Risk-Based Decision Making for Novel Technologies

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SUMMARY

This abstract summarizes a risk-based decision-making process conceived of and developed at JPL and NASA, where it has been used to help plan and guide novel technology applications for use on spacecraft. The abstract indicates the relevance of this work to broad-ranging challenges that arise in planning for the development, deployment and operation of almost all kinds of novel technologies.

THE CHALLENGES

Spacecraft development exemplifies the following key challenges of novel technology applications: Past experience provides only a partial guide: New mission concepts are enhanced and enabled by new technologies, for which past experience provides only a partial guide (e.g., ion engines used for supplementary maneuvering now being used as the main propulsion). Cross-disciplinary concerns are numerous: Spacecraft are cross-disciplinary in nature (e.g., involving navigation, propulsion, telecom, science instruments). Concerns are cross-coupled: These concerns are cross-coupled through severely limited shared resources (e.g., power, mass, volume) and interact in multiple ways (e.g., electromagnetic interference, heat transfer). Time and budget pressures constrain development: Spacecraft development is under time pressures (celestial mechanics favors certain launch windows) and budget pressures, with resulting risks of slippage, and cost overruns. Critical systems: The spacecraft themselves are critical systems that must operate correctly the first time in only partially understood environments, with no chance for repair.

THE SOLUTION APPROACH – CONCEPTS

A risk-based decision-making process has been conceived of and developed at JPL and NASA to specifically to address these challenges. At its heart it makes use of three concepts:

"Objectives" – the things the spacecraft is to achieve (e.g., science return objectives), how it is to operate (e.g., with available power), and how it is to be developed (e.g., within 3 years, with budgets each of those years set at...). Objectives are assigned weights to reflect their relative importance.

"Risks" – broadly speaking, all the problems that, should they occur, will adversely impact attaining those objectives. These include development risks (ambiguous requirements leading to costly rework, poor contract arrangements, lack of configuration management) and risks in the developed spacecraft (erroneous operation, over- consumption of limited resources, degraded capabilities, total loss).

"Mitigations" – the entire range of actions and options to reduce risks, including preventative measures (e.g., training and standards; radiation shielding), alleviations (e.g., redundancy), and detections (e.g., reviews, inspections, analyses and tests) that can potentially detect problems ahead of their manifestation, and so allow for their correction.

The decision-making process rests on quantitative assessments of the relationships between these elements. Objectives and Risks are related by assessing how much of each Objective would be lost should a given risk occur. Risks and Mitigations are related by assessing how much a Mitigation will prevent/reduce/alleviate a given Risk. The solution approach also incorporates the cases where Mitigations in solving one Risk problem may make other ones worse. Note that an Objective may be impacted by multiple Risks (and vice-versa), and a Mitigation may effect multiple Risks (and vice-versa). The result can, and often is, a very tangled interlinking among dozens to hundreds of individual elements. Decision-making is hard because of the intertwined and voluminous nature of this information.

THE SOLUTION APPROACH – SUPPORT

Support for the effective use of the approach has been developed and honed over the past several years. This takes two forms: process guidance, and custom software tool support. The process followed makes use of a cross- disciplinary team of experts in a series of collaborative sessions to brainstorm risk information. Their combined areas of expertise must span the disciplines involved in the spacecraft technology development. Objectives, Risks and Mitigations, and their quantitative interrelationships, are gathered from the team in a series of sessions, structured to focus on the main concept areas (e.g., Objectives, Risks and how they interrelate). One of the distinguishing features of this approach is that it asks those experts to assess what the fundamental risks are separately from the mitigations they plan to do (or can choose to do) to reduce those risks. Information on the mitigations is explicitly gathered. In contrast, traditional risk assessment techniques tend to focus on only the risks that remain after all planned mitigations are assumed to have been applied. Another distinguishing characteristic of the process is that the level of detail is determined on the fly, and is non-homogeneous. Greater detail is used where there is greater risk and/or the need to draw distinctions (e.g., between alternative risk mitigation options). This contrasts to simplistic approaches that ask for, say, top-ten risk lists from each discipline without regard to the relative importance of those disciplines. Custom software tool support has been developed for this process. This supports the elicitation of the information from experts in real time. It also allows those experts to study the resulting combined set of information from a variety of perspectives. Finally, it offers aids to support their decision-making - for example, heuristic search techniques are available to locate "optimal" points in the cost/benefit risk space (e.g., select from among the mitigations those that maximally achieve objectives while remaining in budget).

APPLICATIONS AND OUTCOMES

The majority of the applications of this approach have been to study novel technologies with potential for use on spacecraft. Almost every such application yielded beneficial outcomes in one form or another. It is typical that the experts who take part are initially skeptical, yet emerge convinced that the approach has yielded insights that are both surprising and beneficial – that is, those insights have led them to make some decisions differently than would otherwise have been the case. They agree that they would not have arrived at those insights until much later in development, by which time it would have cost much more to correct erroneous decisions. There have also been applications to guide early phase project-level design decisions, and, at an even broader level, preliminary studies in the areas of prioritizing investments across a whole suite of related missions. In general terms, the approach yields:

- Thorough understanding of risks, including their relative severity.
- Calibration of risks across discipline boundaries.
- An optimized plan of how to best to address those risks.
- The ability to trade risks between disciplines, and to trade risk for cost and/or performance.
- Insight into the magnitude of the remaining risk, and how it relates to objectives.
- Insight into which objectives are the most costly to attain (because the risks that impact them are the most costly to reduce), and so are leading candidates for abandonment if need be. Conversely, detailed understanding of how an increase in resources on risk reduction will increase objectives' attainment gives ammunition for arguing for increases in funding, etc.
- Detailed comparison of design alternatives and the risks they each embody.
- Insight into when and where risk arises in the development process, and when the actions that reduce these risks will be performed. This helps in establishing a plan that matches budget flows, and also indicates where to monitor the development to detect if and when actual practice is diverging significantly from expectations.

CONCLUSION

The purpose of this abstract has been to summarize that the risk-based decision making approach pioneered at JPL. The majority of its applications to date have been to nove technologies for use on spacecraft, however the approach itself is applicable to the study of novel technologies of all kinds. More details on this approach can be found in externally accessible reports given to several communities, including the following: Overall approach and applications reported to the Aerospace community [Cornford et al, 2000], [Cornford et al, 2001]. The custom software that supports the process reported to the Software Engineering community [Feather et al, 2000]. Relationships to the Design community discussed in [Feather et al, 2002]. Information is also available via a publicly accessible web site: http://ddptool.jpl.nasa.gov

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