JPL

Risk-Based Technology Roadmapping

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JPL Technology Infusion Impediments

New mission concepts enabled by new technologies (autonomy, agents, ...), but...

Infusion of advanced technologies problematic :

- **Requirements-related:** Miscommunicated, misunderstood or under-defined customer (mission) requirements
- **Readiness-related:** Technology deemed non-flightworthy (unforeseen unresolved engineering issues)
- **Competitiveness-related:** Near-equivalent technologies are or will become available

Needs:

Clearer definition of mission requirements

Early identification of technology-specific engineering difficulties

Ability to decide among architectures, technologies

Projected status of competing technologies

Challenges:

- **Groundbreaking nature of new mission concepts and autonomies:** Past experience provides only a partial guide
- **Multi-disciplinary nature:** No individual is an expert in all areas; No individual can juggle all the details at once
- **Resource constrained** Many risks that, if untamed, lead to abandonment or wasted resources
- **Need good decisions early** Early on, lack information (e.g., detailed design) on which to base decisions

Risk-based Roadmapping

What do you want?

"Objectives"
"Requirements"
"Goals"

Mick Jagger
(Rolling Stones):

"You can't always get what you want"

Descoping – strategic abandonment of objectives.

Reprioritize objectives; primary, secondary…

Determine attainment if given additional resources ($, mass, …)

What can get in the way?

"Risks"
"Failure Modes"
"Defects"

Dr. Michael Greenfield
(NASA HQ):

"Risk as a resource"

Trade risk for other resources.

Use risk as an intermediary between other resources.

Issues outside of technologist expertise.

Issues unique to flight development.

What can you do about it?

"Mitigations"
"Solution Options"
"Preventions, Analyses, Controls, Tests – PACTs"

Matt Landano
(JPL):

"Do the right thing & do it right"

Can't afford all possible mitigations, so must choose judiciously.

Know the purpose(s) of each mitigation.

Day 1 – day of the pessimists!

Objectives – *what you want*
Risks* – *what could occur to detract from attaining objectives*
Impact (Objective x Risk) - *proportion of the Objective lost if Risk occurs*

* ***All*** risks, ***including*** those whose mitigation is planned:
- Makes available for scrutiny explicit assertions of risk reduction
- Allows risk and its mitigation to be involved in trades
- Reveals dependencies on mitigations (what if can't do it on time?)

Day 2 – day of the optimists!

Mitigations – *what could be done to reduce risk*
Effect (Mitigation x Risk) – *proportion by which Mitigation reduces Risk*

Experts' estimates, past experience if available, models & simulations...

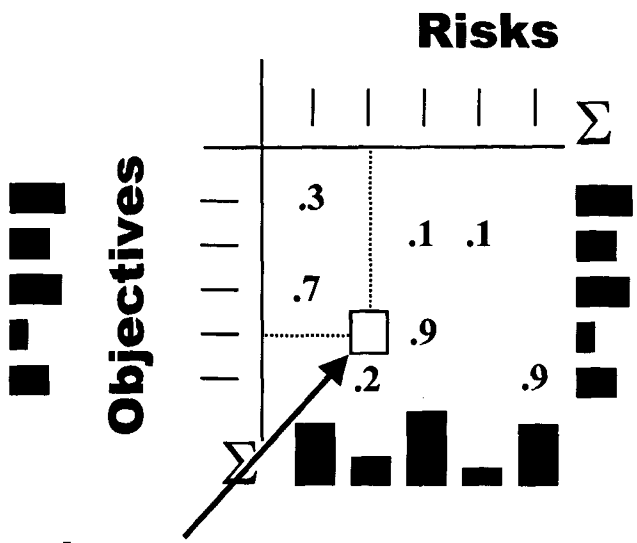
Day 3 – day of the realists!

Select – Mitigations to perform
Objectives to discard
Resources to ask for

Decision-making guided by accumulated information

Getting the right people is key!!!
Mission scientists, technologists, relevant disciplines' engineers, assembly/integration, testing, QA, operation, programmatics

Day 1 – day of the pessimists!



Impact – **proportion of objective lost if risk occurs**

Sum the rows: how much each objective is "at risk".
Sum the columns: how much each Risk causes loss of Objectives.

Objectives – *what you want*
have **weights** (their relative importance)

Risks – *what could occur to detract from attaining objectives*
have **a-priori likelihoods** (how likely they are to happen if not inhibited by Mitigations), usually left at the default of 1 (certain!)

Impact (Objective x Risk) - *proportion of the Objective lost if Risk occurs*
Combine *additively*: I1 & I2 = I1 + I2 (therefore objectives can be more than 100% killed!)

Disagreement about an impact number usually (always?) resolved by refinement of Objective and/or Risk

Day 2 – day of the optimists!

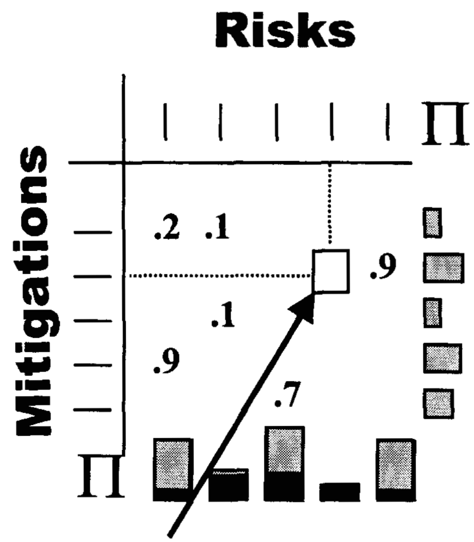
Mitigations

– *what could be done to reduce risk*
have **costs** ($, schedule, high fidelity test beds, memory, CPU, …)
have **type** (prevention, detection, alleviation)
have **status** applied / not applied: major purpose is to decide which to apply!

Effect (Mitigation x Risk) – *proportion by which Mitigation reduces Risk*
Combine as serial "filters":
E1 & E2 = (1 – (1-E1)*(1-E2))

e.g., a 0.8 effectiveness Mitigation catches 80% of incoming Risk ,
a 0.3 effectiveness Mitigation catches 30% of incoming Risk ;
100% -> 20% -> 14% so together have 86% effectiveness
(1 – (1 – 0.8)*(1 – 0.3)) = (1 – 0.2*0.7) = (1 – 0.14) = 0.86

Note: a law of diminishing returns as apply additional Mitigations

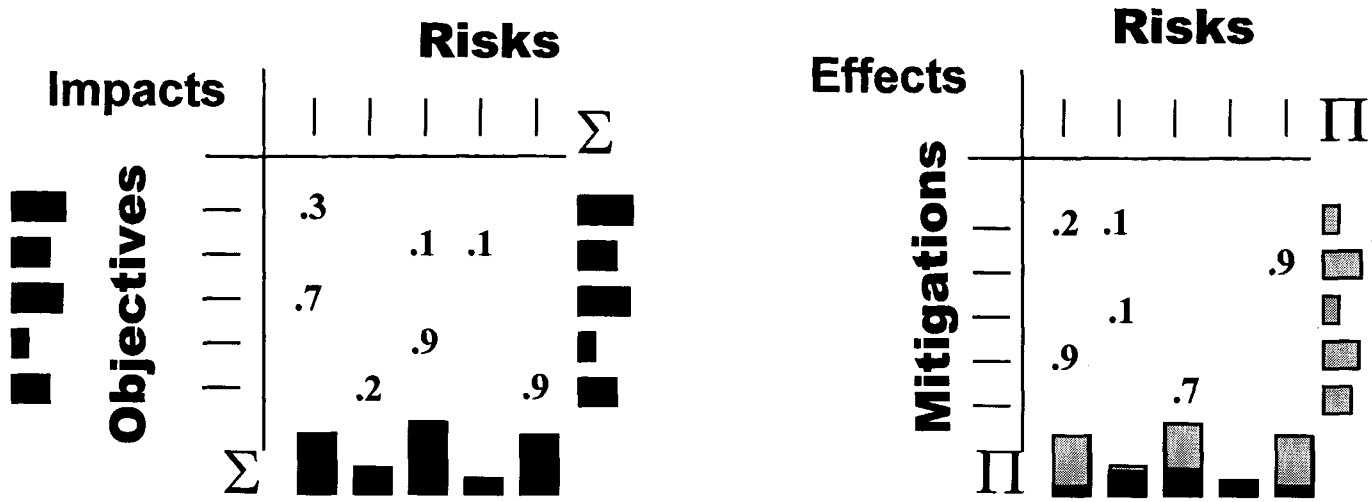


Effect – proportion by which risk reduced if mitigation applied

Sum the rows: how much each Mitigation reduces Risks; "solo" or "delta".
Sum the columns: how much each Risk detracts from Objectives (1) when Mitigations off, (2) when Mitigations on.

Note: some mitigations can make risks *worse* (increase likelihood or impact)!

Day 3 – day of the realists!

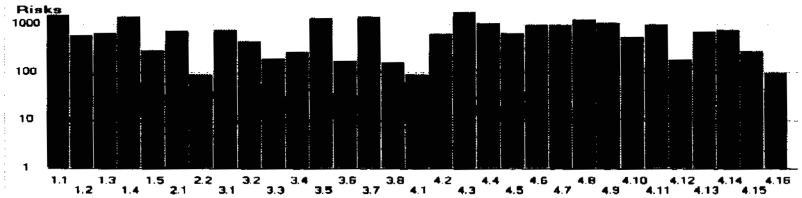


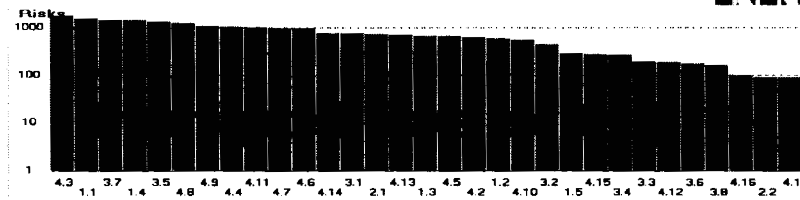
Decision step: select mitigations so as to cost-effectively reduce risk

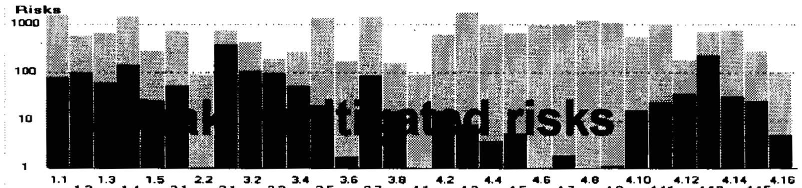
Outcome – Final Report:

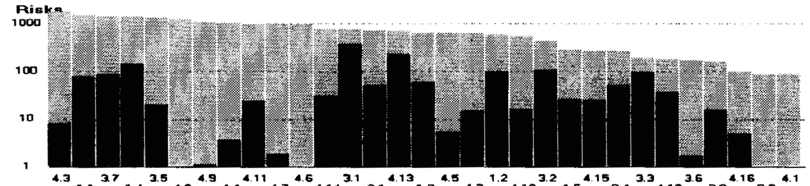
- Background: Capsule description of technology, relevance to mission, placement viz-à-vis. Competition.
- Risk profile: Detailed list of risks, magnitudes derive from trace to objectives, reductions traced to (time ordered) mitigations.
- Risk mitigations: Detailed list of mitigations, how, when and where they reduce risk, *purposes* of individual mitigations (track & control), cost estimates.
- Recommendations: Defensible selections of mitigations, costed plans, justifiable expectations.

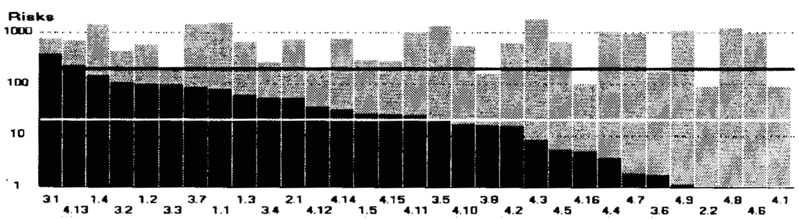
JPL Visualizations of aggregate information



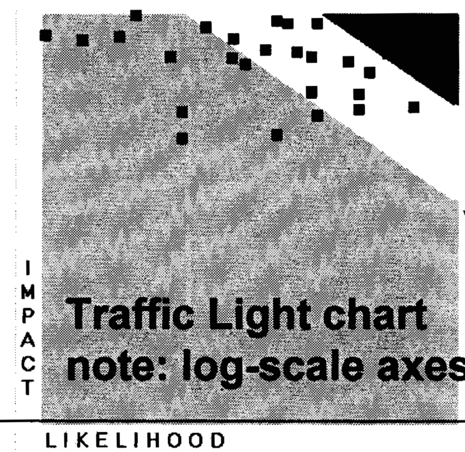








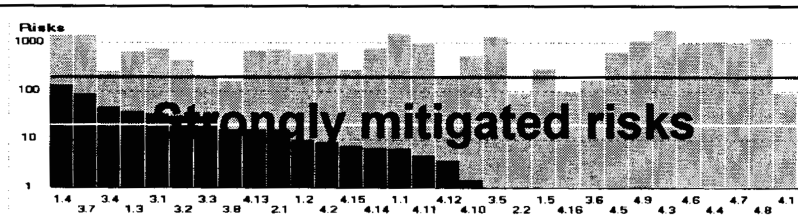
Red = remaining risk
Green = mitigated risk (but at a cost)

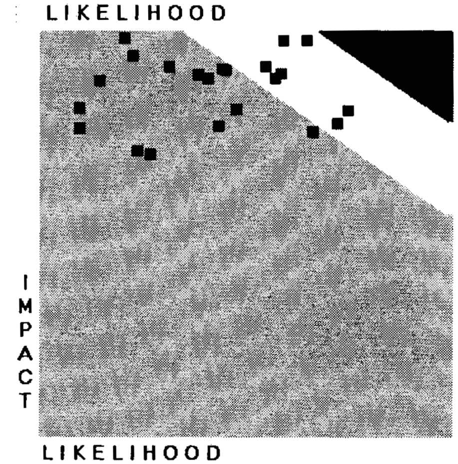


$ Objvs: 2,120 out of 3,610	
	Cost
ALL	4,740,000
Checked	396,000

$-o-meter

boundary =
iso-risk line!

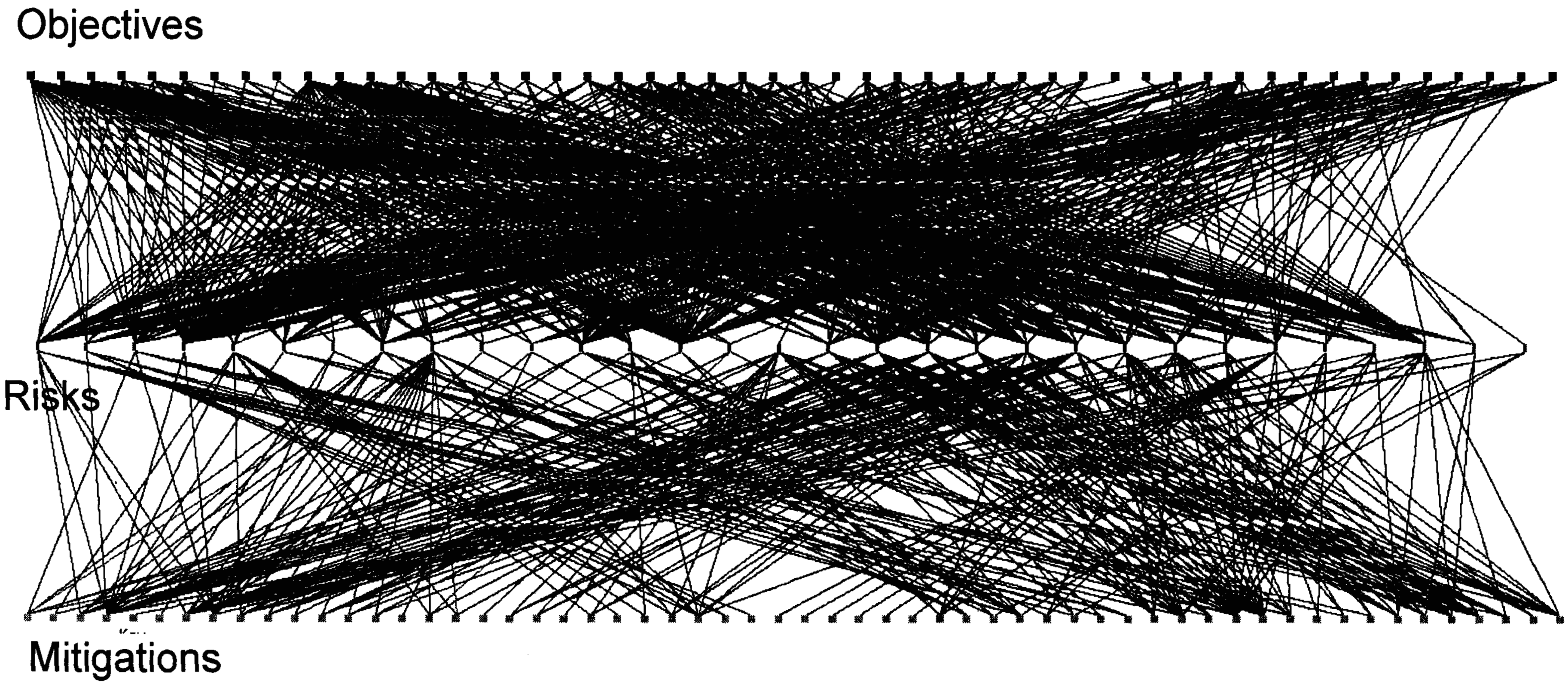




$ Objvs: 3,110 out of 3,610	
	Cost
ALL	4,740,000
Checked	996,000

Big-picture view *and* ability to drill down to detailed level

Typical DDP information set: 50 objectives, 31 risks, 58 mitigations



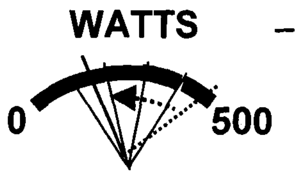
DDP process and custom tool enables models of this scale to be built and used effectively

Example benefits :

- **Cost & Time Saved** (per study cost: $10K - $30K)
  - At least two instances of savings > $1M
    - E.g., Storage technology study revealed *problematic (at risk) overly-stringent requirement*, whose removal permitted dramatic cost & time savings. Technology near cancellation became proposal-winning concept. Requirements honed to requisite level of mission specificity.

$$$

- **Designs Improved**
  - Savings of critical resources (power, mass, ...) seen in comparison of designs before & after DDP sessions
    - E.g., *Risk-informed* redesign of flight experiment systems architecture: power needs decreased by 68%, mass decreased by 13%, cost decreased by 9%, major category of risk changed from architectural to well-understood design.



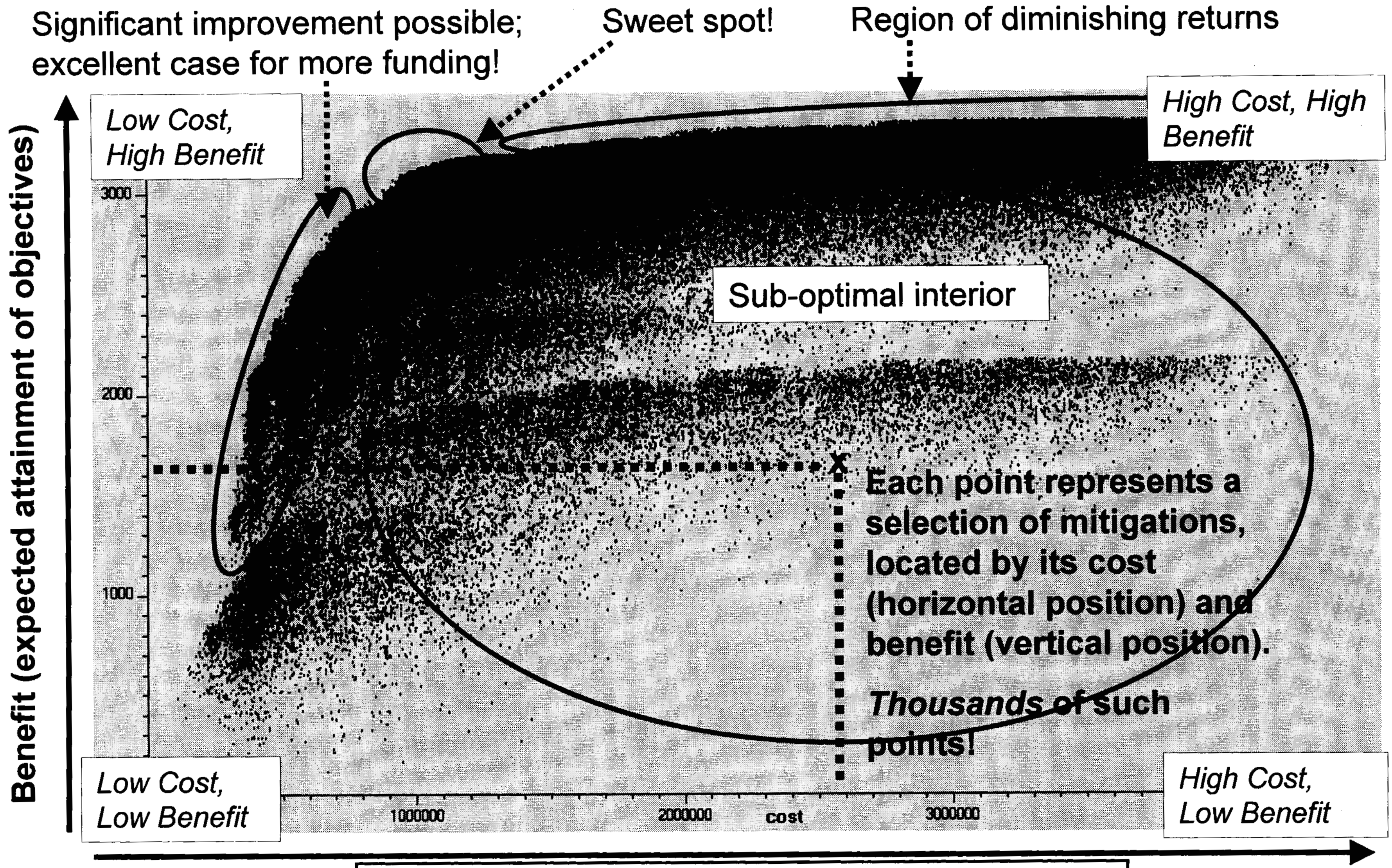
- **Thorough and Early Risk Identification and Mitigation**
  - Technology-to-flight entire range of risks identified, and mitigations planned
    - E.g., testing commensurate with anticipated mission radiation dosages; pinpointed use of antiquated design tools as a contributing risk factor; ...

- **Technology Adoption**
  - Achieved sufficient understanding of benefits/risks to make "go" decision
    - E.g., GUI-driven autocoding adapted to run as flight instrument controller: benefits understood, risks unknown; *identified risks* (e.g., unrelocatable code) & *mitigations*. Agency usage, industry business case expansion.

[redacted]

Cost-Benefit trade space insights

58 mitigations = 2^{58} (approx 10^{18}) ways of selecting.
Simulated Annealing used to search for near-optimal selections.



Risk basis for calculations: risk detracts from attainment of benefits; mitigation of risk costs resources.

DDP Timeline

Code Q "Failure Detection and Prevention Program" (1998-?)

PEMs: Tim Larson, Kelly Moran
PI: Steve Cornford

Code Q / IV&V "Advanced Risk Reduction Tool" (1999-2002)

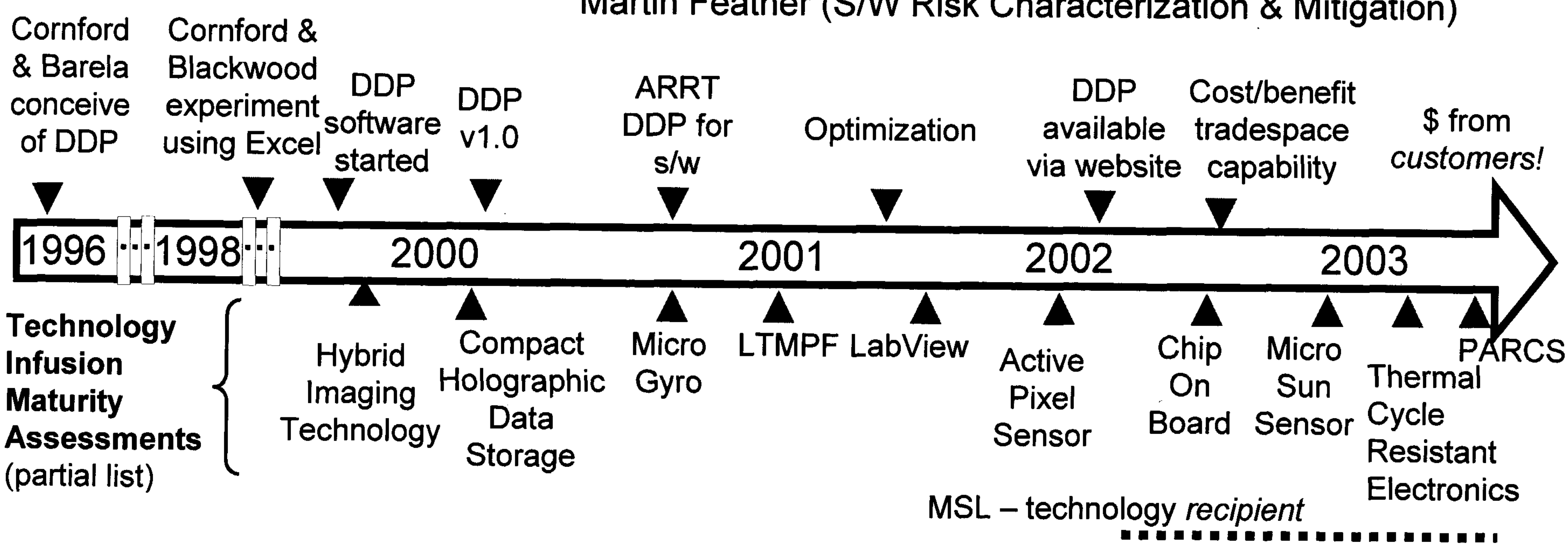
PEMs: John Kelly, Burton Sigal, Allen Nikora
PIs: John Kelly, Martin Feather

DDP

Code R "Engineering of Complex Systems" (2002-?)

Level 2 Manager: Stephen Prusha

PIs: Ken Hicks (Risk-Based Design), Steve Cornford (Risk Workstation), Martin Feather (S/W Risk Characterization & Mitigation)



CONCLUDING SUMMARY

- Information: make most use of information available early in lifecycle
  - Combine knowledge from experts and past experience
  - Accommodate both evidence and estimates
- Process: gather the right information the right way
  - Objectives, including their relative importance
  - Risks, and by how much they impact objectives and requirements
  - Mitigations, and by how much their use would reduce risk
- Tool support: effectively handle voluminous amounts of information
  - Capture experts' knowledge on-the-fly during intensive sessions
  - Present information through cogent visualizations
  - Derive additional knowledge via calculation and search
- Utilizable Product:
  - Specific collection of tasks, purposeful, costed, scheduled
  - A traceable rationale, quantitative scoring, reviewable
  - Risk-based understanding, thorough, calibrated

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