

**ADVANCED PROGRAMMATIC RISK ANALYSIS:**

**NASA'S FASTER-BETTER-CHEAPER  
MISSIONS AND PROGRAMS**

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**A STUDY FOR THE JET PROPULSION LABORATORY  
1997-2000**

## **OBJECTIVES OF THE STUDY**

- Search for successful management factors in recent “faster-better-cheaper” missions
- Recommend improvements for continued success leveraging lessons learned
- Develop an analytical tool to support managers’ decisions
- Determine how to effectively manage risk under resource constraints

## **PRESENTATION OUTLINE**

- Key learnings from recent NASA/JPL case studies
- Advanced programmatic risk analysis model and tool

## **MISSIONS**

- Cassini (flagship mission: the base case)
- Mars pathfinder
- Mars global surveyor
- Deep space 1

# STRATEGIES IMPLEMENTED TO ACCOMPLISH “FASTER-BETTER-CHEAPER” PROJECTS

## Key Learnings

- Short-term success factors experienced while managing the challenges of implementing new strategies

## Long-Term Considerations

- Enablers for assuring long-term successful implementation of “faster-better-cheaper” strategies

# **STRICTER CONSTRAINTS ON SCHEDULE AND BUDGETS**

## Key Learnings

- Break questionable habits

## Long-Term Considerations

- Set appropriate constraints and watch for short cuts

# FLAT MANAGEMENT STRUCTURE

## Key Learnings

- Decision power is given to people close to the basic expertise

## Long-Term Considerations

- Make sure that those who have the relevant technical expertise also have the big picture

# STREAMLINED PROPOSAL PROCESS

## Key Learnings

- Brings participants on board earlier

## Long-Term Considerations

- Make sure there is time for truly innovative ideas
- Evaluate proposals through consistent multi-attribute criteria

# CONTINGENCY PLANNING REQUIRING APPROPRIATE SYSTEM INTERFACES

## Key Learnings

- Plan for possible de-scoping and fall back positions

## Long-Term Considerations

- Consider the consequences of fall back positions on related projects

# **SIMPLIFIED REVIEW PROCESS FOR EARLY DETECTION OF POTENTIAL PROBLEMS**

## Key Learnings

- Numerous peer reviews have worked

## Long-Term Considerations

- Keep a mix of peer and formal reviews

# **ASSURE ADEQUATE RESERVES AND FRONT-LOADED FUNDING PROFILE**

## Key Learnings

- “F-B-C” may need to “jump start” the project to finish on time

## Long-Term Considerations

- Don't spend too much money defining the project

## SUMMARY

Common issues evidenced in the management of organizational strategies include the need to manage:

- Tradeoffs between “management risks” and “technical failure risks”
- Risks associated with the inter-dependencies of projects within programs

# CURRENT RISK ANALYSIS TECHNIQUES

## Technical Failure Risks

- PRA and other qualitative models
  - Evaluate the technical risks
  - Support design decisions to minimize probability of technical failure

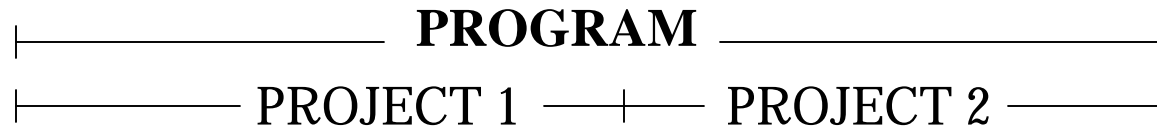
## Management Risks

- Monte Carlo Simulations with WBS or PERT networks
  - Correct unrealistic cost or schedule estimates
  - Limitation: Do not link cost, schedule, and technical risk

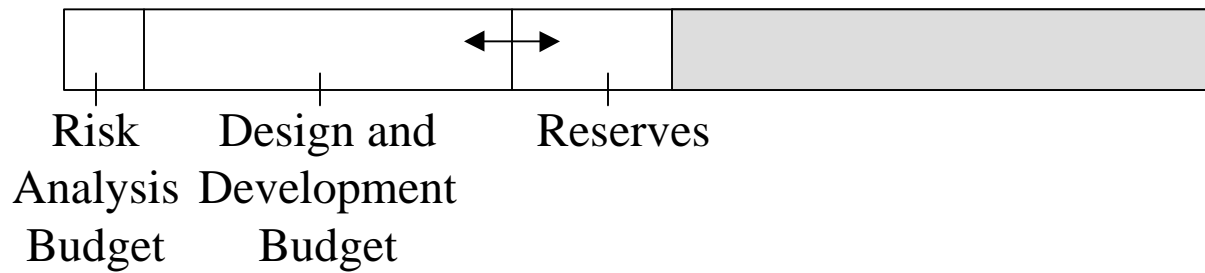
# ANALYTICAL TOOL FOR ADVANCED PROGRAMMATIC RISK ANALYSIS

## *Features*

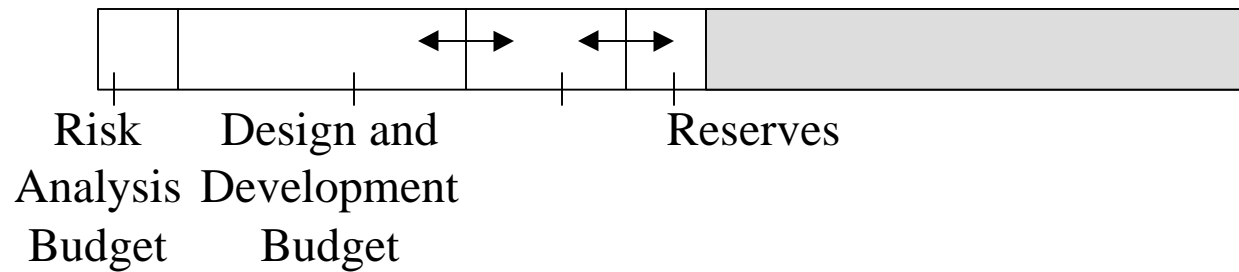
- Facilitates tradeoffs between the Technical Failure and Management Risks
- Considers the effects of inter-dependencies among projects in the program
- Provides improved:
  - Physical system design process
  - Management of budgeted resources
  - Information for making management decisions



**CASE 1- RESERVES VS. DEVELOPMENT**

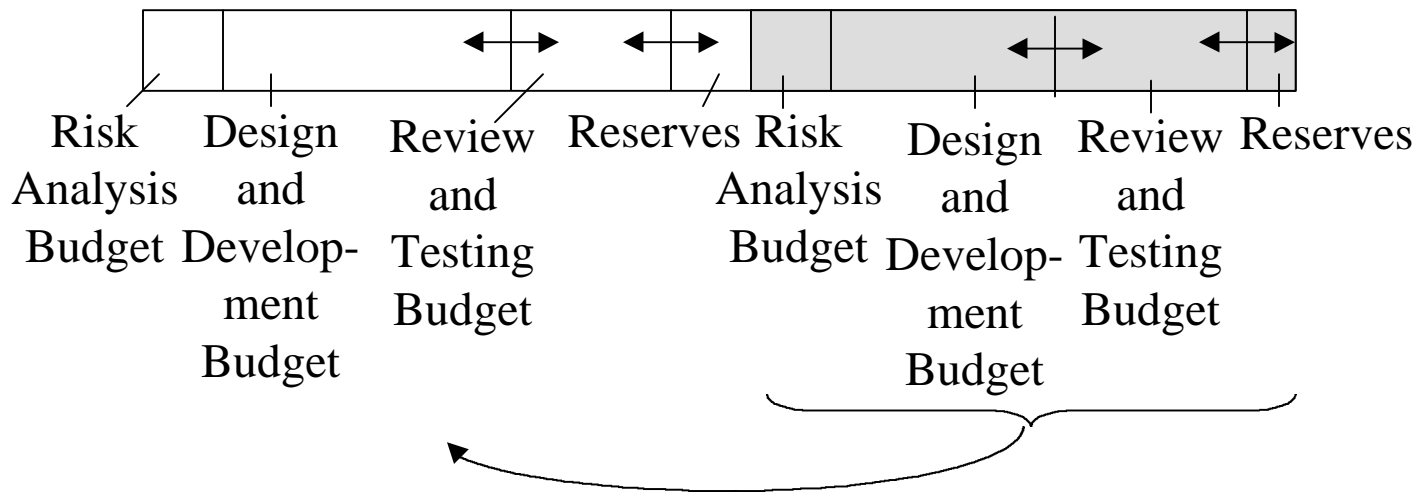


**CASE 2- WITH “WARNING SYSTEM”**



**CASE 3 = CASE 2 WITH PARTIAL TECHNICAL  
AND PARTIAL MANAGEMENT FAILURES**

**CASE 4- DEPENDENT PROJECTS IN A PROGRAM**



# **ADVANCED PROGRAMMATIC RISK ANALYSIS MODEL**

- Identify Possible Design Configurations
- Find Minimum Cost Design and Residual Budget For Each Configuration
- Optimize the Allocation of Residual Budget Between:
  - Reinforcing the minimum design
  - Reserves
- Determine the Optimal Project Budget Allocation

## **CASE 1: ILLUSTRATION**

Mission: Orbiter With Two Instruments

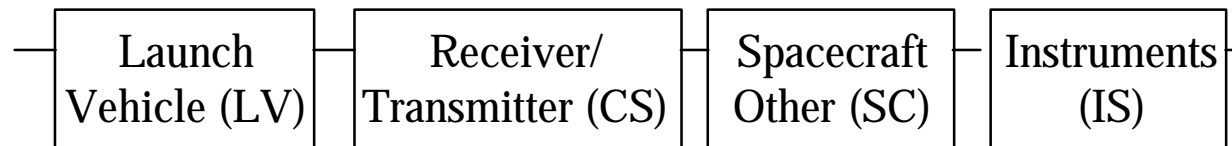
1. A Gamma Ray Spectrometer
2. A Camera

Total Budget: \$150 Million (Including Launch Vehicle)

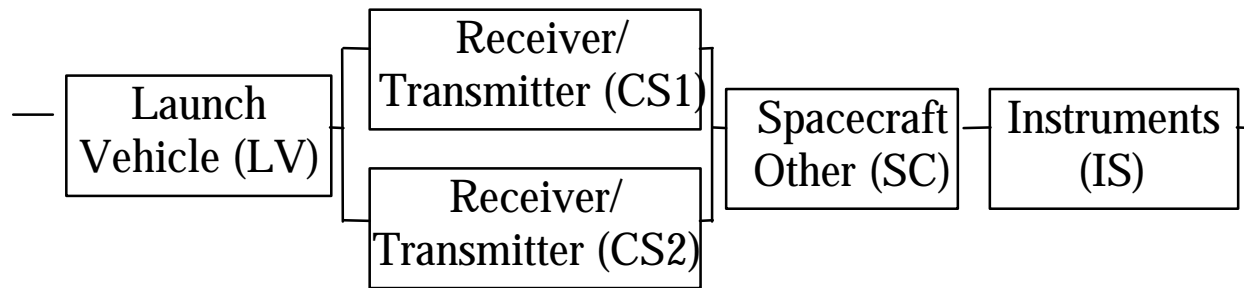
Total Schedule: 3 Years

# IDENTIFY POSSIBLE DESIGN CONFIGURATIONS

- Identify the technical functions of the project and the functional configurations available.



CONFIGURATION 1, Single-string design



CONFIGURATION 2, Design with partial redundancy

## **FIND THE MINIMUM COST DESIGN AND RESIDUAL BUDGET**

Configuration 1, Single-string design

Least Costly Design = \$124 million

Residual Budget = \$25 million\*

Configuration 2, Designed with partial redundancy

Least Costly Design = \$129 million

Residual Budget = \$20 million\*

\*Assumes \$1 million for risk analysis

## **OPTIMIZE THE ALLOCATION OF THE RESIDUAL BUDGET**

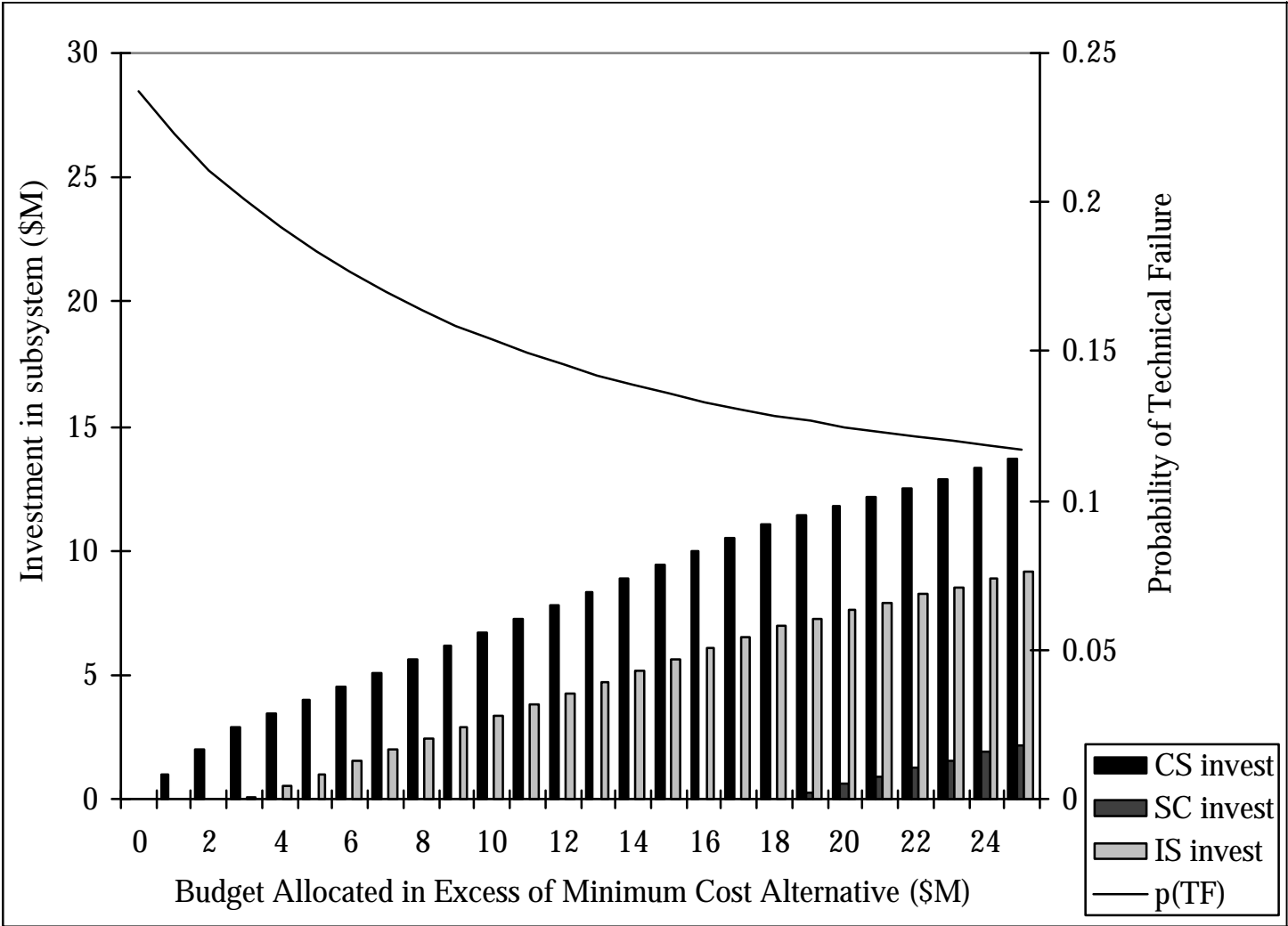
Use a PRA model and the Karush-Kuhn-Tucker (KKT) algorithm to optimize design alternative based on:

- Probability of system failure as a function of component failures
- Available budget
- Effects of investments in a subsystem on reducing the probability of system failure

## INVESTMENTS IN IMPROVEMENTS ABOVE THE ‘MINIMUM’

- Assuming that the reduction of  $p(\text{component failure})$  as a function of investment is exponential, then:
  - If  $p(\text{instrument failure})$  for the cheapest components is 0.05
  - And an additional investment of \$10 million is required to reduce  $p(\text{instrument failure})$  by a factor of 10
  - Then,  $p(\text{instrument failure}) = 0.05 \times \text{EXP}[-0.23 \times \text{investment}]$
- KKT optimization is used to minimize  $p(\text{system failure})$  subject to the residual budget constraint

# VARIOUS INVESTMENT ALLOCATIONS AMONG SUBSYSTEMS FOR CONFIGURATION 1



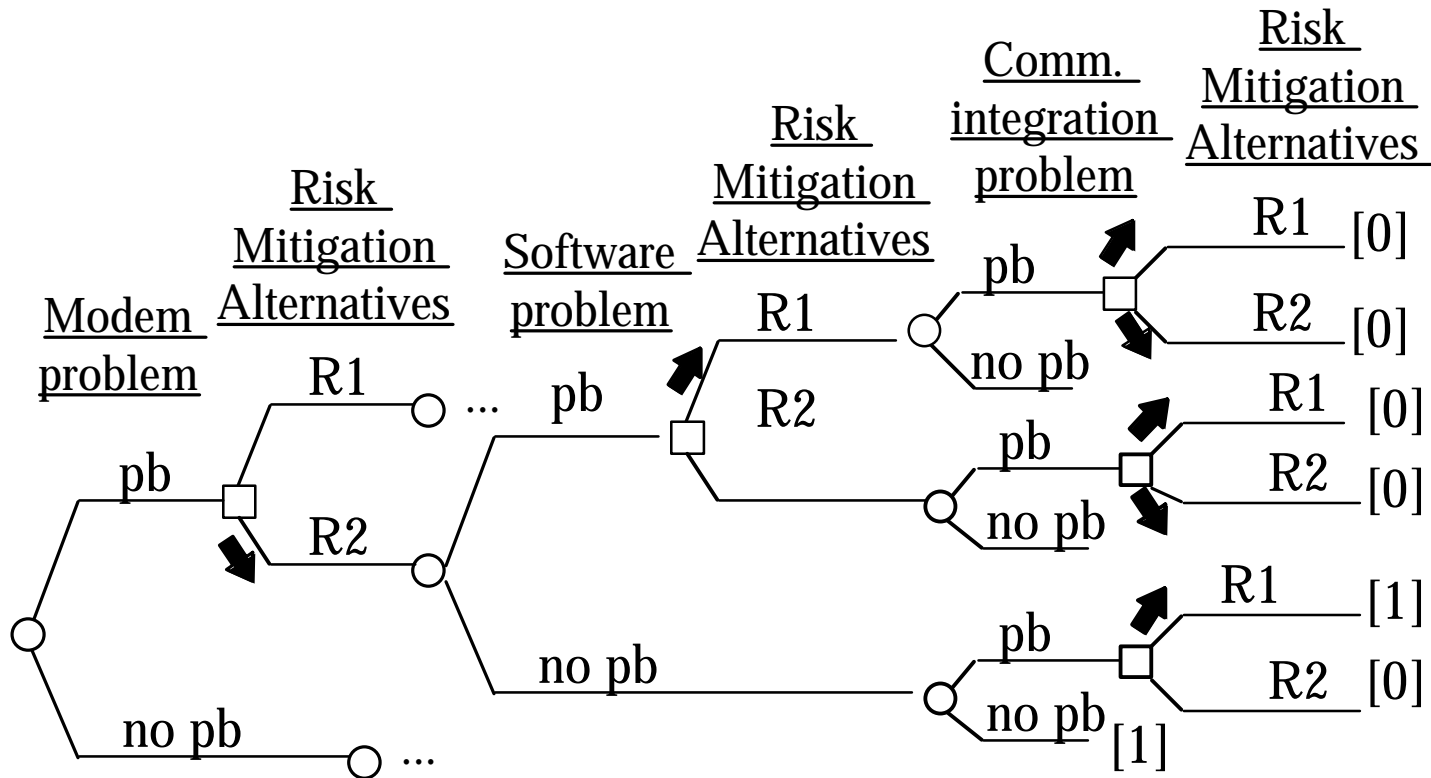
## **DEVELOP MANAGEMENT RISK STRATEGIES**

- For each technical design alternative, identify potential management problems and mitigation responses.
- Construct decision trees of problems and responses.
  - Outcome is [1] if the scenario does not exceed the cost and schedule reserves.
  - Outcome is [0] if the scenario does exceed reserves.
- Resolve the decision tree to determine the probability of management failure conditional on the level of reserves.

## MANAGEMENT RISK DATA FOR CONFIGURATION 1

Potential Problems (Risks) conditional on technical design	Prob.	Mit. Alt. 1 (Solve with \$)	Mit. Alt. 2		Other Mit. Alt.
			(Cost)	(Sch.)	
modem procurement problem	0.4	\$5 M	\$3 M	1 mo.	n.a.
software development pb.	0.2	\$5 M	\$3 M	1 mo.	simplify software
communications integration pb.	0.3	\$3 M	\$2 M	0.5 mo.	n.a.
insufficient test personnel	0.5	\$3 M	\$1.5 M	1 mo.	reduce testing
late instrument delivery	0.2	\$3 M	\$1.5 M	1 mo.	substitute instrument
instrument power problems	0.1	\$3 M	\$1.5 M	1 mo.	n.a.
spacecraft mass problems	0.1	\$3 M	\$2 M	1 mo.	n.a.
Unknown problems	0.5	\$5 M	\$3 M	1 mo.	n.a.

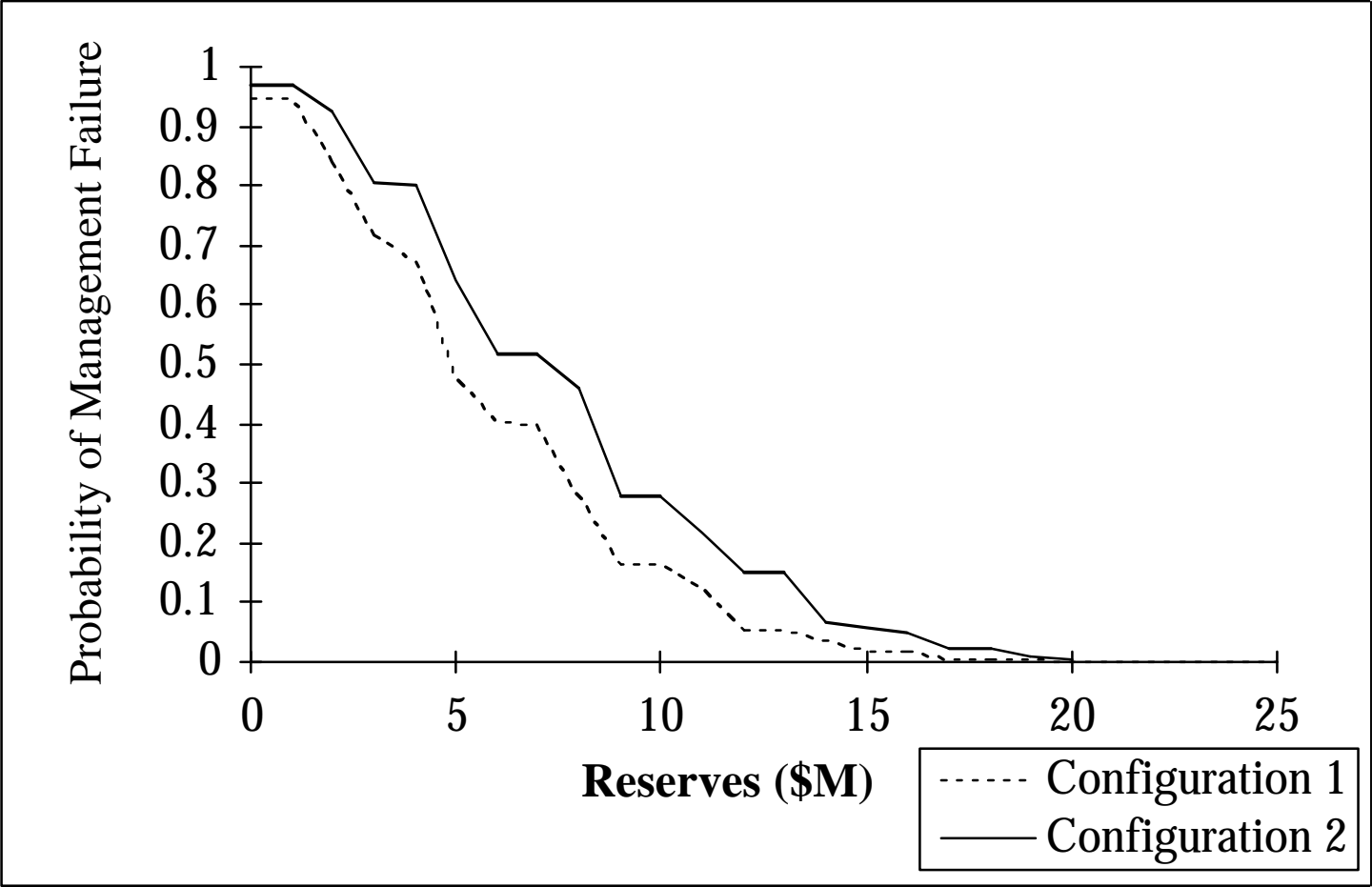
# PORTION OF THE DECISION TREE FOR CONFIGURATION 1



- Outcomes:
- [1] No Management Failure
  - [0] Exceeds Budget or Schedule or Both (MF)

Assumes all problems are detected and corrected, and that there are no false positives.

# PROBABILITY OF MANAGEMENT FAILURE CONDITIONAL ON THE LEVEL OF BUDGET RESERVES



# DETERMINE THE OPTIMAL BUDGET ALLOCATION

## Results For Configuration 1 (Single-String)

Total Available Budget = \$150M, C(TF) = \$150M, C(MF) = \$150 M

Development (M)	p(TF)	Reserves (M)	p(MF)	EV(COST OF FAILURE) (\$M)
\$150	0.12	\$0	0.95	143.4
\$145	0.13	\$5	0.48	82.1
\$140	0.14	\$10	0.16	41.6
\$136	0.15	\$14	0.03	26.3
<b>\$135</b>	<b>0.15</b>	<b>\$15</b>	<b>0.02</b>	<b>25.1</b> ← $x_1^*$
\$134	0.16	\$16	0.02	26.5
\$133	0.16	\$17	0.01	25.3
\$132	0.17	\$18	0.00	25.5
\$131	0.18	\$19	0.00	27.0
\$130	0.18	\$20	0.00	27.0
\$125	0.24	\$25	0.00	36.0

# DETERMINE THE OPTIMAL BUDGET ALLOCATION

## Results For Configuration 2 (Partially Redundant)

Total Available Budget = \$150M, C(TF) = \$150M, C(MF) = \$150 M

Development (M)	p(TF)	Reserves (M)	p(MF)	EV(COST OF FAILURE) (\$M)
\$150	0.11	\$0	0.97	146.0
\$145	0.12	\$5	0.64	102.5
\$140	0.12	\$10	0.28	55.0
\$135	0.13	\$15	0.06	27.3
\$134	0.14	\$16	0.05	27.5
<b>\$133</b>	<b>0.14</b>	<b>\$17</b>	<b>0.02</b>	<b>23.6</b> ← $x_2^*$
\$132	0.15	\$18	0.02	25.1
\$131	0.15	\$19	0.01	23.8
\$130	0.16	\$20	0.00	24.0

# SUMMARY OF OPTIMIZATION ALGORITHM

## STEP 1:

Identify functional configurations.

Identify for each configuration the lowest cost design (cheapest components).

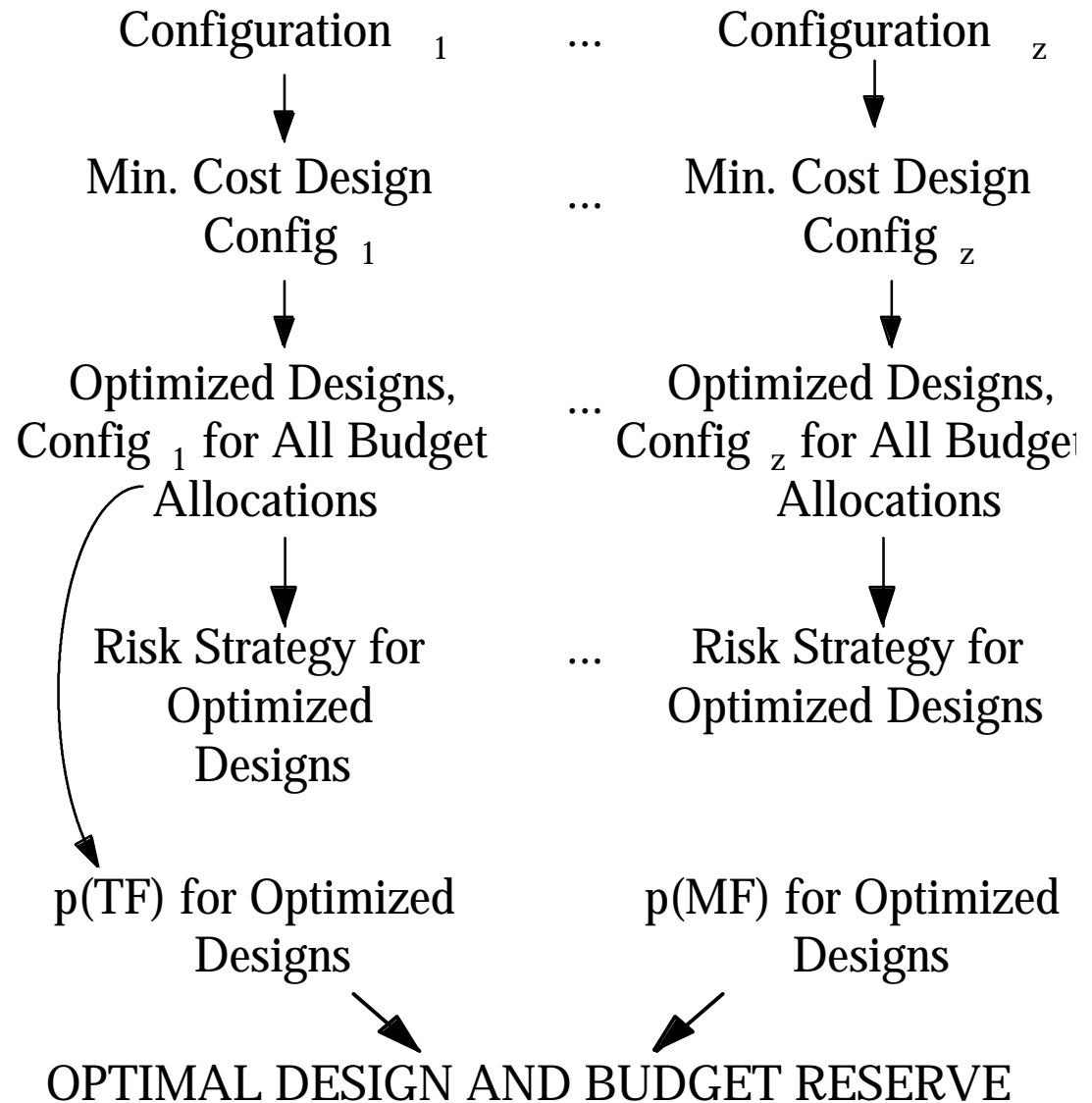
Optimize design for each configuration and budget allocation (KKT algorithm).

## STEP 2:

Optimize mitigation strategy for each configuration, optimal choice of components, development problem scenario, and reserve allocation (decision trees).

## STEP 3:

Select optimal design to minimize expected cost of failure states.



# FRAMEWORK SUPPORTS FURTHER ANALYSIS

- Shadow costs of constraints
- Optimal level of review and testing (“warning system”)
- Partial failures
- Dependencies among projects

# IMPLEMENTATION - MODULES OF THE DECISION SUPPORT SYSTEM

## PRA module

### Inputs:

- Functional block diagram/fault tree for projects
- $p(\text{failure modes})$  for least costly design
- Relationships between  $p(\text{FM})$  and reinforcement investments

### Outputs:

- $p(\text{TF})$  as a function of subsystem design and investment

## KKT/Optimization module

### Inputs:

- $p(\text{TF})$  as a function of subsystem design and investment

### Outputs:

- Minimum  $p(\text{TF})$  for each design alternative and budget allocation given the optimal investment in each component

# MODULES OF THE DECISION SUPPORT SYSTEM

## Decision trees for the management of problems

### Inputs

- Potential problems and mitigation actions for each alternative
- Probability of problem detection

### Outputs

- $p(\text{MF})$  for each design alternative and level of reserves

## Selection module

### Inputs

- $p(\text{TF})$  for each possible alternative and budget allocation
- $p(\text{MF})$  for each possible alternative and level of reserves

### Outputs

- Optimal design alternative and associated level of budget reserve

## CONCLUSIONS

When resources are constrained:

- Technical Failure and Management Risks increase
- Adapted Management Practices are needed (e.g., flat management structure, simplified review processes, etc.)
- Inter-dependencies among projects must be explicitly considered
- Tradeoffs between management risks and technical failure risks must be considered

## **TECHNOLOGY RECOMMENDATIONS**

- Continue to invest research and development resources in new technologies
- Target and retain core expertise
- Ensure that all reviews and tests add value

## **MANAGEMENT RECOMMENDATIONS**

- Manage project staffing to capture the experience of previous projects and avoid employee “burnout”
- Be aware of the overhead burdens placed on small projects
- Provide project funding up-front (to resolve technical uncertainties early)
- Design the project plan and stick to it
- Use available analytical tools to optimize systems budgets and reserves

## **FUTURE RESEARCH DIRECTIONS**

- Implementation of model for a set of projects from the Mars Sample Return mission
- Application of model to other industries