Software Risk Estimation and Risk Reduction using the "Defect Detection and Prevention" Risk Approach & Tool(*)

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http://ddptool.jpl.nasa.gov

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* **Steve Cornford** (JPL) leads the DDP effort

Roadmap

Part I – Motivation, approach and experience

Part II - Software specific focus

Part III – Live demo!

(separate slides)

Guide to the DDP tool

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

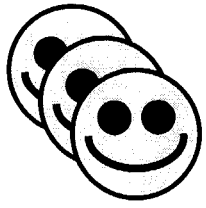
Projected status of competing technologies

Our worries are spacecraft, but these problems, needs and challenges are very widespread!

Challenges:

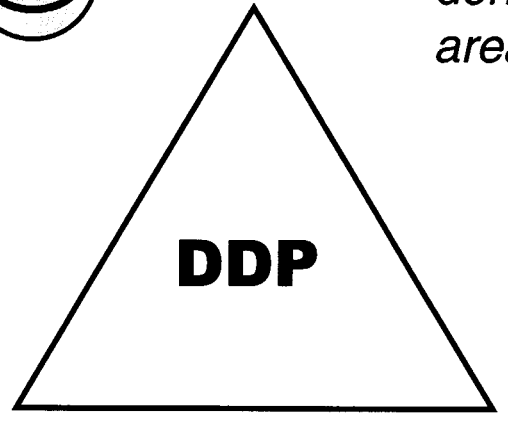
- **Groundbreaking nature of new mission concepts and autonomies:**
  Past experience provides only a partial guide
- **Multi-disciplinary nature:**
  No individual is an expert in all areas; No individual can juggle all the details at once
- **Resource constrained**
  Many risks that, if untamed, lead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

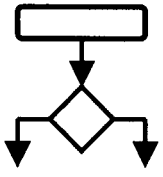
People + Process + Program



Human Expertise

Information gathering and decision making done by relevant subject area experts

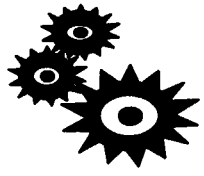




Risk-Based Process

Stakeholders → objectives → risks → mitigations → costing → selection → documentation

Software Support



Information repository, calculations, visualizations, decision support

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.

Objectives	Risks	Mitigations
~~Return data~~	~~Software bug ridden~~	~~Become CMM level 3~~

Insufficient detail for decision making. Elaborate!

In flight s/w upgrades	Requirements risks	Requirements practices
Code/Data separable	Unstable	Documented
Real-time control loops	Incomplete	Formal CM
Sync to external clock	Unclear	Peer review
Tolerate memory errors	Invalid	Formal inspections
Run time memory =…	Infeasible	Formal reviews
Storage = …	Unprecedented	Criticality analyses
CPU utilization = …	Large size/complex	Verifiability check
…	…	…

Risk x Objective :
***How much* of objective will be lost if risk occurs? – "Impact"**

Mitigation x Risk:
***How much* will risk be reduced if mitigation applied? – "Effect"**

Elaborate enough to be able to say by *how much*

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!

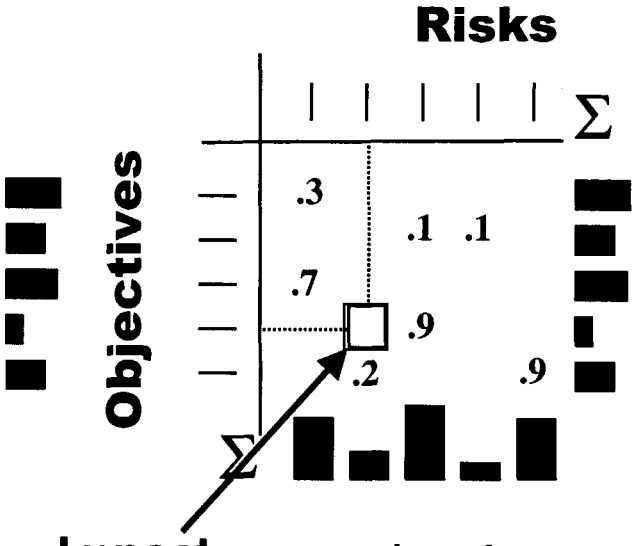
Select – Mitigations to perform
Objectives to discard
Resources to ask for

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

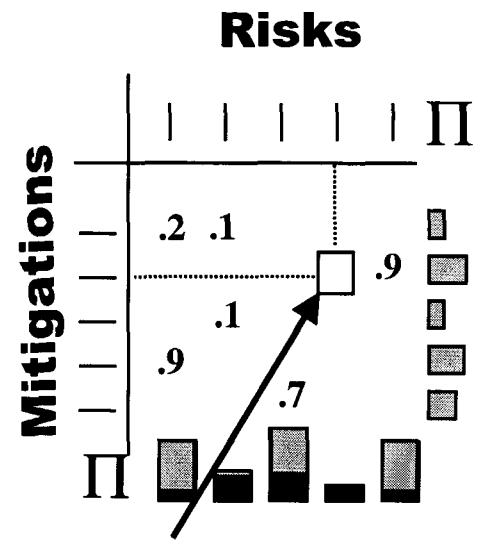
– *what could be done to reduce risk*
have **costs** ($, schedule, high fidelity test beds, memory, CPU, …)
have **type** (prevention, detection, alleviation)
have **status** applied / not applied: major purpose is to decide which to apply!

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

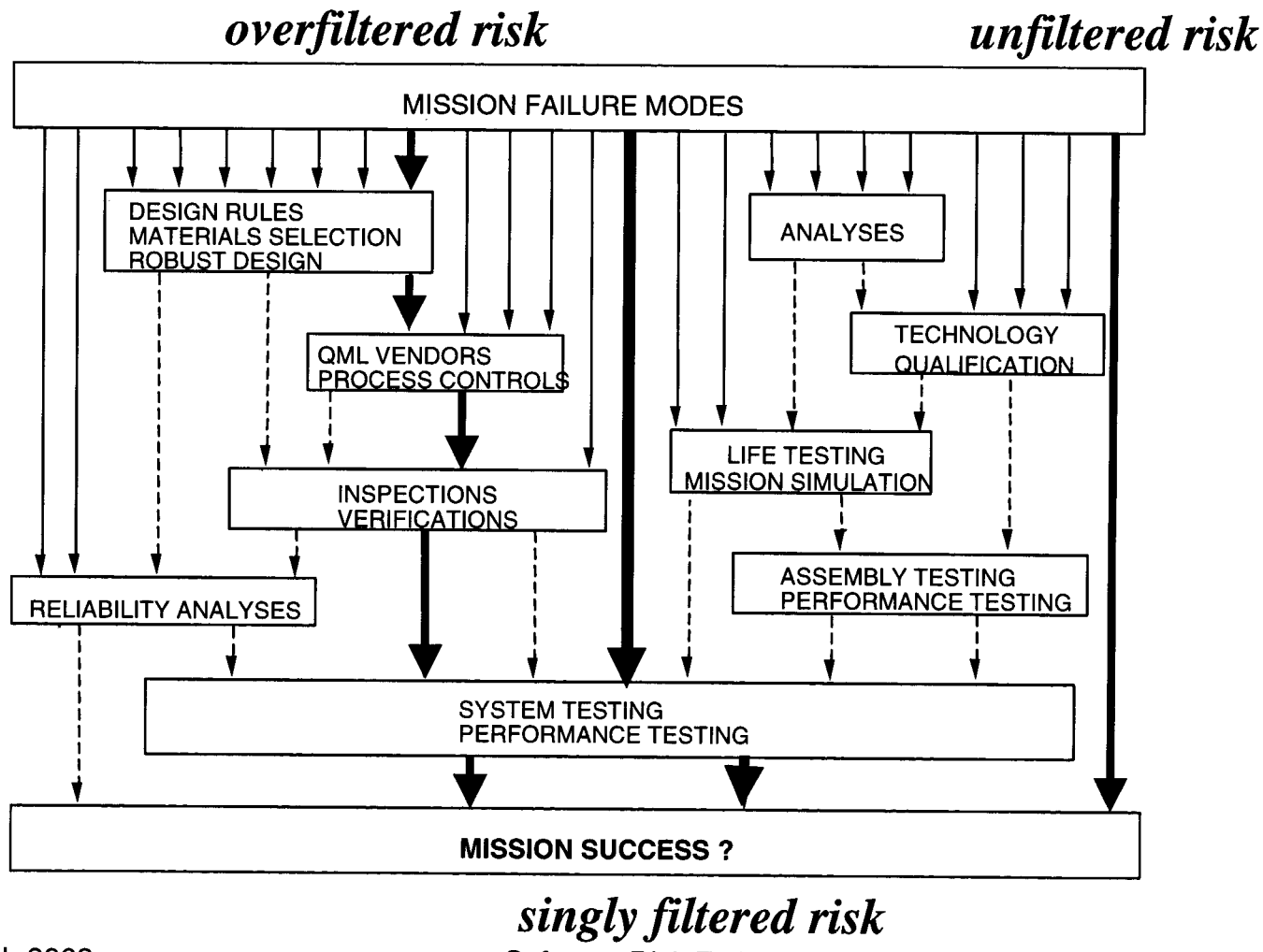


Effect – proportion by which risk reduced if mitigation applied

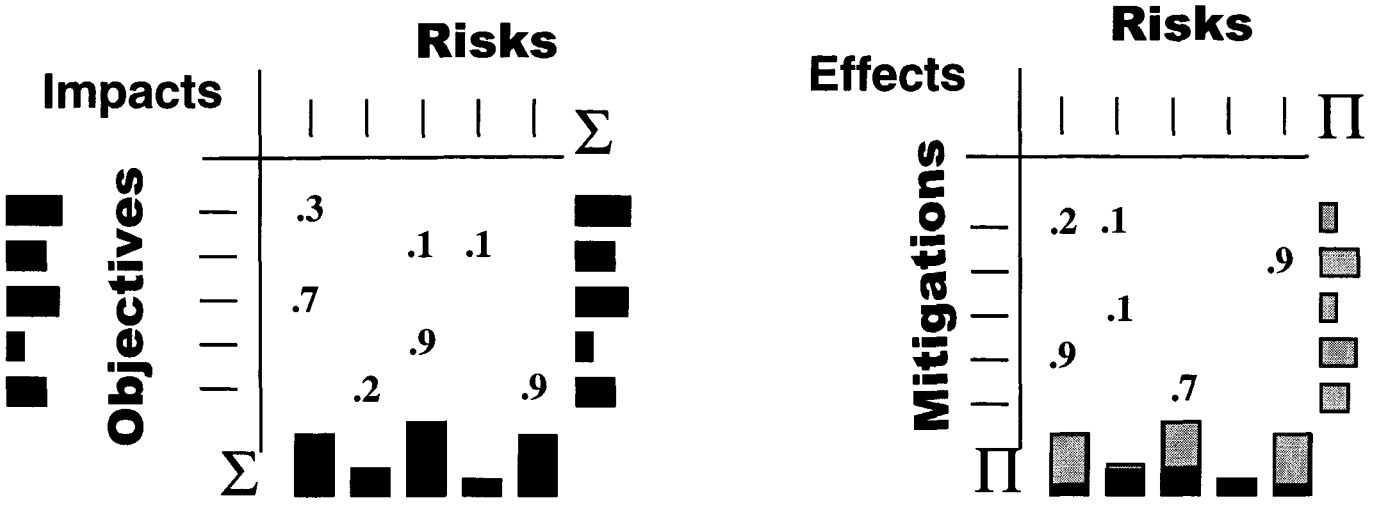
Sum the rows: how much each Mitigation reduces Risks; "solo" or "delta".
Sum the columns: how much each Risk detracts from Objectives (1) when Mitigations off, (2) when Mitigations on.

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

Motivation
Steve Cornford's flow-down image:
assurance activities "filter out" risk



Day 3 – day of the realists!

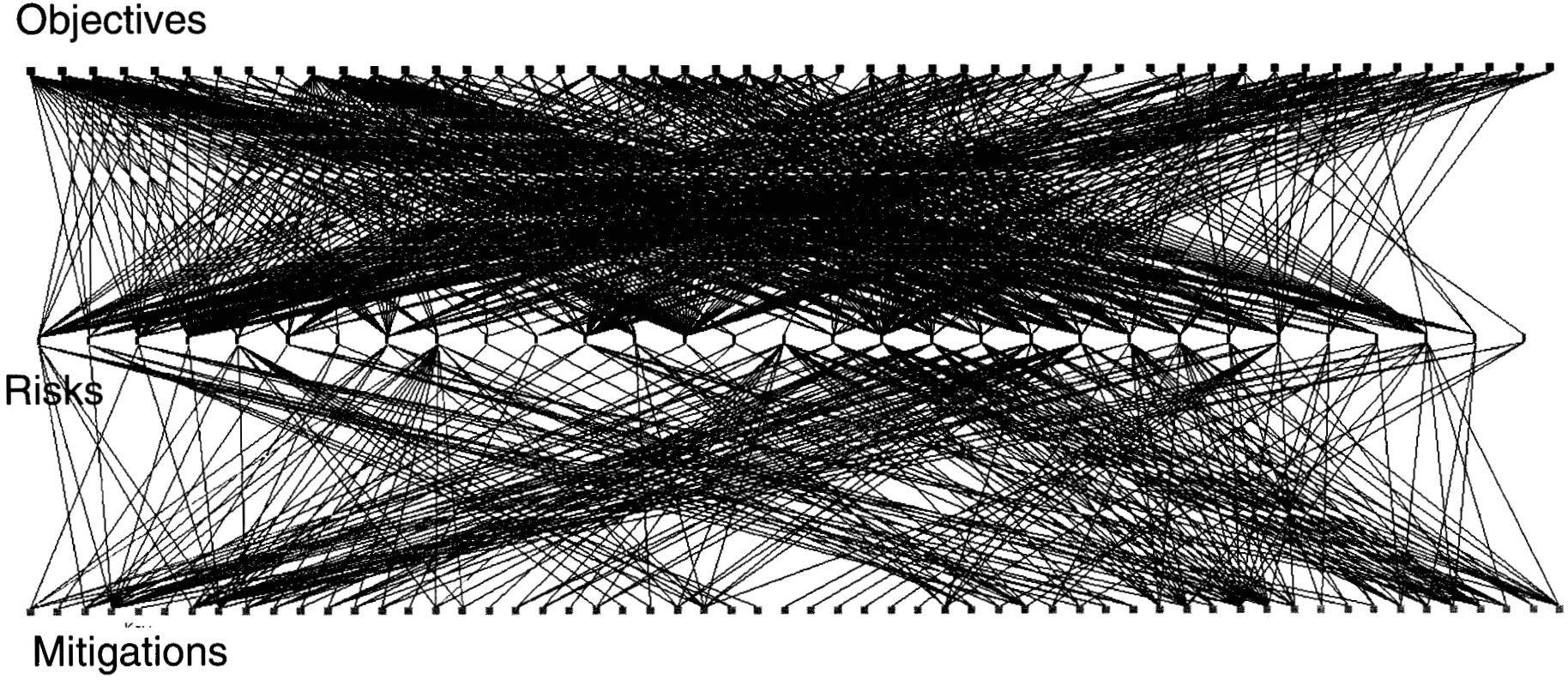


Decision step: select mitigations so as to cost-effectively reduce risk

Outcome – Final Report:

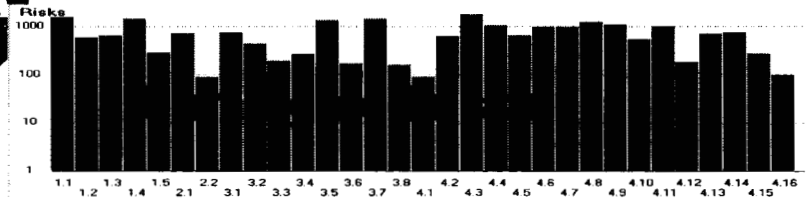
- Background: Capsule description of technology, relevance to mission, placement viz-à-vis. Competition.
- Risk profile: Detailed list of risks, magnitudes derive from trace to objectives, reductions traced to (time ordered) mitigations.
- Risk mitigations: Detailed list of mitigations, how, when and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

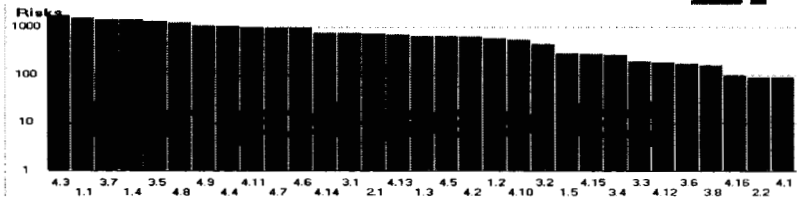
Typical DDP information set: 50 objectives, 31 risks, 58 mitigations

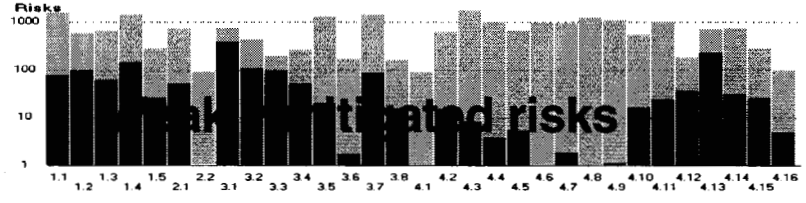


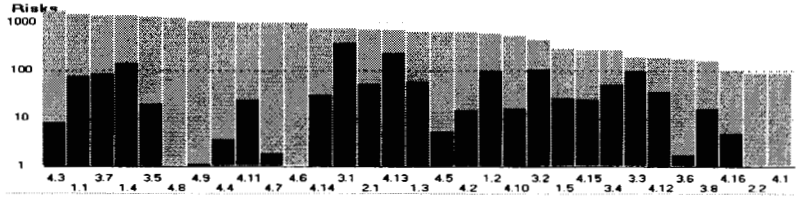
DDP process and custom tool enables models of this scale to be built and used effectively

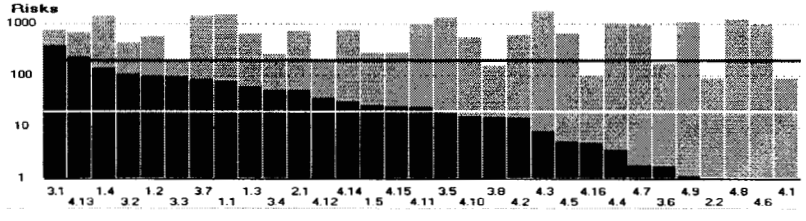
Visualizations of aggregate information



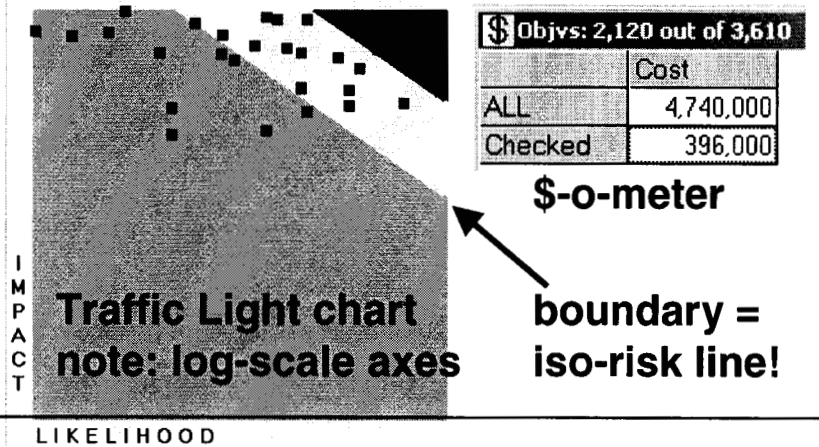








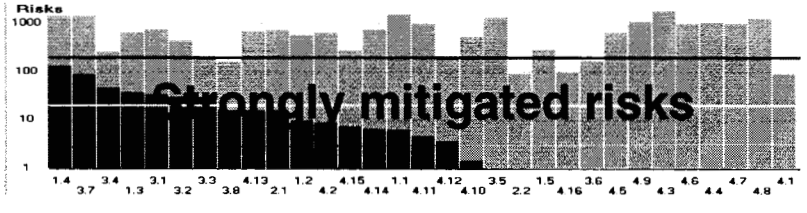
Red = remaining risk
Green = mitigated risk (but at a cost)

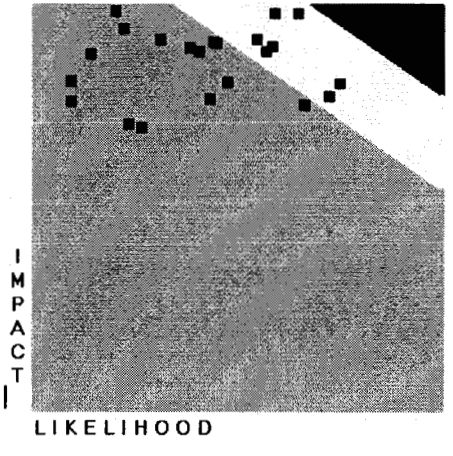


$ Objvs: 2,120 out of 3,610	
	Cost
ALL	4,740,000
Checked	396,000

$-o-meter

boundary = iso-risk line!





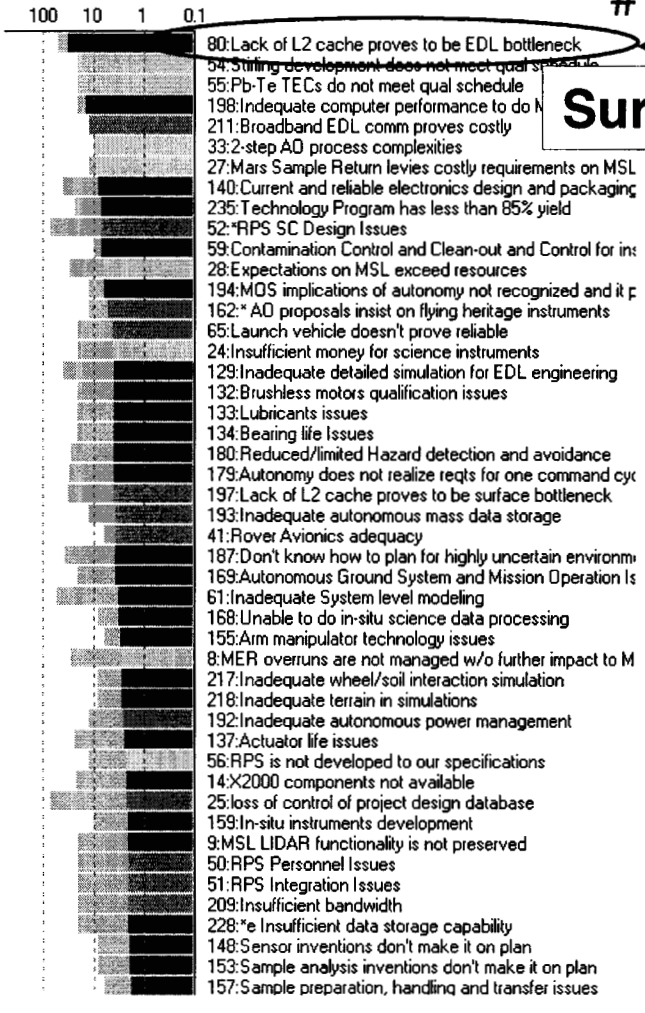
$ Objvs: 3,110 out of 3,610	
	Cost
ALL	4,740,000
Checked	996,000

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

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.

Flight Project risk insights from DDP



#1 risk:

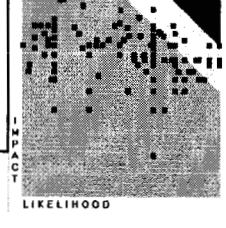
Lack of L2 cache proves to be EDL bottleneck

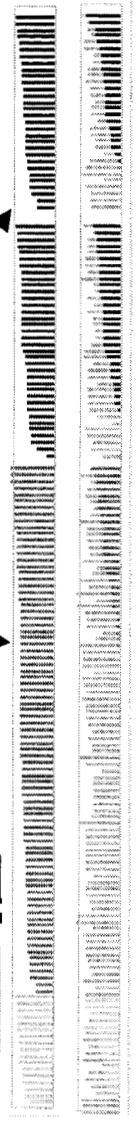
Surprise!

MSL: flight project application

- Large number of risks (>150) and mitigations (>300)
- Mix of several *kinds* of risks (Technology, Engineering, Programmatic, …)

DDP enables both big-picture understanding and detailed scrutiny





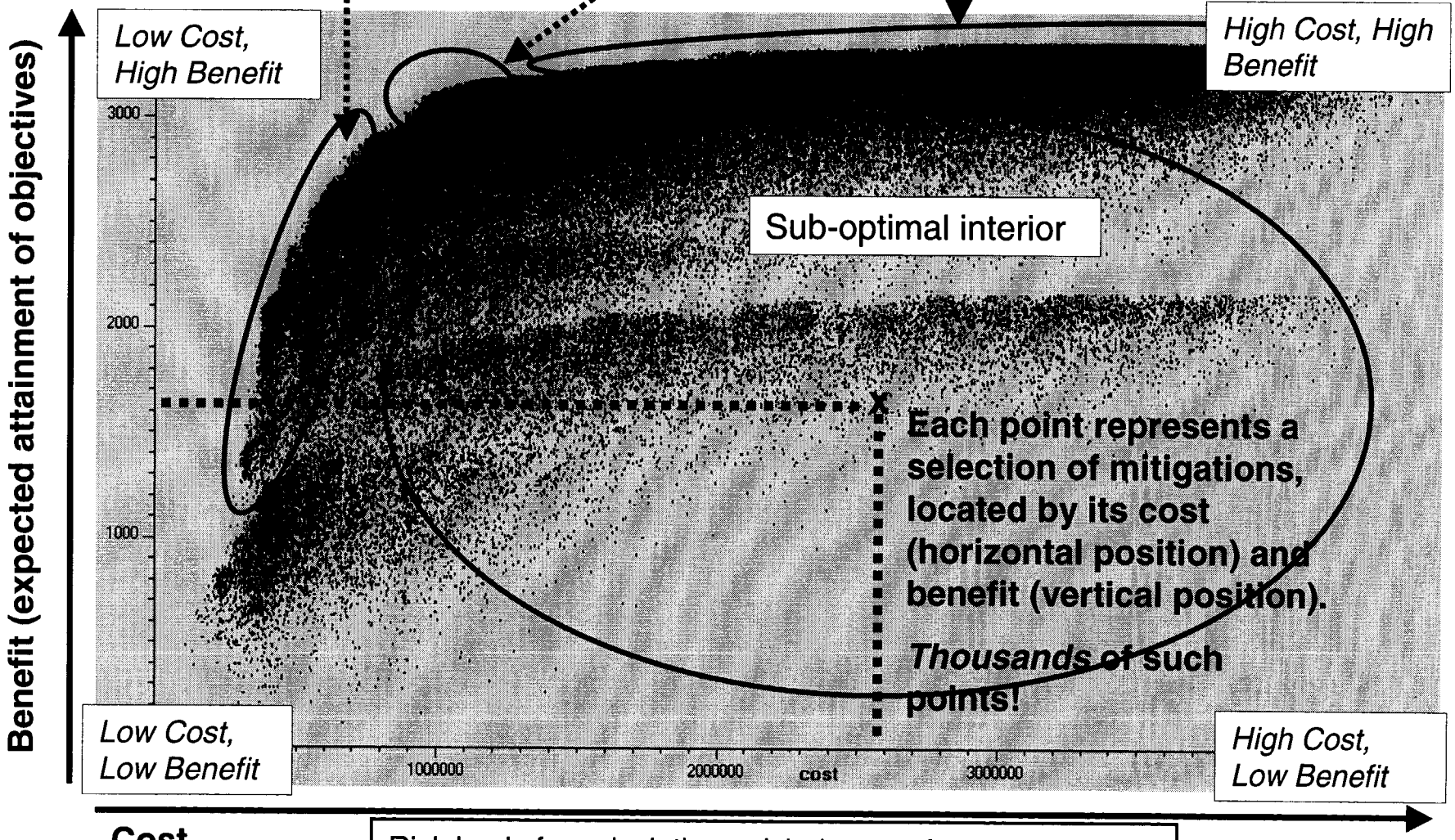
Cost-Benefit trade space insights

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

Significant improvement possible; excellent case for more funding!

Sweet spot!

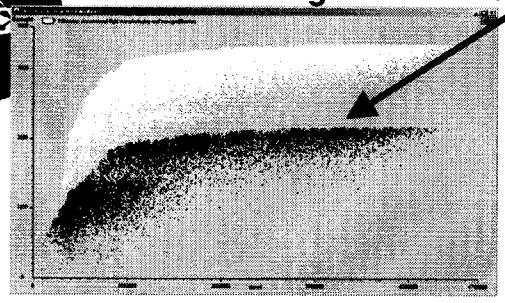
Region of diminishing returns



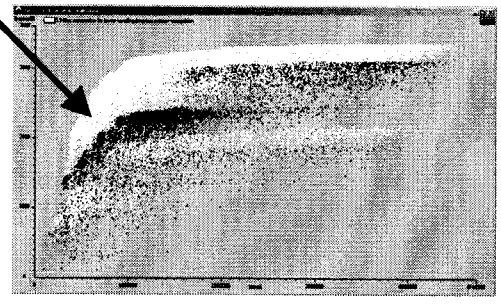
Risk basis for calculations: risk detracts from attainment of benefits; mitigation of risk costs resources.

Effects of individual mitigations

Affordable & high value – "shadow" = loss of benefit if omitted

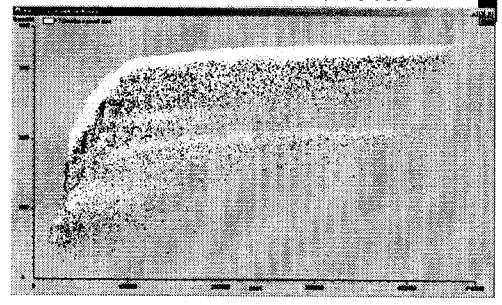


1.4: ($160,000) Develop documented flight manufacturing and test/qualification practices



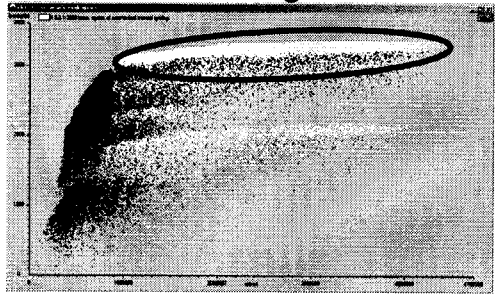
3.9: ($75,000) Use automation for bump bonding (requires pattern recognition capability)

Affordable & modest value



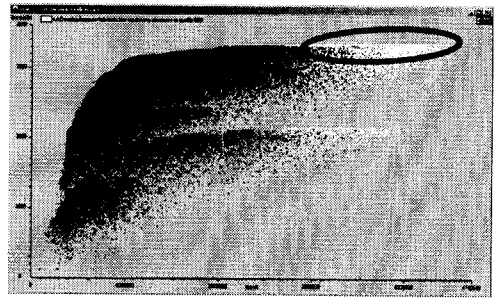
1.7: ($60,000) Develop a rework plan

High value but increasingly expensive – use only when can afford to do so



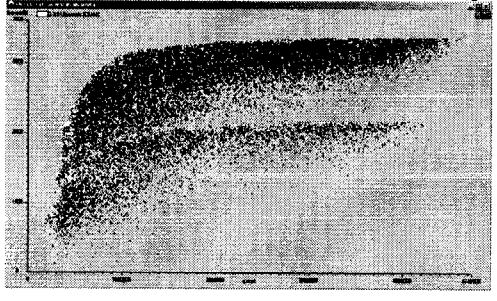
4.5: Conduct qualification/reliability tests
4.5.2: Thermal
4.5.2.1: ($200,000) 3000 temp. cycles of mechanical thermal cycling

1.3: ($500,000) Develop die packaging selection criteria (flip-chip, micro BGA, wire bond)

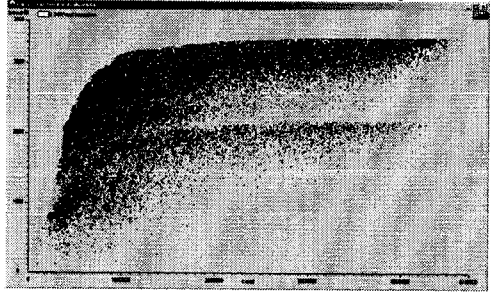


4.4: ($700,000) Develop/procure/fabricate test equipment/structures to qualify COB manufacturing approaches

Low value & inexpensive – may need to scrutinize more close up

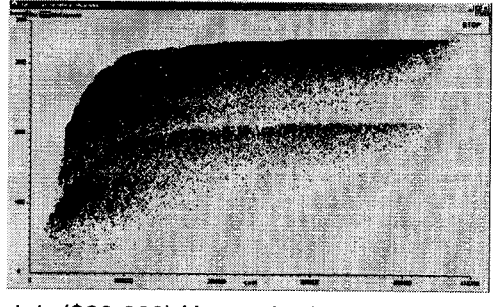


3.3: inspection
3.3.5: ($5,000) Ultrasonic (CSAM)



3.3: inspection
3.3.4: ($5,000) Visual inspection

Very dubious value!



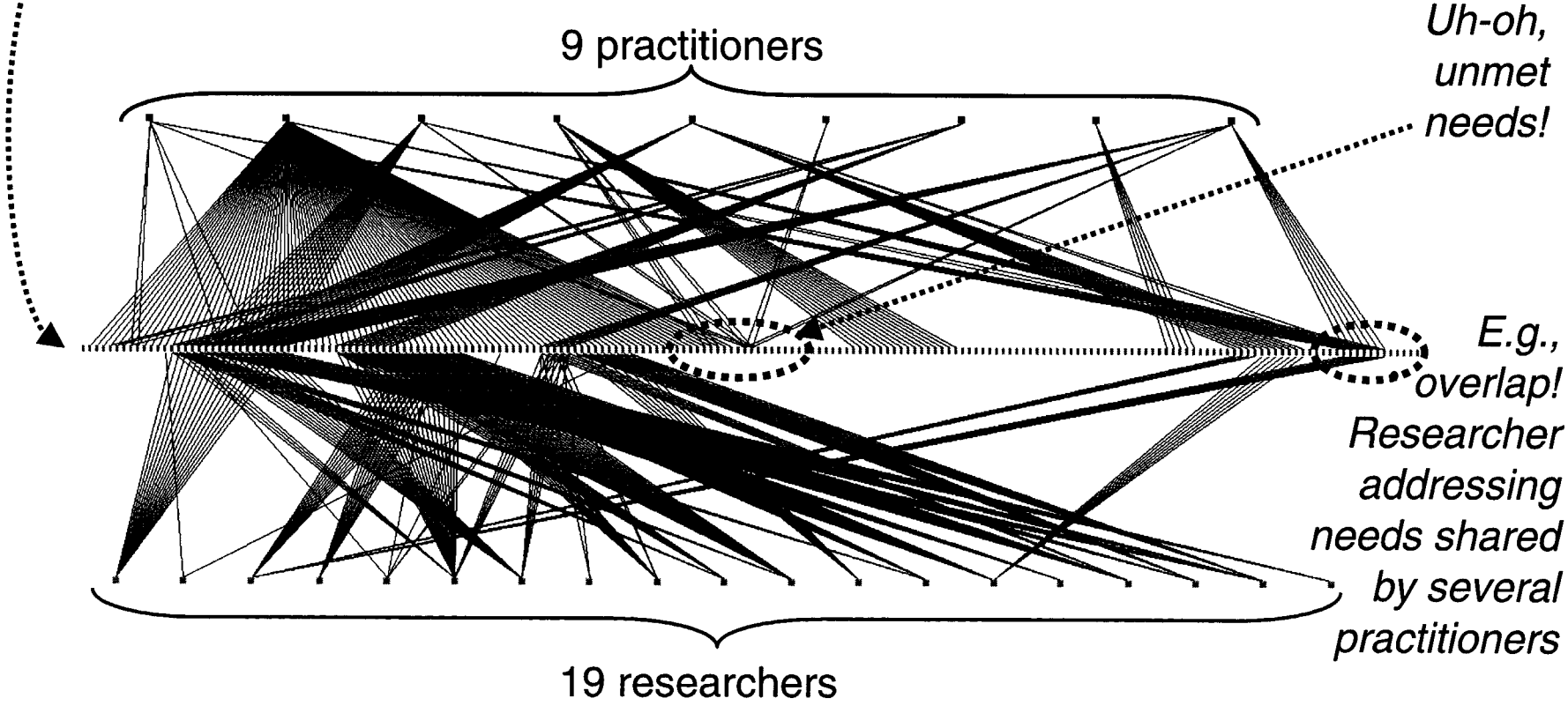
1.1: ($20,000) Use embedded passives

Matching Needs To Research(!)

!! Needs = Objectives
Areas = Risks
Research = Mitigations

Motivation: Dave Tralli: activity selection across an entire program of NASA Earth Science Missions [Tralli, 2003].

The 198 leaf nodes, placed side-by-side, of the "software" portion of the ACM taxonomy of computer science



DDP Timeline

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

PEMs: Tim Larson, Kelly Moran
PI: Steve Cornford

DDP

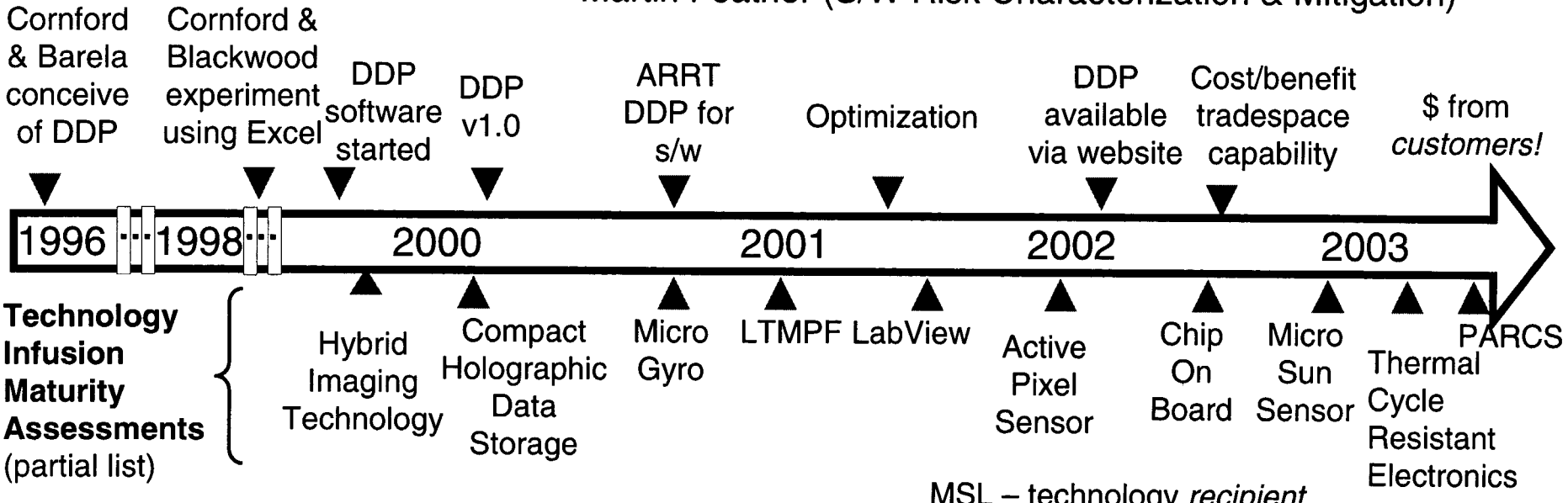
Code Q / IV&V "Advanced Risk Reduction Tool" (1999-2002)

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

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

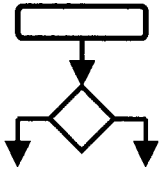
Level 2 Manager: Stephen Prusha

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

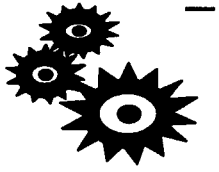


Reflections: Major Factors

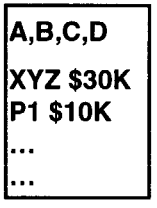
- Information: make most use of information available early in lifecycle
  - Combine knowledge from experts and past experience
  - Accommodate both evidence and estimates



- 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

Part II - Software specific focus

Up to this point, approach general enough to apply to software, hardware, research portfolios, ...

Focus shifts now to *software,* in particular planning its assurance / V&V

Software Engineering Community Starting Points

Risks: Software Risk Taxonomy (SEI)

Mitigations: several datasets:

1. CMM Key Practices (Infrastructure and Activities)
2. Software Quality Assurance activities from Ask Pete (NASA Glenn tool)
3. JPL QA & V&V activities

Effects: cross-linkings of the above

1. Expert's best estimates of *which* help
2. Experts' 1000+ best estimates of *how much* (quantified effectiveness) they help

Note: Objectives are PROJECT SPECIFIC

Seeking experience-based data

DDP Trees

enter, organize & view trees of objectives/risks/mitigations

- 1:Product Engineering
  - 2:Requirements Risks
  - 10:Design Risks
    - 11:Functionality: Potential problems in meeting functio
    - 12:Difficulty: Difficult design to achieve
    - 13:Interfaces: ill-defined or uncontrolled internal interfa
    - 14:Performance: Stringent response time or throughpu
    - 15:Testability: Product difficult to test
    - 16:Hardware Constraints: Tight constraints because of
    - 17:Non-Developmental Software: Problems with softwa
  - 18:Code and Unit Test Risks
    - 19:Feasibility: Implementation of design difficult
    - 20:Unit Test: Level and time for unit test inadequate

taxonomy of software development risks (SEI)

Taxonomies are good for reminders, navigation & abstraction (DDP computes aggregate values)

DDP software provides trees, matrices, stem-and-leaf views, and bar charts to enter, organize & view information

Software Risk Mitigations (partial list)

- 1:Concept Phase Activities
  - 2:Concept of operations and operational scenarios
  - 3:Attend concept reviews.
  - 4:Identification of risks and mitigations
  - 5:Review program/project plans
  - 6:Perform Preliminary Hazard Analysis (PHA)
  - 7:Determine software safety level of effort/scope.
  - 8:Develop list of safety efforts/activities.
  - 9:Start Software Hazard Tracking Log
- 10:Requirement Phase Activities
  - 11:Provide Generic Safety Requirements.
  - 12:Assist in the generation of overall requirements.
  - 13:Perform Software Safety Requirements Analysis.
  - 14:Perform Requirements Criticality Analysis.
  - 15:Verify inclusion of any safety critical end of life-cycle requirements.
  - 16:Produce CIL.
  - 17:Participate in requirement working group or JAD meetings
  - 18:Attend requirement reviews,
  - 19:Review and analyze requirements for industry acceptable and required charac
  - 20:Track and resolve any software safety requirements related issues.
  - 21:Generation and/or review requirement traceability/verification matrices
  - 22:Review software development, CM, and test plans
  - 23:Requirements Flow-down Analysis.
  - 24:Review and provide guidance on program/project metrics.
  - 25:Verify software safety requirements.
  - 26:Determine impact of changes and defects on software safety.
  - 27:Perform Phase 1 Safety Review.
- 28:Design Phase Activities
  - 29:Assess safety related issues during design meetings.
  - 30:Design reviews and track any issues related to safety.
  - 31:Analyze software using tools

Quantitatively Relating Software Risks to Mitigations (fragment of 64 x 107 matrix)

Mitgn x Risk [-1...+1]: 0 or empty = no effect; 1 = 100% effect; -ve = induced Risk

Layout | Num Edit | (Off)

Mitgn x Risk Col = Completeness: Incomplete requirements
Row = Conduct Formal Reviews

		Risks	[-]Product Engineering						
		Risks	[-]Requirements Risks						
		Risks	Stabilit Unstab require	Complt Incom require	Clarity: Unclea require	Validity Invalid require	Feasib Infeasi require	Precec Unprec require	Scale Large size o
Mitgns	Mitgns	counts	27	28	27	28	19	25	43
[-]Requir	Software	11							
	Implement	7	0.9	0.3	0.9	0.9	0.3	0.3	0.1
	Managemen	1							
	Documentec	12	0.3	0.9	0.9	0.1	0.3	0.3	0.1
	Peer review	9	0.9	0.9	0.9	0.9	0.9	0.9	0.1
	Conduct	9	0.9	0.9	0.9	0.9	0.9	0.9	0.1
	Software	9	0.9	0.9	0.9	0.9	0.9	0.9	0.1
	Requiremen	18	0.9	0.9	0.9	0.9	0.9	0.9	0.1
	Peer review	25							
	Implement	8	0.3						0.3
	Conduct	14							
	Conduct	8	0.3	0.9	0.9	0.9	0.9	0.9	0.1
	Document	6							
	Customer	9							

Coarse distinctions (0, 0.1, 0.3, 0.9) do suffice for insightful decision making

n.b. Blank = 0, no benefit

"Stem-and-leaf"(*) visualization of DDP sparse matrices:

E.g., Risks & their Mitigations

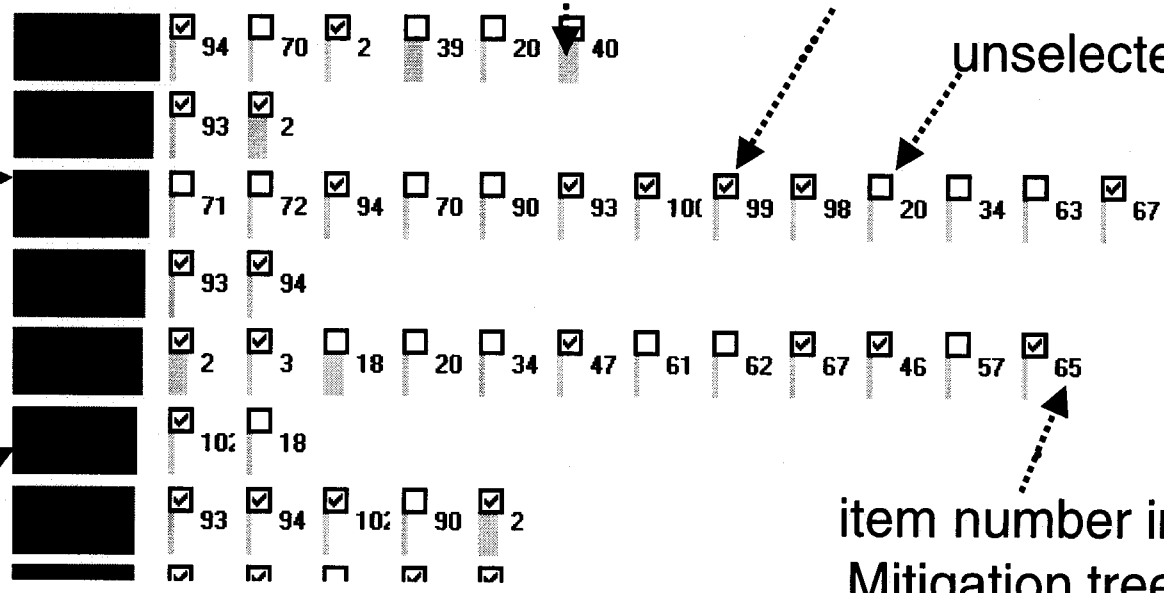
Mitigations – turquoise width ≅ effect

selected

unselected

Risks – red width ≅ log outstanding Σ impact

item number in Risk tree

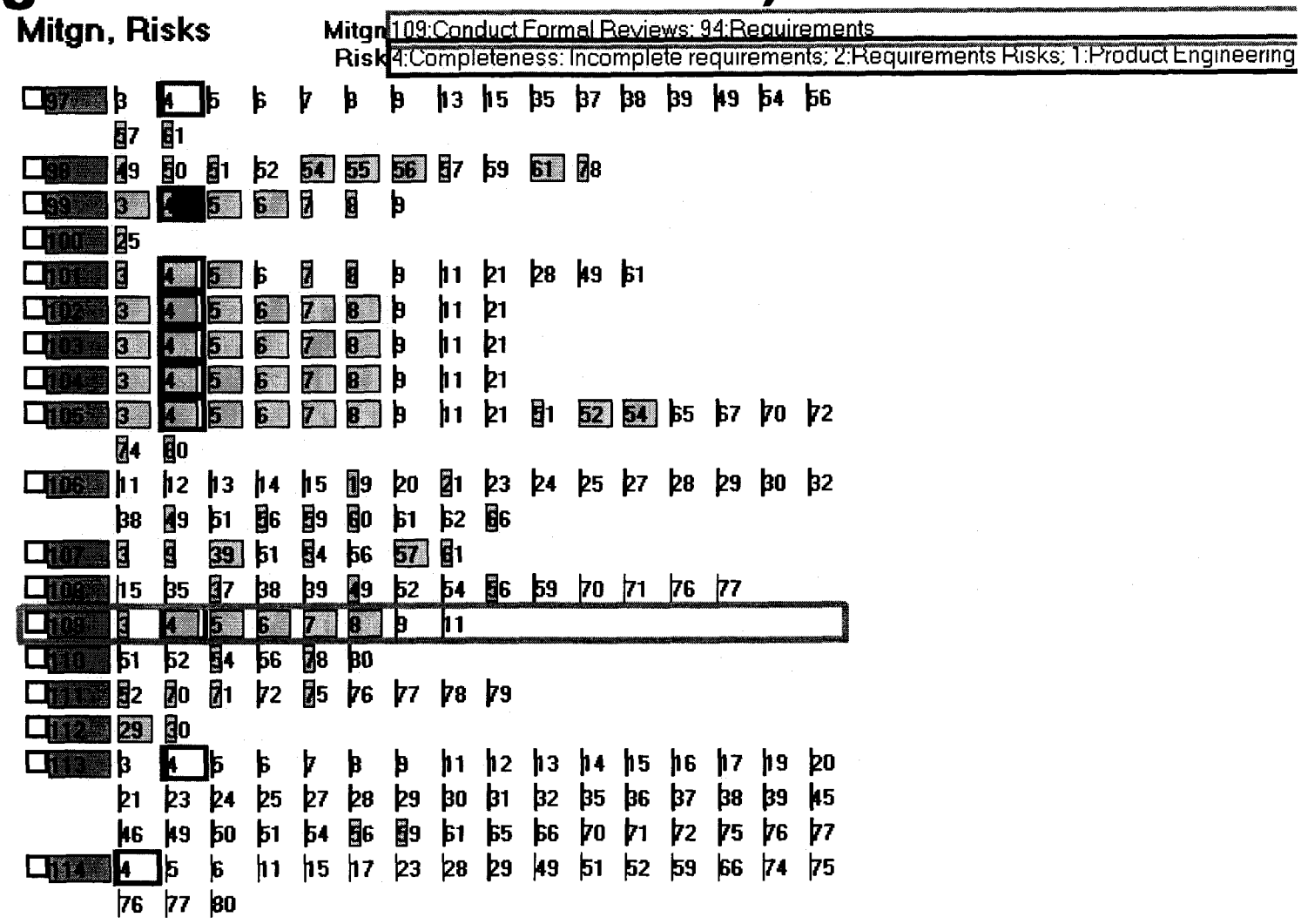


item number in Mitigation tree

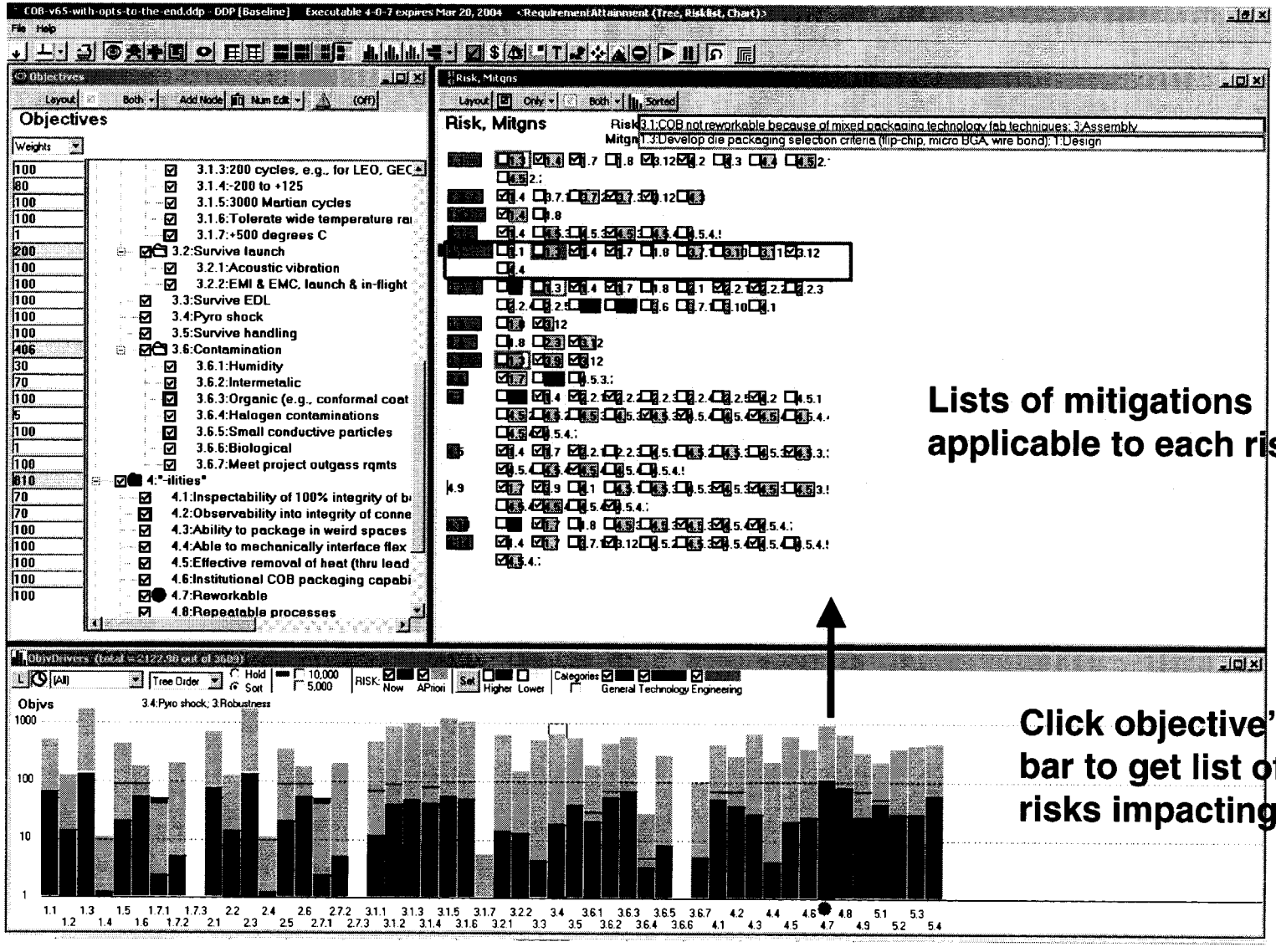
(*) Tufte attributes these to John W. Tukey, "Some Graphical and Semigraphic Displays" Their usage was introduced into RBP (DDP without numbers) by **Denise Howard** & **Chris Hartsough**, extended further by us in DDP.

Quantitatively Relating Software Risks to Mitigations (fragment of 64 x 107 matrix)

Mitigations & the risks they reduce



Typical DDP screen



Lists of mitigations applicable to each risk

Click objective's bar to get list of risks impacting it

Reflections: Probabilistic Risk *Reduction*

PRA

Benefits

Probabilistic Risk **Assessment** computes risk from knowledge of:

- Individual components' reliabilities (e.g., MTBF)
- System architecture (e.g., Fault Tree)
- Calculate system risk / reliability
  when system too expensive/complex/ long lived/critical to directly measure
- Gain insight into system vulnerabilities
  (e.g., cut-sets indicate key contributors to failure)

SFTA / FMECAs appropriate for software/system boundary (e.g., effect of erroneous inputs to / outputs from software)

PRR

Benefits

Probabilistic Risk **Reduction** computes risk from knowledge of:

- Individual risk mitigation activities (e.g., inspection, unit testing)
- Potential risks - both product risks and process risks (e.g., late/over-cost)
- Quantitative assessments of mitigations' effectiveness (at reducing risk) and risks' impacts (on system objectives)
- Calculate system risk / reliability
  when development process key to system assessment (e.g., software)
- Select mitigations to most cost-effectively reduce risk
- Identify problematic objectives (those with expensive-to-reduce risks)
- Gain insight into risks (reduction of, remaining) & mitigations (purpose)

Appropriate for software itself? Encompass both software structure and unreliability of development

Message to Remember – Risk-informed Decision Making!

What do you want? **What can get in the way?** **What can you do about it?**

- 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

Backup slides

DDP Sensitivity Analysis

1) Menzies' technique showed optimal solution robust

2) Vary effect values one by one, recompute requirements attainment, tabulate results:

Change	% Change	PACT	Failure Mode
-2.02	0.76	Select/make laser	Insufficient power
-0.834	0.314	CCD Qualification	CCD degredation
-0.6	0.226	System Study	Other technologies are better
-0.329	0.124	Hermetic packaging	non-Hermetic
-0.246	0.0926	Fibre qualification	Fibre degredation

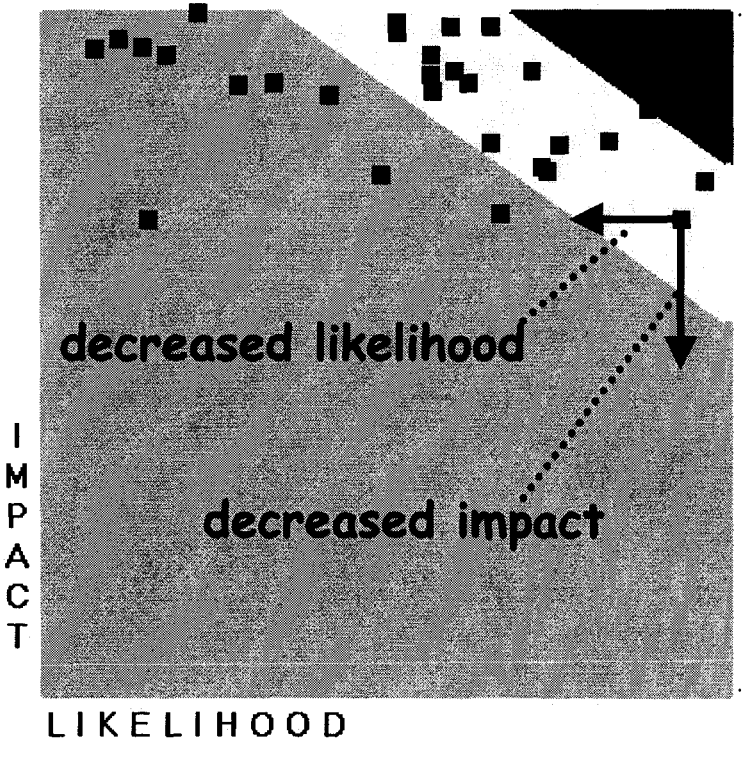
3) Use results for relative decision making, *not* as absolute measures of reliability.
Having identified areas of critical concern, apply other techniques (e.g., probabilistic risk assessment).

DDP Risk Model – Refinements (1)
Mitigation Subtypes

Preventions: decrease likelihood of risk arising (e.g., training; coding conventions)

Alleviations: decrease impact (severity) of risk if it occurs (e.g., defensive programming)

Detections: identify risks prior to use (e.g., testing, analysis), leading to repair of risks so detected; net result: decreased likelihood of risk remaining.
Repair cost =
risk's unit repair cost x
decrease in risk's likelihood



DDP - Defect Detection and Prevention

DDP Risk Model – Refinements (2)
Time phases

Mitigations grouped into user-defined **phases**

E.g., requirements, designing, coding, unit testing, integration testing …

or

"DBAT" (hardware) Design, Build, Assemble, Test

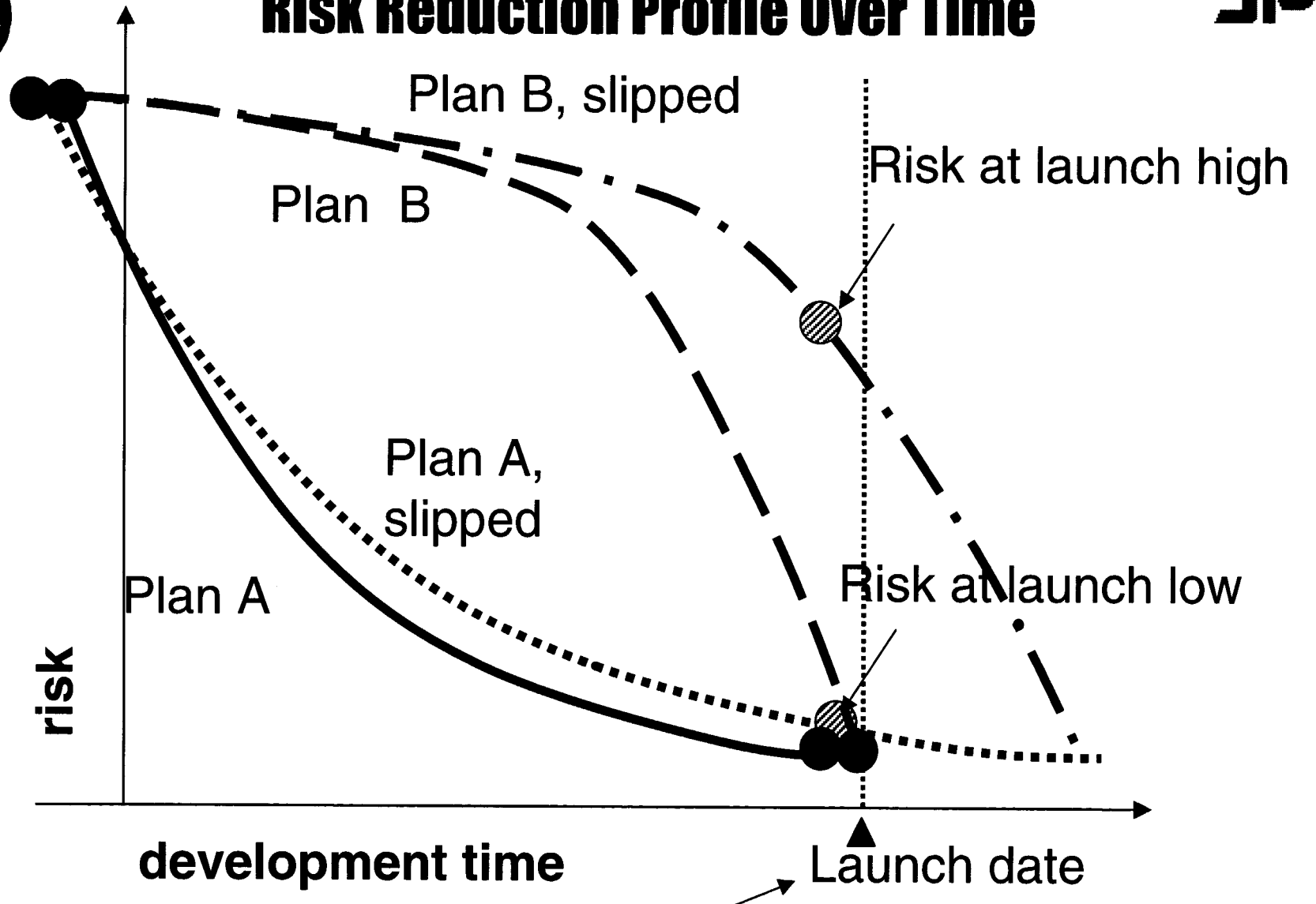
or

Pre-phase A, Phase A, Phase B, … (JPL s/c development terms)

Uses:

- Incorporate budget constraints on per-phase expenditure
- Capture cost-of-repair escalation in later phases (1:10:100…)
- Insight into risk profile over time

Risk Reduction Profile Over Time



For terrestrial software, think "release date"!

DDP Risk Model – Refinements (3) Induced/Aggravated Risks

Mitigation that make risks *worse*

- hardware shake test breaks something else
- software bugfix introduces new bugs
- turning on/off array bound checking changes timing
- adoption of design element introduces design-specific risks

Mitigation **induces** risk by extent e ($-1 \leq e < 0$)

Risk likelihood before = L

Risk likelihood after = $(1 - (1-L)(1+e))$

E.g., e = -0.9, Likelihood after = $(1 - (1-L)*0.1)) = 1 - .1 + .1L = .9 + .1L$

Mitigation **aggravates** risk by extent e ($e < -1$)

Risk impact before = I

Risk impact after = $I*(-e)$

E.g., e = -3, Risk impact after = $I*3$