Achieving a Risk-informed Decision-making Environment at NASA:
The Emphasis of NASA’s Risk Management Policy

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Background

- Approved December 16, 2008, NPR 8000.4A, Agency Risk Management Procedural Requirements, evolves NASA’s risk management (RM) approach to entail two complementary processes:

  - **Risk-informed Decision Making (RIDM)**
    - To risk-inform direction-setting decisions (alternative selection)
    - To risk-inform the development of credible performance requirements as part of the overall systems engineering process

  - **Continuous Risk Management (CRM)**
    - To manage risk associated with the implementation of baseline performance requirements

\[ \text{RM} \equiv \text{RIDM} + \text{CRM} \]
Approved January 15, 2009, NASA NPD 1000.5, Policy for NASA Acquisition, states:

“It is NASA policy to incorporate in the overall Agency risk management strategy a risk-informed acquisition process that includes the identification, analysis, and management of programmatic, infrastructure, technical, environmental, safety, cost, schedule, management, industry, and external policy risks that might jeopardize the success with which the Agency executes its acquisition strategies.”

NPD 1000.5 defines “Acquisition” very broadly: “the process for obtaining the systems, research, services, construction, and supplies that the Agency needs to fulfill its mission. Acquisition—which may include procurement (contracting for products and services)—begins with an idea or proposal that aligns with the NASA Strategic Plan and fulfills an identified need and ends with the completion of the program or project or the final disposition of the product or service.”
Motivating Factors

- To promote a RM approach that is heuristic, proactive, and coherent across the Agency
  - Agency strategic goals explicitly drive RM activities at all levels
  - All risk types and their interactions are considered collectively during decision-making
  - Focusing on "forest-level" risk picture, from which the tree-level "individual risks" should be derived and within the context of which the "tree-level" risks are prioritized and managed
  - RM activities are coordinated horizontally and vertically across the Agency

- To better match the stakeholder expectations and the "true" resources required to address the risks to achieve those expectations
  - To have an integrated perspective of risks when analyzing competing alternatives
  - To better comprehend the risk that a decision-maker is accepting when making commitments to stakeholders
  - To have a consistent basis for comparing alternatives

- To risk-inform the development of credible performance requirement
What is RIDM and When is it Invoked?

- A risk-informed decision-making process that uses a diverse set of performance measures (some of which are model-based risk metrics) along with other considerations within a deliberative process to inform decision making. Paragraph A.14 of NASA NPR 8000.4A
  - Within RIDM, decisions are informed by an integrated risk perspective rather than being informed by a set of individual "risk" contributions whose cumulative significance is not understood
  - A decision-making process relying primarily on a narrow set of model-based risk metrics would be considered "risk-based"
- RIDM is invoked for key decisions such as architecture and design decisions, make-buy decisions, and budget reallocation (allocation of reserves), which typically involve requirements-setting or rebaselining of requirements
The RIDM Process
Based on NPR 8000.4A

- Identification of decision alternatives (*decision context*) and considering a sufficient number and diversity of Performance Measures

- *Risk analysis* of decision alternatives (uncertainty analysis of performance associated with the alternative)

- *Deliberation and Selection* of a decision alternative *informed by* (not solely based on) Risk Analysis Results
The Continuous Risk Management (CRM) Process

CRM is conducted in the context of performance requirements

Steps in the CRM Process

Identify
- Identify Risk Contributors (Shortfall in Performance Relative to Baseline Performance Requirements)

Analyze
- Estimate Likelihood and Consequence Components of the Risk Through Analysis (Including Uncertainty Evaluation), Estimate Aggregate Risks if Possible

Plan
- Decide on Risk Disposition and Handling, Develop and Execute Mitigation Plans: Decide What Will be Tracked

Track
- Track Observations Relating to Performance Measures (e.g., performance data, schedule variances, etc.)

Control
- Control Risk by Evaluating Tracking Data to Verify Effectiveness of Mitigation Plans: Make Adjustment to the Plans, and Execute Control Measures

CRM Feedback
RM = RIDM + CRM

- RIDM and CRM operate at each level of the NASA hierarchy, with interfaces for the flowdown of requirements, the elevation of risk management decisions, and the communication of risk information.
Performance Measures, Performance Objectives, and Performance Requirements

- **A Performance Measure (PM) is a metric used to quantify the extent to which a Performance Objective is fulfilled**
  - **Safety** (e.g., avoidance of injury, fatality, or destruction of key assets)
    - Maintain Astronaut Safety $\rightarrow$ Probability of Loss of Crew ($P(LOC)$)
  - **Technical** (e.g., increase thrust or output, maximize amount of observational data acquired)
    - Maximize Payload Capability $\rightarrow$ Payload Capability (kg)
  - **Cost** (e.g., execution within minimum cost)
    - Minimize Cost $\rightarrow$ Cost ($\$\$)
  - **Schedule** (e.g., meeting milestones)
    - Minimize completion time $\rightarrow$ Schedule (months)

- **The PM values imputed to the selected alternative are Performance Requirements**
  - They essentially define “success”
  - Significant shortfalls in performance are “failures”
Definition of Risk According to NPR 8000.4A

- In general, risk is uncertainty regarding the future outcome of an undertaking of some kind, e.g., a decision alternative, a project, a launch, etc.

- In the context of mission execution, risk is the expression of the potential for performance shortfalls, which may be realized in the future, with respect to achieving explicitly established and stated performance requirements.
  - The performance shortfalls may be related to any one or more of the following mission execution domains:
    - Safety
    - Technical performance
    - Cost
    - Schedule
Risk-Informed Decision Making (RIDM)

Part 1 - Identification of Alternatives
Step 1 – Understand Stakeholder Expectations and Derive Performance Measures
Step 2 – Compile Feasible Alternatives

Part 2 - Risk Analysis of Alternatives
Step 3 – Set the Framework and Choose the Analysis Methodologies
Step 4 – Conduct the Risk Analysis and Document the Results

Part 3 - Risk-Informed Alternative Selection
Step 5 – Develop Risk-Normalized Performance Commitments
Step 6 – Deliberate, Select an Alternative, and Document the Decision Rationale

To Requirements (Re)Baselining
RIDM Process: Part 1

Part 1 – Identification of Alternatives

Begin RIDM Process

Step 1 - Understand Stakeholder Expectations and Derive Performance Measures
- Identify stakeholders and get input
- Negotiate flowed-down requirements
- Define top-level objectives
- Develop top-level boundaries and milestones
- Construct objectives hierarchy
- Derive performance objectives from top-level objectives
- Develop performance measures and imposed constraints

Step 2 - Compile Feasible Alternatives
- Get stakeholder input
- Construct trade tree of candidate alternatives
- Perform preliminary evaluation
- Prune infeasible alternatives

Output of Part 1
- Feasible alternatives
- Performance measures
- Imposed constraints
Derive Performance Measures from Objectives

- In general, it can be difficult to assess decision alternatives against multifaceted and/or qualitative top-level objectives.

- To deal with this situation, objectives are decomposed, using an objectives hierarchy (OH), into a set of lower-level performance objectives that any attractive alternative should have.
Derive Performance Measures from Objectives (cont.)

- A performance measure is then developed for each performance objective, as the quantity that measures the extent to which a decision alternative meets the performance objective.

- Some performance measures may have imposed constraints
  - Example: A hard limit on minimum acceptable payload capability.

- Some performance measures are unconstrained but have a desirable direction of goodness.
Compiling Alternatives

- Alternative design solutions are generated as part of the Systems Engineering process.

- Low-fidelity feasibility assessment (e.g., first-order analysis, engineering judgment) is used to prune the trade tree and narrow the set of alternatives to analyze further.
RIDM Process: Part 2

Part 2 - Risk Analysis of Alternatives

From Part 1
- Feasible alternatives
- Performance measures
- Imposed constraints

Technical Basis for Deliberation

Step 4 – Conduct the Risk Analysis and Document the Results
- Implement a graded approach to analysis
- Construct scenarios and identify uncertainties
- Quantify performance measures probabilistically
- Perform sensitivity studies
- Downselect alternatives for additional analysis
- Develop the Technical Basis for Deliberation

Step 3 – Set the Framework and Choose the Analysis Methodologies
- Structure the multidisciplinary analysis process for each alternative
- Determine each alternative's performance parameters
- Maintain configuration control
Risk Analysis of Alternatives

• The goal is to develop a risk analysis framework that integrates domain-specific performance assessments and quantifies the performance measures
  
  - **Risk Analysis** - probabilistic modeling of performance

• The challenge is to establish a transparent framework that:
  
  - Operates on a common set of performance parameters for each alternative
  - Consistently addresses uncertainties across mission execution domains and across alternatives
  - Preserves correlations between performance measures
Setting Risk Analysis Framework

- Setting the risk analysis framework (alternative specific)
RIDM Process: Part 3

Part 3 - Risk-Informed Alternative Selection

**From Part 2**
- Technical Basis for Deliberation (TBfD)

**Risk-Informed Selection Report**

**Step 5 – Develop Risk-Normalized Performance Commitments**
- Establish risk tolerances on performance measures
- Establish performance measure ordering
- Determine performance commitment values

**Step 6 – Deliberate, Select an Alternative, and Document the Decision Rationale**
- Deliberate pros and cons of each alternative and associated performance commitments
- Identify contending alternatives (downselection)
- Select an alternative
- Finalize the performance commitments
- Document decision rationale

**Additional Risk Analysis, Information Gathering, Performance Commitment Revision, as Needed**

*To be defined in formal project management documentation.*
**Performance Commitment**

- A *Performance Commitment* is the level of performance whose probability of not being achieved matches the decision maker’s risk tolerance
  - Anchors the commitment the decision maker (DM) is willing to make for that performance measure

- Allow comparisons of decision alternatives in terms of performance capability at the specified risk tolerances of each performance measure

- Serve as the starting point for requirements development, so that a linkage exists between the selected alternative, the risk tolerance of the decision-maker, and the requirements that define the objective to be accomplished
Develop Risk-Normalized Performance Commitments

Performance commitments are set at performance measure values that correspond to given risk tolerances.

Risk tolerances given by the shaded areas under the pdfs, on the "bad" side of the performance commitments.

Alternative A
- Performance Measure: \( PC_{A1} \)
- Payload Capability
- Imposed Constraint

Alternative B
- Performance Measure: \( PC_{B1} \)
- Reliability

Alternative C
- Performance Measure: \( PC_{C1} \)
- Cost & Schedule

Performance Measures*

Notional Risk Tolerances: 
- High
- Moderate
- Low

* These are arbitrary, notional choices
Initialization of the CRM Process

- RIDM represents an initial identification and assessment of risk significant uncertainties, and the scenarios modeled in the risk analysis imply initial strategies for managing off nominal conditions.
- This information is available to the CRM process to initialize its Identify, Analyze, and Plan activities.
Need for Rebaselining of Requirements

- A newly identified risk issue for which no mitigation is available within the scope of the current requirements; or
- An emerging inability to control a previously identified risk issue.
Interaction of RIDM & CRM

Agency ➔ Strategic Goals ➔

Mission Directorates (Level 1)

Decomposition of Objectives into Imposed Constraints and Performance Measures

Program Level (Level 2)

Project Level (Level 3)

Subsystem Level (Level 5)

RIDM ARCHITECTURE ALTERNATIVES ➔ PROGRAM REQUIREMENTS
(Negotiated in light of Performance Commitments)

Reassess Alternatives if rebaselining is necessary

RIDM SYSTEM ALTERNATIVES ➔ PROJECT REQUIREMENTS
(Negotiated in light of Performance Commitments)

CRM

Risks To Reqs.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>CRM</td>
<td>Continuous Risk Management</td>
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<tr>
<td>DM</td>
<td>Decision Maker</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
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<tr>
<td>P(LOC)</td>
<td>Probability of Loss of Crew</td>
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<td>pdf</td>
<td>Probability Density Function</td>
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<tr>
<td>PM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Performance Measure i</td>
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<tr>
<td>PRA</td>
<td>Probabilistic Risk Assessment</td>
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<td>RIDM</td>
<td>Risk-Informed Decision Making</td>
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<td>RISR</td>
<td>Risk-Informed Selection Report</td>
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<td>RM</td>
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<tr>
<td>MO</td>
<td>Means Objectives</td>
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<td>OH</td>
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<td>SP</td>
<td>Special Publication</td>
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<tr>
<td>TBfD</td>
<td>Technical Basis for Decision</td>
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Backups
How is an OH Different from a Means Objectives Network?

**Objectives Hierarchy (OH)**
- Explains what is meant by the higher-level objective
- Partitions the higher-level objective into its constituent parts
- Doesn't impose a solution
- Is structured as a hierarchy

**Means Objectives (MO) Network**
- Shows ways of accomplishing higher-level objectives
- May relate to multiple higher-level objectives
- Implies a solution
- Is structured as a network
Setting Risk Analysis Framework

- Quantification via probabilistic modeling of performance

*Sampling is needed for uncertain performance parameters only
Risk Analysis Methods

- Domain-specific general guidance on applying a graded approach to selection of analysis methodologies as a function of life cycle phase

The RIDM Handbook contains general guidance on methods, with reference to existing domain-specific NASA guidance documents.