# Initiating the 2002 Mars Science Laboratory (MSL) Focused Technology Program

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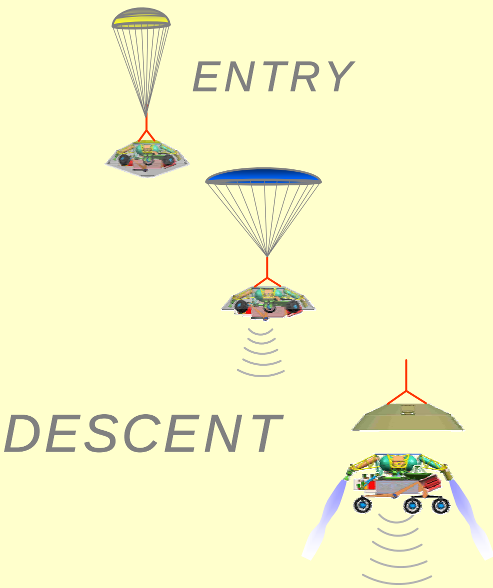
# MSL Focused Technology Status Review



- Introduction
- MSL Technology overview
- 2002 Technology Implementation
  - Technology Definition
  - Technology Selection
  - Technology Management
- Technology Tools
  - Aggregate Project Plan
  - Technology Funnel Chart
  - Decision Analysis Tools
- Conclusion

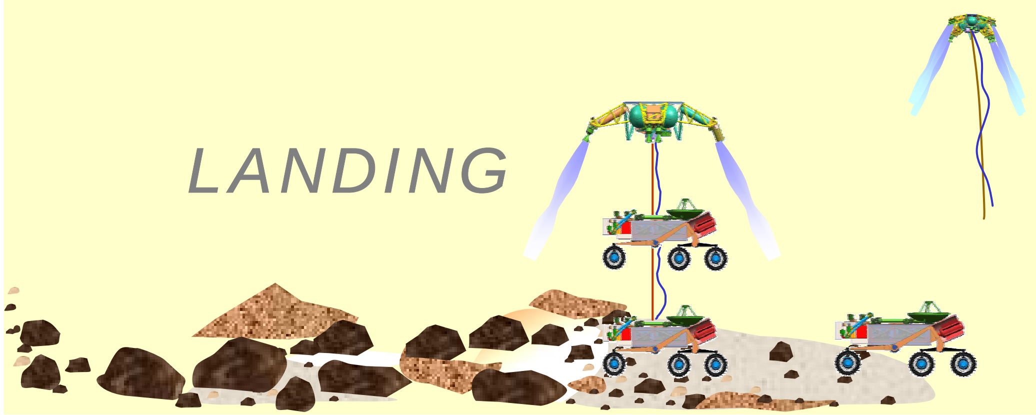
# Next Generation Capabilities for EDL






## EDL

- Guided Entry
- Hazard Detection and Avoidance
- Modified Viking Engine for Descent
- Robust Landing System




## Key Features

- **Precision Guided Entry**
  - Hypersonic Aeromaneuver Guidance
  - Small Landing Error Ellipse (<10km)
- **Autonomous Terminal Descent HDA**
  - Position/Velocity Measurements Using Phased Array Terrain Radar
  - Autonomous Crater Detection and Avoidance
  - Subsonic Chute for Longer Hang Time Needed for Hazard Detection
- **Efficient Touchdown System**
  - Safe Landing of Large Mass using “Skycrane”

# Next Generation Capabilities for Surface Mission

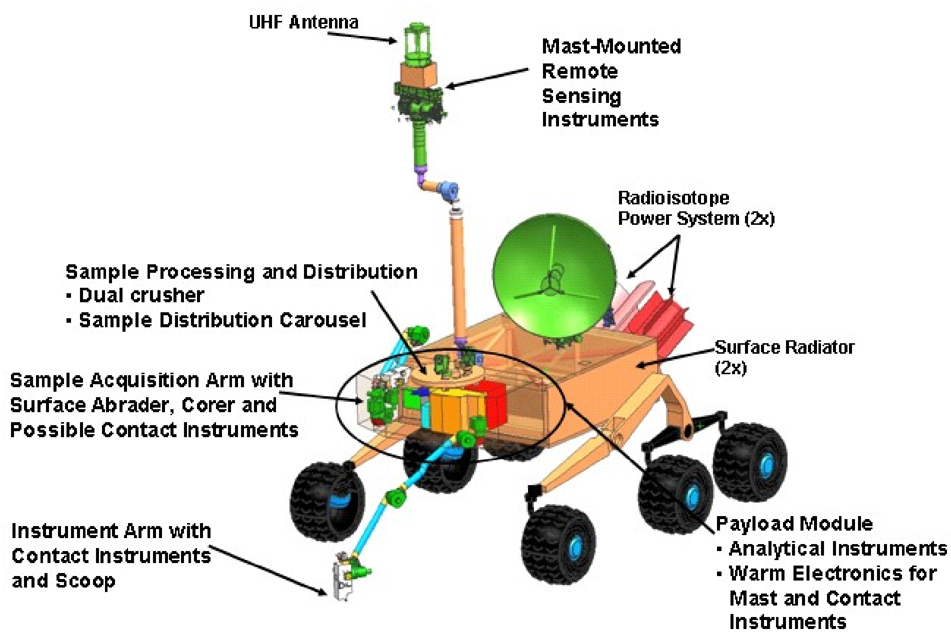


## Key Features

- **Robust Software Architecture**
  - Unified Framework for Flight/Ground Software
  - Reusable Components
  - Infusion of Validated Navigation/Placement/Manipulation Technologies
  - Early Demonstration of Fully-Integrated Software
- **Long-lived Mobility Asset**
  - Electronics and Actuators Designed for 1500 Thermal Cycles
  - Recycling of RTG Waste Heat to Control Electronics Base Temperature using Pumped Fluid Thermal System
  - Potential Technologies to Improve Mission Ops Efficiency
- **Sample Acquisition & Distribution**
  - Two Functional Redundant Arms
  - Rock Crusher and Distribution Mechanisms

## Surface Systems

- **Flight Software Architecture**
- **Navigation & Instrument Placement**
- **Long Life Elect/Mech Systems**
- **Sample Processing & Distribution**



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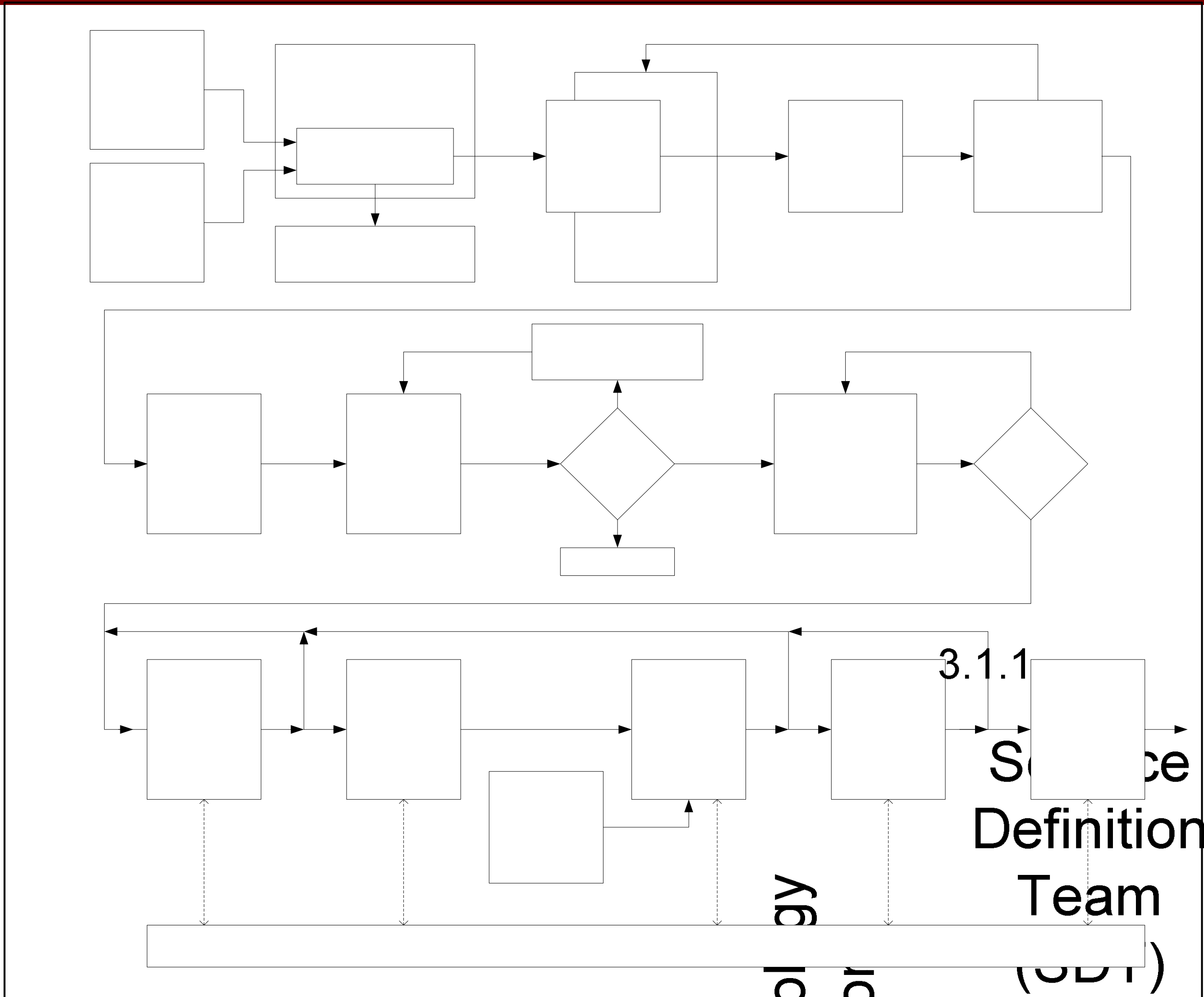
# Technology Program Implementation Flow





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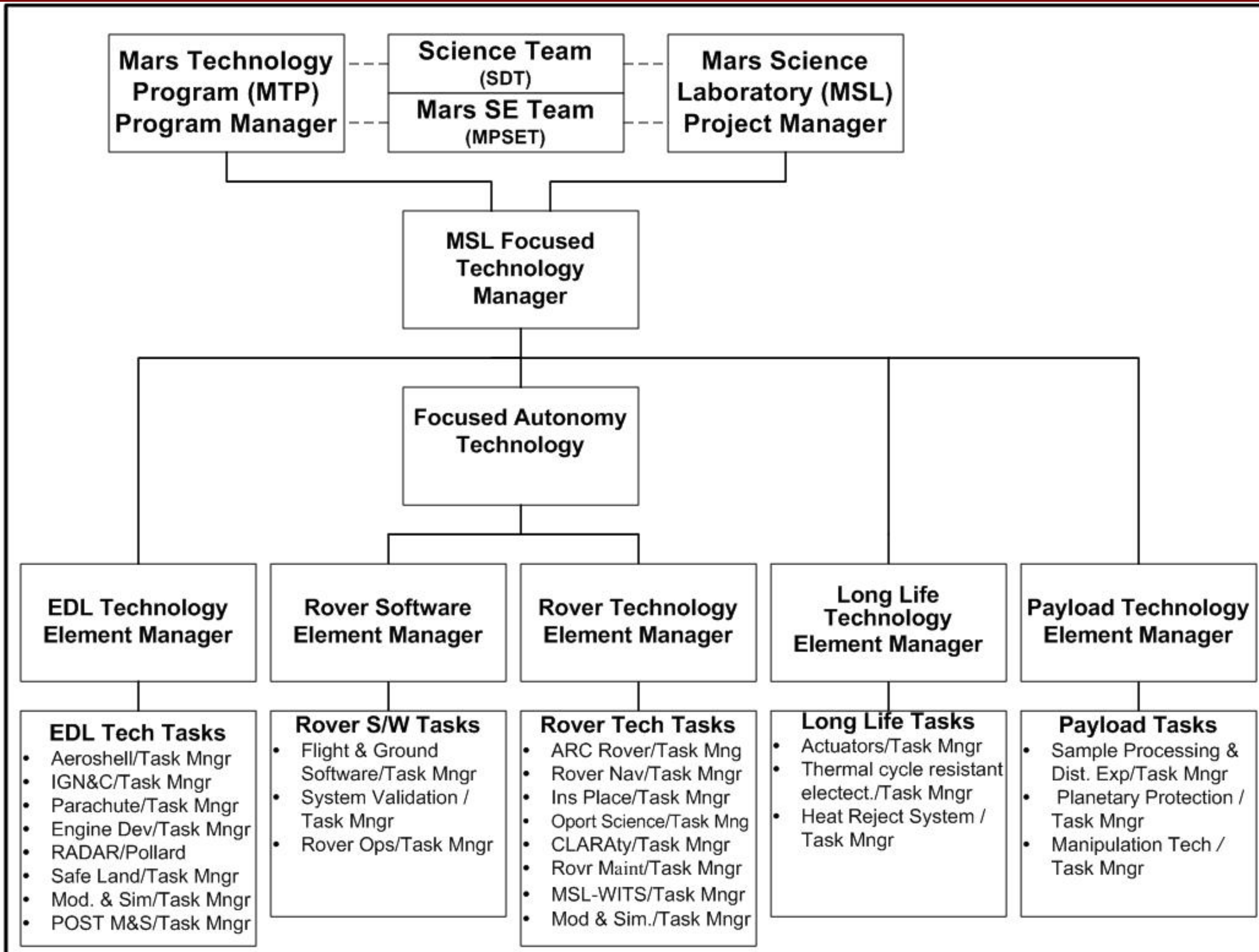
# MSL Focused Technology Org Chart





# Mars Program SE Team (MPSET) Charter



- Composed of senior system engineers chartered by and reporting to the Mars Program Manager. …takes on studies, provide advice, and serve as a review body with the explicit objective of ensuring that the Program is optimized as a whole and not on a basis of project by project.
- The Team will identify and prioritize critical trade issues with multi-project implications. It will penetrate the issues to a level needed to draft work statements for targeted study teams who will perform these studies/sensitivity analysis. MPSET will review the output of these studies and make recommendation to the Program for a course of action that balances cost, schedule, risk and capability."

# Risk Assessment and Technology Planning

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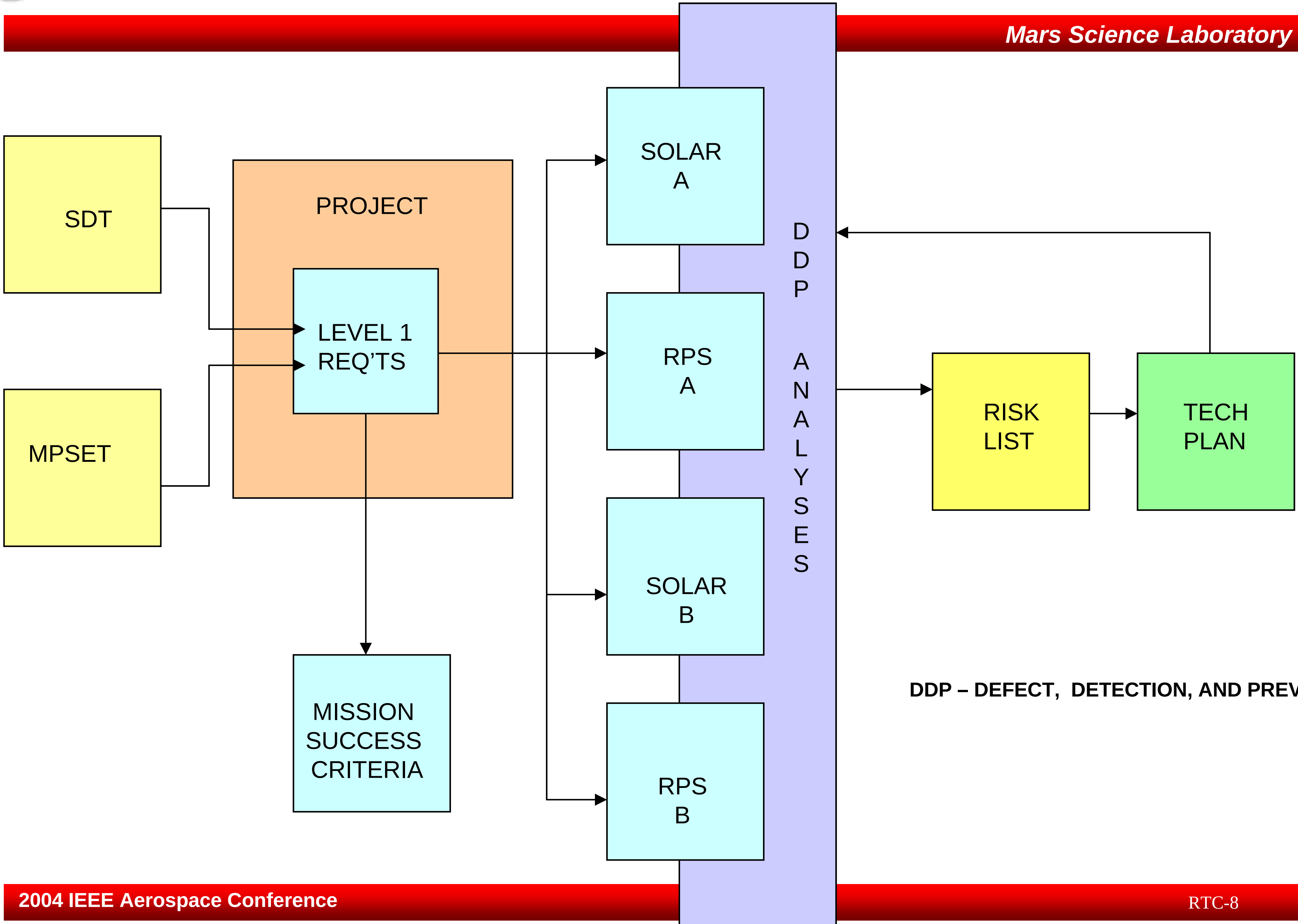


**DDP – DEFECT, DETECTION, AND PREVENTION**



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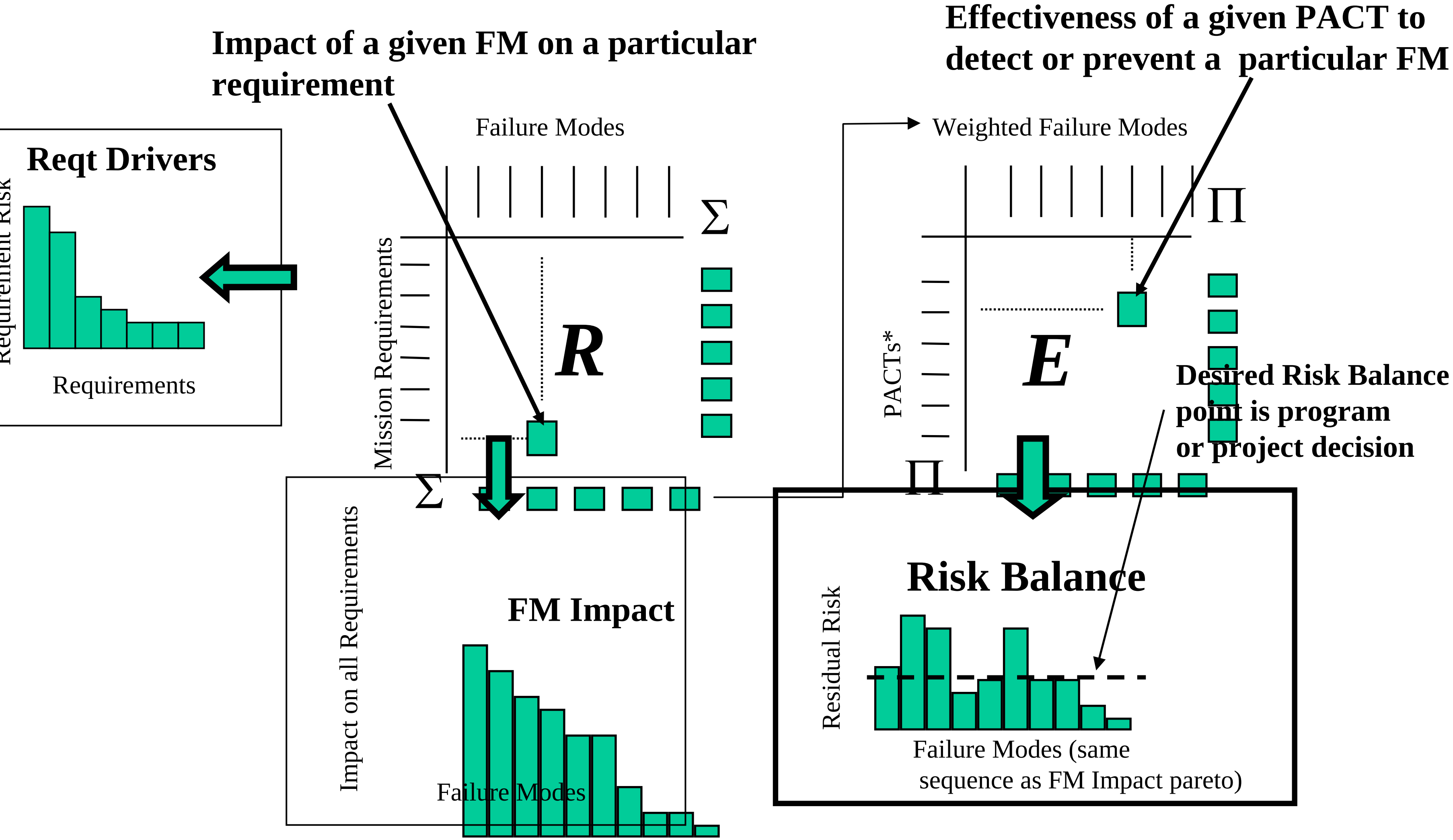
# Simplified DDP Summary

**DDP utilizes two matrices: the Requirements matrix (*R*) and the Effectiveness matrix (*E*)**





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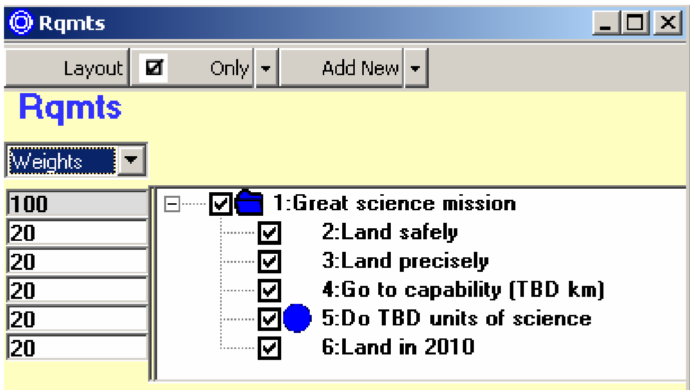
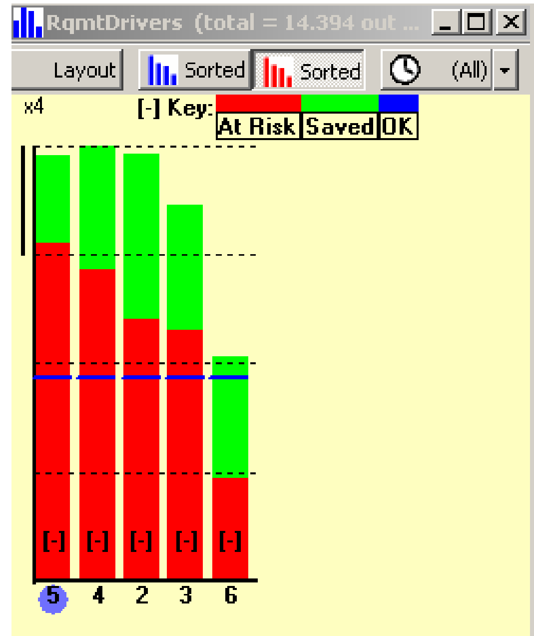
# MSL Level 1 Requirements

**at risk/mitigated by Technology Program investment**






Total Height= Extent to which requirement is at risk due to Technology Risks
Green is extent to which risk is reduced with application of Technology Plan
Red is extent to which requirement is still at risk

# Risk Identified



- 124:MSL Minimum Nuclear Risk List
  - 125:Programmatic
    - 126:Foreign participation issues
      - 127:Untenable international agreement
      - 128:ITAR issues hinder collaborations
      - 129:Lack of secure collaborative development
    - 130:Key assumptions turn out not to be true
      - 131:MDS baseline is under-funded
      - 132:MER overruns are not managed w/o furthe
      - 133:MSL LIDAR functionality is not preserved
      - 134:Radar technology is under-funded
      - 135:OpNAV is under-funded
      - 136:Electra is under-funded
      - 137:JPL in-house capability is inadequately pre
      - 138:X2000 components not available
      - 139:Launch approval not covered by LA group
      - 140:Partners are not adequately funded
    - 141:DSN Loading Issues
    - 142:Mars Program uncertainities disallow timely defi
    - 143:loss of control of project design database
    - 144:Reduction in Science value of mission
      - 145:Reduced GOTO capability
      - 146:Reduced science capability
    - 147:Requirements refinement and consistency
    - 148:Insufficient landing site options
    - 149:Insufficient money for science instruments
    - 150:V&V Issues
      - 151:Inadequate physical test and verification p
      - 152:Inadequate virtual test and verification pro
      - 153:cross validation of physical & virtual test...
      - 154:Lack of early test environment for avionics
    - 155:RPS Issues
      - 156:Stirling development does not meet qual sc
      - 157:Pb-Te TECs do not meet qual schedule
  - 158:Launch
    - 159:Launch vehicle doesn't prove reliable
    - 160:Launch vehicle has failure just before our launc
    - 161:RPS Accomodation Issues
      - 162:RPS induced radiation effects unknowns
      - 163:RPS induced thermal management
  - 164:Cruise
    - 165:Performance and operation of OpNAV system
    - 166:Cruise stage issues
    - 167:RPS Accomodation Issues
      - 168:RPS induced radiation effects unknowns
      - 169:RPS induced thermal management
  - 170:EDL
    - 171:Inadequate avionics
      - 172:Inadequate flight computer
        - 173:inadequate throughput to meet EDL re
        - 174:Lack of L2 cache proves to be bottler
      - 175:Inadequate system bus
      - 176:Long lead issues in optimum avionics desig
    - 177:Descent engine issues
    - 178:Wrong Angle of attack at supersonic chute dep
    - 179:Terminal descent ground effects
      - 180:Terminal descent ground effects
      - 181:Terminal descent aero effects unknown
      - 182:Terminal Descent Plume effects
    - 183:Integrated GN&C/EDL unknowns
      - 184:General Integrated GN&C/EDL unknowns
      - 185:Integration of haz. avoidance GN&C subsy:
    - 186:Landing errors exceed requirement
    - 187:Engine vibration destabilizes LIDAR mirror durin
    - 188:Lander pitch during horizontal deflection prever
    - 189:Algorithms select safe sites with significant egre
    - 190:Inadequate design for surface imaging haz dete
      - 191:LIDAR/radar or algorithms report false safe
    - 192:Mars atmosphere model inadequate
    - 193:Retirement of key personnel
    - 194:mission design tools inadequate
    - 195:incestuous validation
    - 196:simulation environment funding is not preserved
    - 197:Pallet/surface and soil interactions
    - 198:Radar Altimeter unknowns
    - 199:2-chute system, large cost uncertainty
    - 200:Entry body issues
    - 201:lack of TPS instrumentation to take measureme
    - 202:lack of EDL avionics redundancy
    - 203:CG offset is tough to implement
    - 204:Rock net design
    - 205:Lander/carrier stage separation issues
    - 206:MOI Issues
    - 207:Approach nav issues
    - 208:Earth set during EDL
    - 209:Proximity Navigation Issues
    - 210:RPS Accomodation Issues
      - 211:RPS induced radiation effects unknowns
      - 212:RPS induced thermal management
    - 213:lack of robust EDL data return strategy
  - 214:Surface
    - 215:Long life device issues
      - 216:Qualificaton of brushless motors
      - 217:Lubricants insufficient
      - 218:insufficient bearing life
      - 219:MER class thermal enclosure materials too
      - 220:MER dust sealant systems insufficient for l
      - 221:current and reliable electronics design & p
      - 222:Battery long life issues
      - 223:Solar array long life non-dust issues
    - 224:Sample preparation, handling and transfer issue
    - 225:Surface System power inadequacy
      - 226:Dust-induced power loss
      - 227:Solar cell not developed within requiremen
      - 228:No commercial DC-DC power converters fo
    - 229:Payload inventions don't make it on plan
      - 230:Sensor inventions don't make it on plan
      - 231:Drill unknowns
        - 232:Rock corer unknowns
        - 233:1m Drill unknowns
      - 234:Sample analysis inventions don't make it o
    - 235:Rover not able to egress from pallet
    - 236:50 W TWTA suffers from corona/multipaction b
    - 237:Inadequate UHF data return due to mechanical
    - 238:Autonomy Issues
      - 239:Autonomy lack of definition
      - 240:System integration of disparate autonomy t
      - 241:Autonomy doesn't realize anticipated perfo
        - 242:On-board autonomy insufficient to safe
        - 243:Rover unable to reach goal from landi
        - 244:Unable to accomplish traverse scienc
        - 245:Autonomy does not realize reqts for or
        - 246:poor Instrument placement
        - 247:can't do Hazard detection and avoida
        - 248:Mis-Determination of opportunistic sci
      - 249:Rigorous testing of autonomous systems pr
      - 250:don't understand ops implications of auton
      - 251:Validation of autonomy problematic
    - 252:MDS Adaptation Issues
      - 253:Rover technology adaptation issues
      - 254:Avionics performance in all measures
    - 255:Rover system design issues
    - 256:System FMs and responses not identified
    - 257:Unknown number of RPSs required for design
    - 258:Telecom issues
      - 259:Lack of telecomm scenario definition result
      - 260:Surface system antenna patterns
      - 261:Undefined DTE telemetry
    - 262:Lack of detail in mission scenario including grou
    - 263:Consequences of 30 day solar conjunction ever
    - 264:Excessive instrument mass
    - 265:RPS Accomodation Issues
      - 266:RPS induced radiation effects unknowns
      - 267:RPS induced thermal management

## before/after application of Technology Program investments

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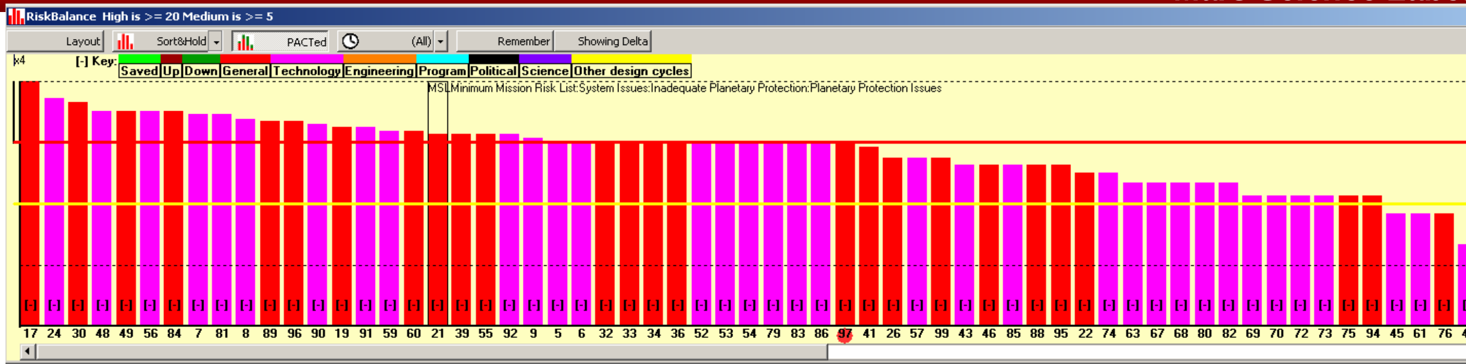


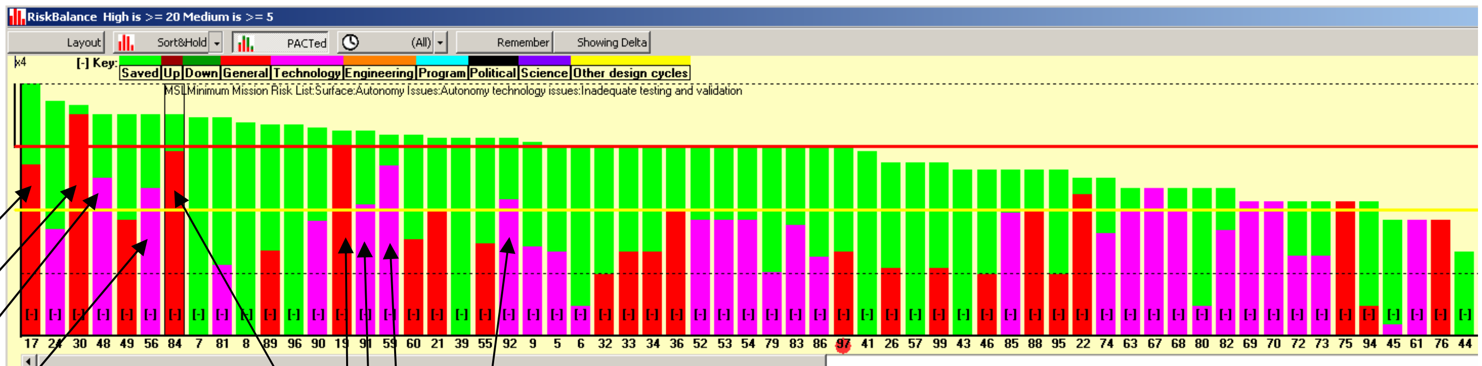


tem FMs and responses not identified

Inadequate autonomy testing and validation

k of L2 cache proves to be bottleneck

System mass of engineering elements of rover exceed allowable limits

Dust-induced power loss

lequate detailed simulation for EDL new tech

Inadequate autonomic Hazard detection and avoidance

rent and reliable electronics design & packaging
nologies insufficient in Mars thermal environment

Validation of autonomy problematic

**Legend**
Purple= Technology Risks
Red=Technology/Engineering Risks
Green=Mitigated Risks
Red line= High/Medium risk boundary
Yellow line= Medium/Low risk boundary



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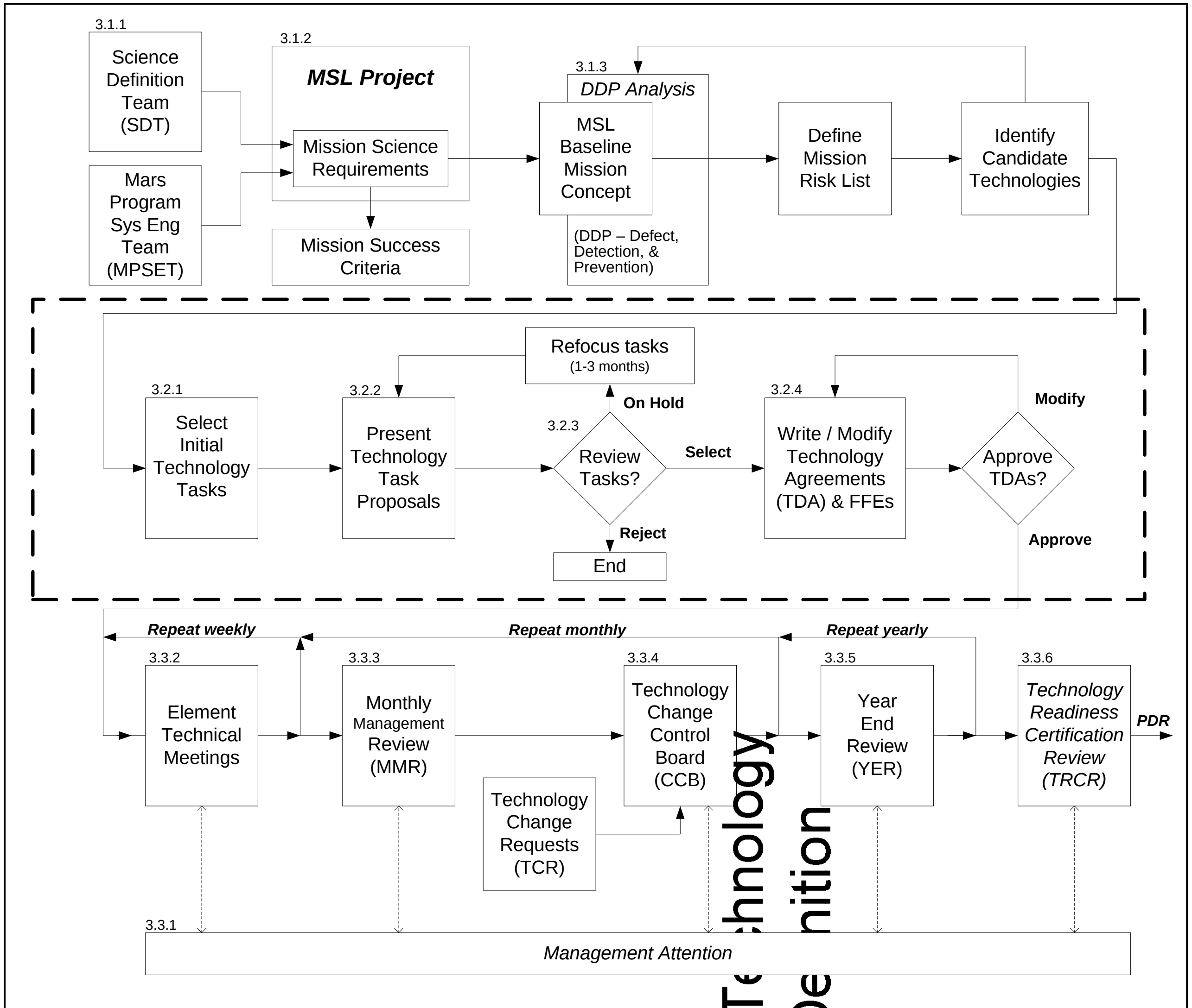
# Technology Selection Process





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# Prepare/Present Task Proposals

**(*based on mission concept, performance requirements*, risk list)**



- *Overview (Quad Chart)* – One slide summary of the task including a picture, objectives, milestones, organizations, subtasks, schedule, and funding levels
- *Objectives and approach* – Describes objectives, state of the art, performance goals, and implementation approach
- *Backup data* – Data for reviews to assess the impact, sensitivity, risks, and procurements of the task
- *Receivable/Deliverable Lists* – List all items being received by the task and delivered from the task to a project element.
- Budget Estimates – Assessment of costs to complete task

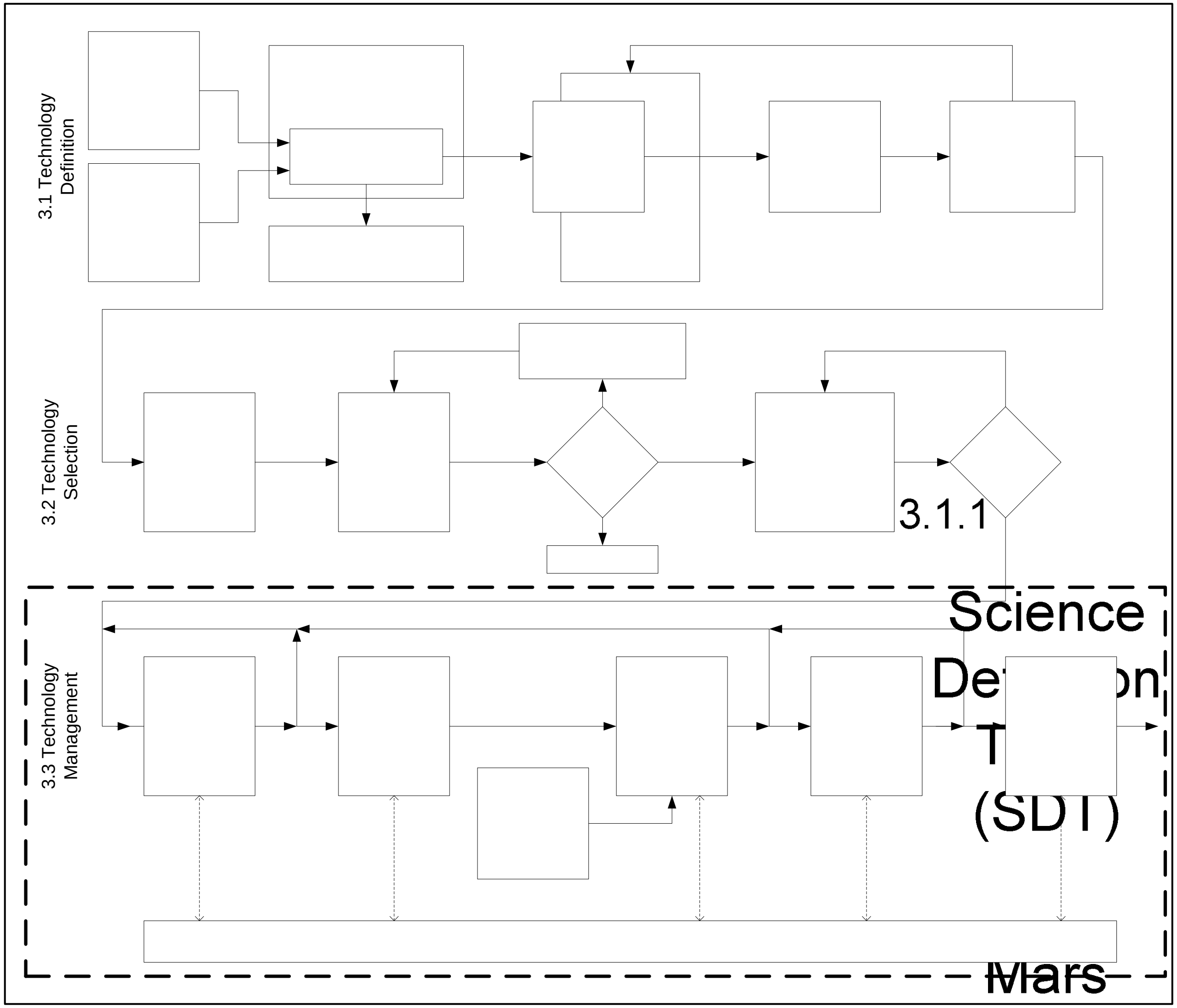
# Prepare, Review, and Approve TDA



- *Introduction* – Describes the technology, assesses the state-of-the-art, and defines the current TRL.
- *Objectives* – Describes the task's technical objectives and goals.
- *Technical Approach* – Describes the methodology and approaches to conduct the proposed development.
- *Significance* – Explains how the task will contribute to a NASA Mission.
- *Milestones and Deliverables* – Identifies when major milestones will be achieved.
- *Funding Distribution* – Lists the budget, who is funded, which year, and totals
- *Documented Partnerships/Cooperative Agreements* – Describes any partnerships, cooperative agreements, or other agreements that involve this task.
- *Comments* – The following questions determine the tasks funding sensitivity, work breakdown, task dependencies, and other issues associated with the task:
- *Infusion Plan* – Defines the plan for applying the technology developed in this task to a practical implementation.
- *Reporting Plan* – Defines the plan for reporting status/progress on this task to project.
- *Commercialization Plan* – Defines the plan for transferring the technology developed in this task to commercial use.
- *Approval* – The TDA sequence of approval is: Task Manager, Element Manager (or Level-1 Manager), Section Manager, and Project Office.

# Technology Management Process





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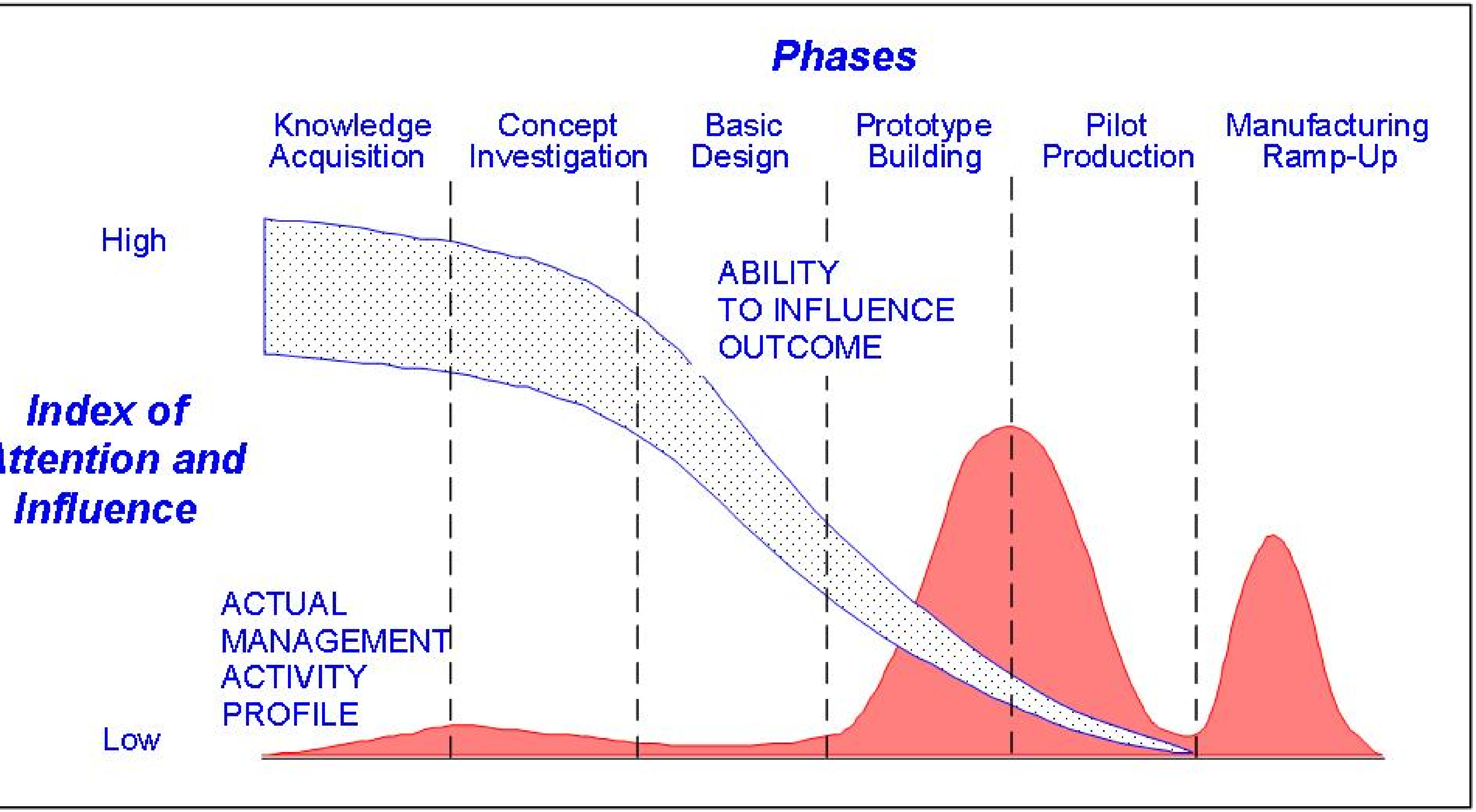
# Timing and Impact of Management Attention and Influence





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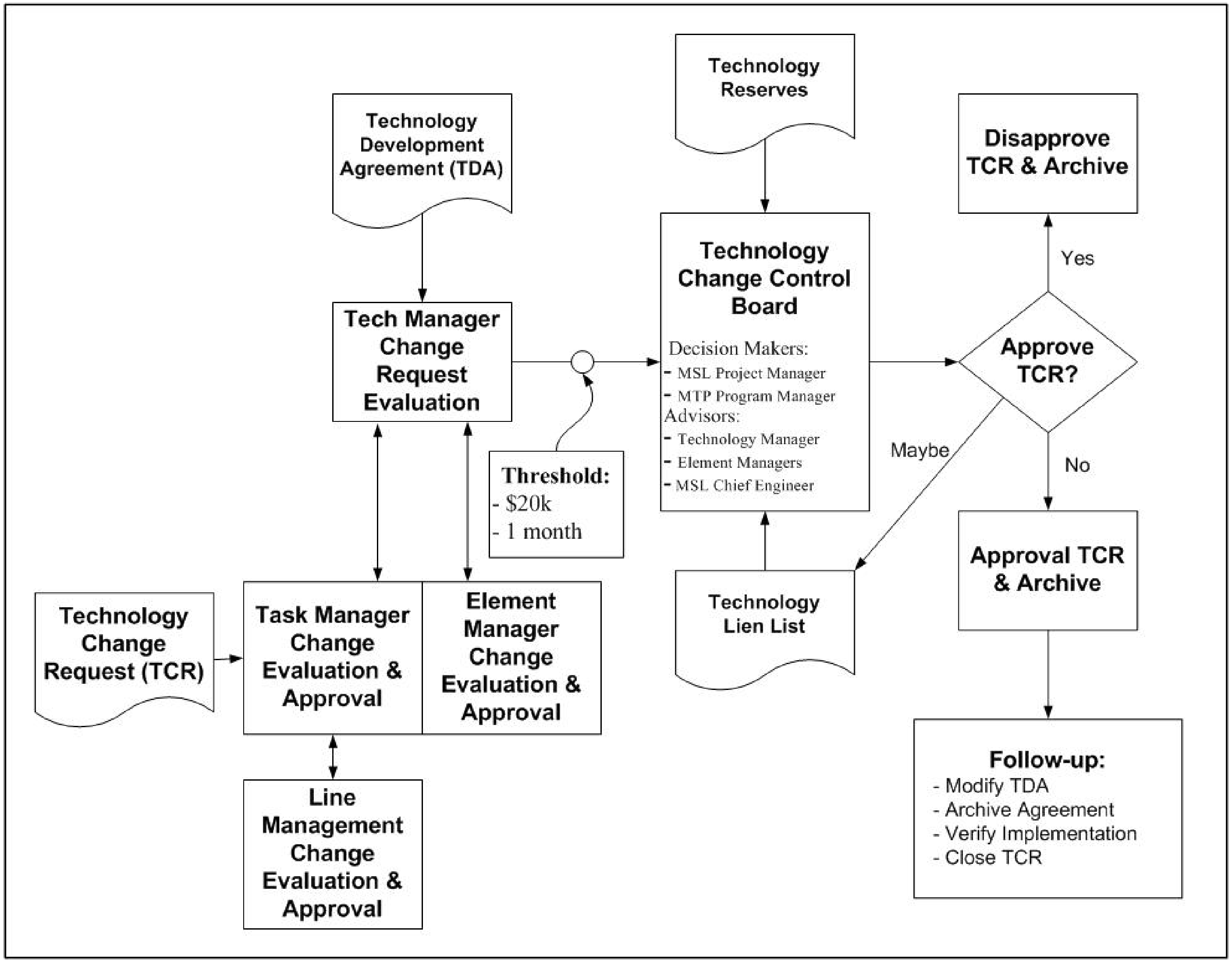
# MSL Technology Change Control Flow





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# Technology Readiness Certification Review



**Goals:**
- **Establish MSL technology infusion maturity requirements**
- **Establish criteria based on TRL guidelines**
- **Specific criteria to be assigned to individual MSL FT tasks**

**Maturity criteria—Hardware**
- **Design**
  - Drawings
  - Materials/parts selection
  - Analyses - Thermal, loads and accoustics
  - CG, Mass, Volume, and Power estimates
  - Performance (improvement) estimate
- **Fabrication and Assembly**
  - Fab instructions
  - Flight-like materials used
  - Inspection
  - Unit assembled in flight-like configuration
  - Mass, CG properties
- **Test (after application of power)**
  - Performance/functional testing
  - Environmental testing
  - Power measured
  - Idiosyncracies documented

**Maturity criteria—Software**
- **Design**
  - Performance estimate
  - State analysis products (or FDDs)
  - CPU, memory utilization
  - Source code/algorithm descriptions
  - Test Cases
- **Fabrication**
  - Flight-like development environment
  - Flight approved compiler and libraries
  - Flight computer/OS compatible
- **Test**
  - Executed on flight-like hardware and OS
  - Performance/functionality demonstrated
  - Measured CPU, memory utilization
  - Idiosyncrasies documented



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# Technology Management Tools



- Aggregate Project Plan (Bubble Chart)
- The MSL Technology Funnel Chart
- Technology Decision Analysis Tools
- Deliverable / Risk Analysis Tools

# Aggregate Project Plan (Bubble Chart)

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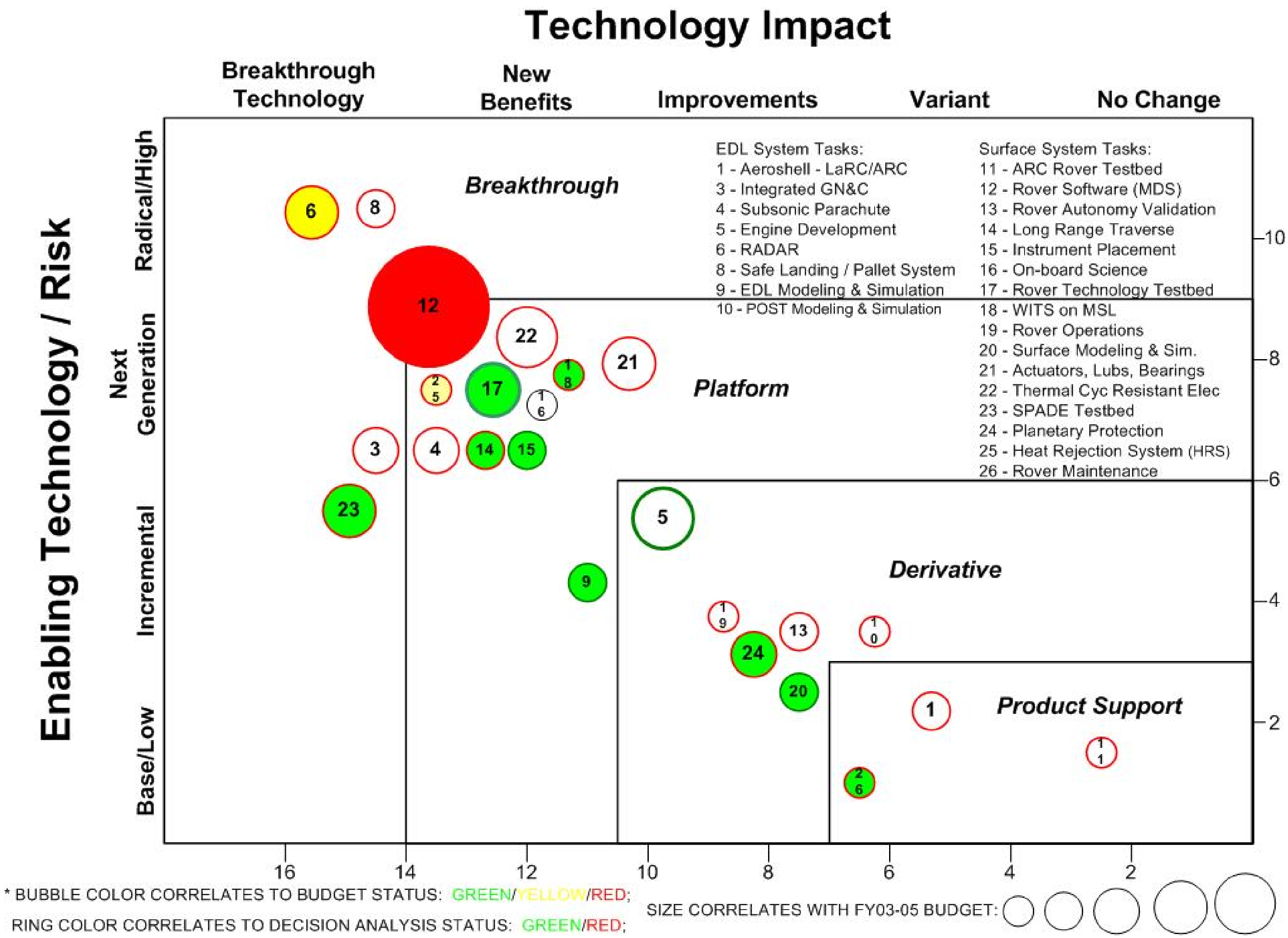




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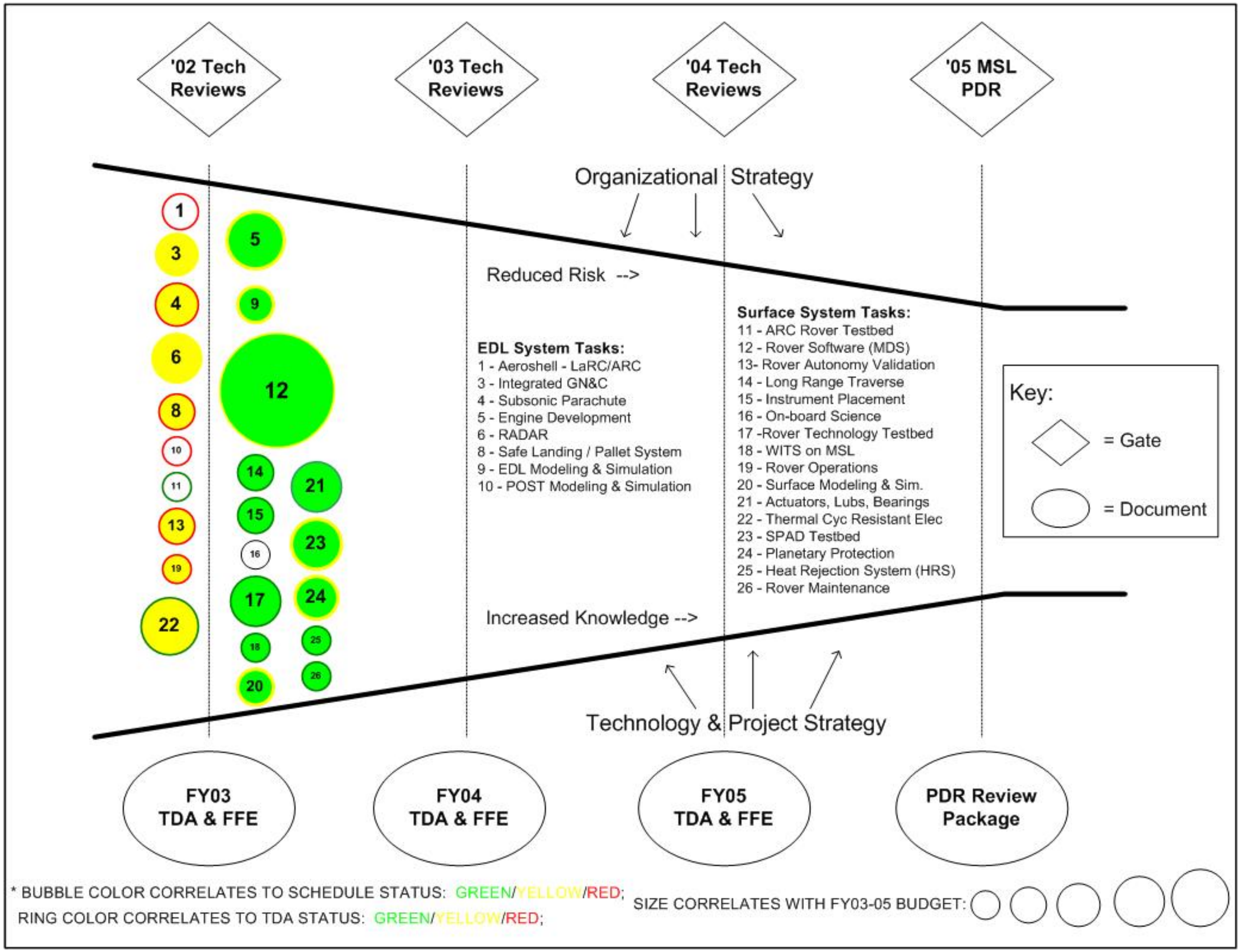
# The MSL Technology Funnel Chart





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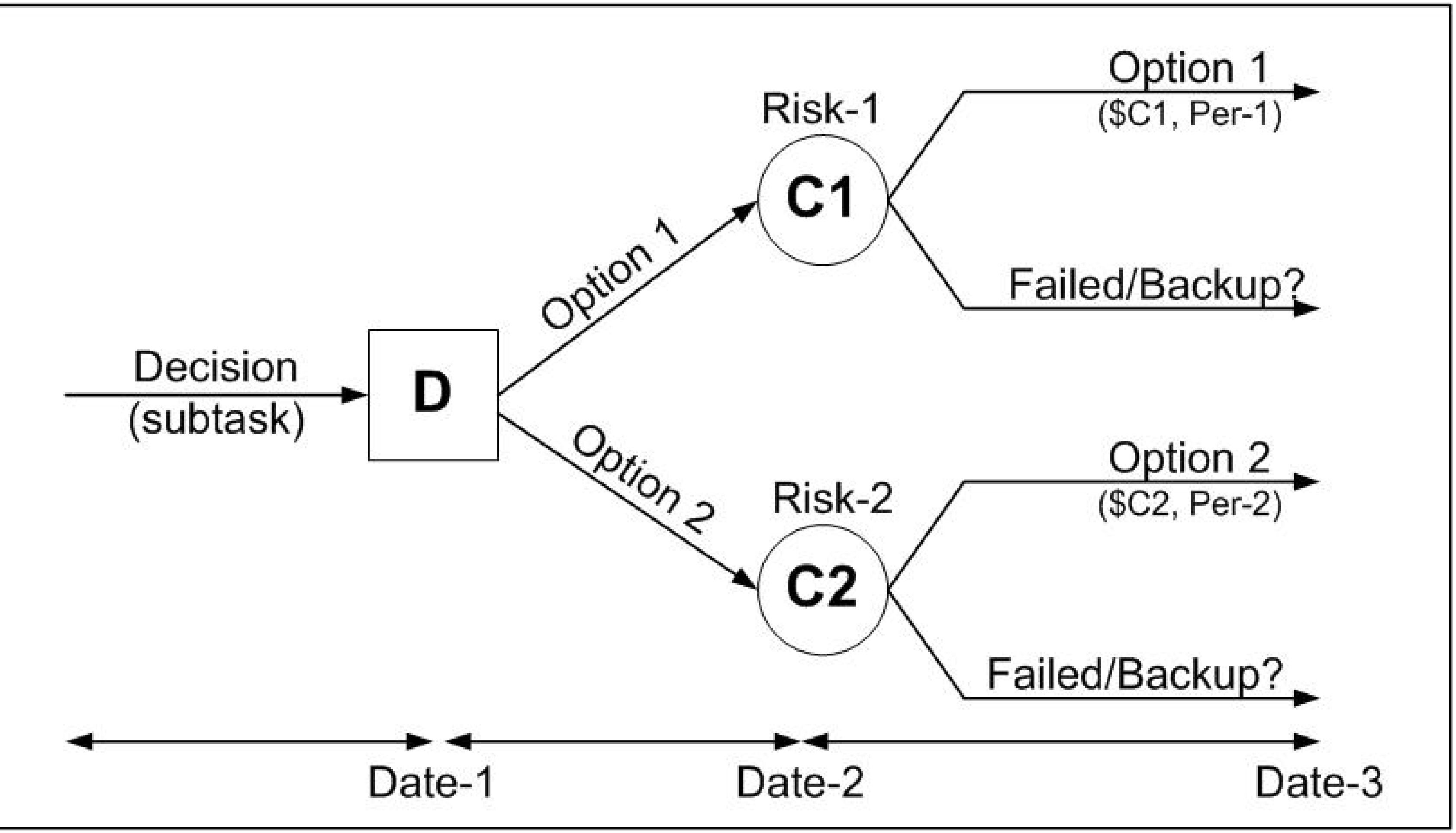
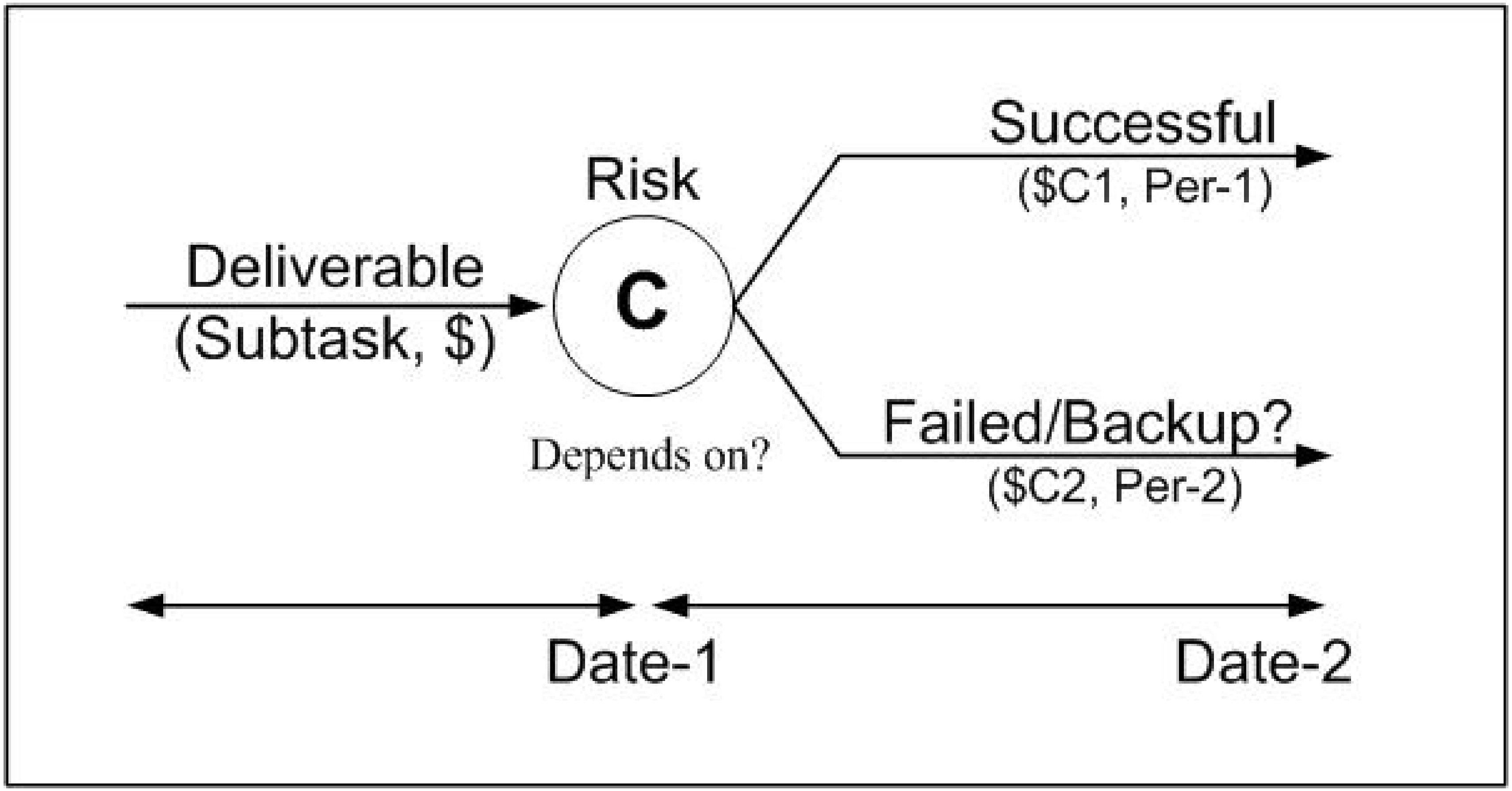
# Technology Decision Analysis Tools





# Deliverable / Risk Analysis Tools





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# MSL Focused Technology Summary



- **The MSL Technology Program is tightly coupled to the MSL mission and the its milestones**
- **It involves critical deliverables that must be developed in time for infusion into the MSL mission**
- **The plan is to reach TRL 6 for each technology by the mission's PDR**
- **This program transcends the usual gulf between technology and projects by vertically integrating the technology work with pre-project development in a project-like environment with critical dates for technology infusion**
- **The program addresses developing key technology to enable MSL's revolutionary science mission**

# Acknowledgements




- Michael Sander (MSL Project Manager)
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- Nancy Schweiner and Irene Lopez (project sup)
- All the MSL Task Managers




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