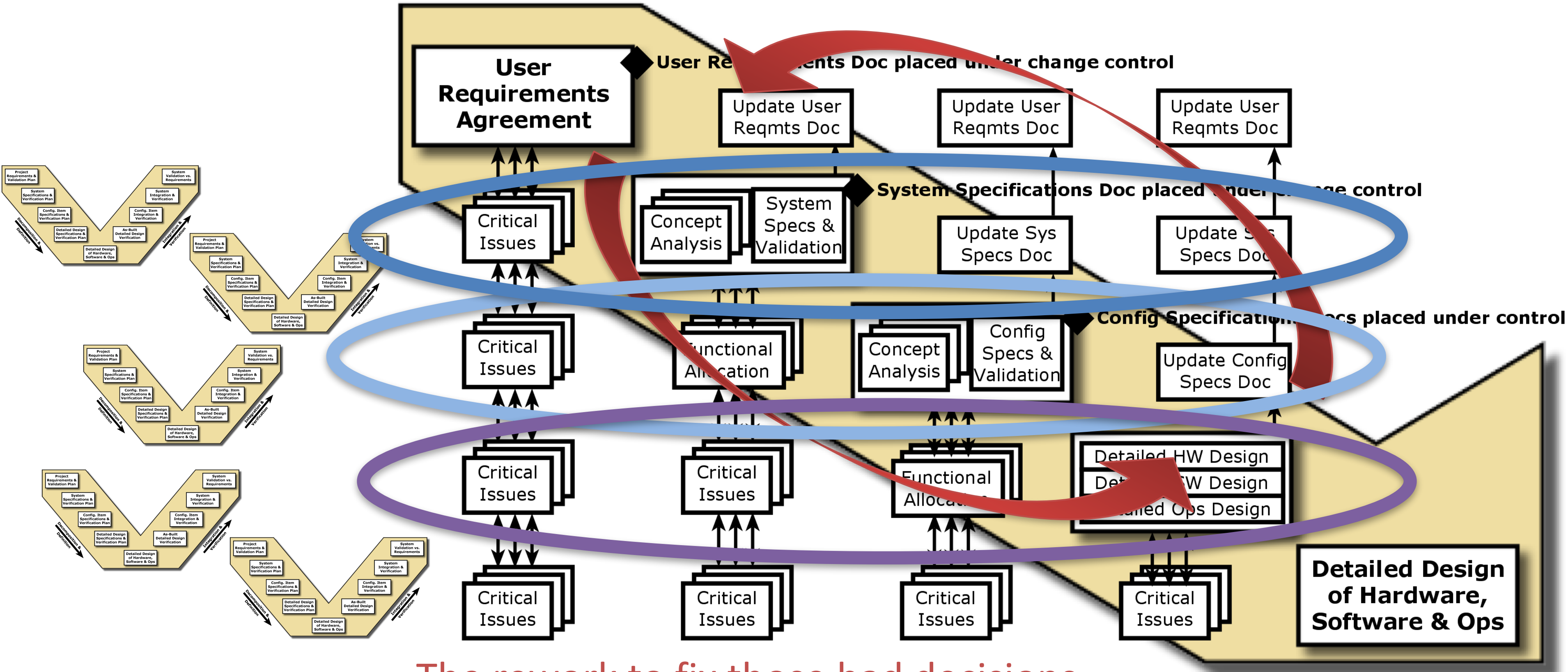
# In the case of Systems of Systems, there are "V"s at those lower levels…




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

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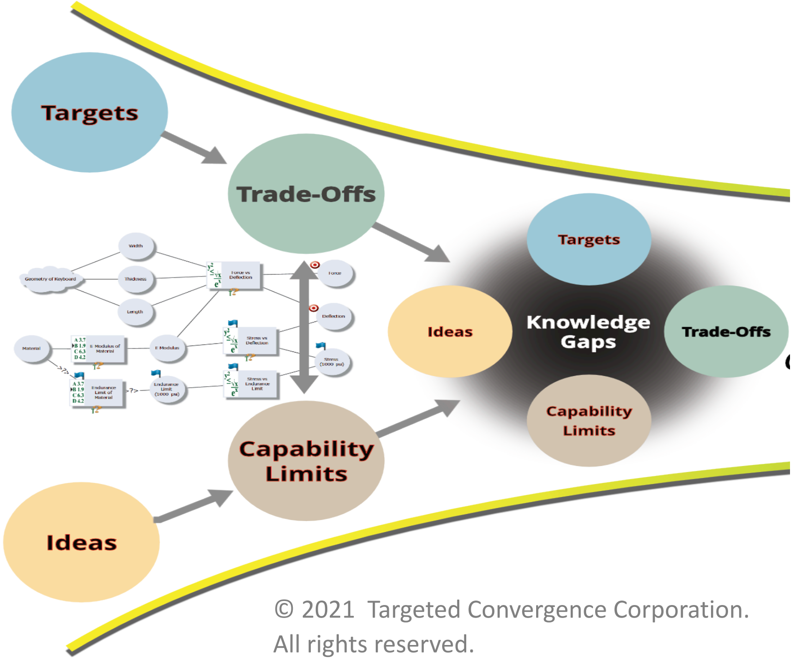
# The Set-Based practices start with what we tend to know…

- 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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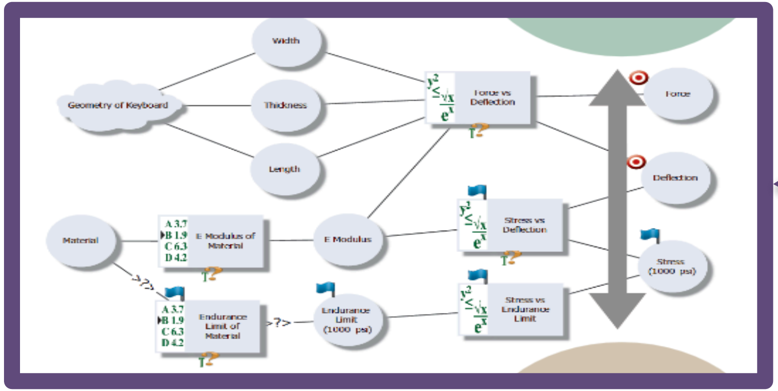
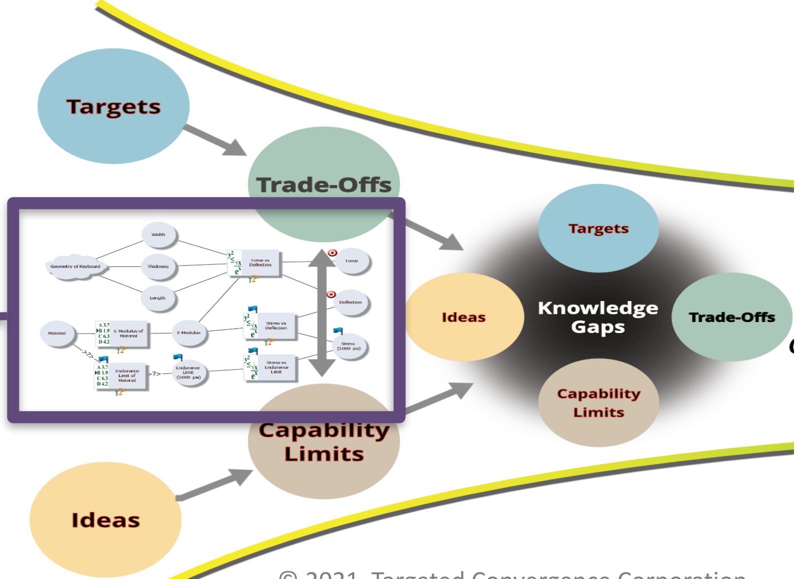
# We use Visual Models to Identify the Key Knowledge Gaps…

- 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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# Set-Based Design of the Space Shuttle's External Fuel Tank

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

K-Brief | 80 | Multi-Column

## A Simpler Example: External Fuel Tank for the Space Transportation System (Shuttle)

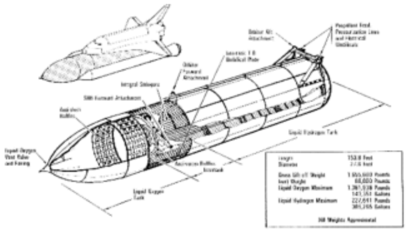
This simplified model of the Shuttle's External Fuel Tank was posed by NASA Scientist and Engineer Jaroslaw Sobieszczanski-Sobieski. He used it to illustrate the impact that objective functions could have on the design results.

That example was then picked up by Olivier de Weck of MIT for his work studying improvements to the Integrated Concurrent Engineering (aka., Integrated Product Definition) process. For a more detailed look at that analysis and a comparison to set-based practices, click here.

So, both NASA and MIT felt this example, though simple, was complicated enough to be representative of real design work. And numerous other papers and analyses have since used this same example.

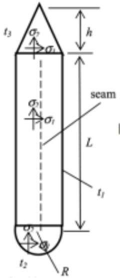
*Click to add Heading or Caption*

*Click to add Explanation*



### The Simplified Model

The simplified model treats the tank as a circular cone sitting on top of a cylinder sitting on top of a hemisphere. Each portion is made of 4 panels of aluminum welded together, and then the three portions welded together. The stress caused by the internal tank pressure depends upon the thickness of the aluminum panels as well as the geometry. That stress cannot exceed the limits of the aluminum. Further, there is a vibration constraint, and the volume is constrained to be near the original volume.




Ai = Component surface area (m^2)
h/R = Cone height to radius ratio
k = Material cost-per-unit-mass ($/kg)
L = Cylinder length (m)
l = seam length (m)
ll (lamda) = Seam cost-per-unit-length ($/m)
Mt = Total tank mass (kg)
Pn = Nominal tank payload (kg)
r = Material density (kg/m3)
R = Tank radius (m)
t1 = Cylinder thickness (m)
t2 = Sphere thickness (m)
t3 = Cone thickness (m)

### The Objectives (The Customer Interests)

The two key customer interests to be optimized are:

1. Total Cost, since it is disposable -- it is not an investment, but more an operating expense.
2. Max Payload -- making the fuel tank heavier will directly reduce the maximum payload (the revenue, so to speak); changes to the radius and the shape of the cone can both affect Drag which will also impact the payload.

Those somewhat offset each other (more revenue from Payload pays for higher operating expenses), however there are other reasons you may want a higher Max Payload (the largest single item that can be put into orbit, for example).

...

### *Causal Trade-Off Analysis*

Each of the experts in those areas contributes the relationships between the Decisions that they know. As additional knowledge is added, the experts in other areas may see additional relationships that they know, and those get added in. Once all agree that everything of concern has been captured, then they can focus on collecting the detailed knowledge and closing any knowledge gaps.

*Click to add Heading or Caption*

In the simplified model, some things
constants as they are tied to the mat
being modeled as a decision that can
Decisions have been marked with an
actually be left out of the model (just
the equations). But leaving them visi
Map captures that knowledge such th
to extend later (if changing the mate
option, for example).

Certain of the Decisions are just mod
much like the constants. For example
aren't fixed values, but they are limit
above a certain level (also a property
Those constrained values, which inclu
inputs that are being selected by the
marked with check marks. The design
being optimized are marked with targ
Tank Volume is logically a target, but
being constrained to be close to the c
thus it is marked with both target and

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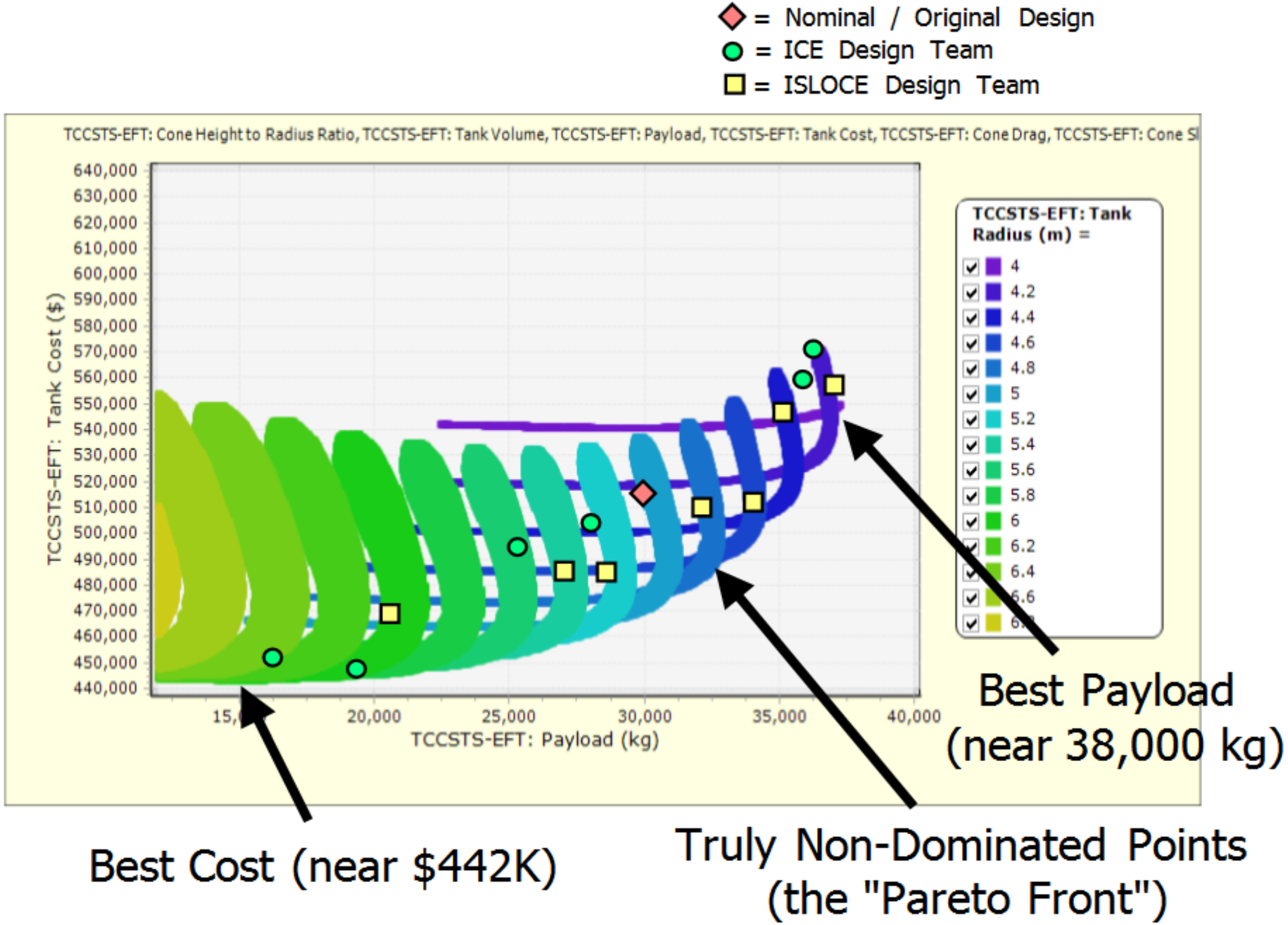
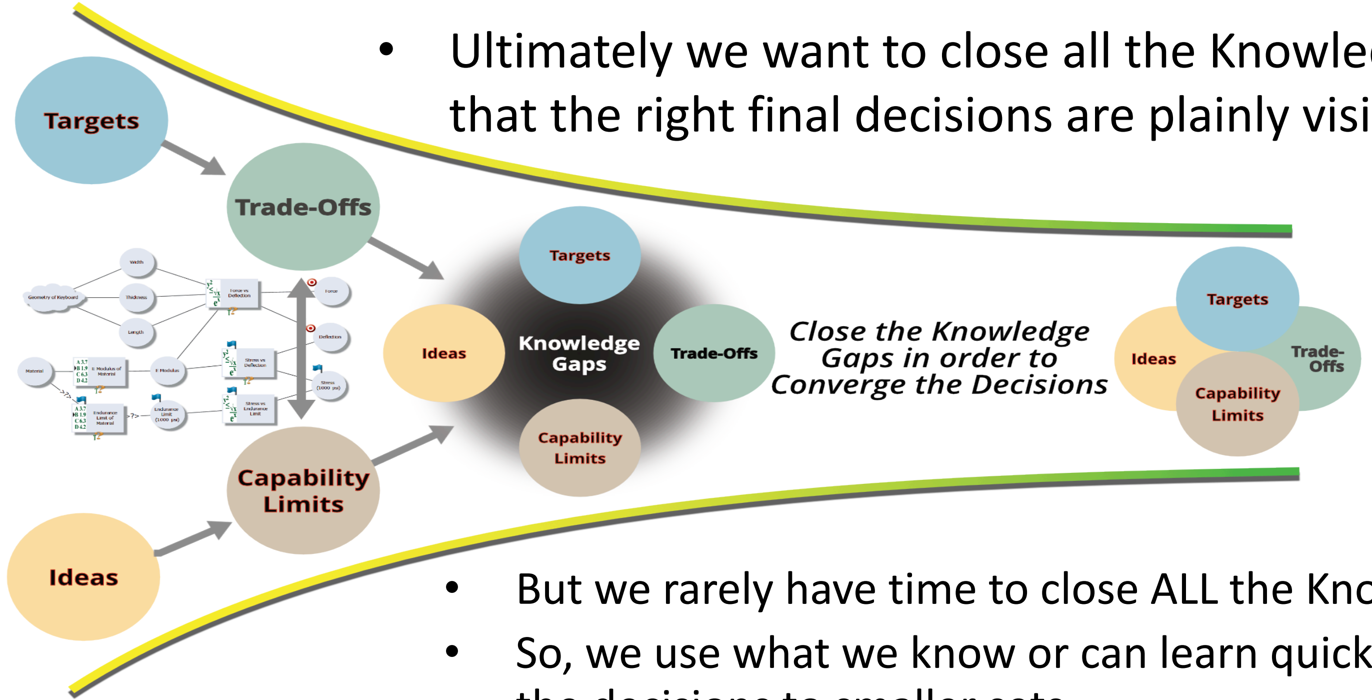
# Set-Based Design of the Space Shuttle's External Fuel Tank



# 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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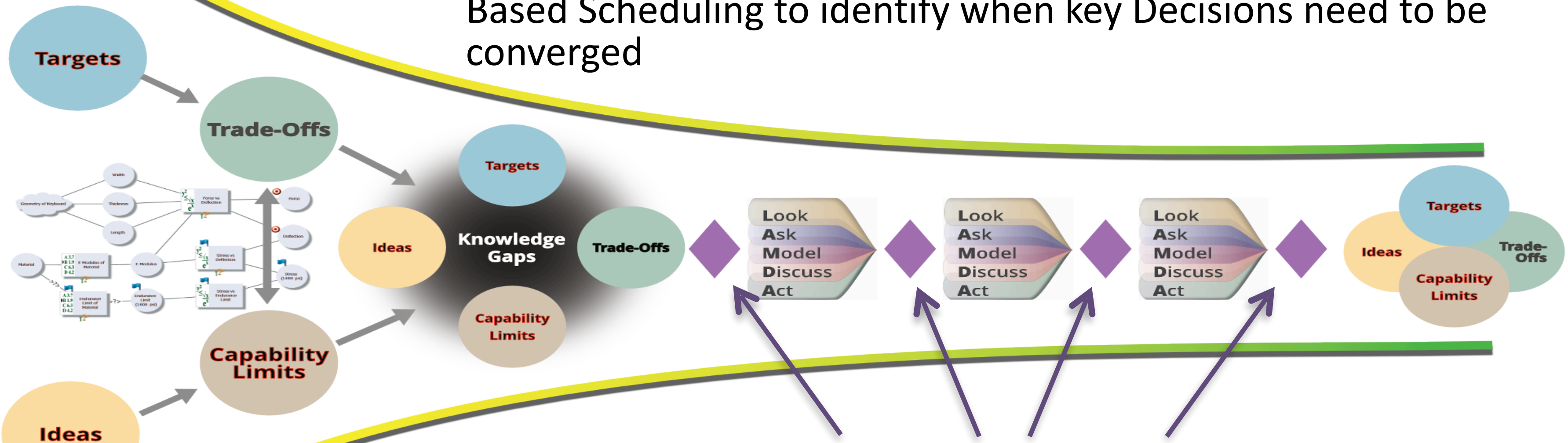
# … Organizing the Decisions into Integrating Events…

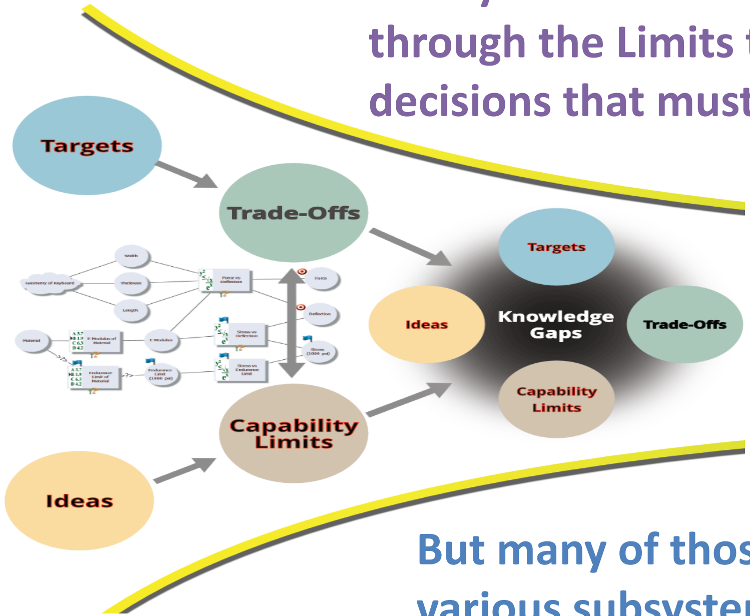
- Rather than traditional Task-Based Scheduling, we use Decision-Based Scheduling to identify when key Decisions need to be converged




- 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 prior to making those decisions in order to avoid rework.

# But that must be Coordinated across Subsystem Teams…

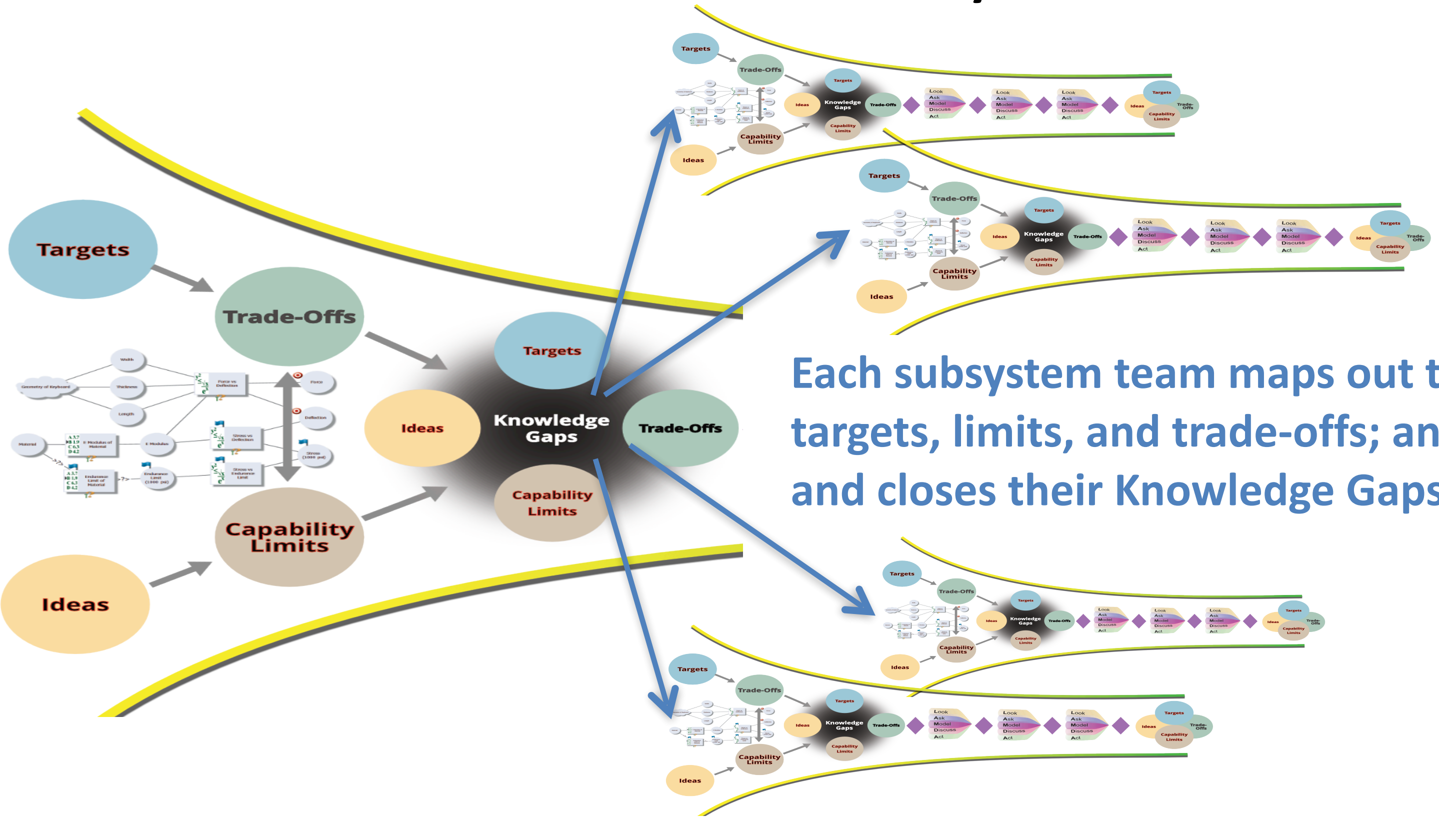
The System team maps the Targets and Ideas through the Limits to identify the Trade-Off decisions that must be made…




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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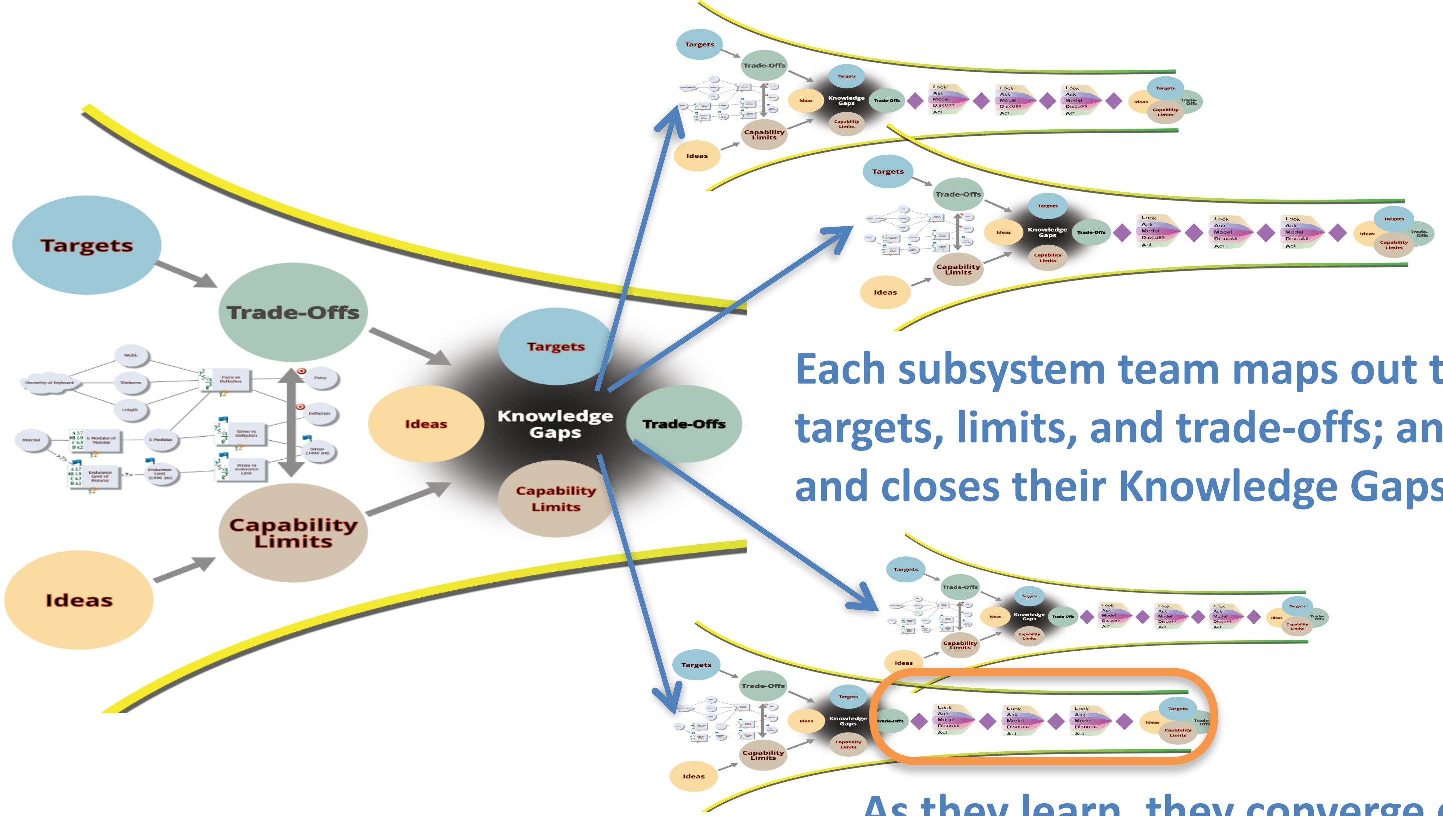
# But that must be Coordinated across Subsystem Teams…




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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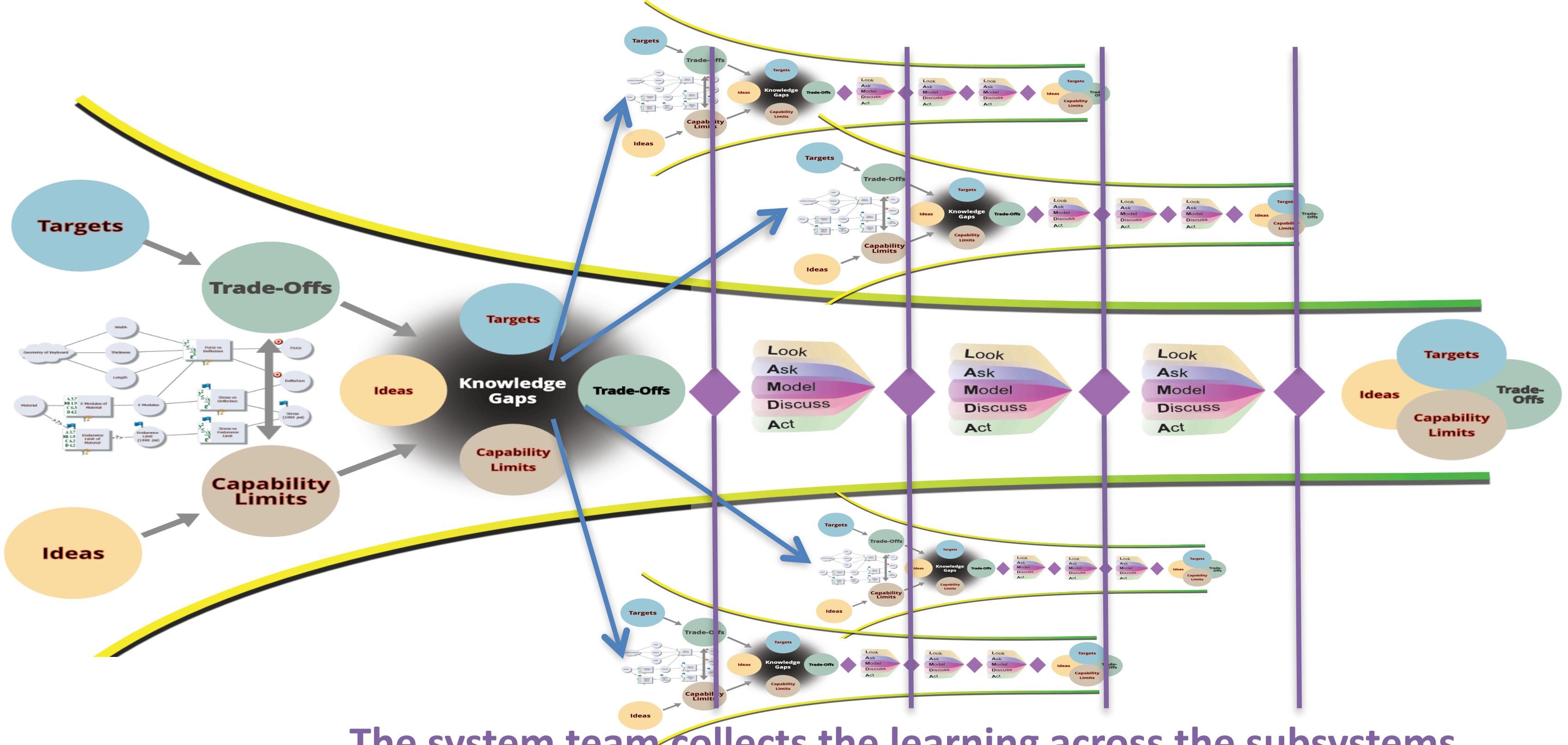
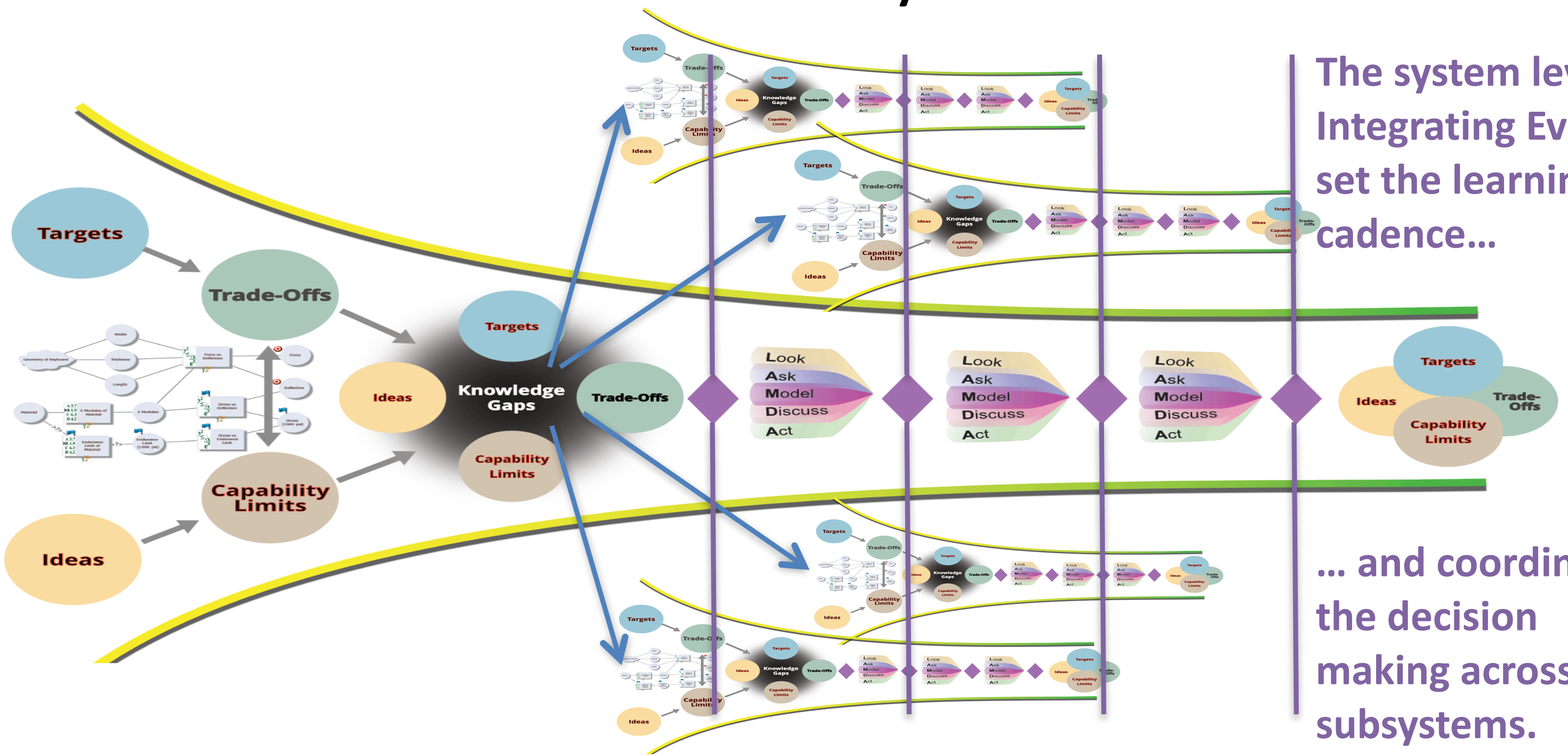
# But that must be Coordinated across Subsystem Teams…




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

# 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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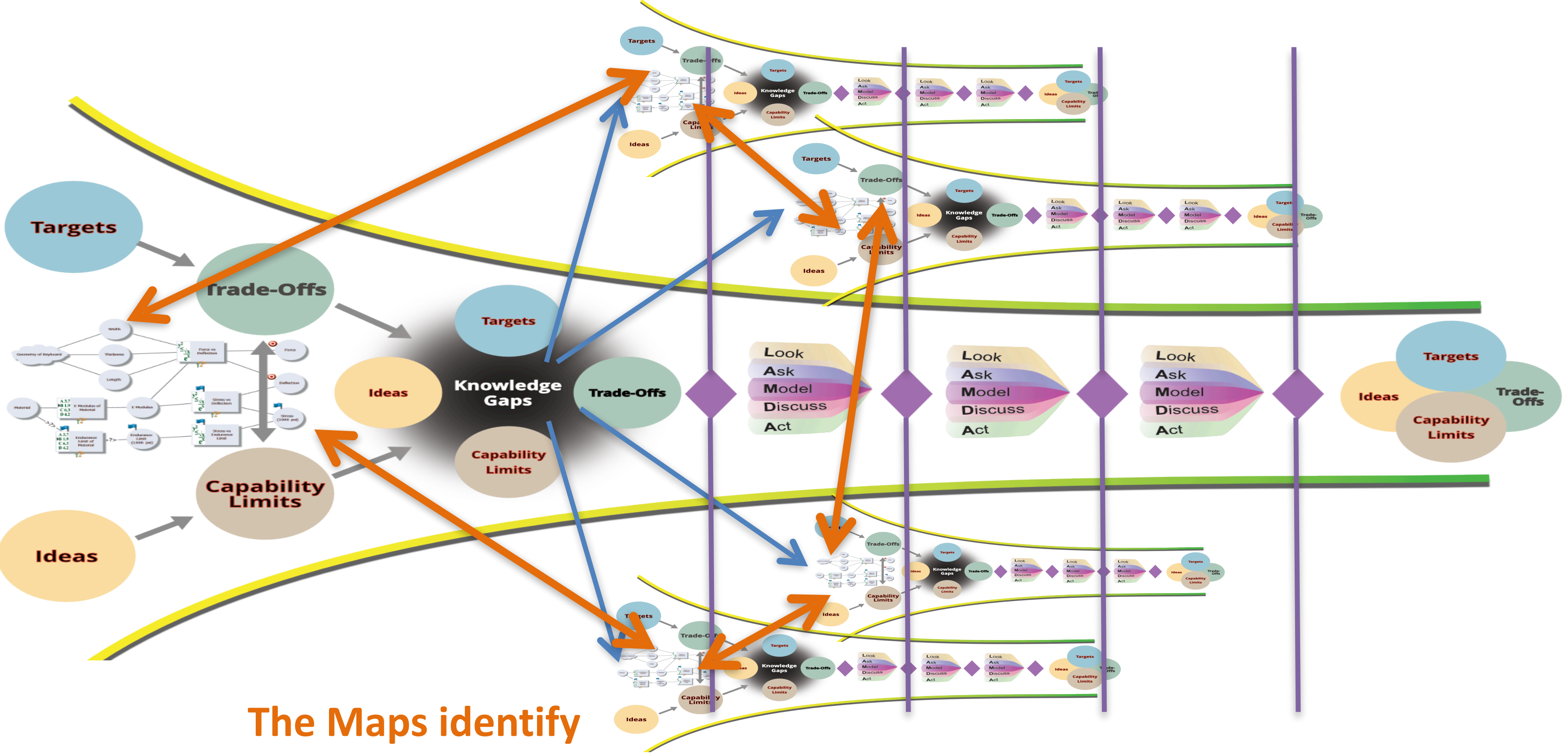
# But that must be Coordinated across Subsystem Teams…




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

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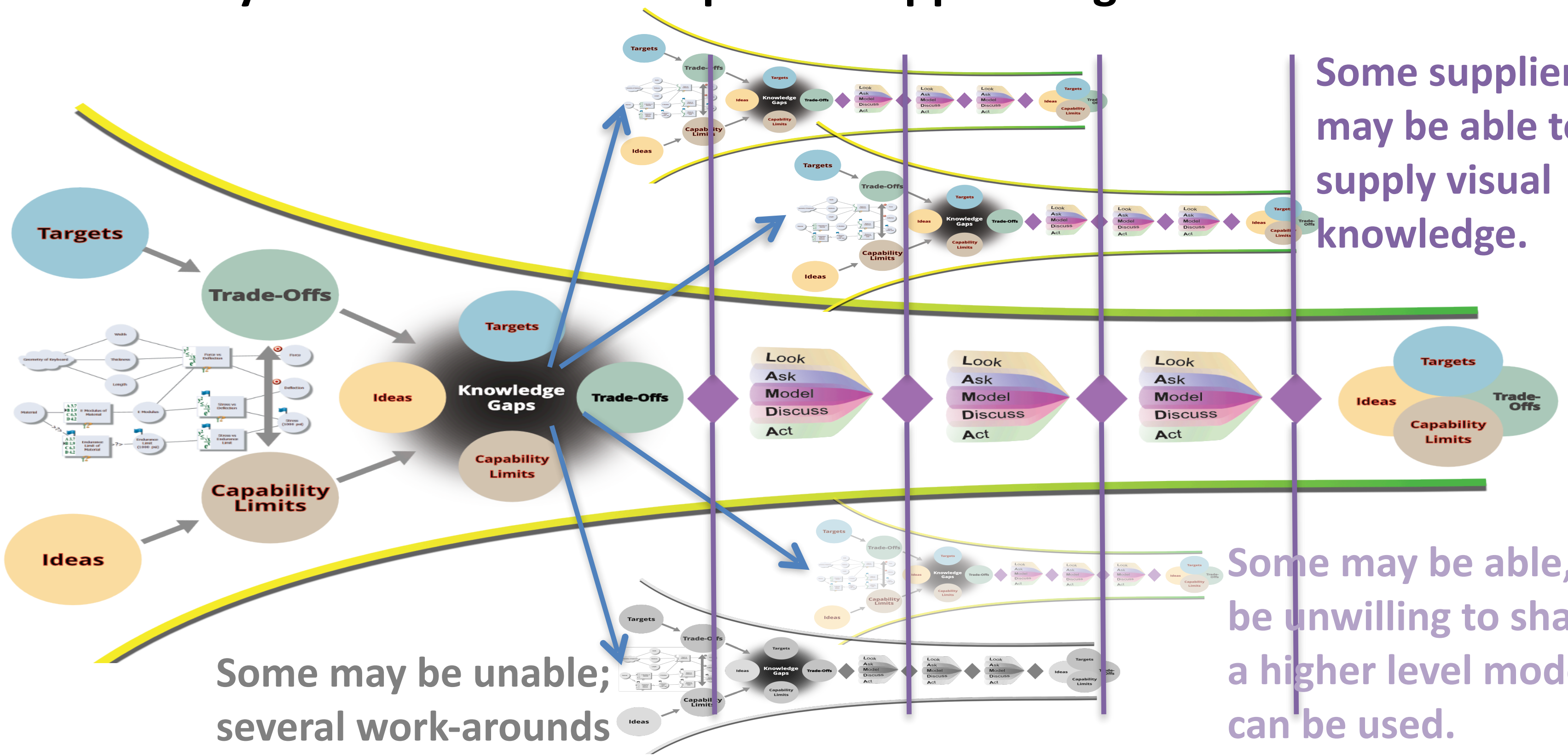
# Often Subsystem Teams are in separate Supplier Organizations…




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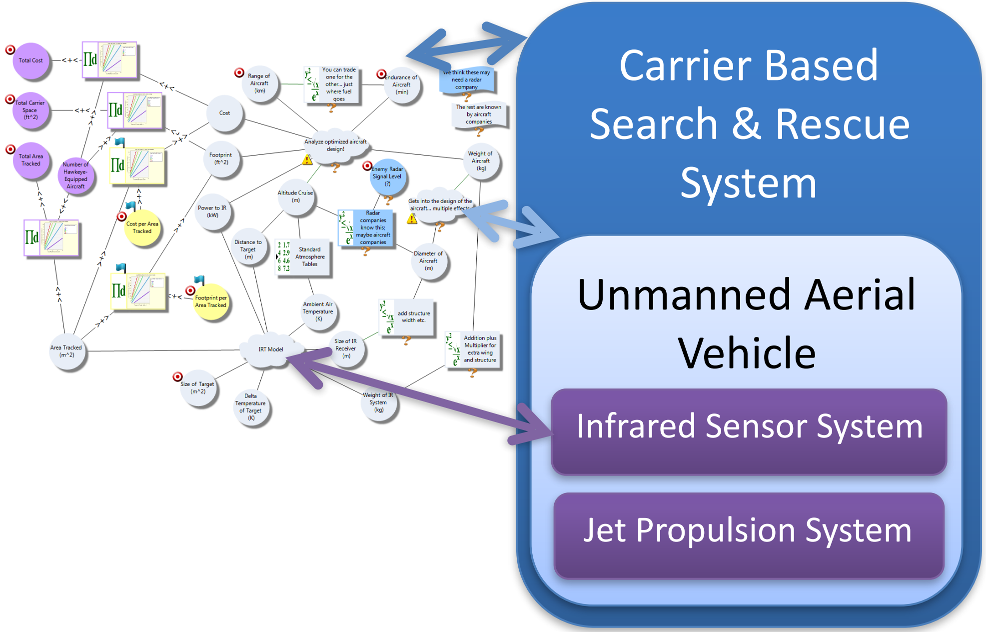
# A System-of-Systems Causal Map might look like this…



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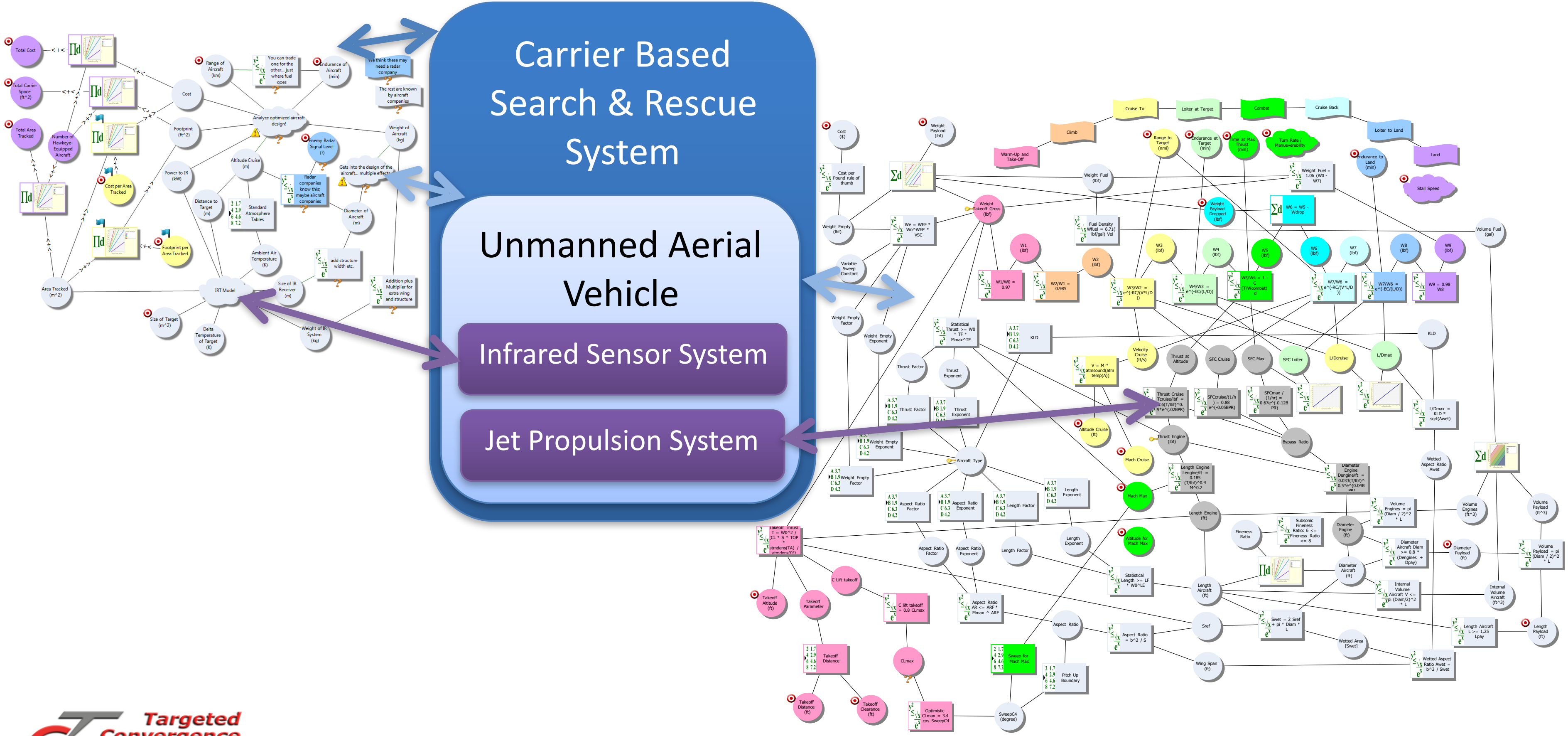


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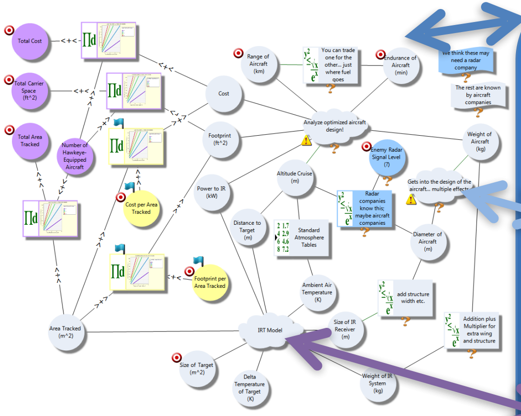

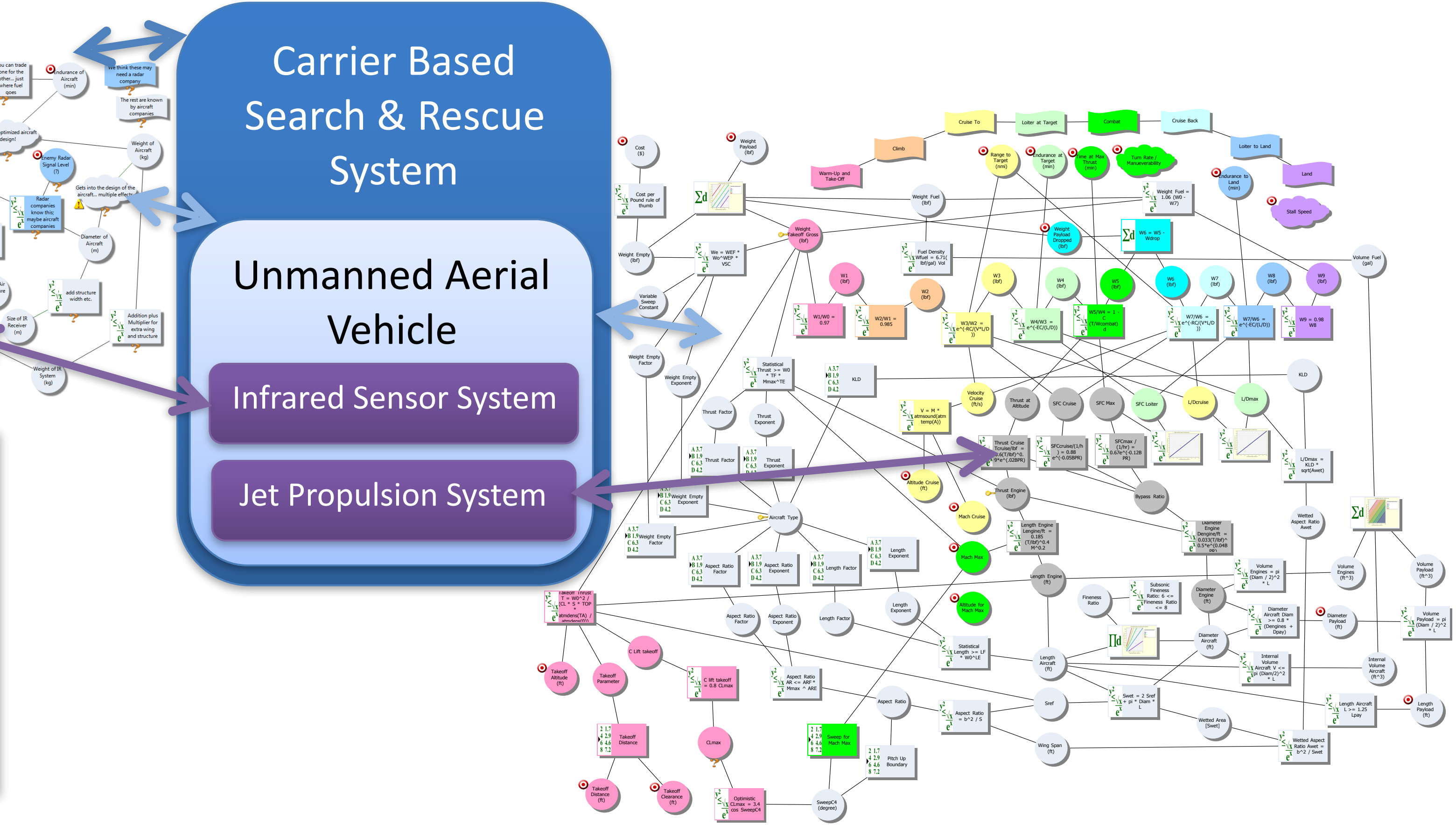


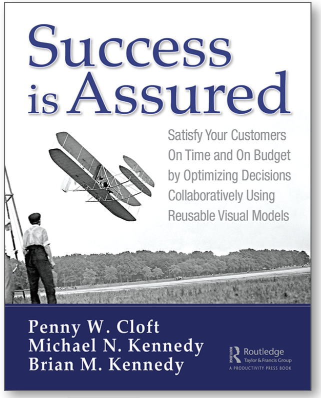


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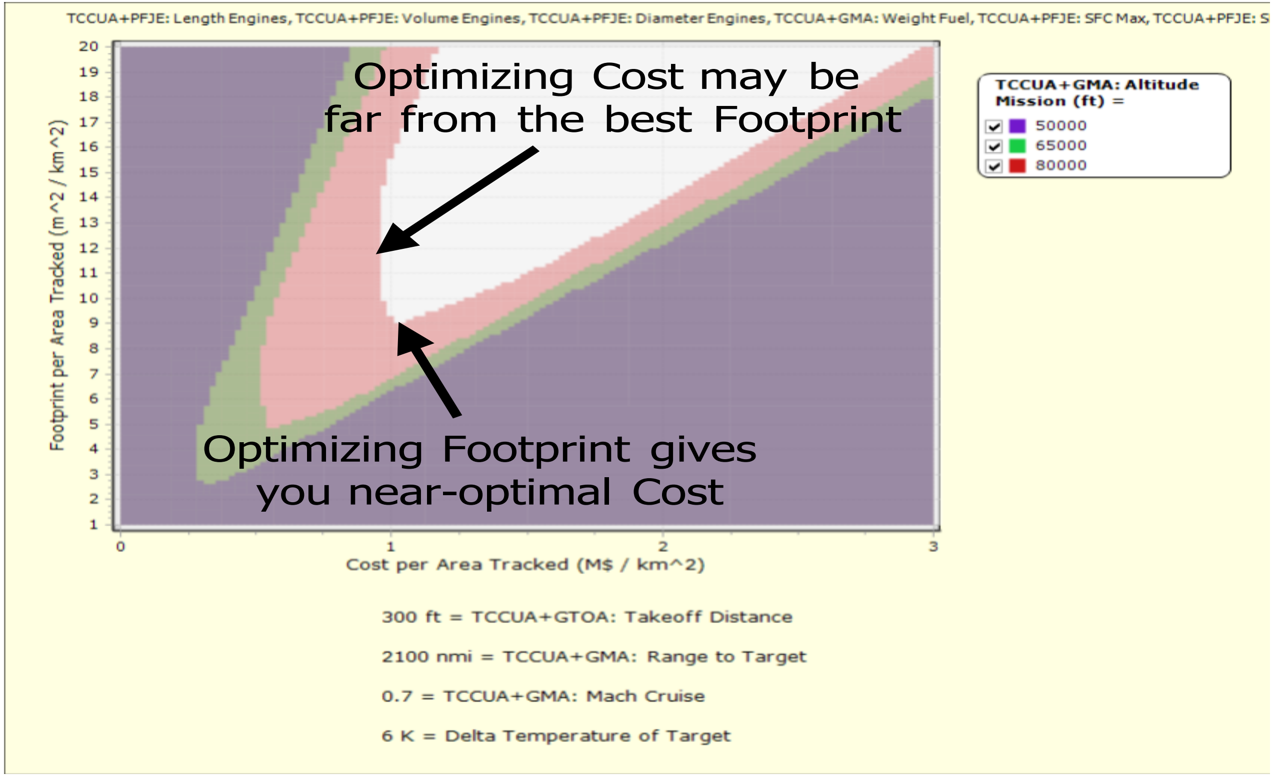
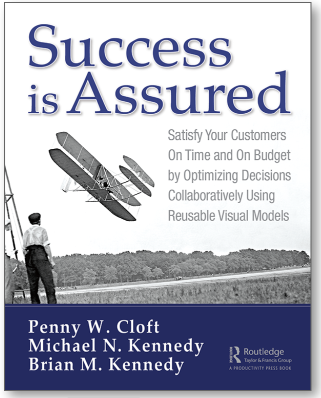
# A System-of-Systems Trade-Off Chart might look like this…

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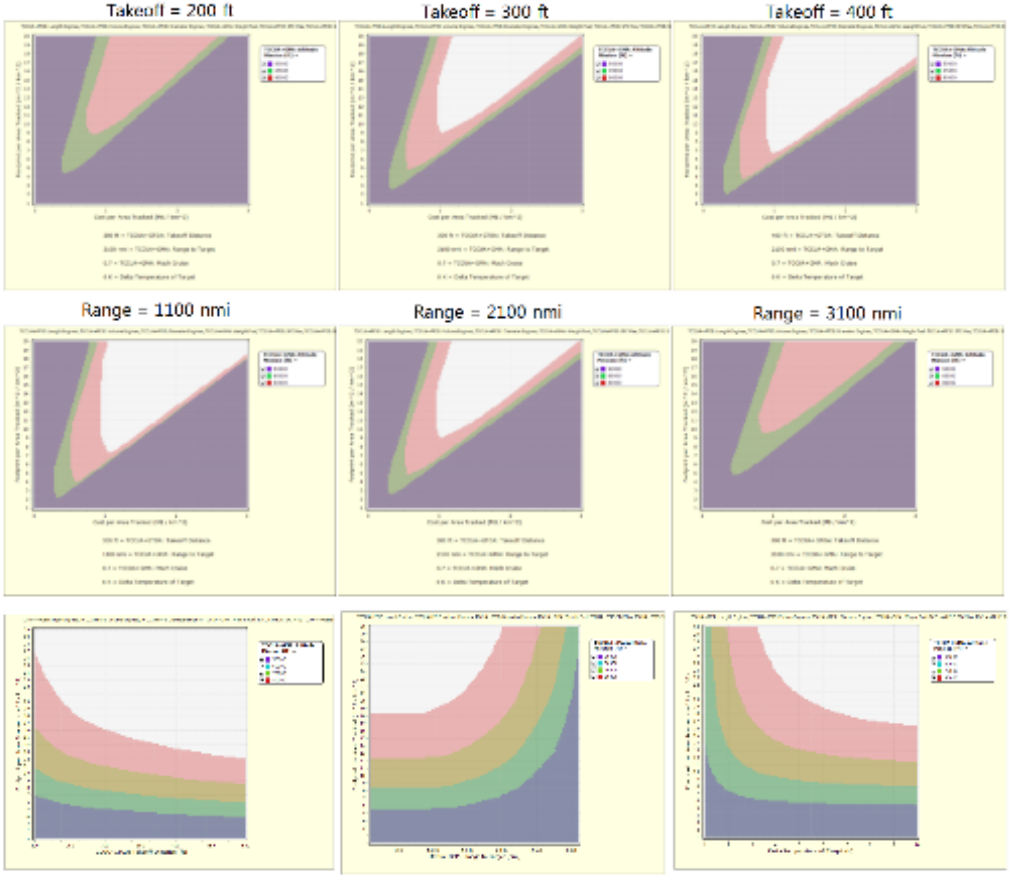
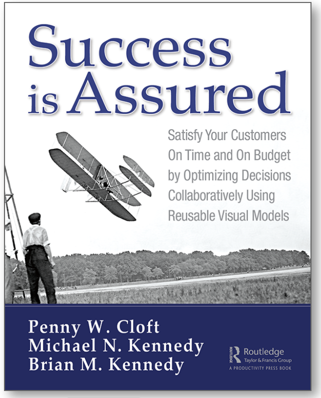
# System-of-Systems Trade-Off Charts might look like these…

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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]

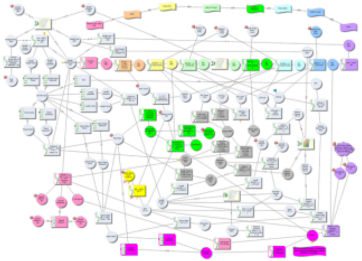
K-Brief ▾ | 80 ▾ | Multi-Column ▾

### *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:

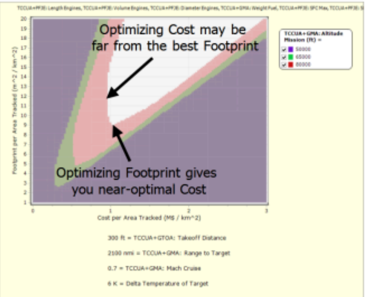
1. Trade-Off Charts
2. Trade-Off Solvers
3. Trade-Off Maps

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.

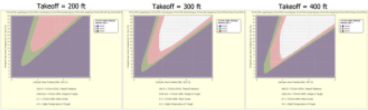
The shaded areas are infeasible; the white is the design space at altitude 80,000 ft. If you turn off the red, the white area inside the green is the design space at 65,000 ft Altitude. The purple at 50,000 ft. In other words, this is showing you a three dimensional design space, where the best cost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



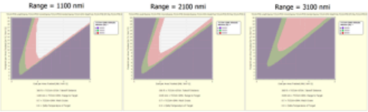

Our brains can only see three dimensions at once. But our problems are always far more than three-dimensions. So, Success Assured™ Trade-Off Charts are designed to use our next strongest sense (eye-hand coordination) to let you see additional dimensions by dragging the sliders along the bottom of the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

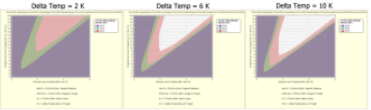
To illustrate that statically (without opening the live Chart), here is the Chart as you drag Takeoff Distance from 200 ft, to 300 ft, to 400 ft. Notice how the design space doesn't move much going from 400 ft down to 300 ft, but it moves a lot more going from 300 ft down to 200 ft. So, there is some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



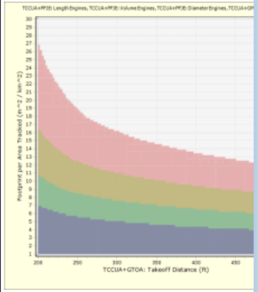

Not surprisingly, Delta Temperature has a similar non-linear effect, but in the opposite direction. There's a knee in the curve at some Delta T... it would be good to know where that it is and stay above it.

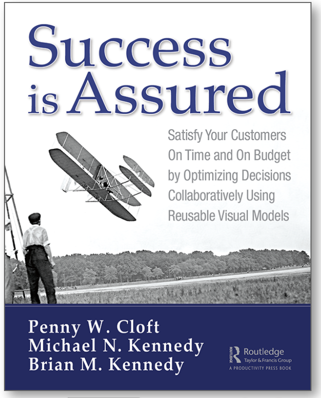



In addition to allowing you to use anim
the multi-dimensional trade space (for
relation Decision Map that crosses mult
the Success Assured™ software is also
it quick and easy to compute very diffe
the same underlying model. Limited to
only 3 dimensions clearly at once, it is
easy as possible for decision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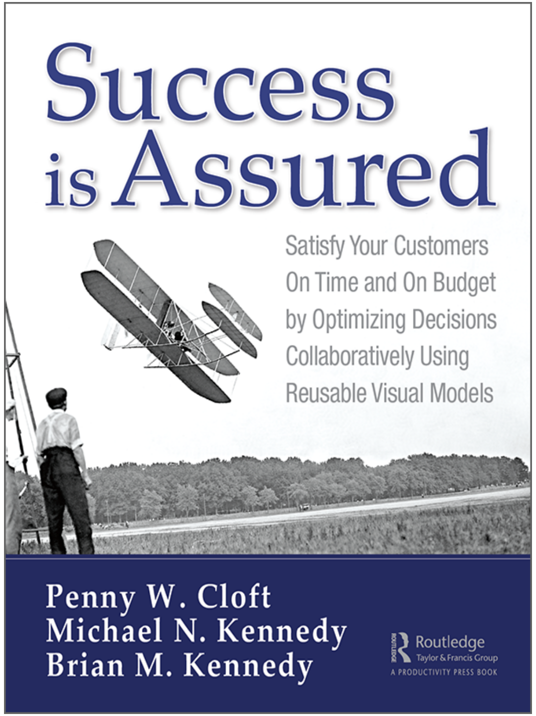
# Any Questions??

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

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