SoSECIE Webinar

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

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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January 26, 2021
Addressing the Sustainable Development Goals with a System-of-Systems for Monitoring Arctic Coastal Regions
Evelyn Honoré-Livermore, Roger Birkeland and Cecilia Haskins

February 9, 2021
Fuzzy Architecture Description for Handling Uncertainty in IoT Systems-of-Systems
Flavio Oquendo

February 23, 2021
Interface Management- the Neglected Orphan of Systems Engineering
Paul Davies

March 9, 2021
Distributed Architecture for Monitoring Urban Air Quality: A Systems Engineering Approach
Adrián Unger, Tom McDermott and Philip Dewire

April 6, 2021
Holistic architecture description for a future Global Health Assurance Systems of Systems
Adrián Unger

April 20, 2021
Leveraging Set-Based Practices to Enable Efficient Concurrency in Large Systems and Systems-of-Systems Engineering
Brian Kennedy

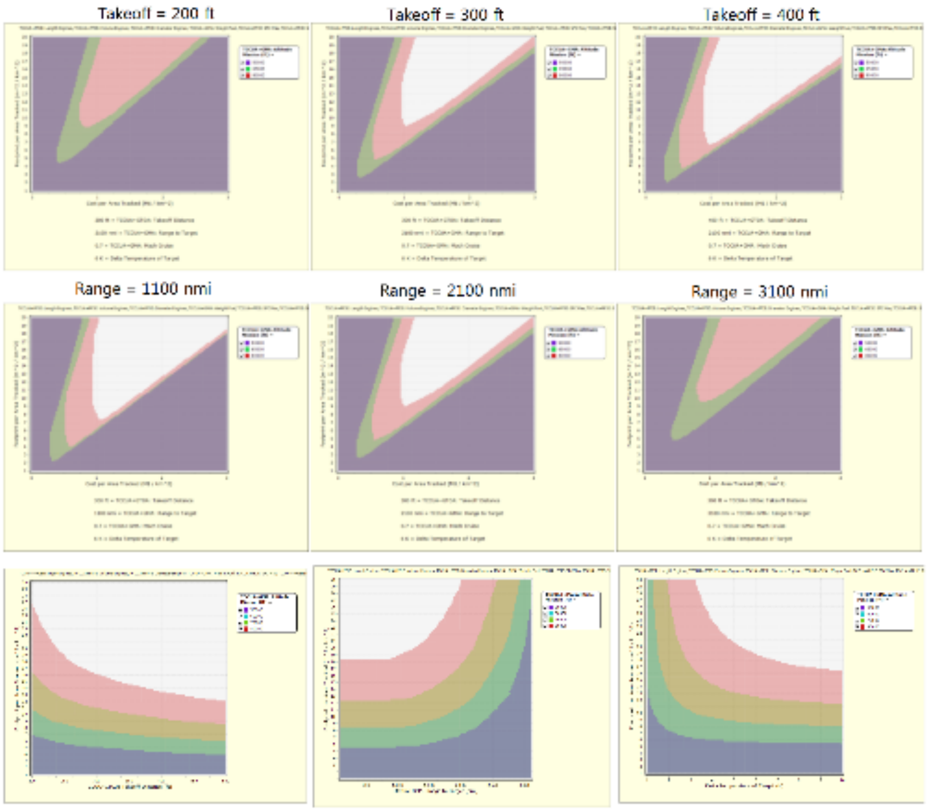
Every Mission-Level or System-Level Trade Study should have an associated Trade Space Map to Facilitate Multi-Discipline Review

Brian M. Kennedy
CTO
Targeted Convergence Corporation

Trade Studies that Require Expertise from Multiple Domains…

… are notoriously error-prone!

- It is very easy for critical dependencies to be overlooked.
- It is very common for assumptions to be made in one part of the model, but different assumptions in other parts!
- Given that, how do decision makers gain adequate confidence to move forward?
- How do they pull in experts they trust to critique the trade studies?
- How often are trade studies done, but not acted upon?



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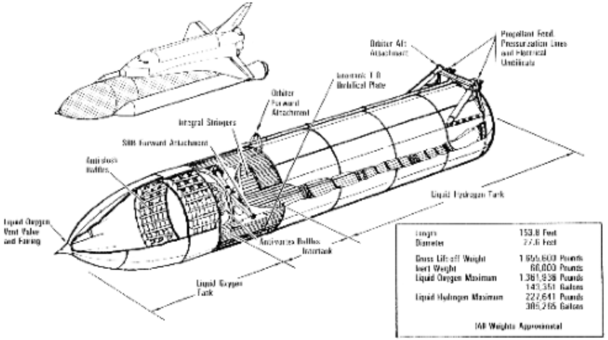
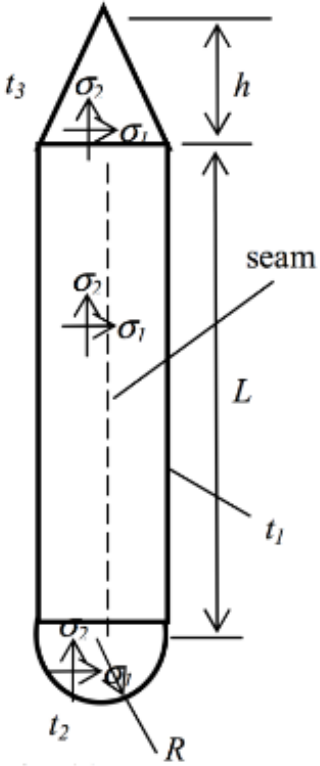
NASA wanted to Minimize Cost of Shuttle's External Fuel Tank





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)

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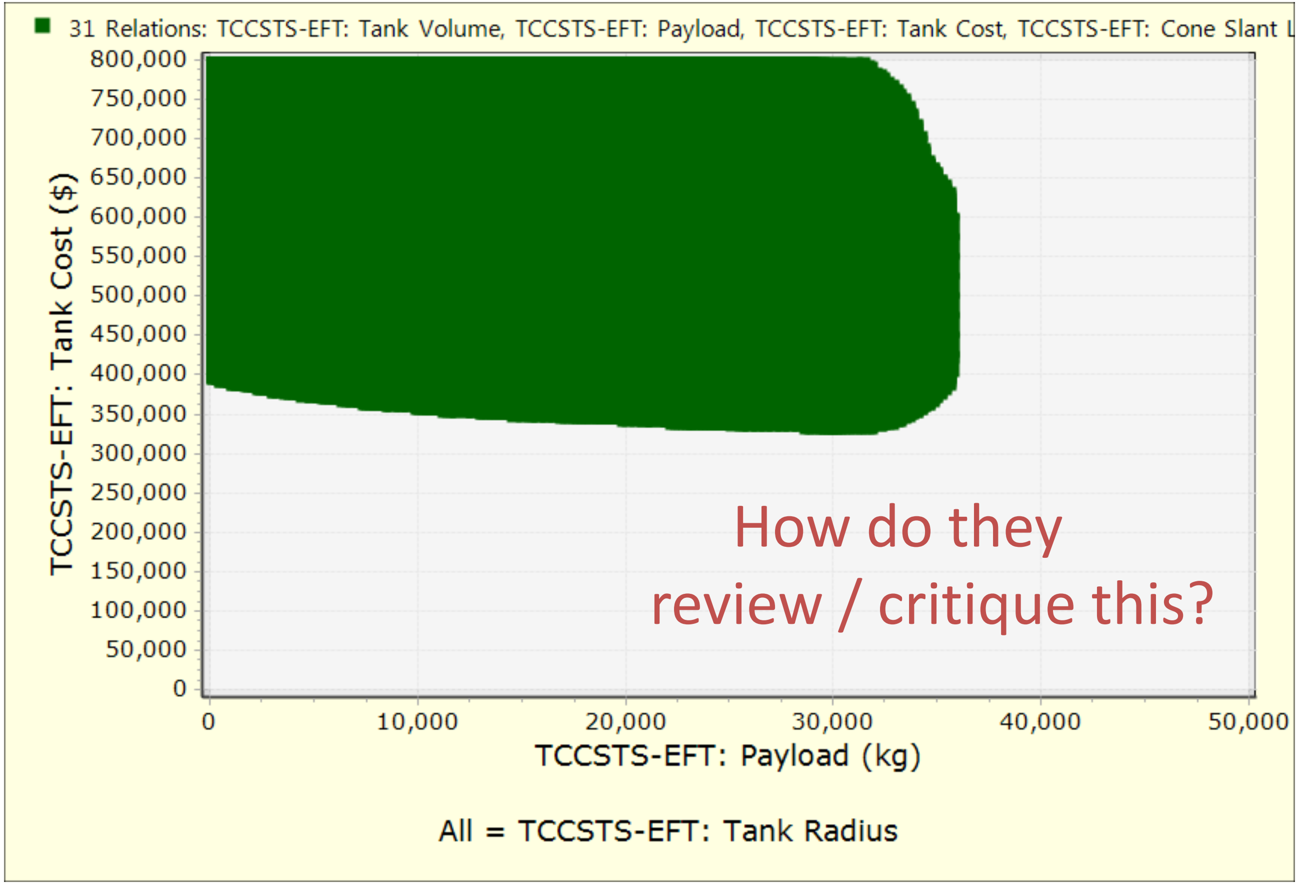
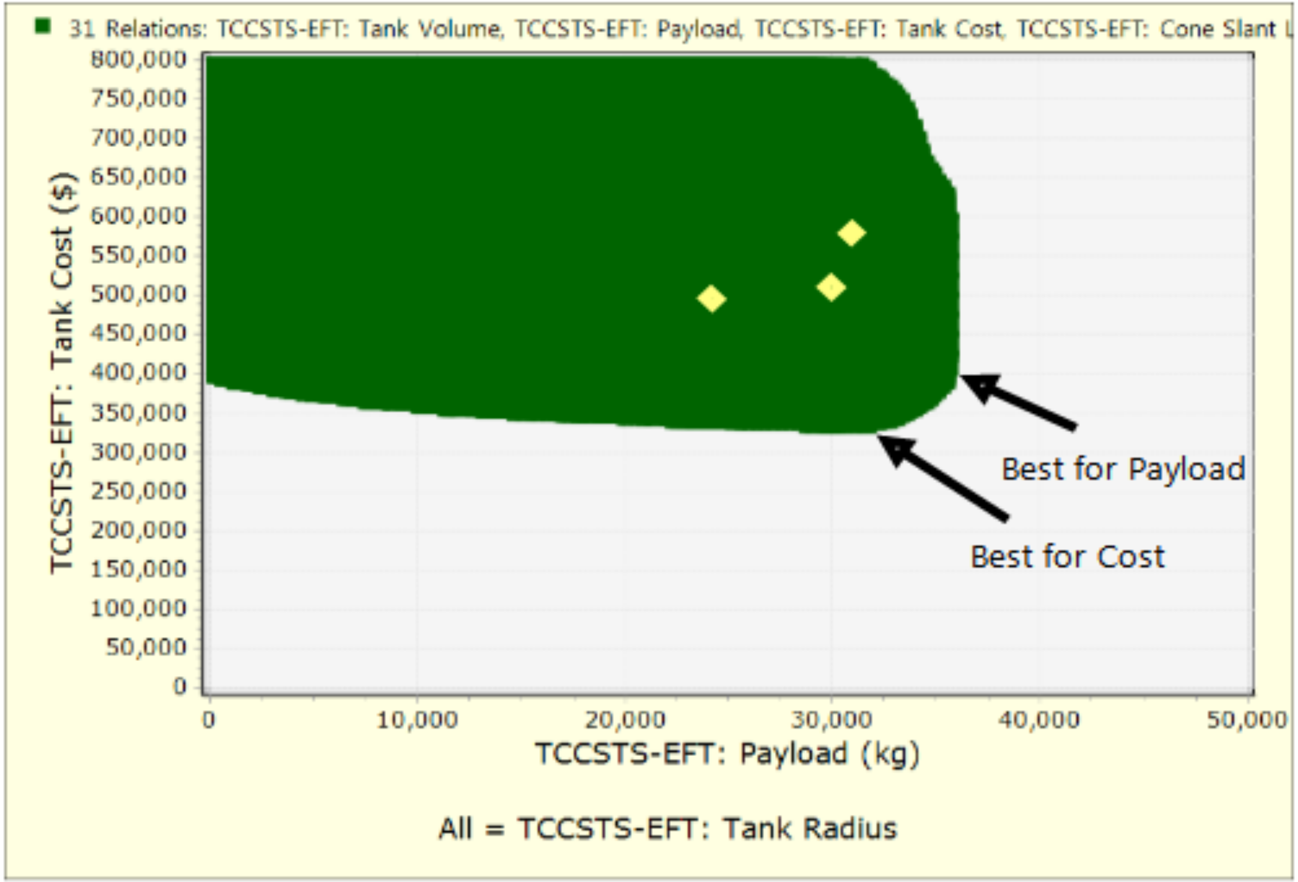
System Engineers Present Trade Study to Decision Makers



Review Against Existing and other Past Designs? vs. Reasonableness?



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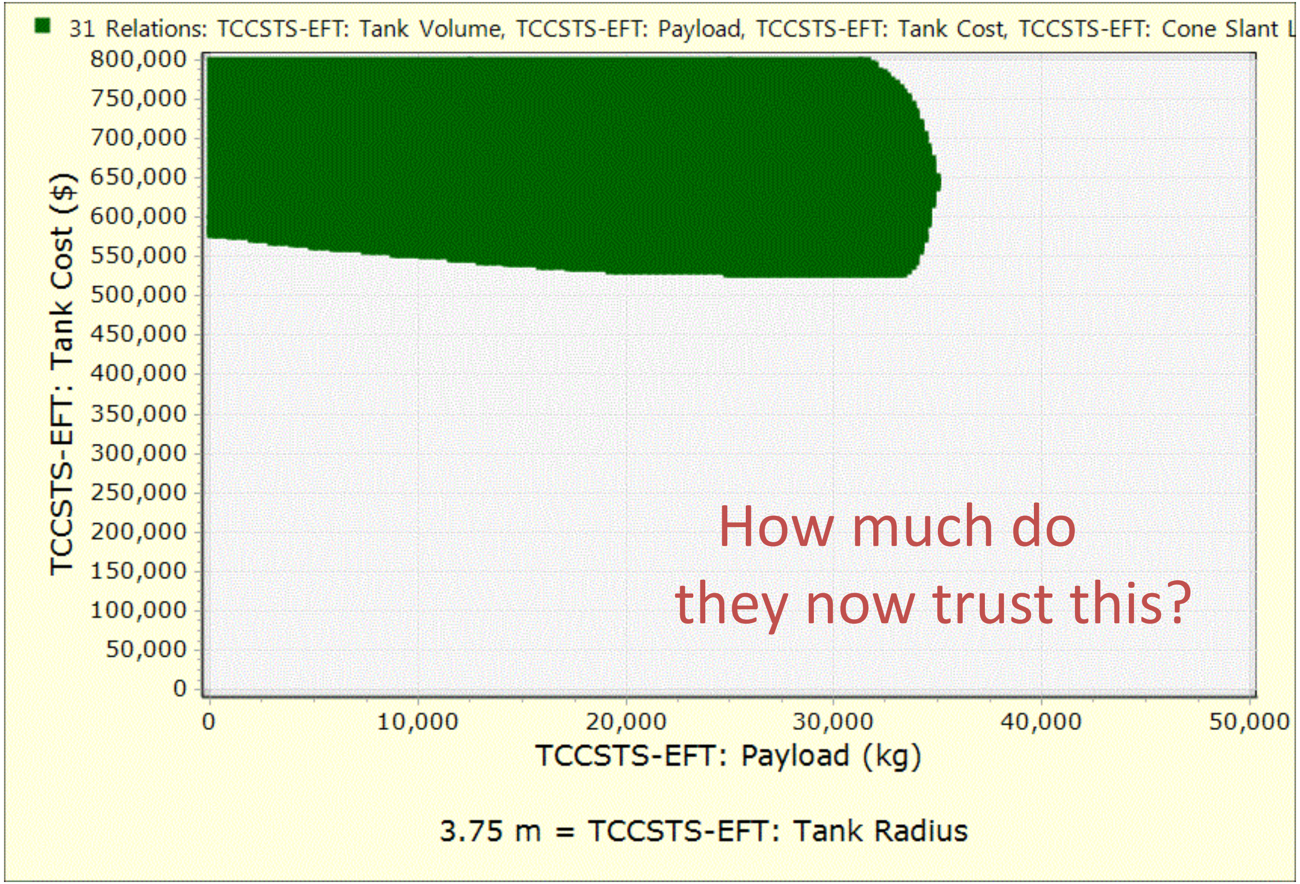
Review Against Sensitivities? (Here's the impact of Tank Radius…)



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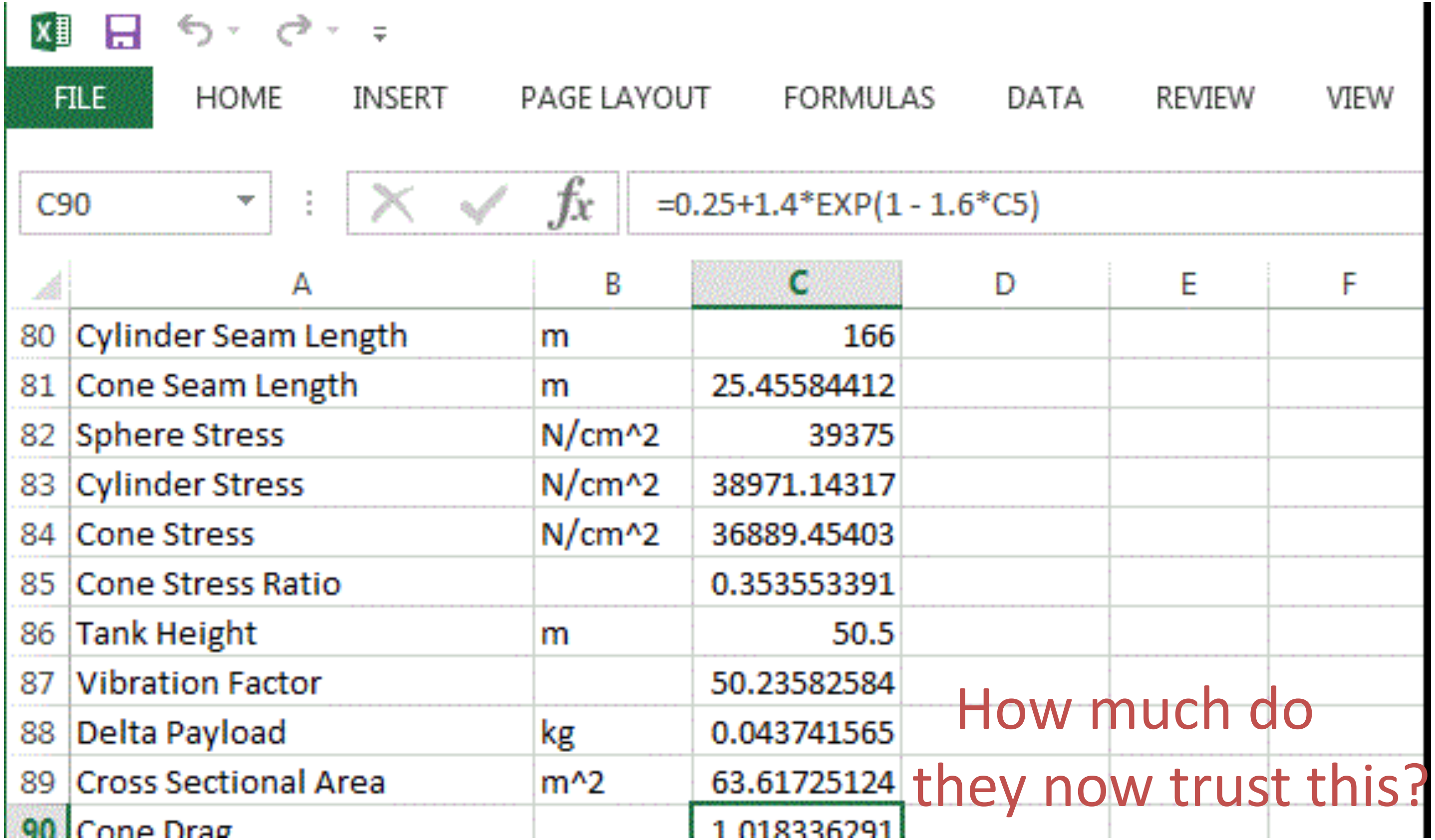
Review the math / Excel / <whatever tools>?



	A	B	C	D	E	F
80	Cylinder Seam Length	m	166			
81	Cone Seam Length	m	25.45584412			
82	Sphere Stress	N/cm^2	39375			
83	Cylinder Stress	N/cm^2	38971.14317			
84	Cone Stress	N/cm^2	36889.45403			
85	Cone Stress Ratio		0.353553391			
86	Tank Height	m	50.5			
87	Vibration Factor		50.23582584			
88	Delta Payload	kg	0.043741565			
89	Cross Sectional Area	m^2	63.61725124			
90	Cone Drag		1.018336291			

How much do they now trust this?

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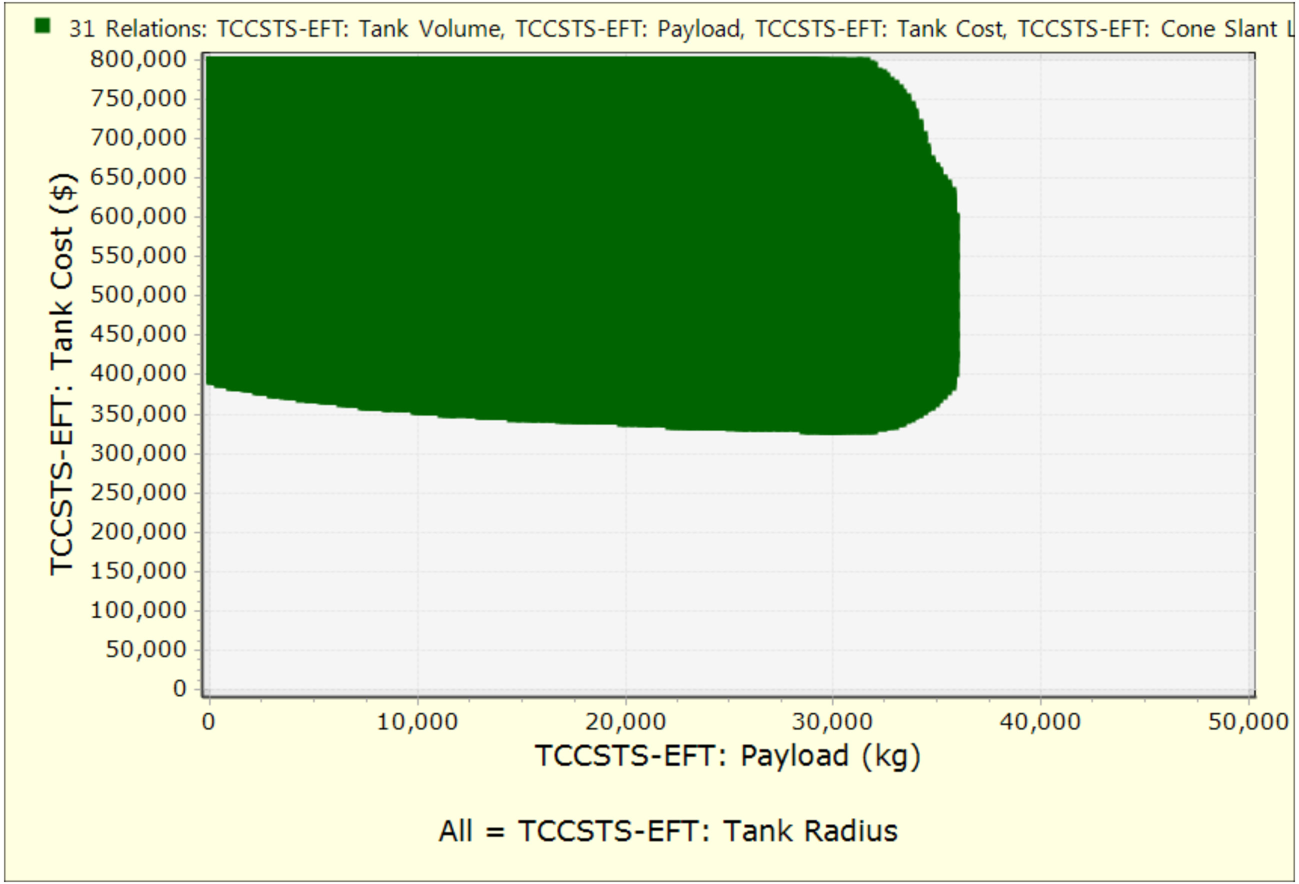
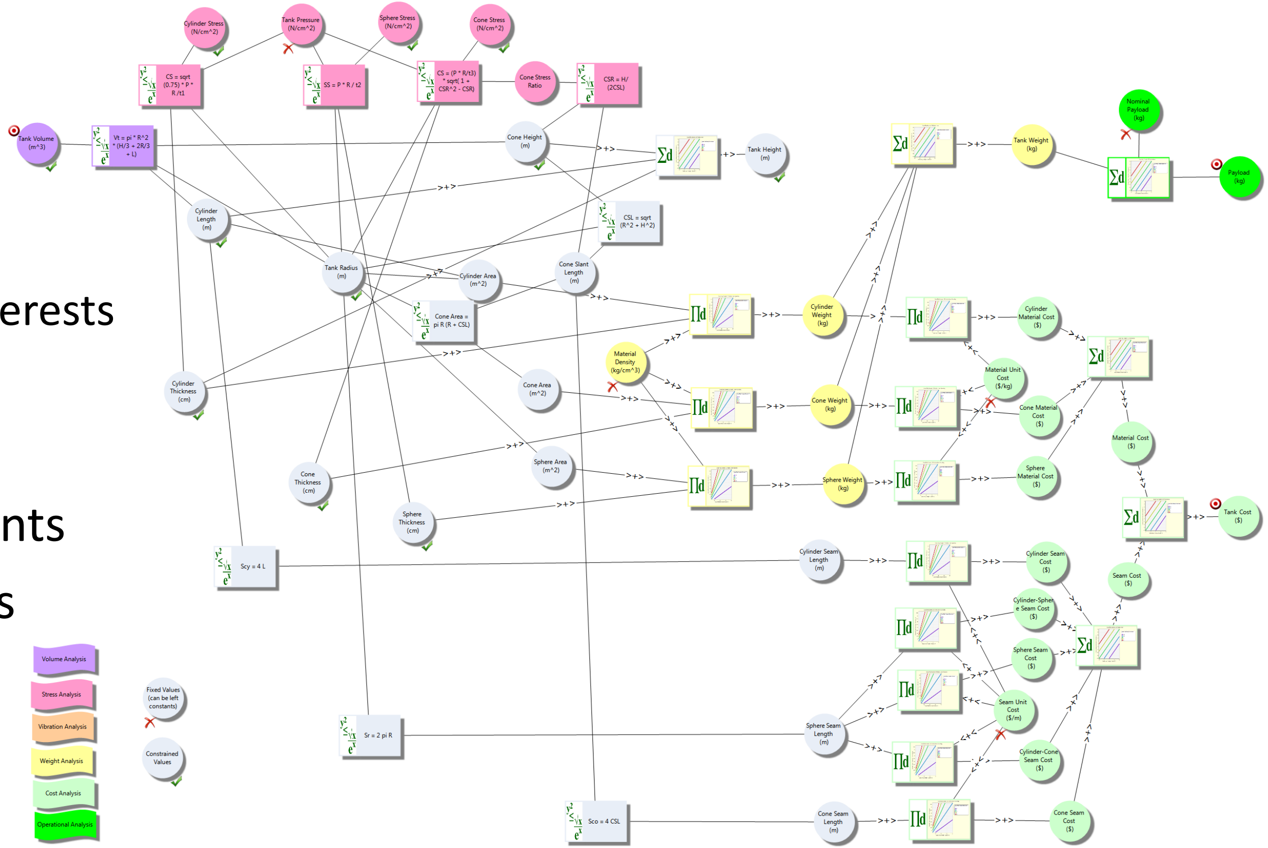
What if every Chart had a button to open up the equivalent "Map"?



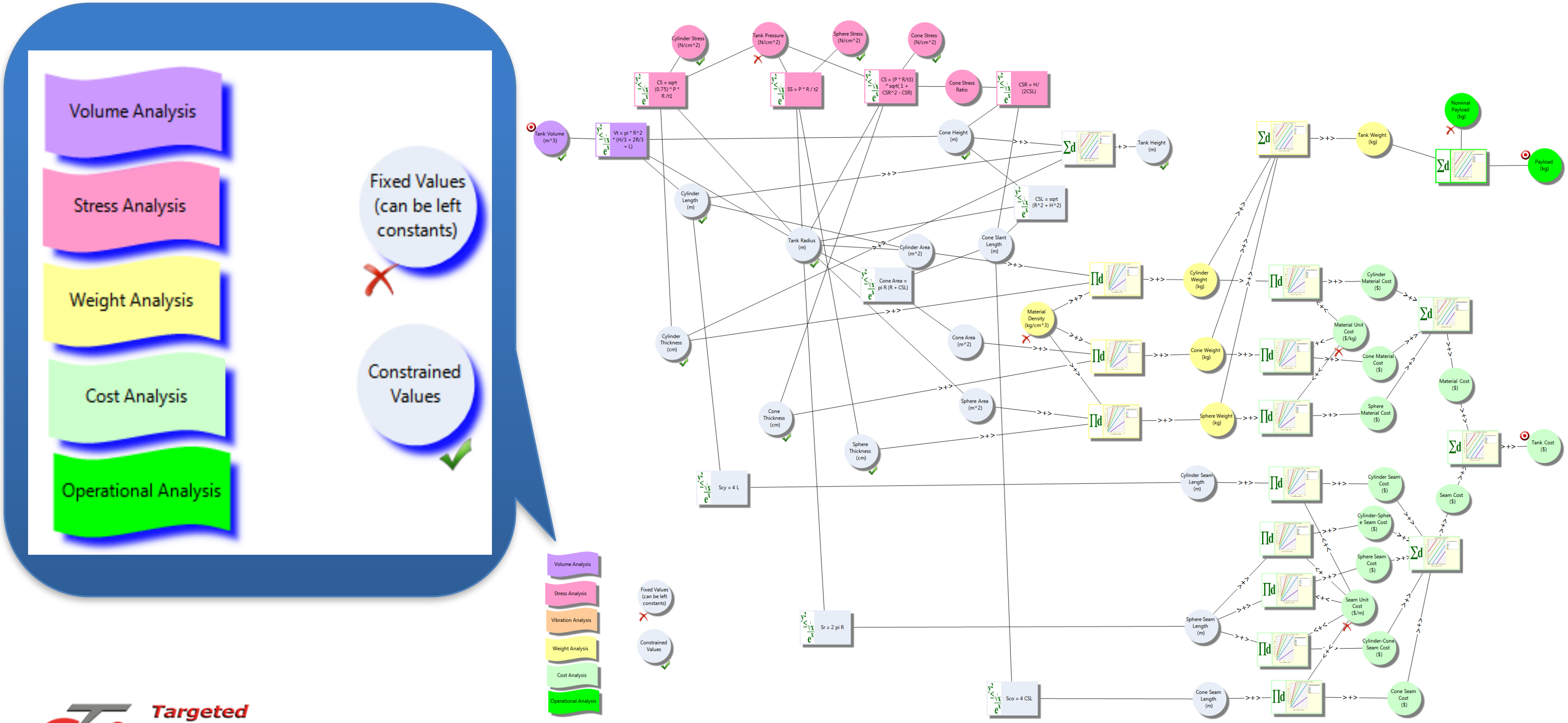
What if every Chart had a button to open up the equivalent “Map”?

Our Causal Maps have just 4 shapes to learn:

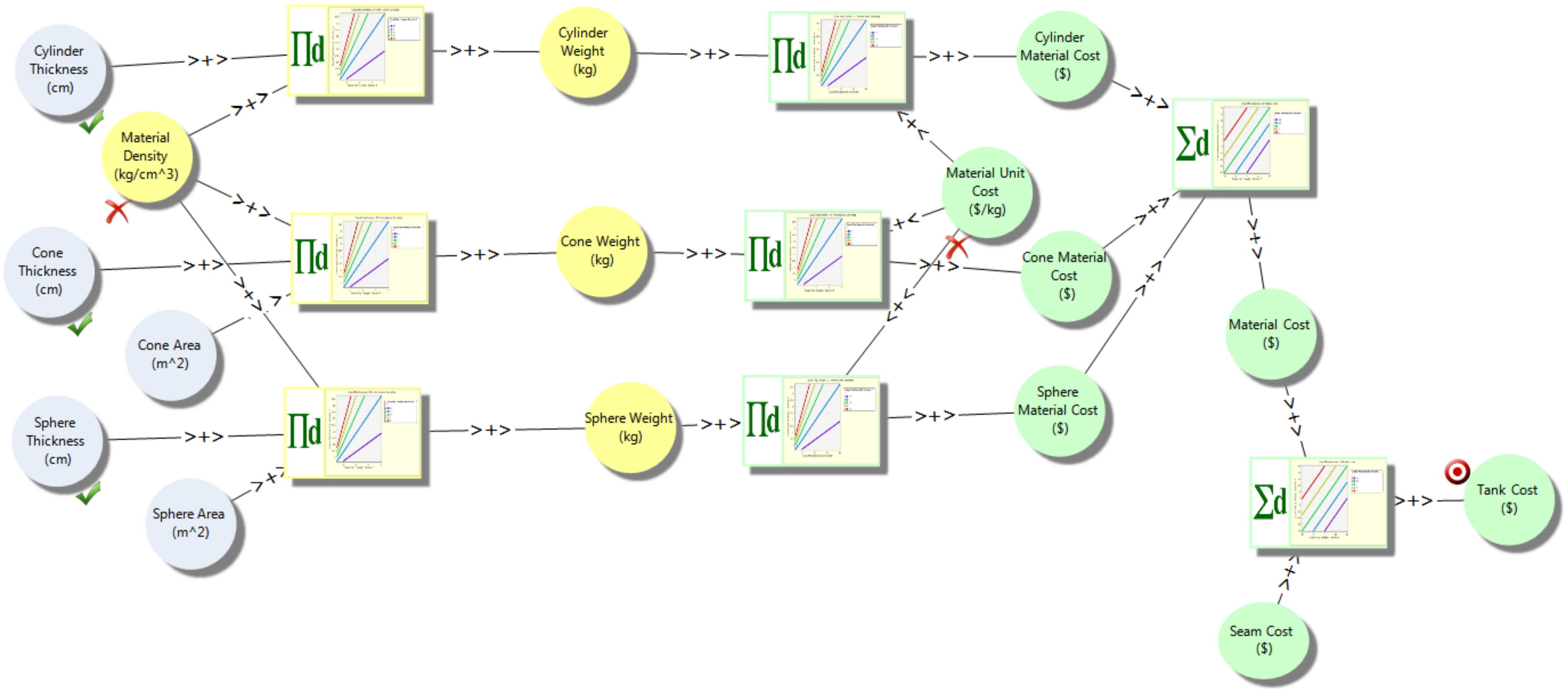
- Circles = Decisions
  - Targets = Customer Interests
- Rectangles = Relations between the Decisions
- Scrolls = Causal Statements
- Clouds = Multiple Others



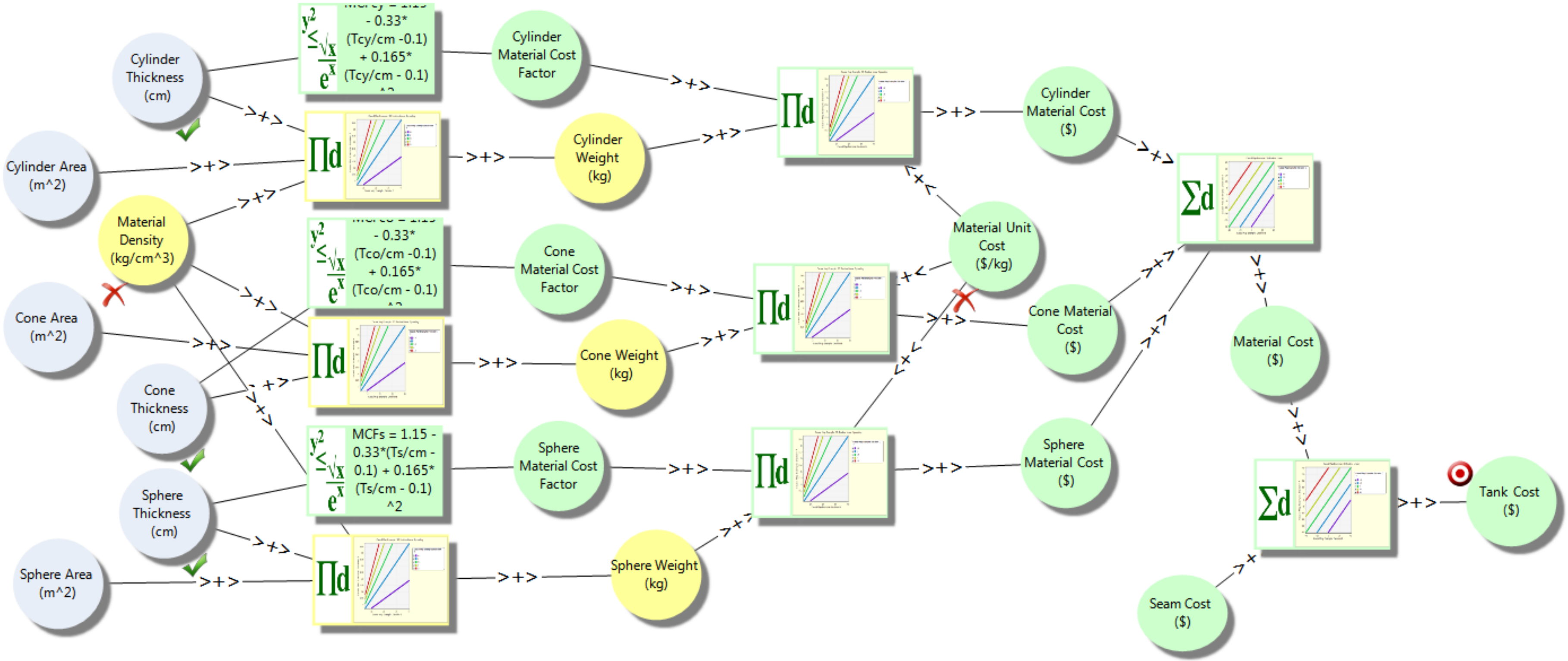
This Causal Map's Color Legend: The Areas of Expertise



Cost Analysis – Material Cost



Cost Analysis – Material Cost – Improved: Thinner => Higher $/kg



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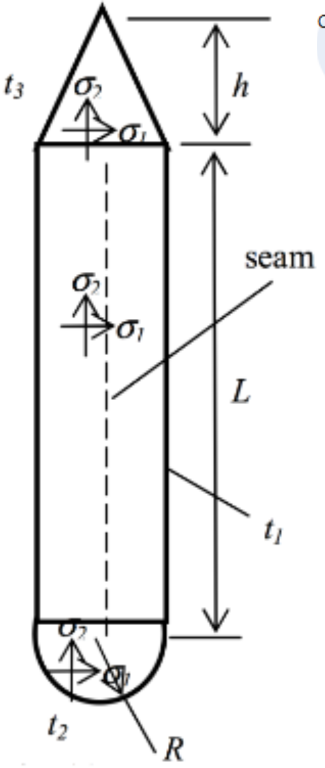
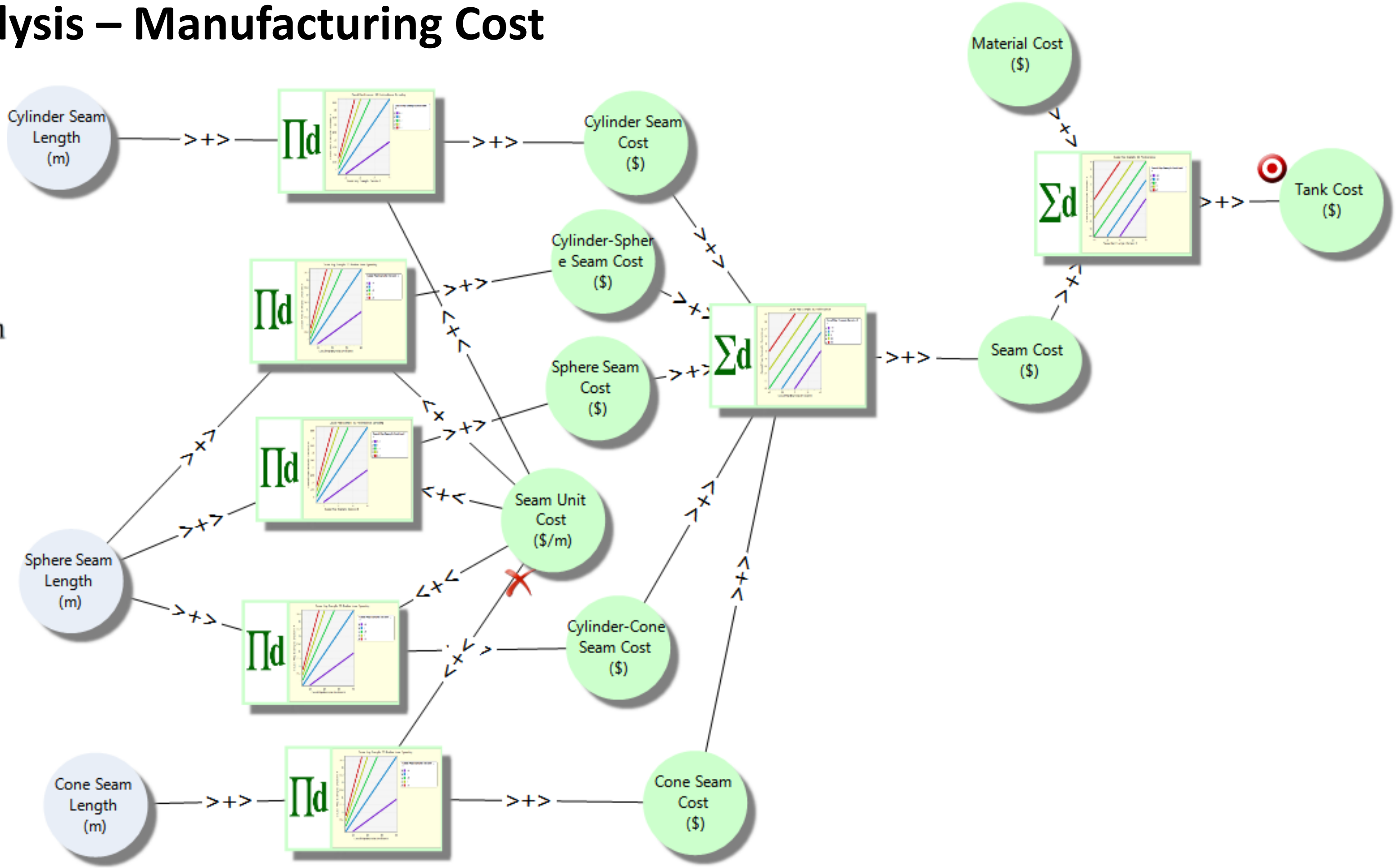
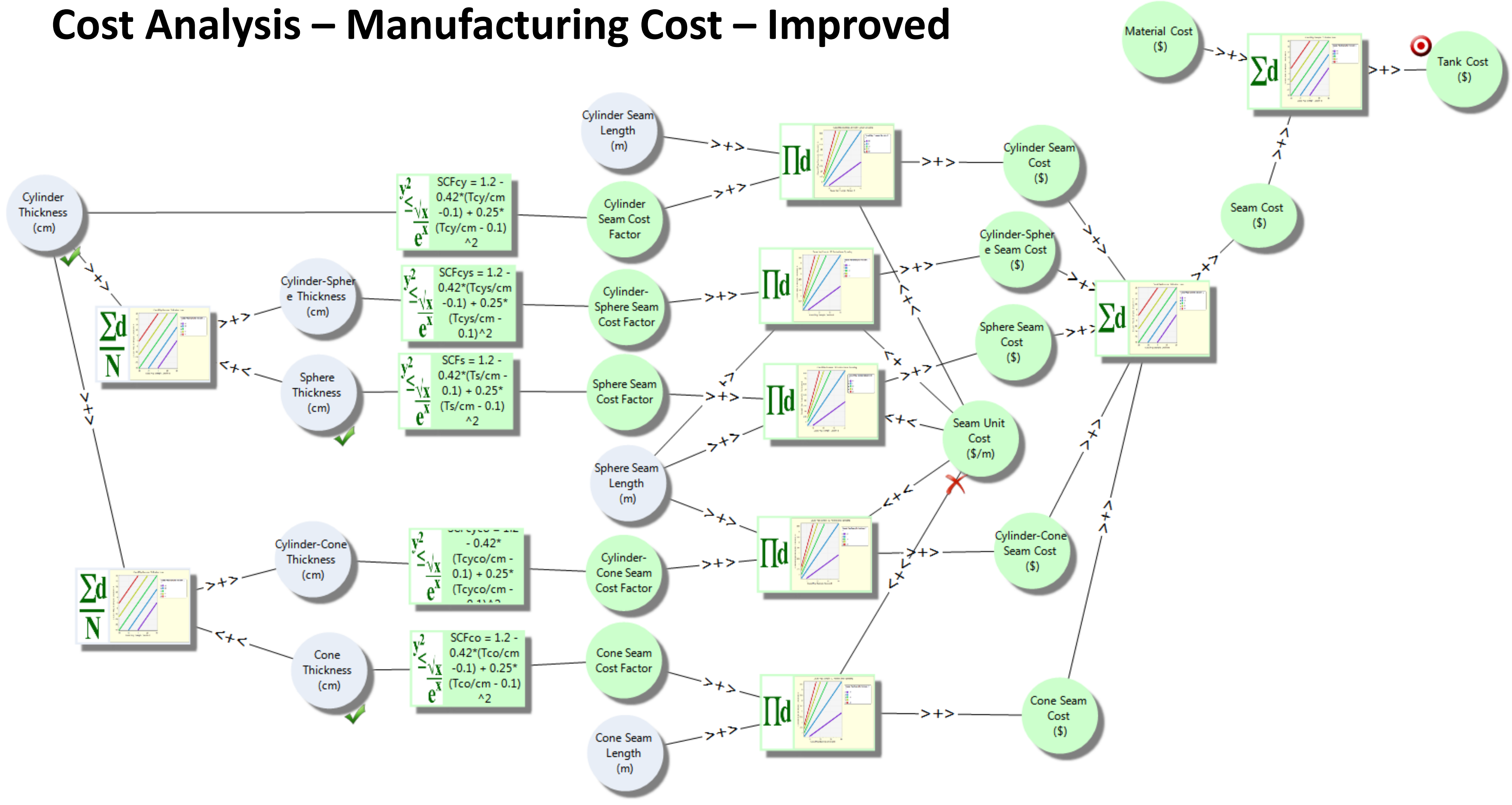
Cost Analysis – Manufacturing Cost

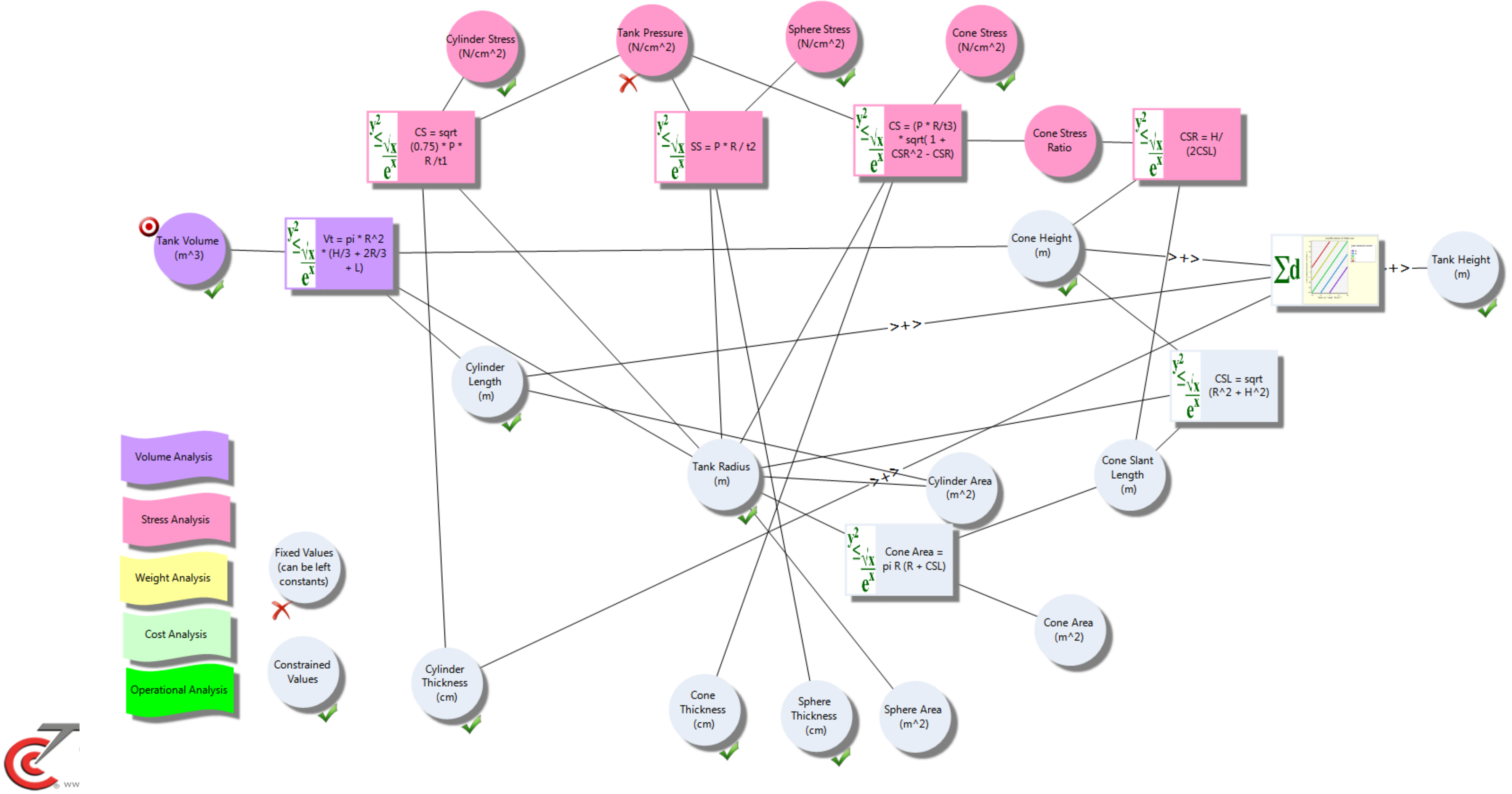




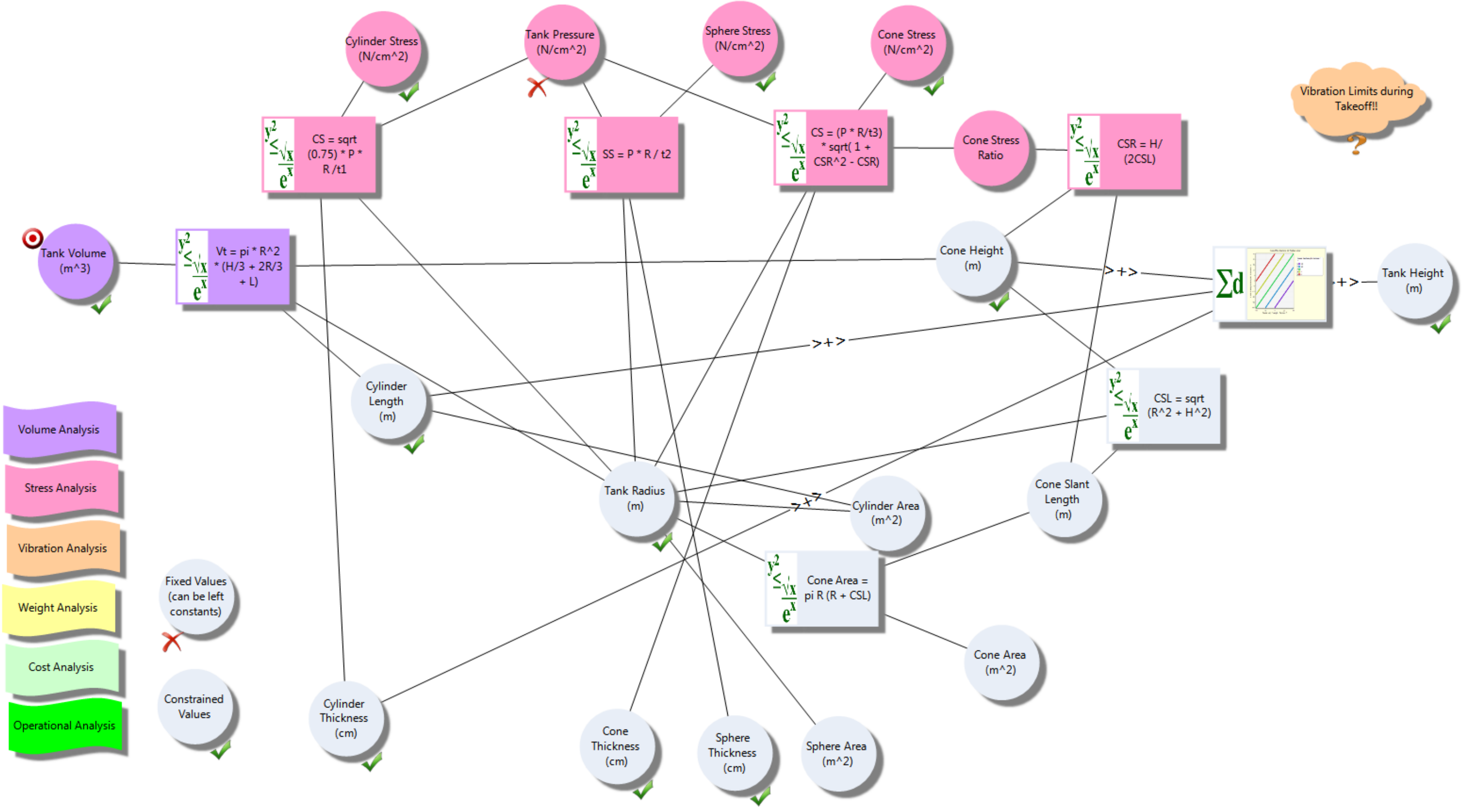
Cost Analysis – Manufacturing Cost – Improved



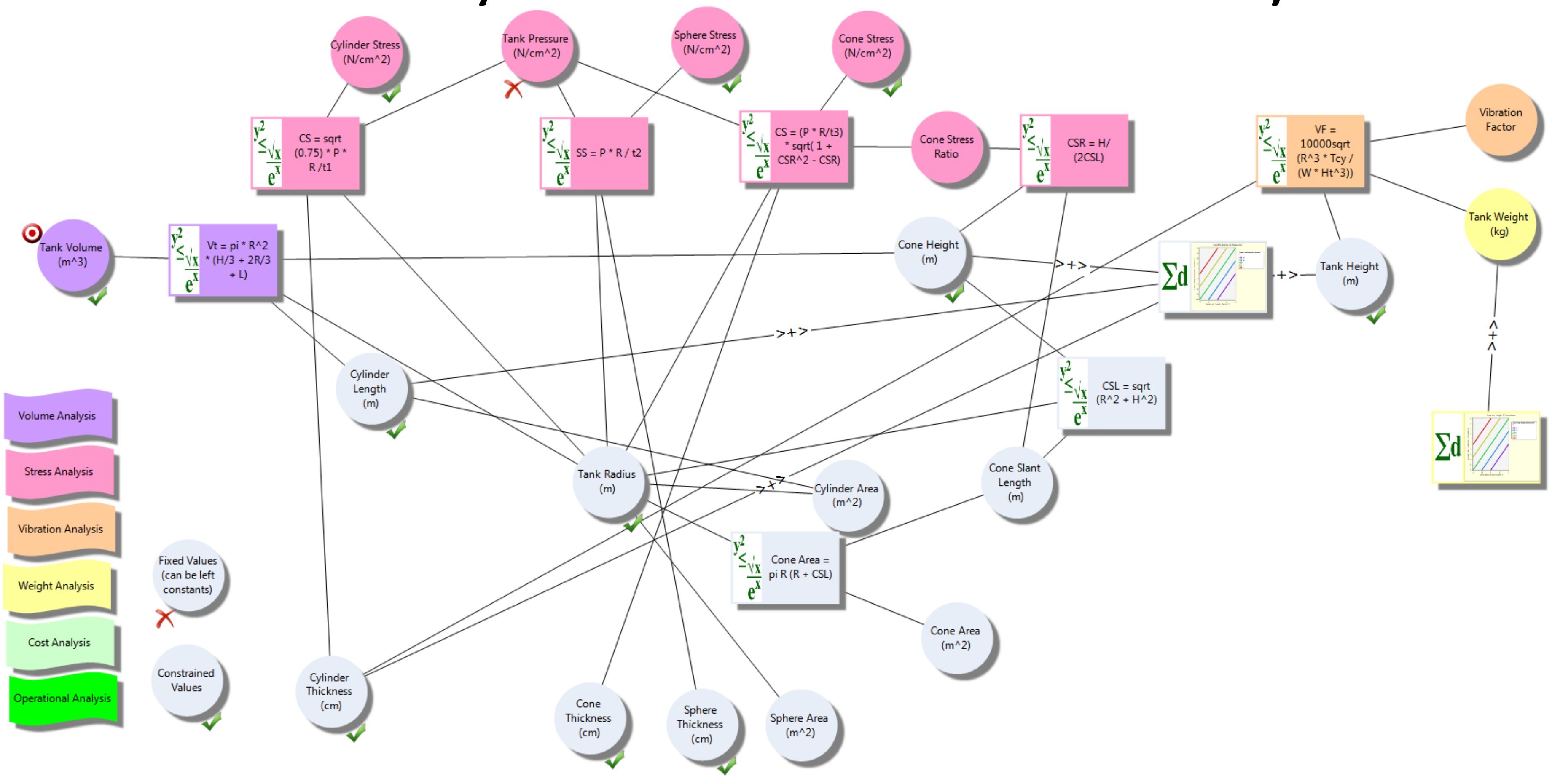
Stress & Volume Analysis



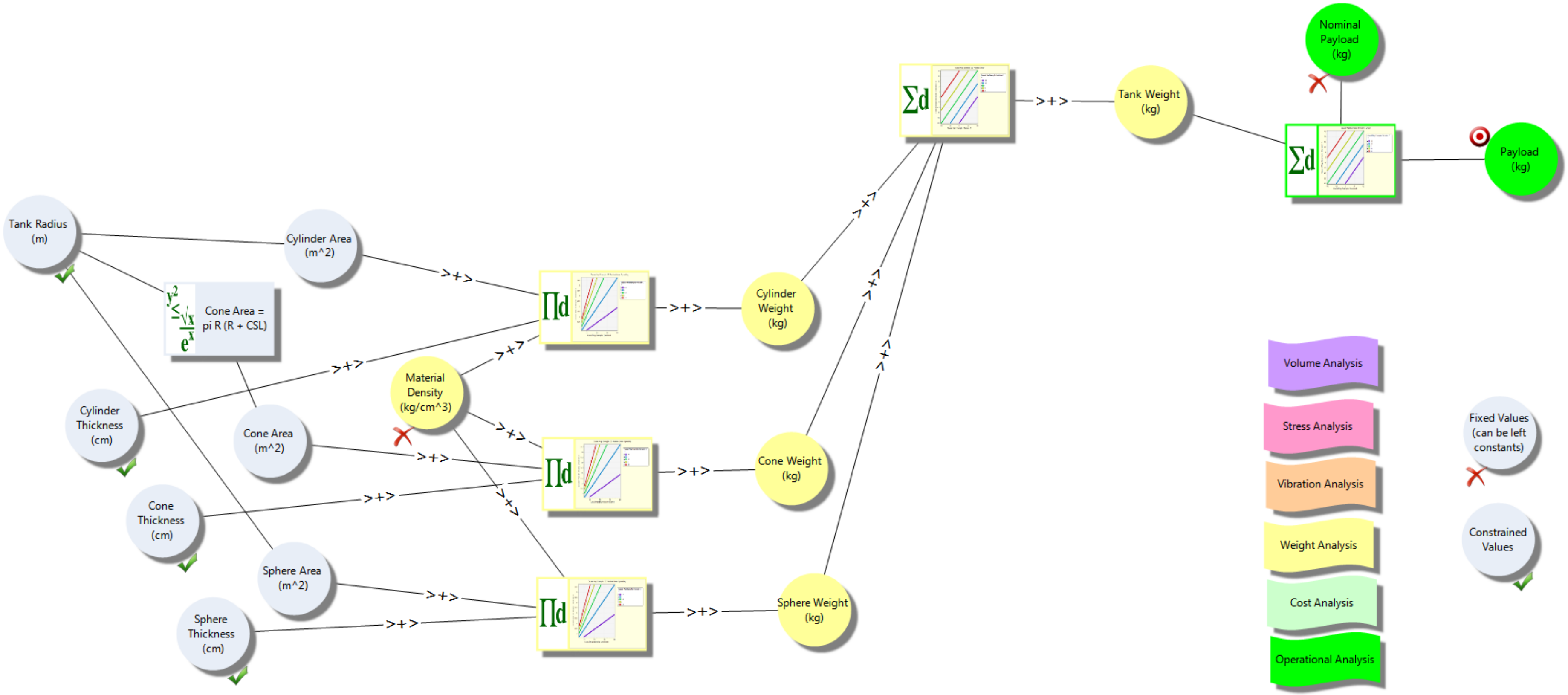
Stress & Volume Analysis – *Vibration Knowledge Gap!*



Stress & Volume Analysis + Vibration Analysis



Payload / Operational Analysis



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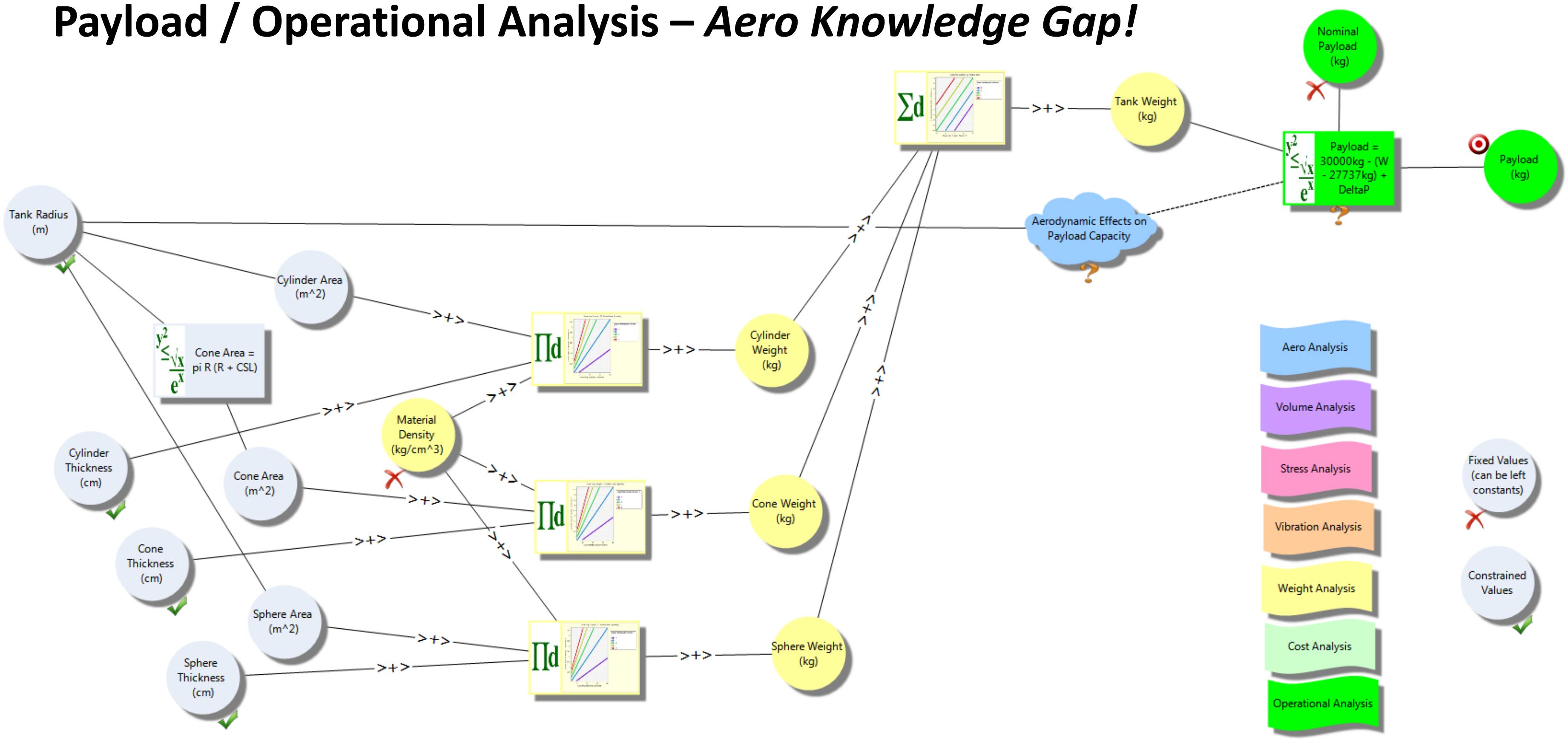
Payload / Operational Analysis – *Aero Knowledge Gap!*



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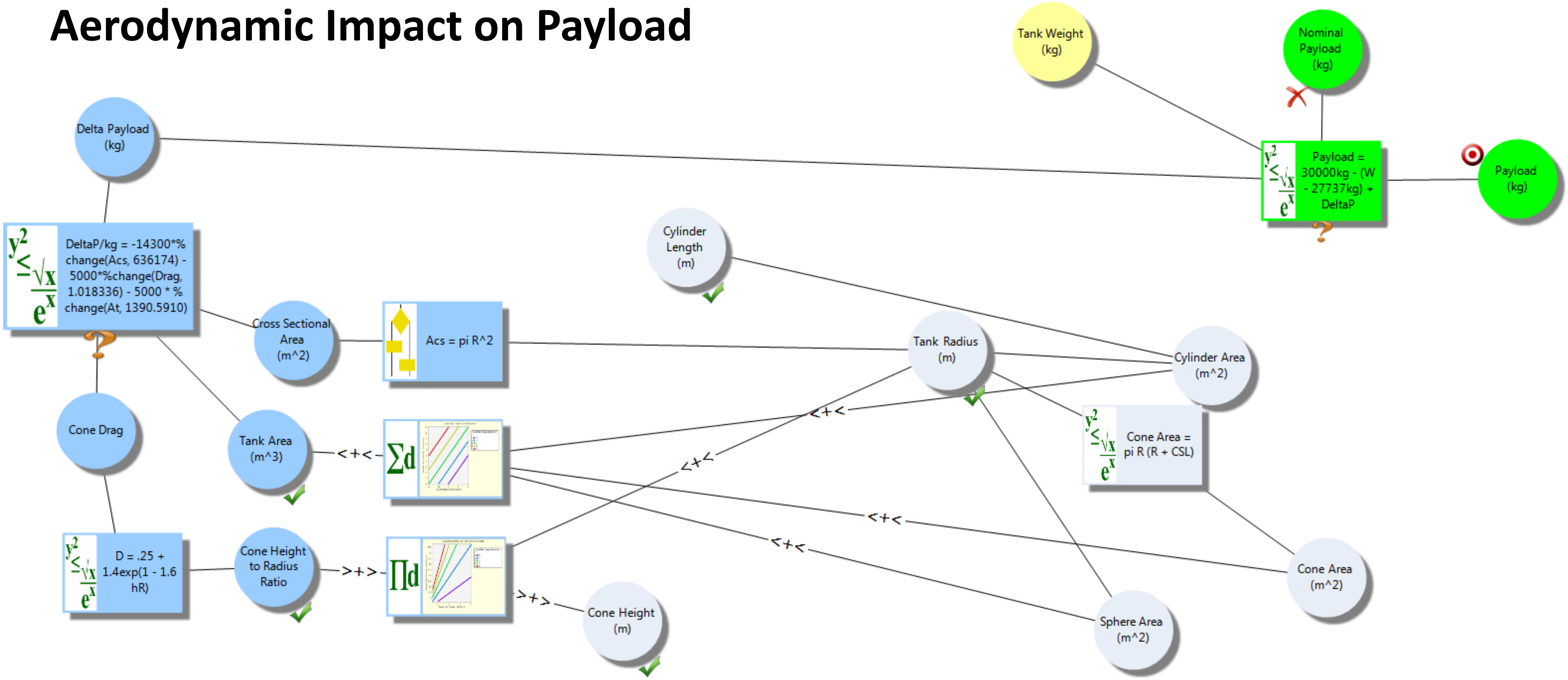
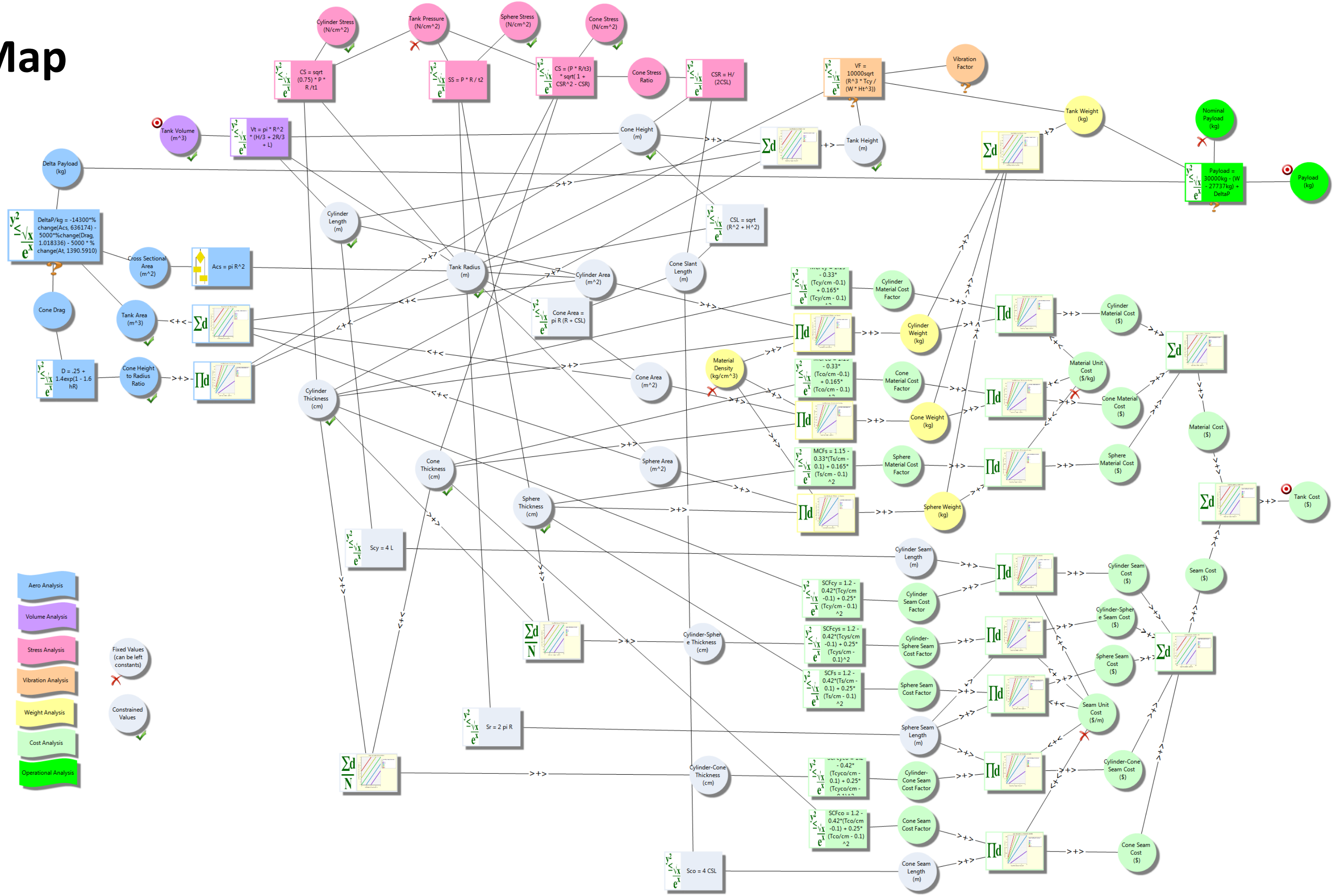
Aerodynamic Impact on Payload



Revised Map



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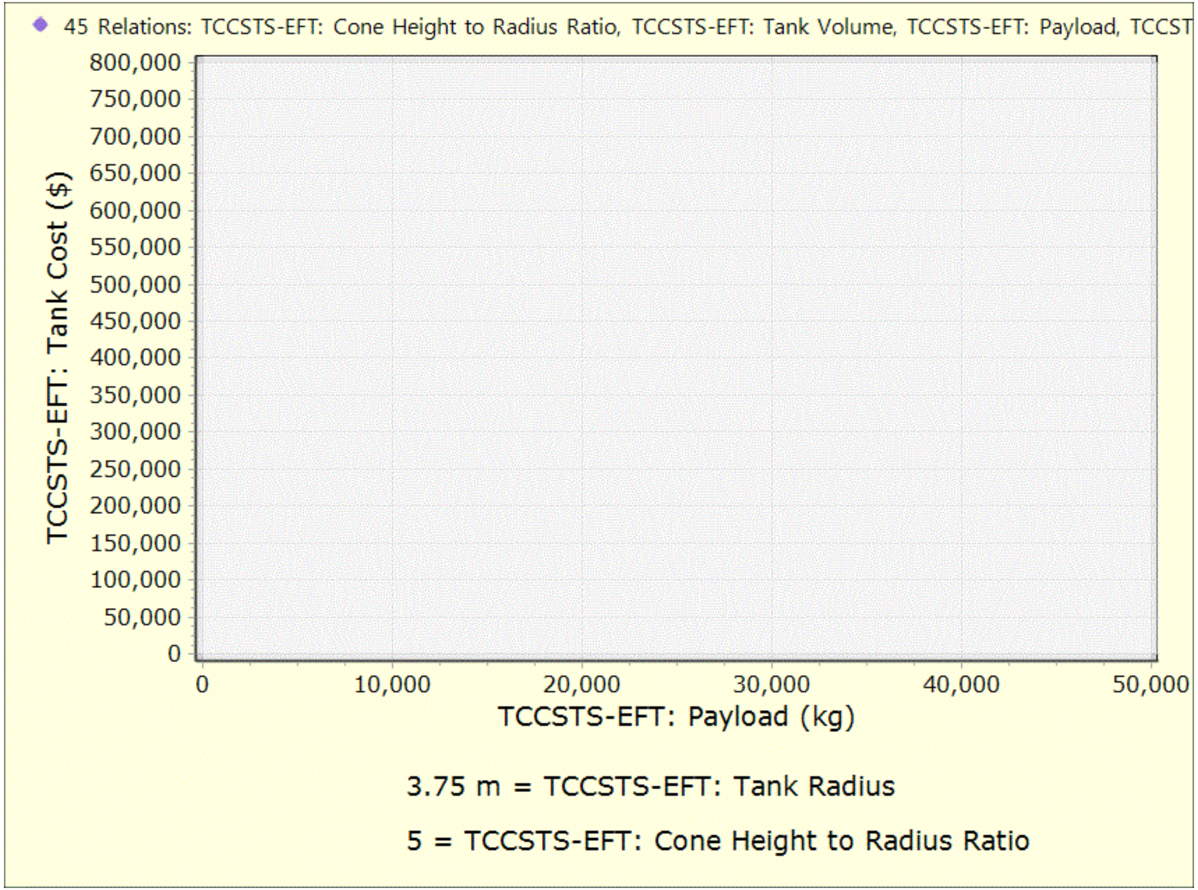
Revised Chart of Trade Space vs. Radius AND Cone Steepness



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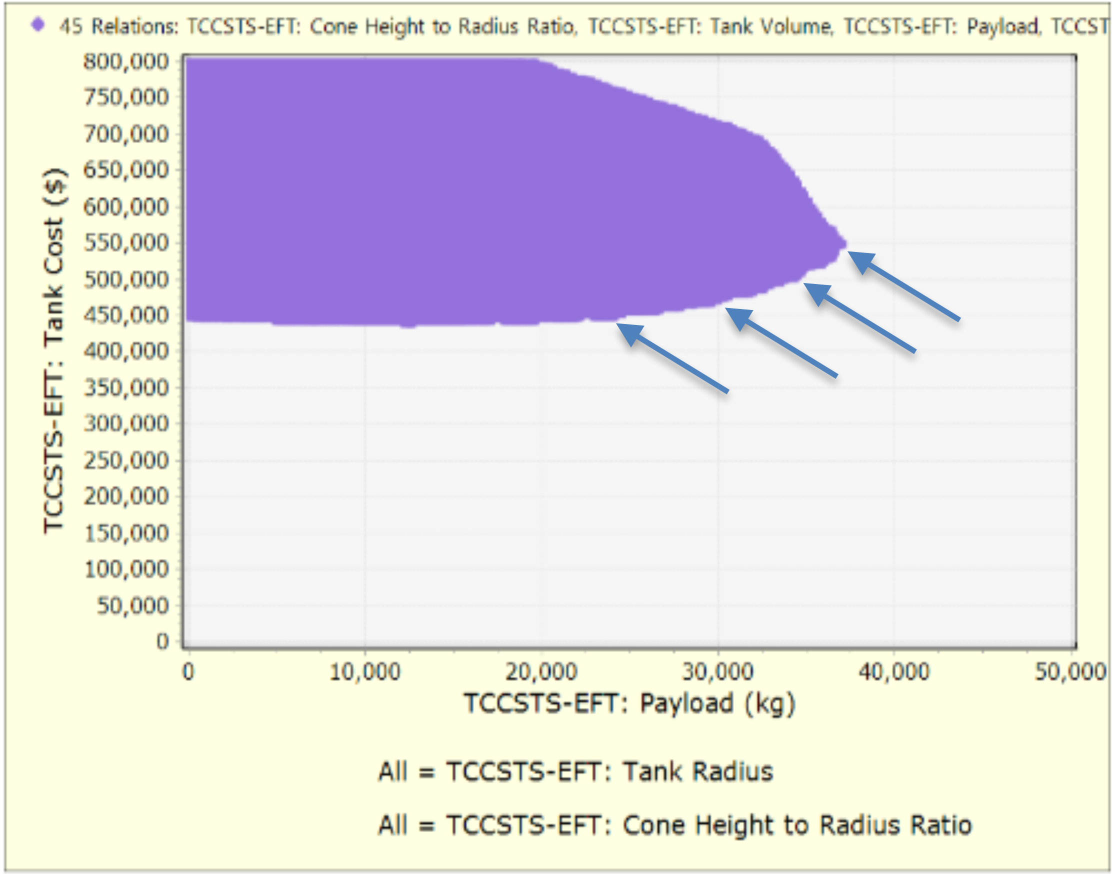
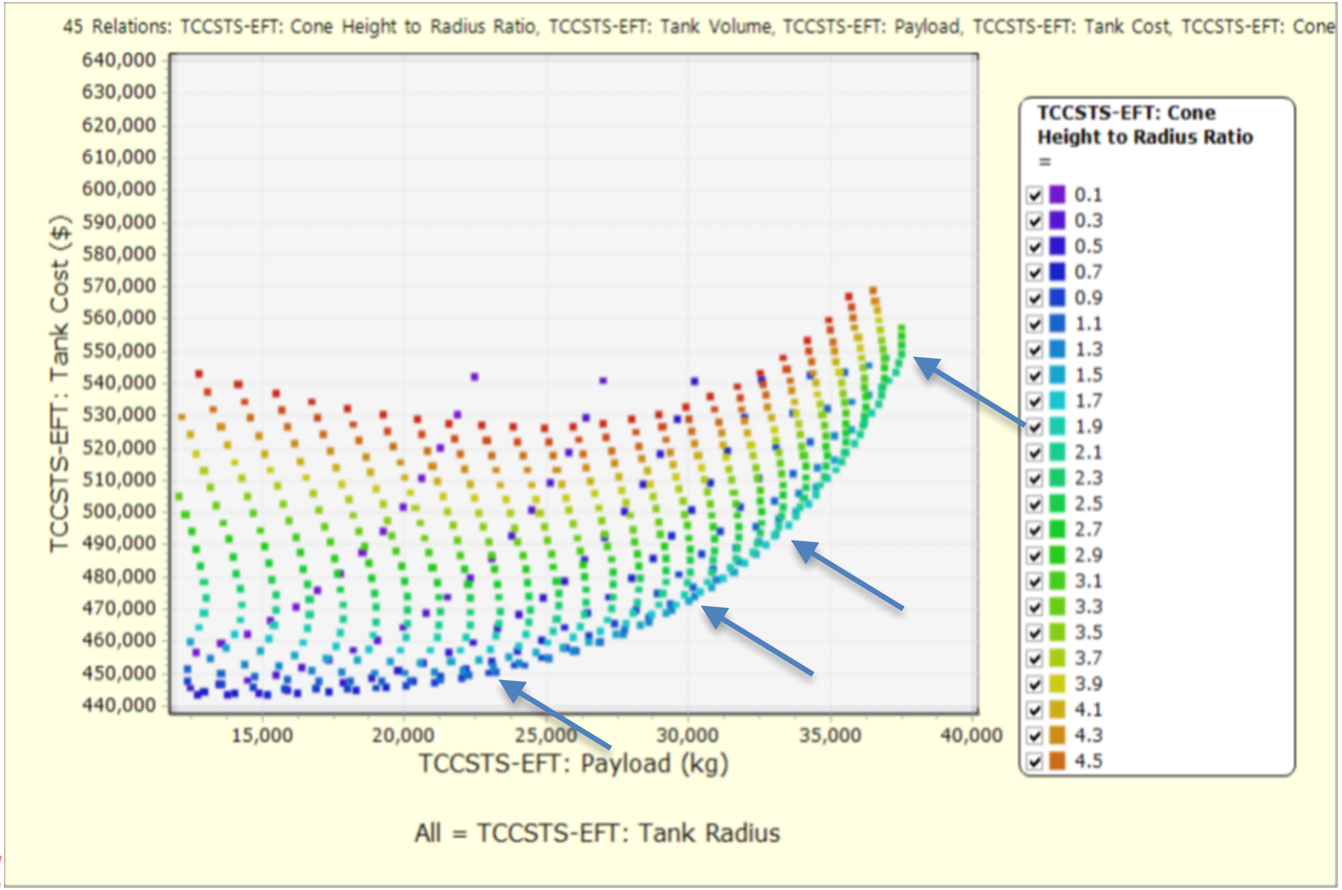
Revised Chart of Trade Space – Entire Set of Possibilities



Revised Chart of Trade Space – Focused on the “Pareto Front”



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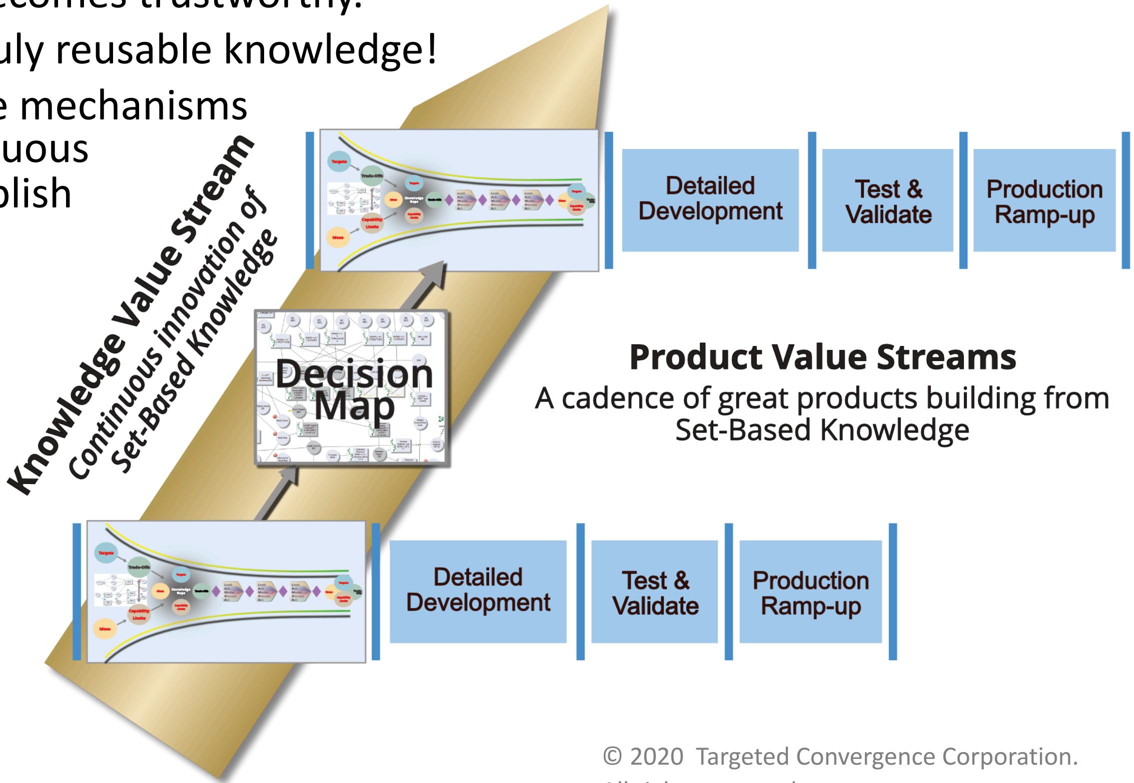
That Set-Based Knowledge is Reusable and Continuously Improvable

- The Visual Knowledge makes it easy to review, critique, and improve.
- And when easy-to-review, it becomes trustworthy.
- And only if trustworthy, is it truly reusable knowledge!
- By putting in place appropriate mechanisms for Knowledge Reuse & Continuous Improvement, teams can establish a Knowledge Value Stream that feeds their Product Value Streams the knowledge needed to make the right decisions up front.
- The key Enablers for that are the Causal Decision Map and the Trade-Off Chart.



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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> Minimize Cost of External Fuel Tank [1068366]

K-Brief ▾ | 100 | Multi-Column

INFORMATION	
Minimize Cost of External Fuel Tank	
LEAD	ID
TCC Developer	1068366
LAST EDITED ON	STATUS
2021-01-04 18:07	Discussion
CATEGORIES	
Space Transportation System (Shuttle) External Fuel Tank (TCCSTS-EFT)	All Properties

ABSTRACT

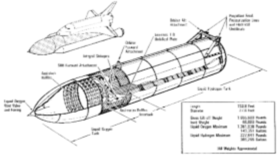
The External Fuel Tanks are not reusable, so they represent a significant portion of the cost of each Shuttle mission; we would like to minimize that cost, but without requiring changes to the Shuttle or its booster rockets.

Background and Objectives

NASA Scientist and Engineer Jaroslaw Sobieszczanski-Sobieski proposed this optimization effort as part of a research effort with MIT under Olivier de Weck, 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.

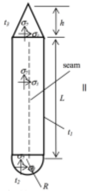
So, both NASA and MIT felt this example, though simple, was complicated enough to be representative of real design work. And numerous other papers and analyses have since used this same example.

In the actual External Fuel Tank design there is much more detailed structure. However, if the design rules and approach to that structure is well-understood and driven by the dimensions of the outer shell, then it may very well be that such can be ignored or consolidated at the higher level when optimizing the design.



The Simplified Model

This simplified model, as proposed by NASA, 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 those 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)

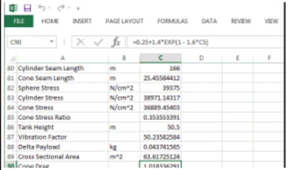
The Objectives (The Customer Interests)

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).

A point-based computation of this simplified model is available in Excel format for comparison purposes.



C90 | =0.25+1.4*EXP(1 - 1.6*C5)

	A	B	C	D	E	F
80	Cylinder Seam Length	m	166			
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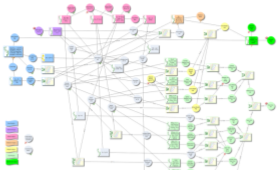
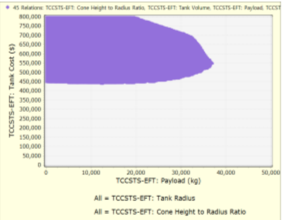
88	Delta Payload	kg	0.043741565			
89	Cross Sectional Area	m^2	63.61725124			
90	Cone Drag		1.018336291			

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.

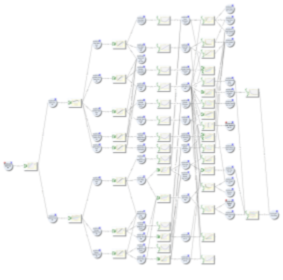


Full Trade Space: Cost vs. Payload



Trade-Off Map for Cost vs. Payload

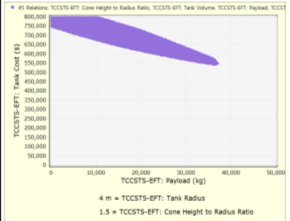
By creating a Relation K-Brief to capture the computational details of each of the Relation shapes in the above Causal Map, and then mapping the shared Decisions as Decision K-Briefs results in a highly reusable Decision Map (interconnected Decision and Relation K-Briefs) from which you can generate Charts, Solvers, and Trade-Off Maps like this one. Here we told it to start with Tank Cost on the left.



...

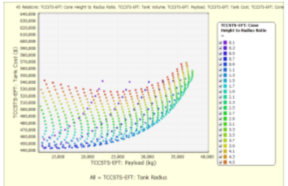
Max Payload near 4 m Radius and 1.5 Ratio

By animating the resulting Chart around, you can find the point where the design space extends furthest to the right, achieving the maximum Payload. That occurs at roughly a 4 m Radius and a 1.5 Cone Height to Radius Ratio.



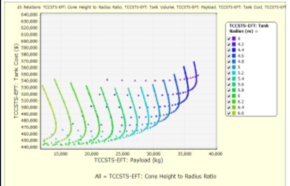
Zooming in on the Lower Right Pareto Front Colored by Cone Height

This is the same as the prior Chart, where we have Cone Height-to-Radius Ratio set to "Legend". But by holding Alt while animating Tank Radius, you can now see all the points of each color at once, such that each colored curve is for a different Ratio, allowing you to see the 3D surface -- imagine purple is further back and orange further forward, and that those lines actually connect forming a continuous surface.



And Colored by Tank Radius

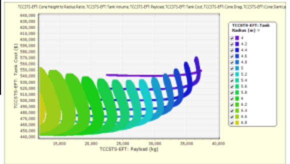
Returning to the earlier Chart with Tank Radius set to "Legend" such that each colored curve is for a different Radius, holding Alt while animating the Ratio allows you to see the 3D surface -- imagine purple is further back and yellow further forward, and that those lines actually connect forming a continuous surface.



Really the Whole Design Space Colored by Tank Radius

Here we set Cone Height-to-Radius Ratio to "Eliminated" such that no points are missed betwee ratios. As with the prior Chart, each colored curve is for a different Radius, allowing you to see the 3D surface -- imagine purple is further back and yellow further forward, and that those lines actually connect forming a continuous surface.

With that, you can now see the full "Pareto Front" (the infinite non-dominated points) that you can choose among, depending upon how you want to trade-off Cost vs. Payload, what specific levels you want to hit, etc. Perhaps there's certain single items that are 29,000 kg -- getting to at least that may be very high priority, whereas further increases not so high.



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In the MIT study
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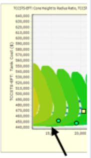

Best Cost (near

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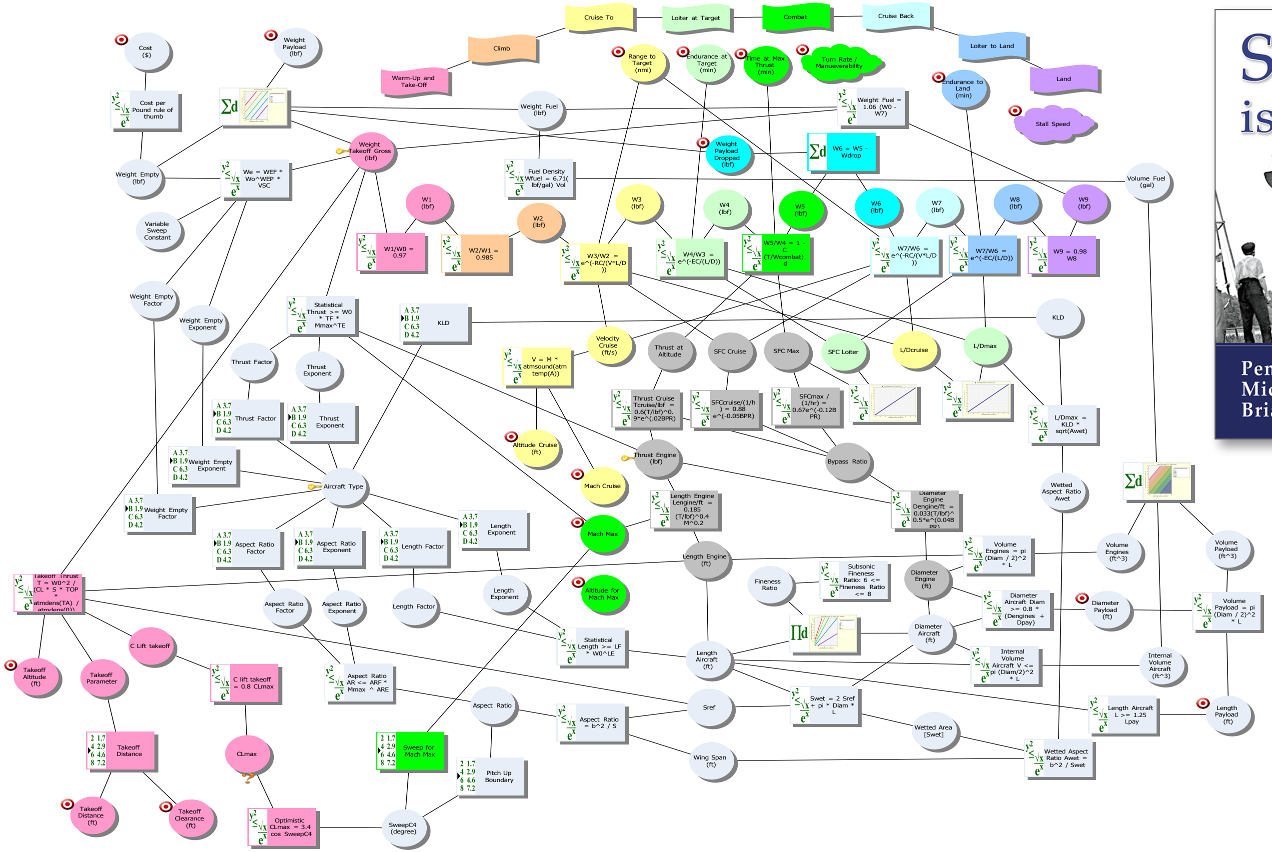
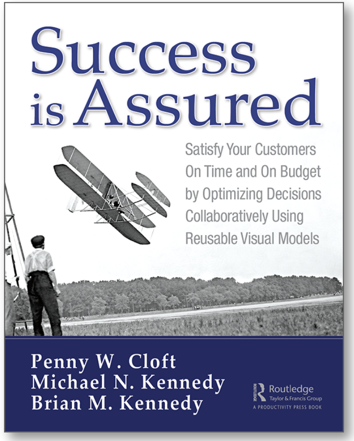
Aircraft Design example (a higher-complexity example)





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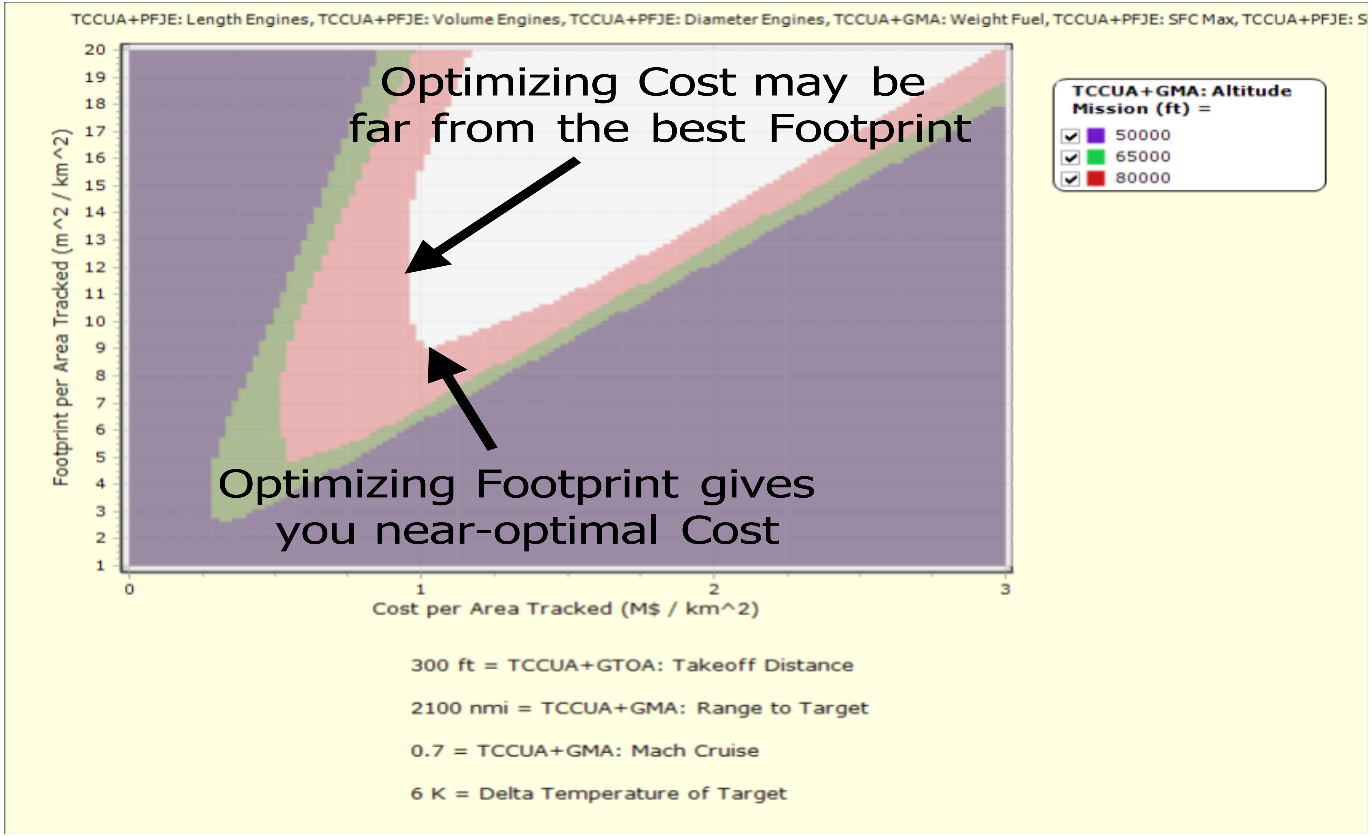
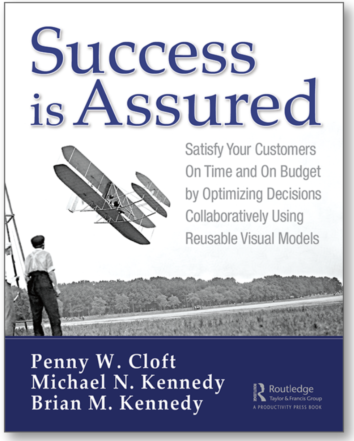
Aircraft Design example (a higher-complexity example)





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Aircraft Design example (a higher-complexity example)

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

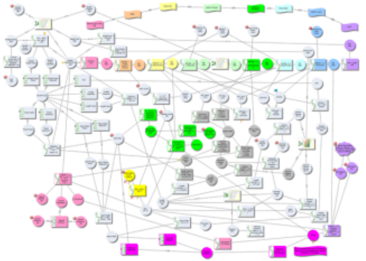
K-Brief 80 Multi-Column

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:

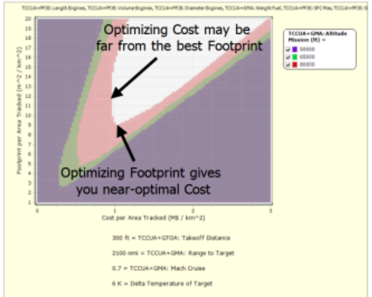
1. Trade-Off Charts
2. Trade-Off Solvers
3. Trade-Off Maps

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.

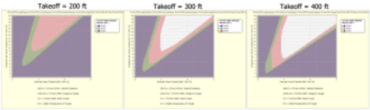
The shaded areas are infeasible; the white is the design space at altitude 80,000 ft. If you turn off the red, the white area inside the green is the design space at 65,000 ft Altitude. The purple at 50,000 ft. In other words, this is showing you a three dimensional design space, where the best cost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



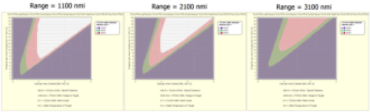
Our brains can only see three dimensions at once. But our problems are always far more than three-dimensions. So, Success Assured™ Trade-Off Charts are designed to use our next strongest sense (eye-hand coordination) to let you see additional dimensions by dragging the sliders along the bottom of the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

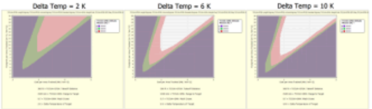
To illustrate that statically (without opening the live Chart), here is the Chart as you drag Takeoff Distance from 200 ft, to 300 ft, to 400 ft. Notice how the design space doesn't move much going from 400 ft down to 300 ft, but it moves a lot more going from 300 ft down to 200 ft. So, there is some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



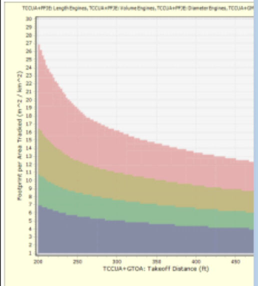
Not surprisingly, Delta Temperature has a similar non-linear effect, but in the opposite direction. There's a knee in the curve at some Delta T... it would be good to know where that it is and stay above it.



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.

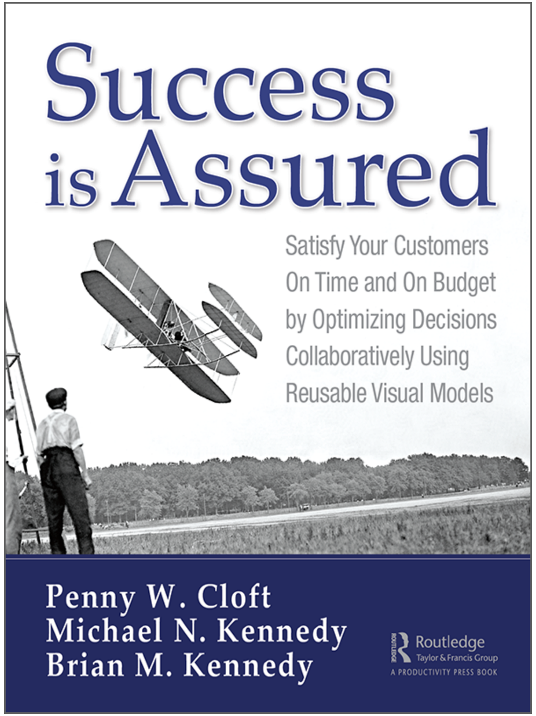
For example, to better see the non-line
Takeoff Distance, you can put Takeoff
X axis such that you can clearly see its
per Area Tracked. Based on this, Take
looks appealing; below that the Footpri
Tracked begins rising more sharply.

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



Any Questions?

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



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