Systems Engineering/Integrated Product and Process Development (IPPD) in Science & Technology

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Topics

- S&T Mission
- IPPD/Systems Engineering Objectives
- IPPD/Systems Engineering Overview
- Best Value Assessment via a Balanced Scorecard
- Discussion/Questions

S&T Mission

To Ensure The Warfighters Today and Tomorrow Have Superior & *Affordable* Technology to Support Their Missions, & To Give Them Revolutionary War-Winning Capabilities

Courtesy: ODUSD(S&T)OTT [Office of Technology Transition]

S&T IPPD Goal

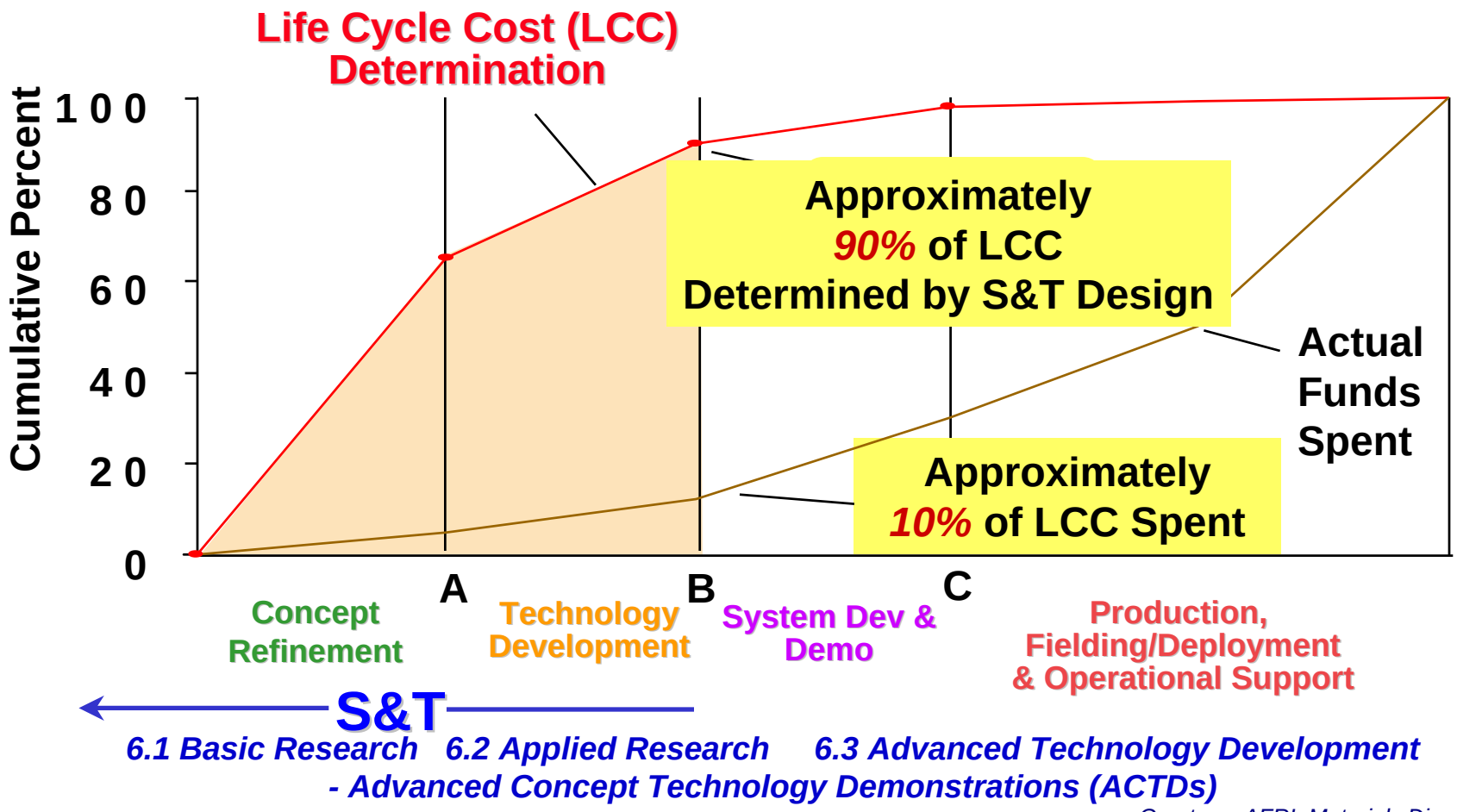
Meet customer needs by addressing the balance of performance, schedule, and life cycle cost during technology development, thereby achieving the best value among available alternatives.

Why the Concern about IPPD/Systems Engineering?

“We’re doing fine! *Why change course?*”

Why IPPD/Systems Engineering in S&T?

Reason #1: The Impact of Early Decisions on Costs



Courtesy: AFRL Materials Directorate

Why IPPD/Systems Engineering in S&T?

Reason #2: Excellence Involves Improving Processes, not Fighting Fires

"Putting out fires is not improvement…of the process. You are in a hotel. You hear someone yell fire. He runs for the fire extinguisher and pulls the alarm to call the fire department. We all get out. Extinguishing the fire does not improve the hotel."

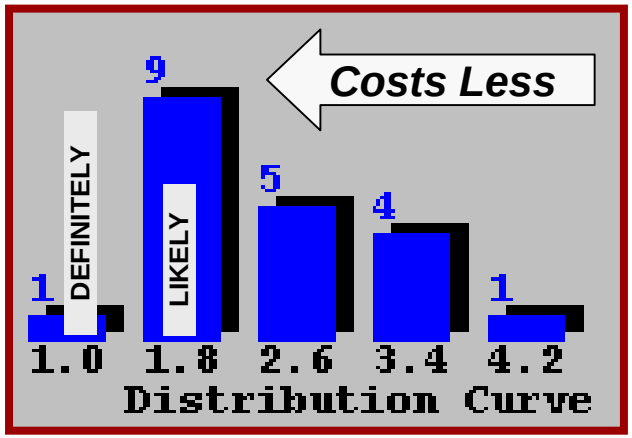
— W. Edwards Deming

"Sound management is not an art or a science. It is a practice."

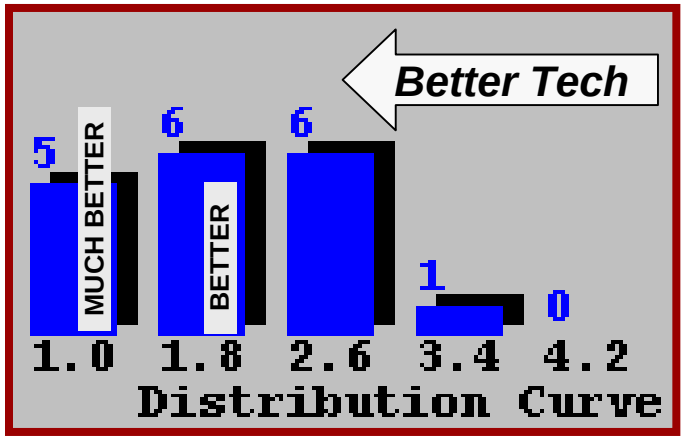
— Peter Drucker

IPPD Costs Less!

Q: What is the impact of IPPD on S&T cost?



Q: Is technology better, or worse, with IPPD?



Lesson from Japan - Quality Costs Less

Lesson from S&T - IPPD Costs Less

Data are from web survey conducted for AFRL, Dec 99 to Mar 00.

Air Force Research Laboratory S&T IPPD History

- 1994 - AF Wright Laboratory Industry Workshop
  - Establish an *IPPD-Driven Approach* to S&T Affordability
  - Develop a Process Incorporating *Proven Best Practices*
  - 30 Companies, 8 AF Organizations
- 1995 & 1996 - Focused Development with Texas Instruments
  - Application of Six Sigma Design Principles to S&T
  - Tailoring of Proven Industry Practice to Unique S&T Environment
  - Development of a 3.5-day In-Depth Course for S&T (*Affordable Technology through IPPD)*
- 1997 & 1998 - Focused Application
  - Trained over 300 people in DoD Programs
  - AF Pilots Began Implementing the Process & Capturing Lessons Learned
  - Development of a 2-day Overview Course for S&T (*S&T Affordability: An Introduction*)
- 1999 to Present - Promulgation
  - S&T IPPD Process Required on New S&T Programs
  - Continuously Improve AFRL Processes and Evolve Training with Lessons Learned

So how do we "do" IPPD?

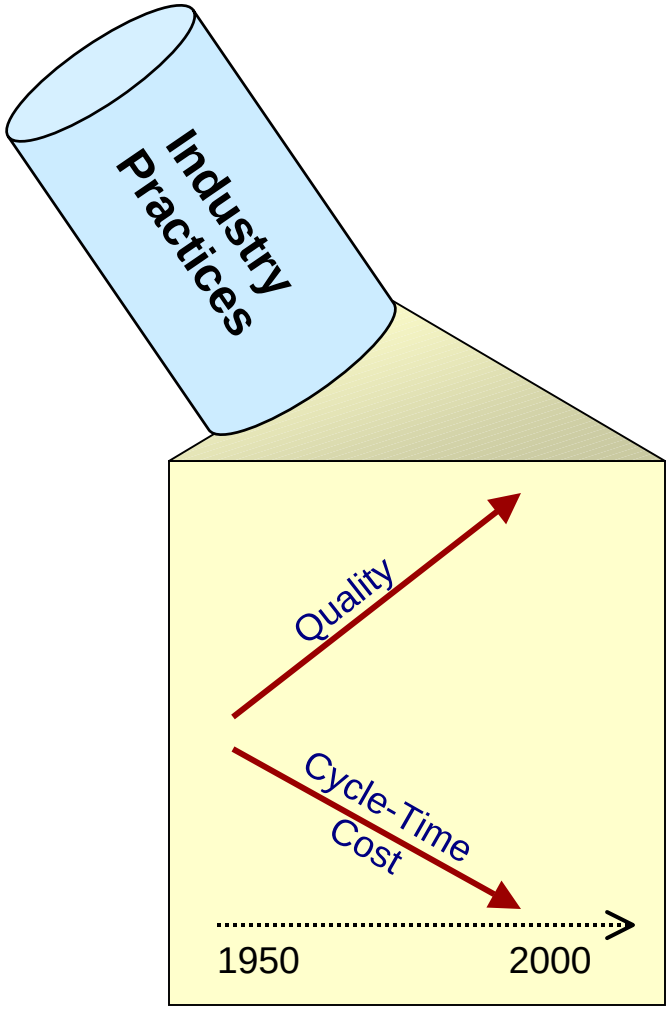
OVERVIEW

IPPD

"from 30,000 feet"

IPPD Principles

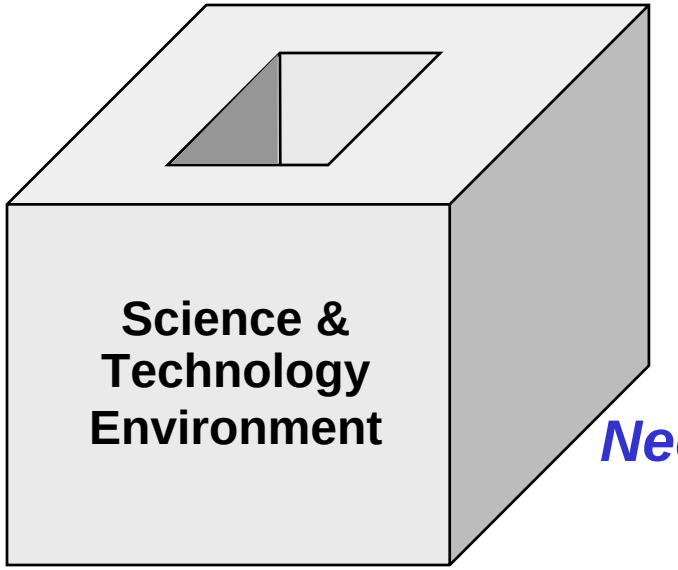
Integrated Product and Process Development (IPPD) involves



- Quality Function Deployment (QFD)
- Total Quality Management (TQM)
- Concurrent Engineering
- Systems Engineering
- Statistics (SPC, Designed Experiments, Taguchi)
- Process Standards (ISO, CMM)
- Lean Production
- Six Sigma
- Metrics
- Balanced Scorecard

Tailoring for the S&T Environment

IPPD Principles grew out of industry manufacturing environments, not R&D...



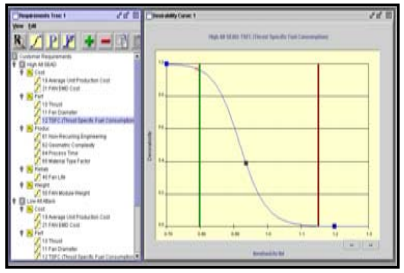
Hence we must…

- Understand unique nature of laboratory research domain
- Recognize S&T does not do acquisition or production
- Adapt what *does* work
- Focus on real *value-added* for S&T

Needed: A Tailorable Process…
Tuned to S&T…

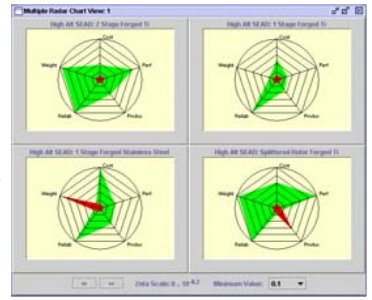
IPPD/Systems Engineering in S&T

- Technology Needs (MAPs, TPIPTs, etc.)
- Customer Dialog
- AF Technology Priorities
- Opportunity Technologies
- Deficiencies



Customer Requirements

Technology Alternatives



Value Analysis

Transition-Ready Technology

1. **Form IPT and Document Customer Requirements**
2. **Establish Quantified Delivery/ Transition Criteria**
3. **Assess Alternatives and Approaches**
4. **Perform Transition Value Analysis**
5. **Develop & Demonstrate Alternative(s) or Technologies**
6. **Deliver Alternative with Business Case/Benefits Analysis**

Integrated Product Teams (IPTs) Execute Every Activity

Transition Focused:

- **Measurement-based methods**
- **Balanced tech trades/options**
- **Quantify desirability & risk**

Make It Measurable

"Every acquisition program shall establish program goals–thresholds and objectives – for the ***minimum*** number of cost, schedule, and performance parameters that describe the program over its life cycle."

— 5000.2, Part 1.1

"To make improvements as technology moves through development and maturation, affordability must be measurable..."

— Gen Paul D. Nielsen, 8 May 00

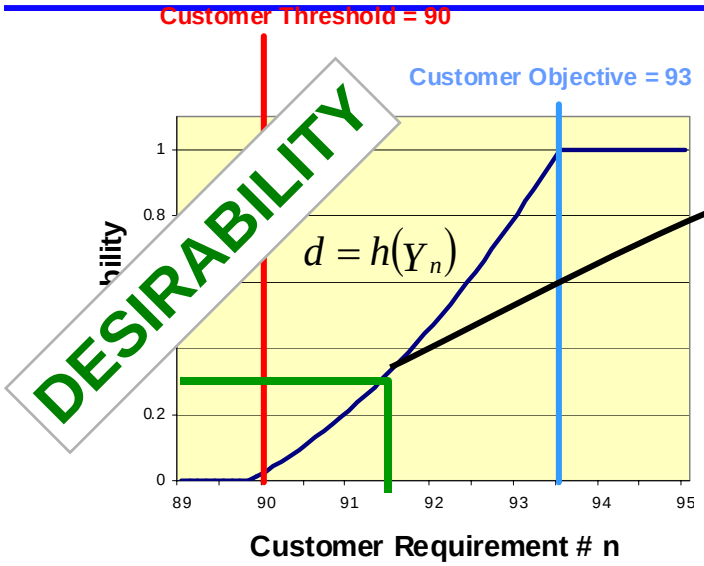
If you have no clearly defined destination, any road will get you there.

Process Addresses Basic Questions

1. Form IPT and Document Customer Requirements
2. Establish Quantified Delivery/ Transition Criteria
3. Assess Alternatives and Approaches
4. Perform Transition Value Analysis
5. Develop & Demonstrate Alternative(s) or Technologies
6. Deliver Alternative with Business Case/Benefits Analysis

- For *whom* are we doing *what*?
- How will we know when we've got it?
- What are the alternatives for achieving it?
- Can we get there from here, and if so, what is the *best* alternative?
- How will we back up our claims?
- How do we get it implemented?

Metrics: Measuring Best Value



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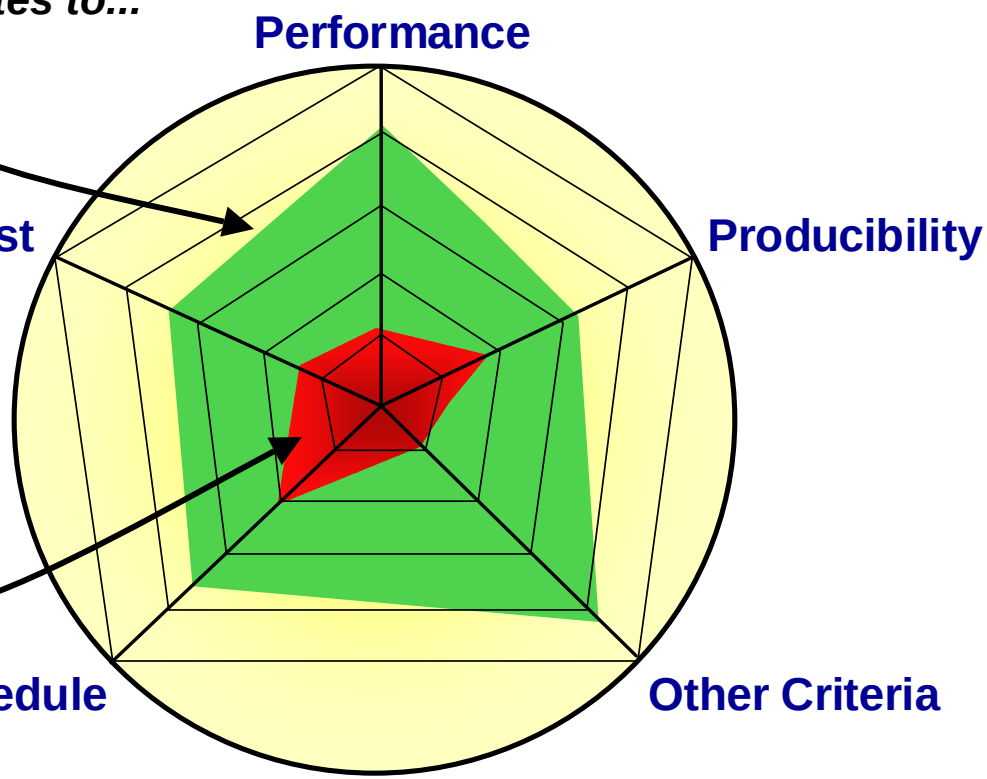

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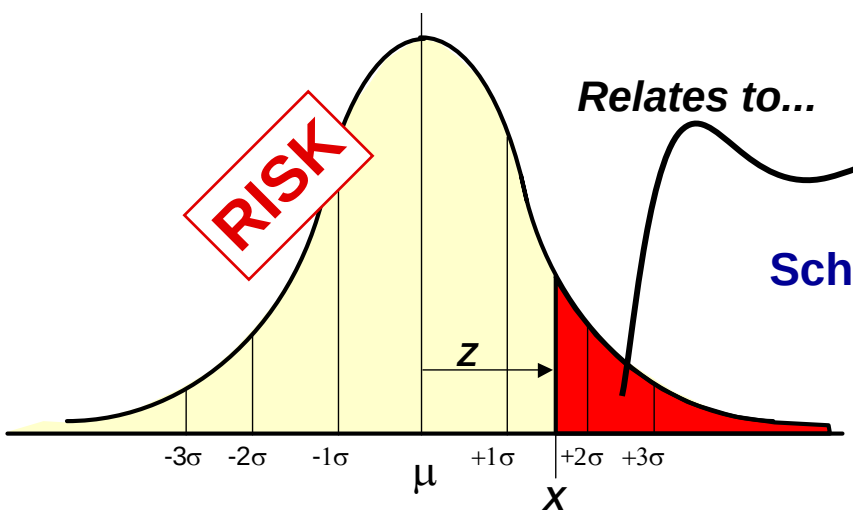
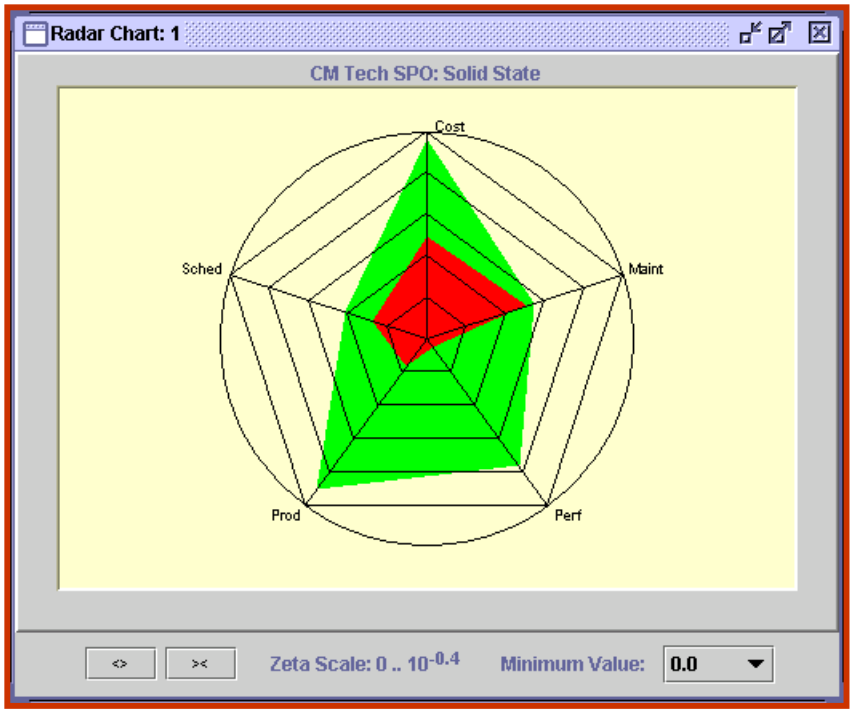
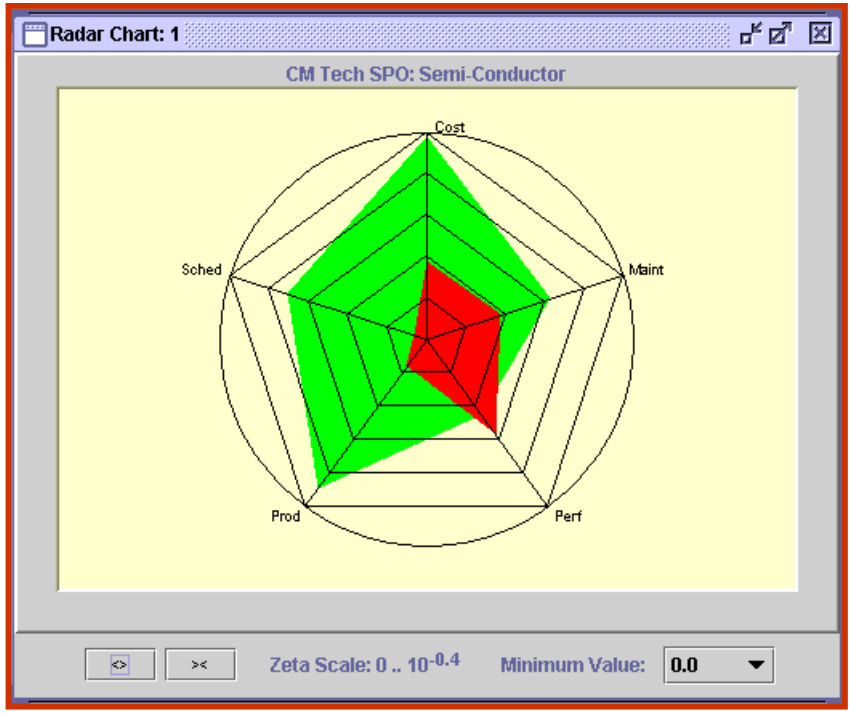


Comparing Technologies

Desirabilities & Risk for Technology A (Customer #1)



Desirabilities & Risk for Technology B (Customer #1)



Who Is Involved?

1 **Form IPT and Document Customer Requirements**

"Integrated Product Teams (IPTs) are composed of representatives from all appropriate functional disciplines working together to build successful programs and enabling decision-makers to make the right decisions at the right time."

-- DoD Acquisition Directive 5000.2-R

For Whom?…
Who Are Your Customers?

1 Form IPT and Document Customer Requirements

- Who are your external customers?
- Who are your internal customers?
- Are “sponsors” the same as “customers”?
- Do you aim to transition your technologies?
  - To whom?
  - How?

“If we build it, they will come…Or will they?…”

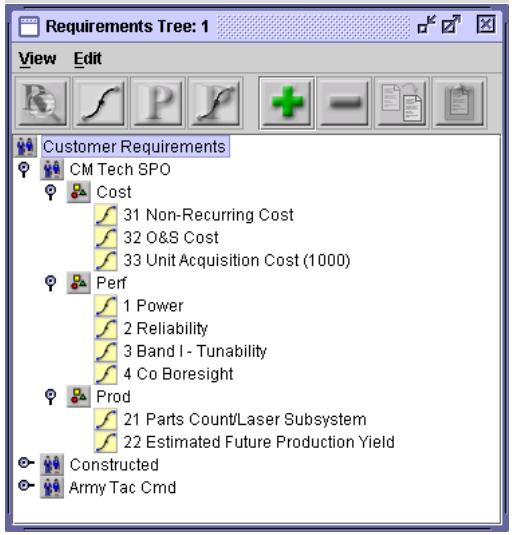
For Whom…Are We Doing What?

1 Form IPT and Document Customer Requirements

Define the Requirements

- *Are they measurable?*
- *What do they want to achieve for each requirement?*
  - *What will they accept?*
  - *If these are the same, why?*
  - *Do all customers have the same goals?*
- *Are some more important than others?*
  - *If not achieved on any single requirement, will a solution be rejected?*
- *Is there an organization to the requirements?*
  - *Categories?*
  - *Work Breakdown Structure?*

Requirements Tree



Focused Yet Flexible Requirements

Focused ⟷ **Flexible**

APPROACH	Requirements expressed as specific technology approach and detailed design	Performance Requirements Expressed as Single Points	Performance Requirements Expressed as Thresholds & Goals	Few requirements, “we’ll know what we want when we see it.”
RESULT	*Very limited trade space*	*Limited trade space*	*Well defined trade space*	*Unlimited or undefined trade space*

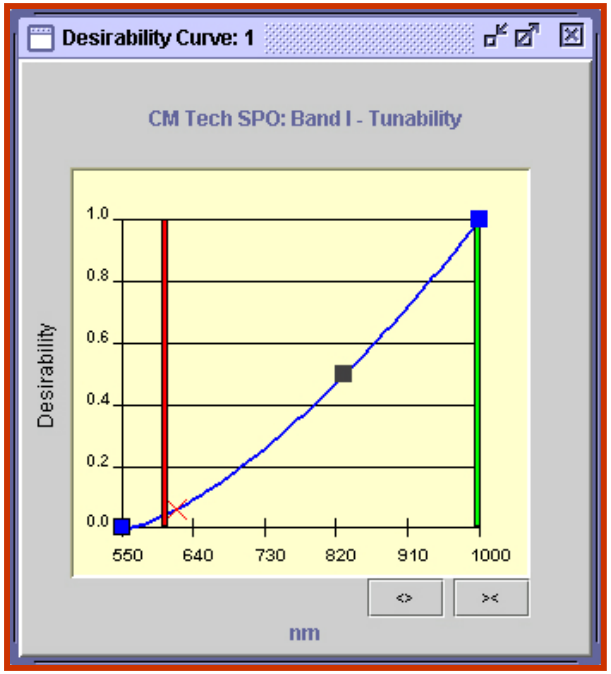
Well defined, ample trade space enables search for best value and minimizes false starts.

How Will We Know When We've Got It?

***Understanding** what the customer wants!*

2

Establish Quantified Delivery/ Transition Criteria



Are the customers flexible?

- ***— which requirements?***
- ***— show stoppers?***
- ***— all customers same?***

What is the trade space?

Can/should all customers be satisfied?

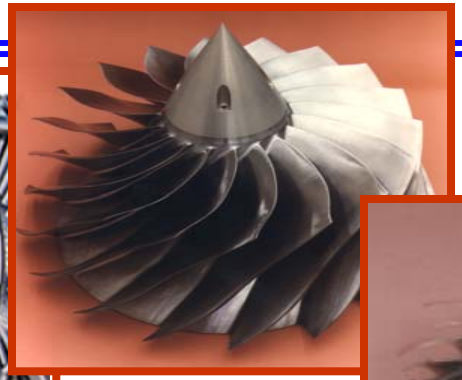
Are some requirements more important than others? How much?

How will your program be judged?

What Are the Alternatives?

3

Assess Alternatives and Approaches



What are the approaches?

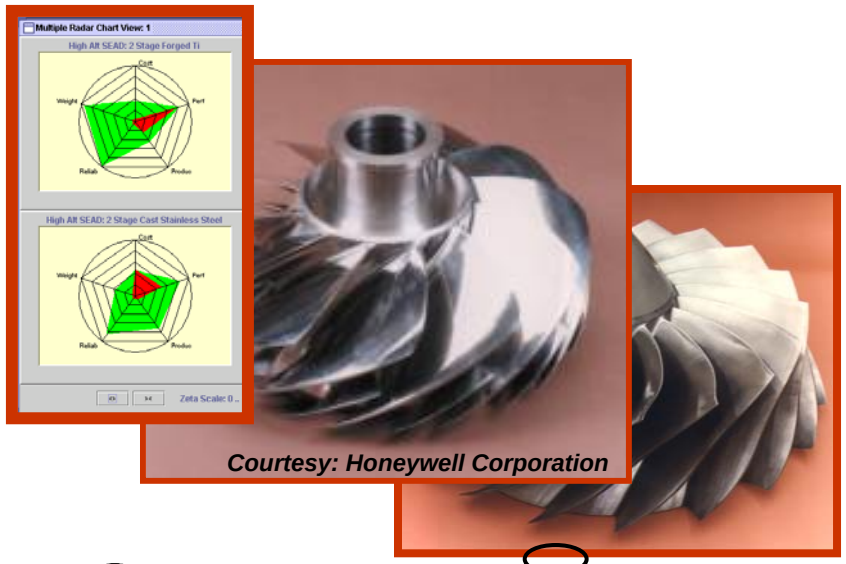
How do they perform against the requirements?

How much can an approach be improved during the program?

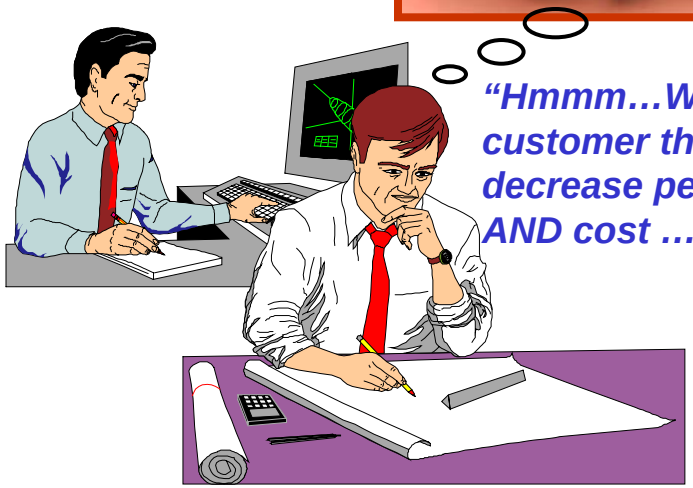
Photos courtesy GE-Honeywell Engines and Systems, Phoenix, AZ

Can We Get There From Here?

Assess the Technologies



Courtesy: Honeywell Corporation



"Hmmm…What will the customer think if we decrease performance AND cost …"

Value Analysis

4 **Perform Transition Value Analysis**

Which one is best value?

- ***For which customer?***
- ***What about my management?***

If we make changes in one area, what is the effect in others?

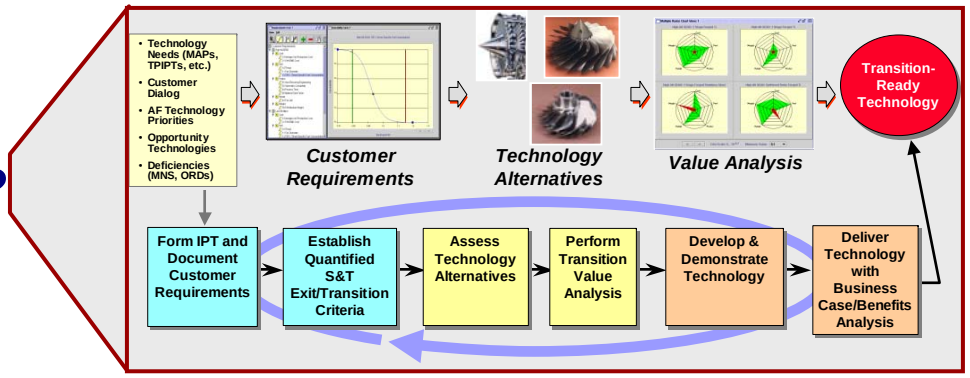
Can we get a better balance cost and performance?

If the customer can change some of their requirements,

- ***which ones?***
- ***how much?***

How Do We Back Up Our Claims?

5 Develop & Demonstrate Alternative(s) or Technologies



Applied a disciplined process?

- ***— Throughout the program?***
- ***— Customer involved?***

Using customer metrics and models when possible?

Audit trail maintained?

- ***— Can the program back up, and take a different path if necessary?***
- ***— "What-if" analyses performed?***

Do the demonstrations confirm expectations,

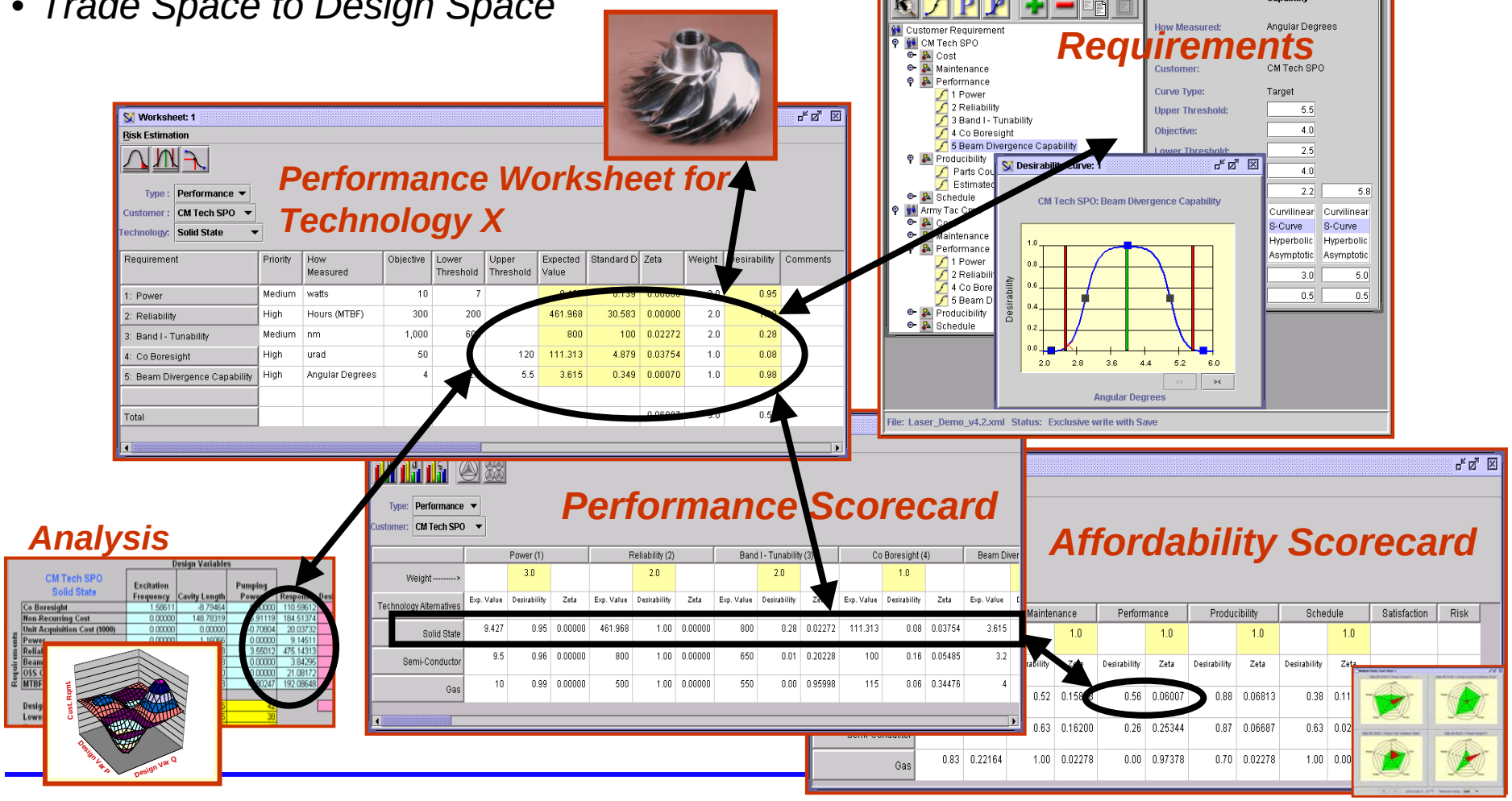
- ***— How much do differences affect best value?***

Technology Audit Trail & Trade Space

"What if" capability, framework for requirements negotiation, greater program continuity

- *Trade Space to Design Space*

6 Deliver Alternative with Business Case/Benefits Analysis

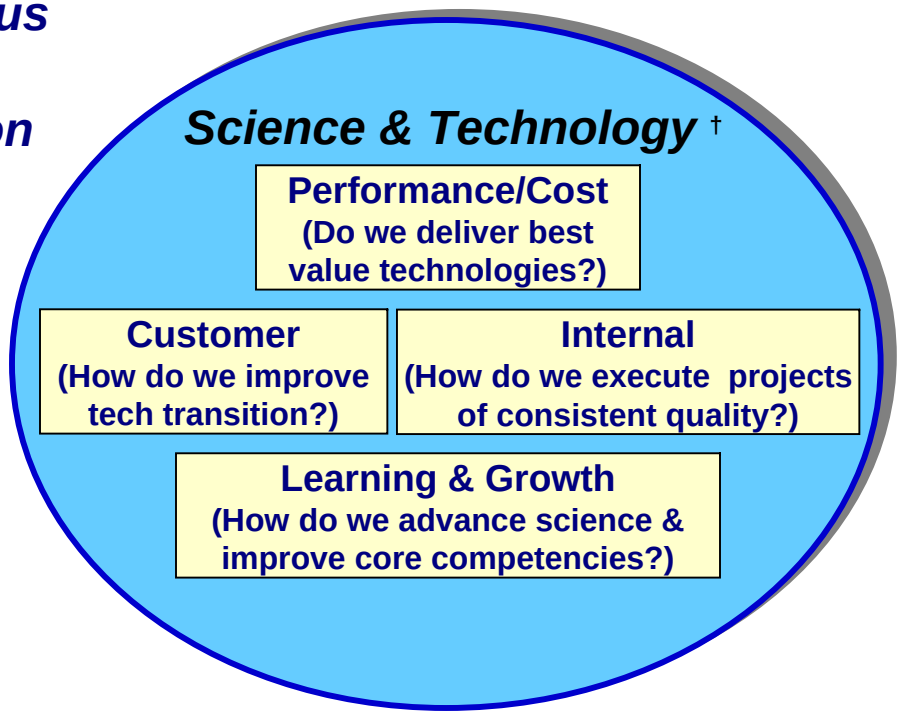


The *Balanced Scorecard**

Achieving Organizational Excellence

Requirements
- ***Customer Focus***
- ***Quantitative***
- ***Communication***

Value Scorecard
- ***Balanced View***
- ***Metrics-driven Decision Support***

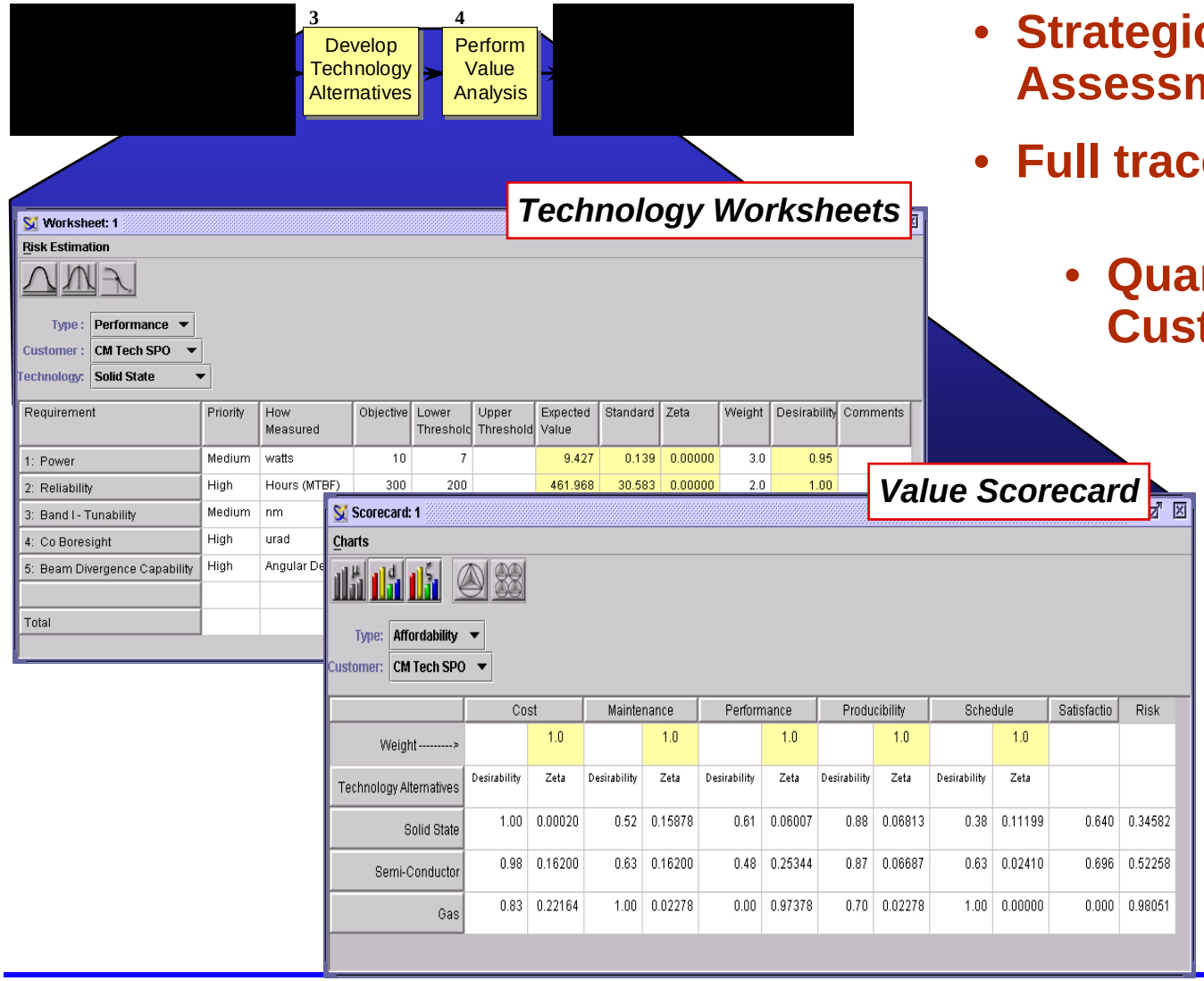


Traceability & Audit Trail

IPPD Methodology
- ***Engenders Credibility***

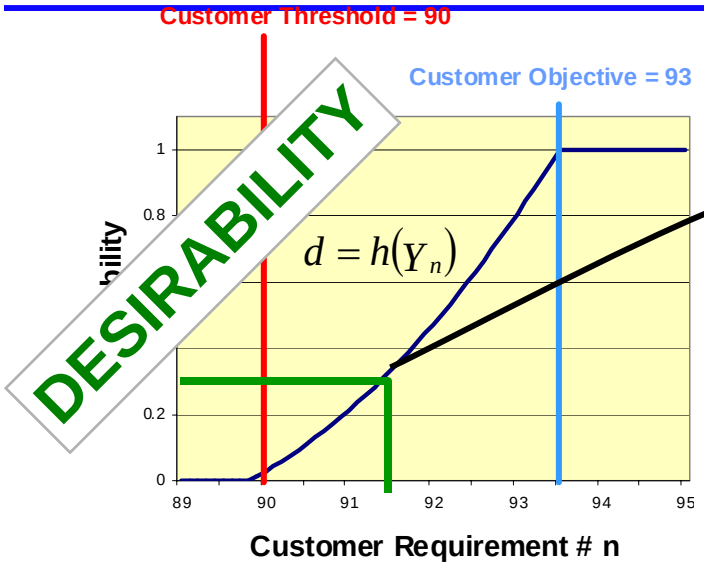
* "The Balanced Scorecard," R. Kaplan and D. Norton, *Harvard Business Review,* HBR#92105,*1992*
* R. Kaplan & D. Norton, *The Balanced Scorecard*, Harvard Business School Press, 1996
† Measuring the Business Case, Brink, J.R. & Peisert, G.D, *CALS Journal*, Fall, 1992.

Value Analysis via a Balanced Scorecard



- **Strategic and Tactical Assessment**
- **Full traceability**
  - **Quantified Risk and Customer Satisfaction**
    - **ID Cost and Risk Drivers Early**
    - **"What-if" and Impact Analyses**
    - **Better Tech Investment Decisions**

Metrics: Measuring Best Value



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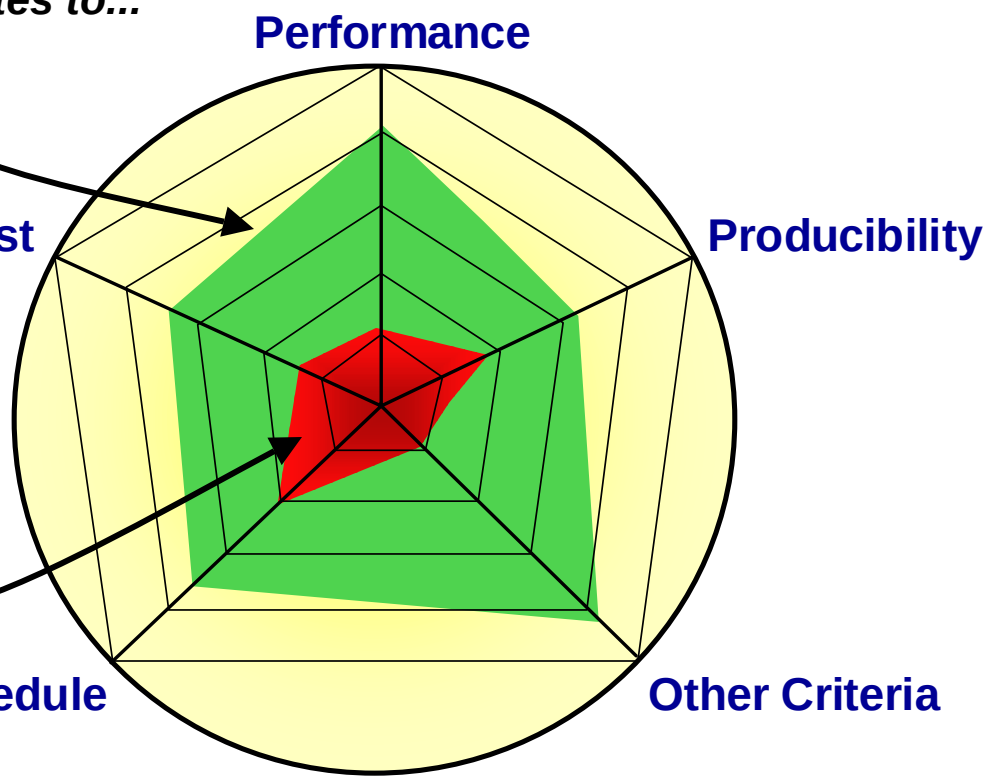

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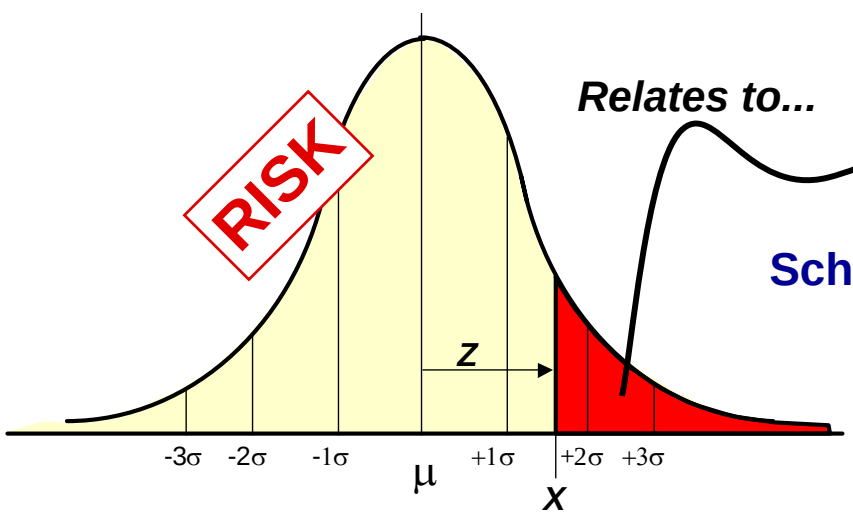
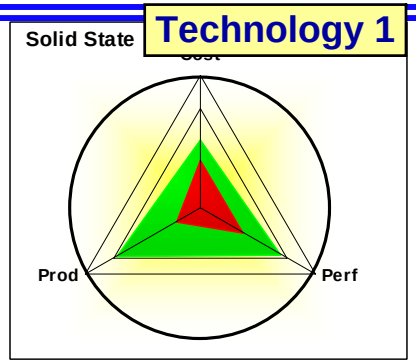
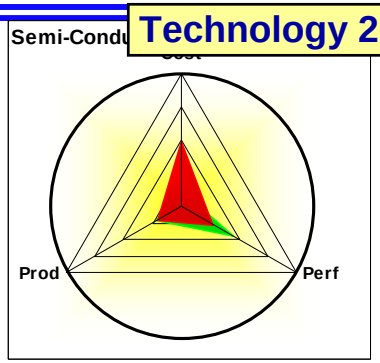
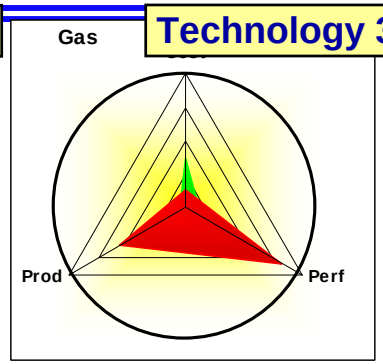
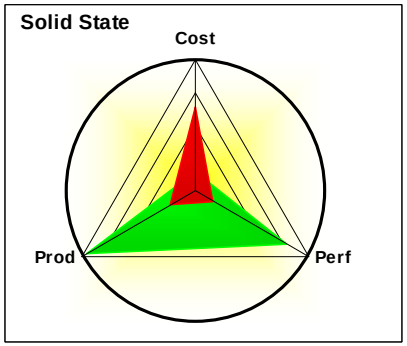
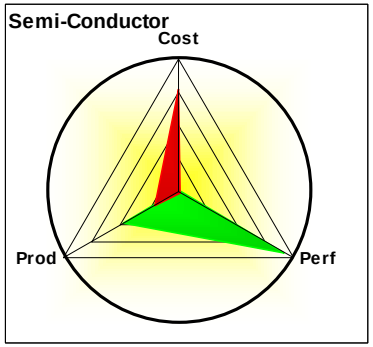
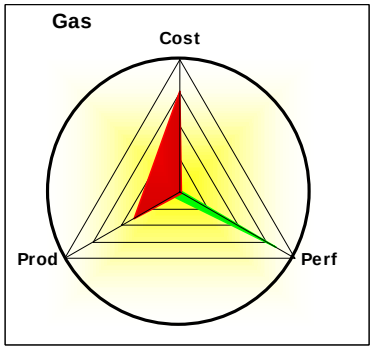
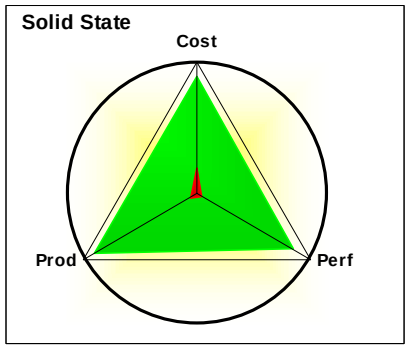
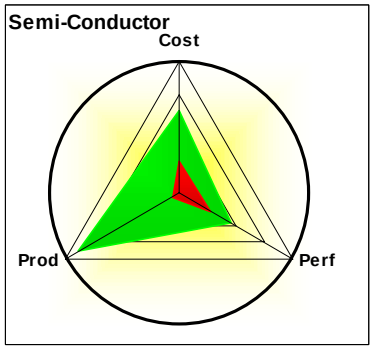
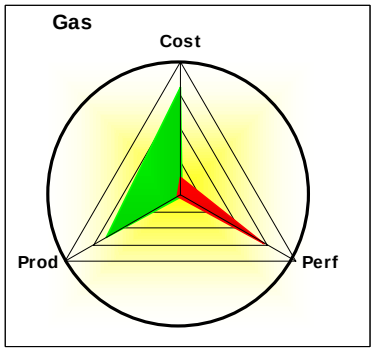


Best Value Assessment

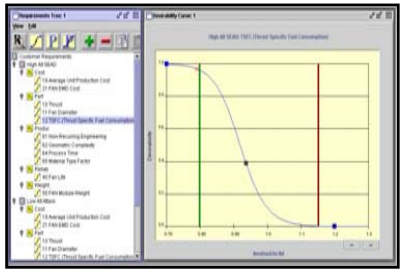
Instructional Example Only

Customer

	Technology 1	Technology 2	Technology 3
Constructed			
Army			
CM SPO			

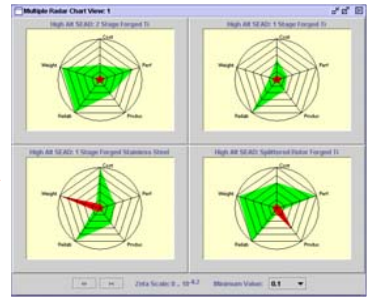
IPPD/Systems Engineering in S&T

- Technology Needs (MAPs, TPIPTs, etc.)
- Customer Dialog
- AF Technology Priorities
- Opportunity Technologies
- Deficiencies (MNS, ORDs)



Customer Requirements

Technology Alternatives



Value Analysis

Transition-Ready Technology

Form IPT and Document Customer Requirements → **Establish Quantified S&T Exit/Transition Criteria** → **Assess Technology Alternatives** → **Perform Transition Value Analysis** → **Develop & Demonstrate Technology** → **Deliver Technology with Business Case/Benefits Analysis**

Integrated Product Teams (IPTs) Execute Every Activity

Initial Technology Transition Plan (TTP)

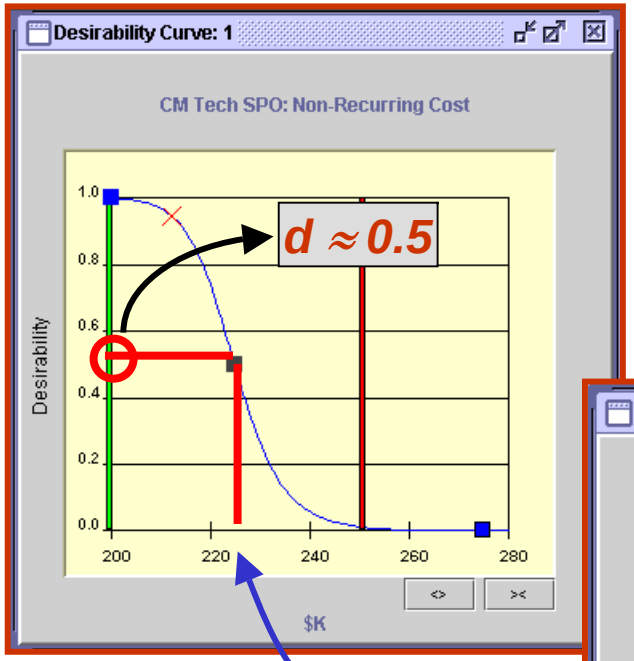
Customer Requirements

Discussion/Questions

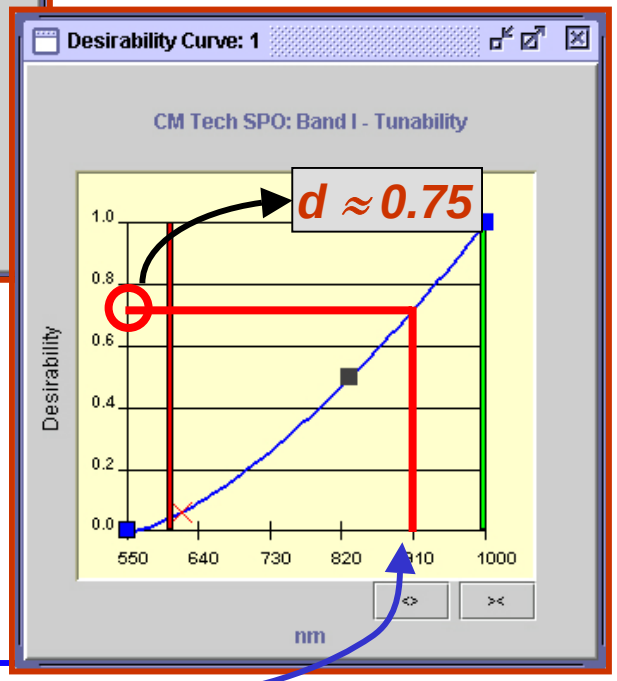
Measuring Customer Satisfaction

For Each Requirement

1. Assess the Technology



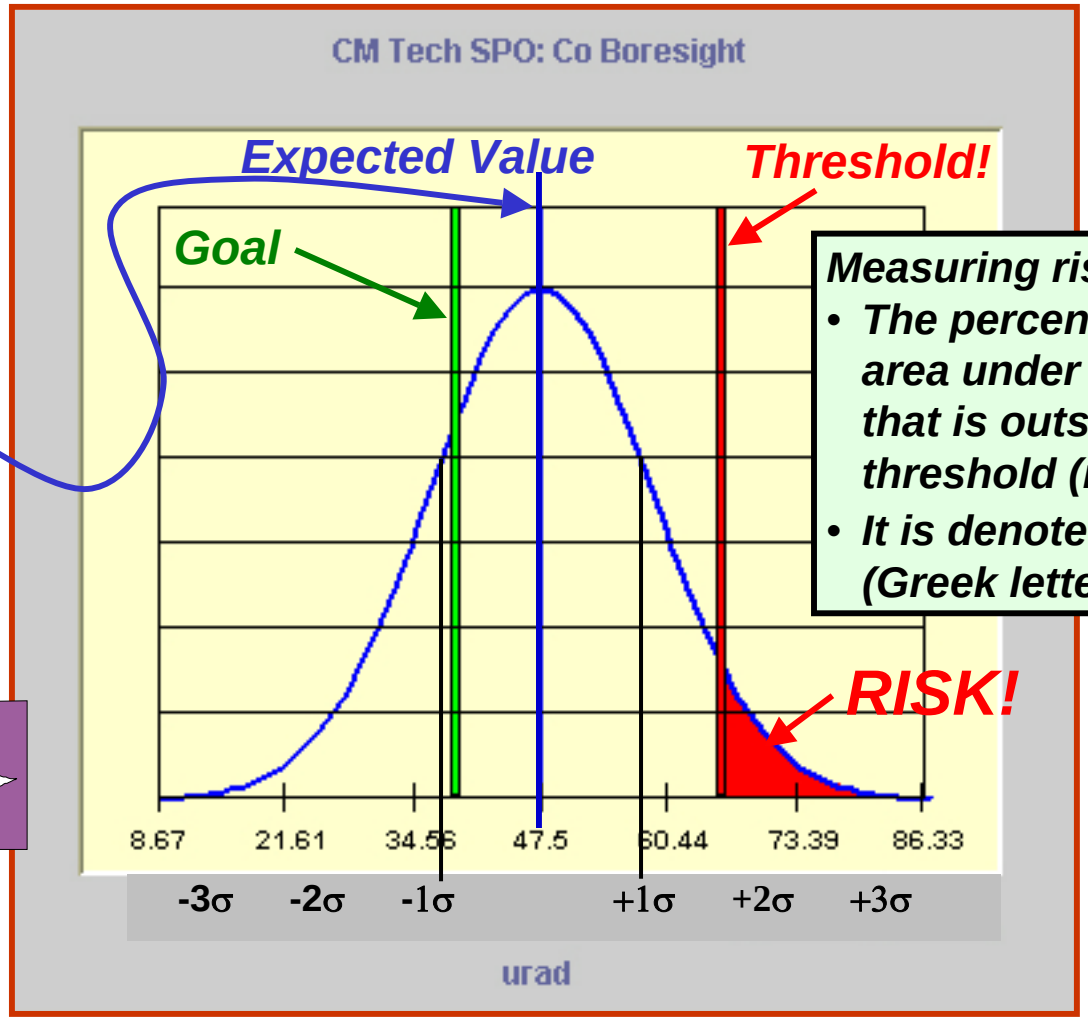
2. Read its Desirability



"Hmmm...Looks like non-recurring cost is about $225k & Band 1 Tunability about 910 nm…"

Estimating Risk (σ & ζ)

"Hmmm...Looks like the Co Boresight is going to hit about 47.5 urad for the solid state technology alternative … but worst case might be as much as 86.3 urad…



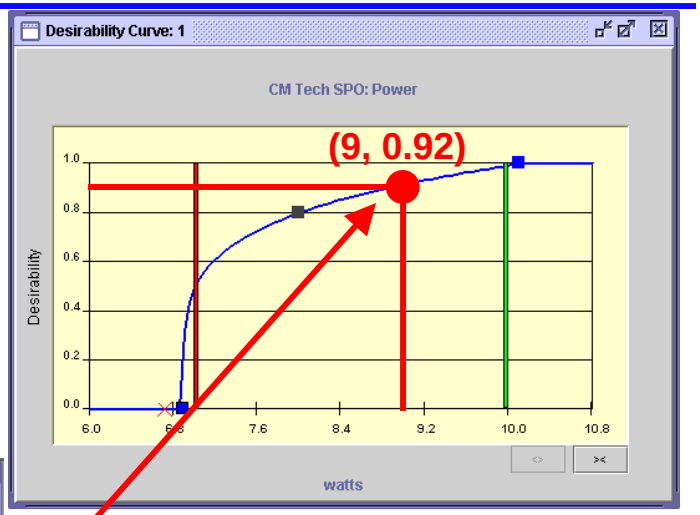
Measuring risk:

- ***The percentage of the area under the curve that is outside the threshold (red area).***
- ***It is denoted "ζ" (Greek letter Zeta).***

Six Sigma

Generating the Worksheet

- The expected values (μ), weights and desirabilities (*d*) are presented on an IPPD *Worksheet*.
- Use one worksheet *per* customer *per* requirement type *per* technology alternative



Worksheet: 1

Risk Estimation

Type: Perf

Customer: CM Tech SPO

Technology: Solid State

Requirement	Priority	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Weight	Desirability	Comments
1: Power	Medium	watts	10.0	7.0		9.0	3.0	0.92	
2: Reliability	High	Hours (MTBF)	300	200		1,000	2.0	1.00	
3: Band I - Tunability	Medium	nm	1,000	600		800	2.0	0.42	
4: Co Boresight	High	urad	50.0		120	47.5	1.0	0.85	
Total							8.0	0.77	

Where do we get a "μ" or "σ"?

Functional Relationships

- An equation relating variables the technologist can control (e.g., distance is a function of initial force and gravity).

Simulations & Simulators

- A series of spreadsheets that calculate a response based on user input and assumptions.
- A computer model that simulates the effect of real-world conditions on a technology. (Possibly streamlined using Multivariable Optimization, Design of Experiments, Regression, Monte Carlo, etc.)

Prototypes

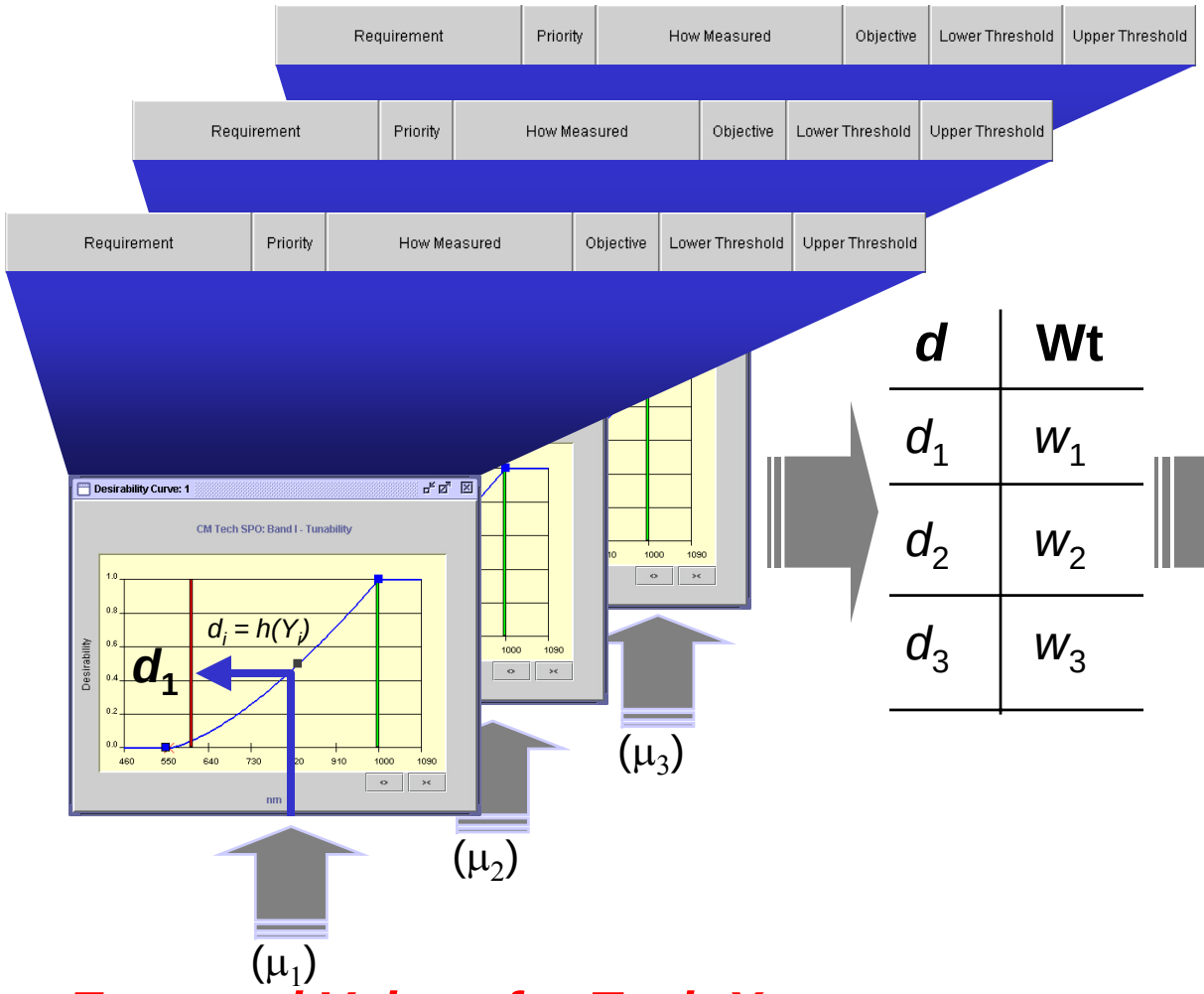
- A prototype or demonstration model of the technology. (Possibly expanded using Multivariable Optimization, Design of Experiments, Regression, Monte Carlo, etc.)

Raw Data

- A statistical prediction (e.g., averages, regression, Monte Carlo).
- Expert estimates
- Historical data, perhaps adjusted via expert judgment.

Rolling Up Desirability For Each Requirement Type

All requirements of a given type.



Note: Desirabilities are SPECIFIC to each customer!

d	Wt
d_1	w_1
d_2	w_2
d_3	w_3

$$D_{type} = \left[(d_1)^{w_1} (d_2)^{w_2} (d_3)^{w_3} \right]^{\left(1/w_1 + w_2 + w_3\right)}$$

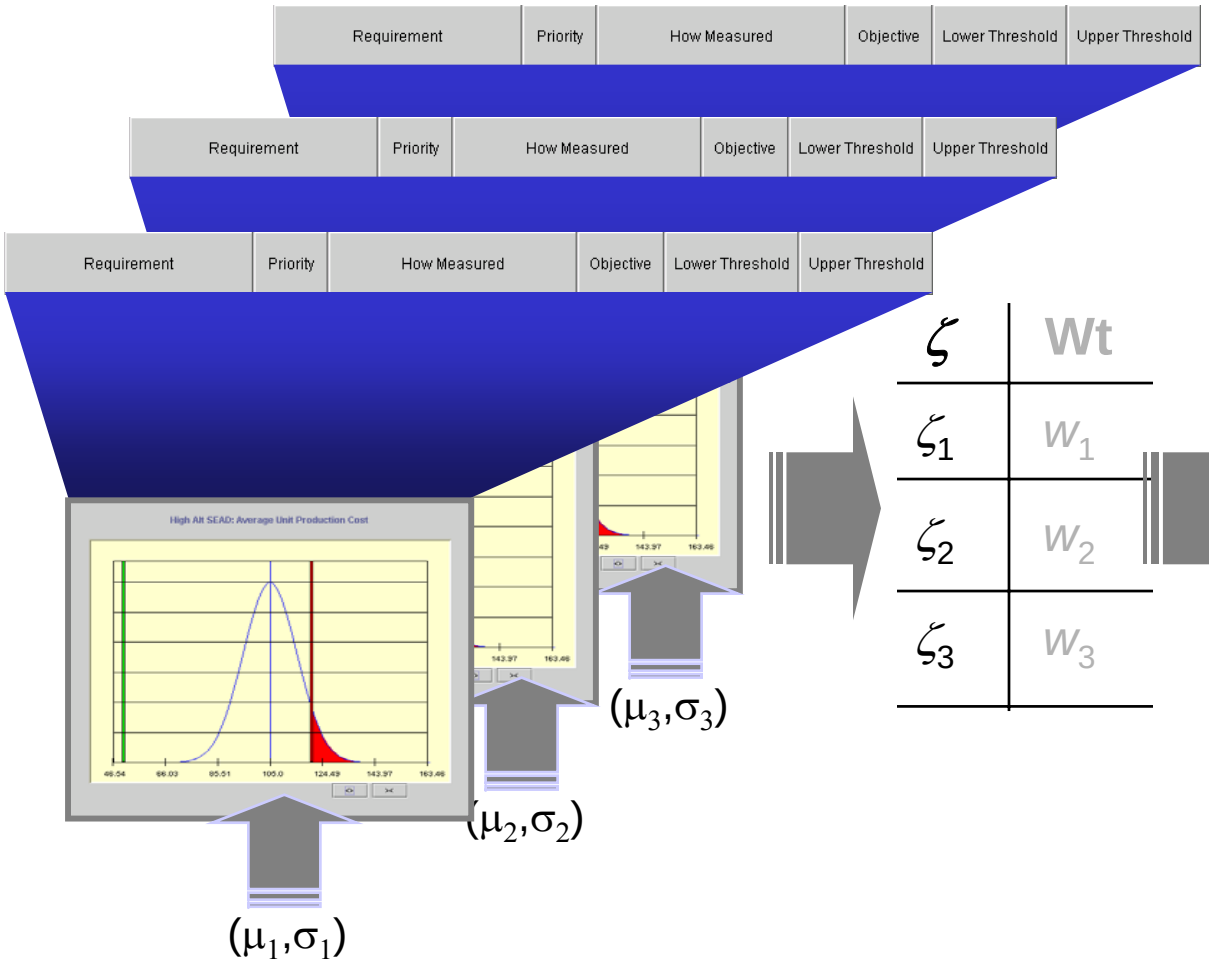
$$D_{type} = \left[\prod_{i=1}^{n} (d_i^{w_i}) \right]^{\frac{1}{\Sigma w_i}}$$

Expected Values for Tech X

Note: If w_i=0, $d_i^{w_i} = 1$.

Rolling Up Risk For Each Requirement Type

All requirements of a given type.



Expected Values & Standard Deviations for Tech X

Note: Risks are SPECIFIC to each customer!

ζ	Wt
ζ_1	w_1
ζ_2	w_2
ζ_3	w_3

$$\zeta_{type}=1-[(1-\zeta_1)(1-\zeta_2)(1-\zeta_3)]$$

$$\zeta_{type} = 1-\left[\prod_{i=1}^{n}(1-\zeta_i)\right]$$

Note: If $w_i=0$, ζ_i set to 0.